CRUX PROJECT

OFFSHORE PROJECT PROPOSAL

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Shell Australia Pty Ltd

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Crux Offshore Project Proposal

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EXECUTIVE SUMMARY

Introduction

Project

Shell Australia Pty Ltd (Shell), together with Joint Venture Participants Seven Group Holdings (SGH) Energy and Osaka Gas, is progressing planning for the prospective development of the Crux gas field, located approximately 160 km north-east of the Prelude field in the northern Browse Basin, offshore the Kimberley coast, Western Australia (WA) (**Figure ES-1**).

The Crux field is located in Commonwealth marine waters in the northern Browse Basin, 190 km offshore north-west Australia and 620 km north-north-east of Broome.

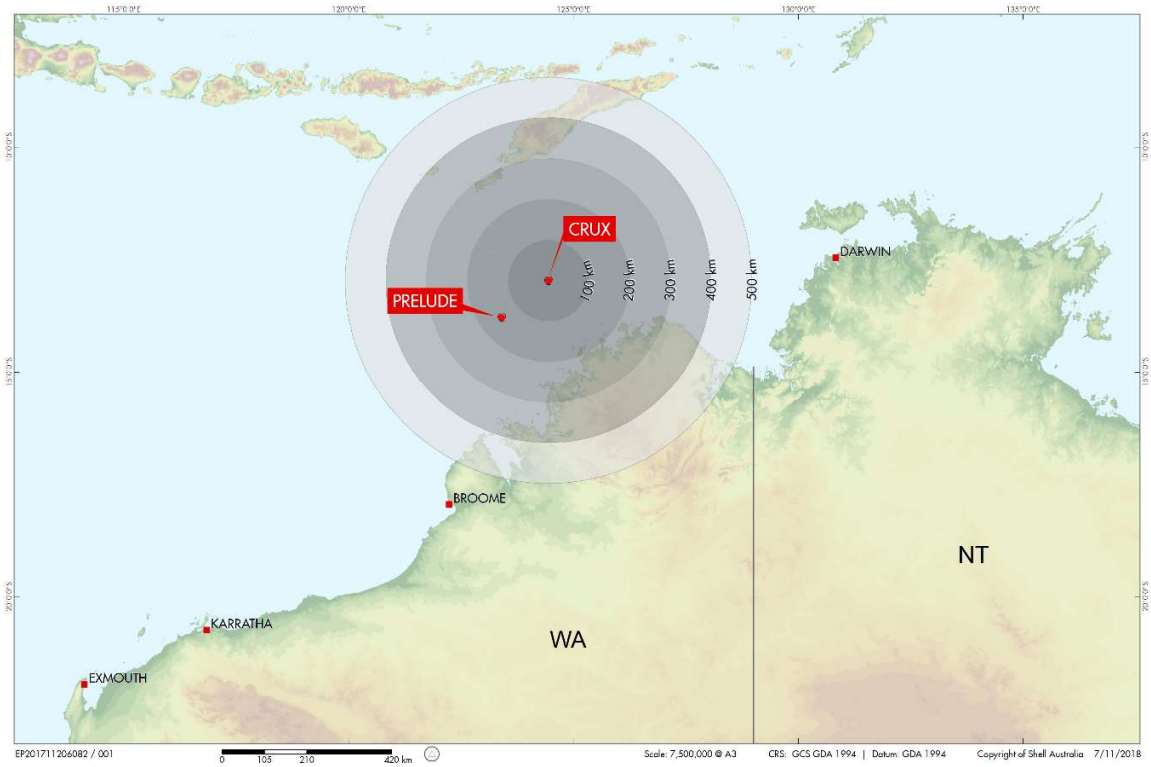


Figure ES-1: Location of the Crux Project

The Crux project has been identified as the primary source of backfill gas supply to the Prelude Floating Liquefied Natural Gas (FLNG) facility. The proposed Crux project consists of a Not Normally Manned (NNM) platform in approximately 165 m water depth; with five production wells, minimal processing and utility systems, tied back to the existing Prelude FLNG facility via a 165 km export pipeline. Crux will be operated remotely from the Prelude FLNG facility.

The current Crux project concept is shown in **Figure ES-2**. Front-End Engineering and Design (FEED) for the project is expected to commence in 2019 with the Financial Investment Decision (FID) currently scheduled to occur in 2020. The project is anticipated

to have a 20-year design life. However, subject to the future investment decisions, the project may extend.

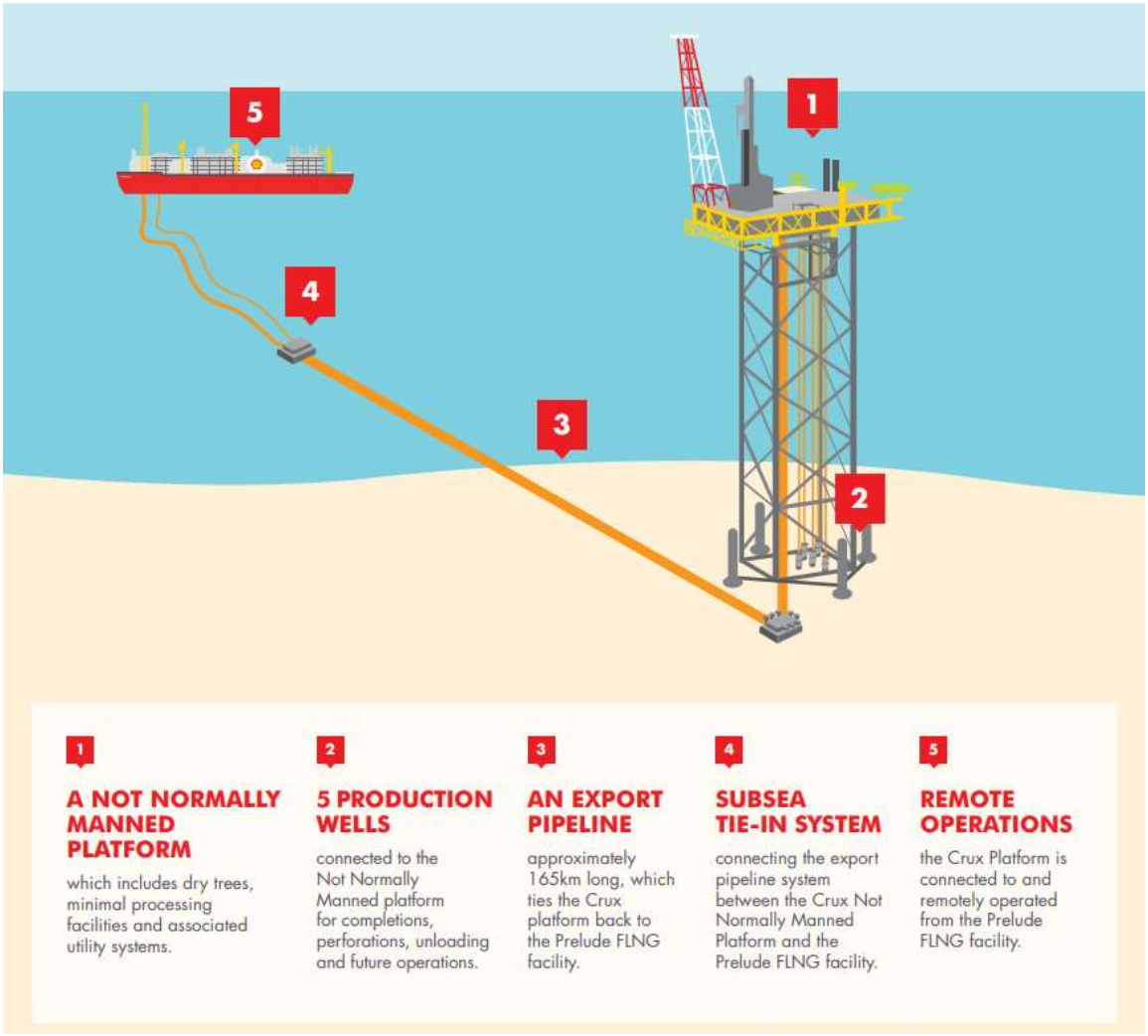


Figure ES-2: Crux Project Concept

Proponent

The project proponent for the Crux project is Shell Australia Pty Ltd (Shell). The Shell Group of companies is the largest equity Liquefied Natural Gas (LNG) producer among international energy companies and has the most diverse LNG supply portfolio in the world. The Shell Group has been in Australia since 1901 and has continued to evolve to meet the changing needs of the Australian and international markets. Today, Shell is focused on the exploration, development and production of LNG, domestic gas and associated products such as LPG and condensate. Shell is a major investor in key Australian LNG projects, including the Shell-operated Prelude FLNG facility.

Shell's Joint Venture Participants for the Crux project are SGH Energy and Osaka Gas. SGH Energy is an Australian oil and gas company with a portfolio of high quality assets and a resources base in the offshore Gippsland Basin in Victoria, and in the Browse Basin in

northern WA. Osaka Gas has over 110 years of experience in the energy sector and has grown into a diversified energy company, across the entire natural gas value chain. The Crux Joint Venture Participants bring collective expertise and support for the sustainable commercialisation of the gas fields, in support of backfill to the Prelude FLNG facility.

Offshore Project Proposal Process

Shell determined that the Crux project constitutes an offshore project that requires approval under the *Offshore Petroleum and Greenhouse Gas Storage Act 2006*. Subsequently, Shell has developed this Offshore Project Proposal (OPP) to meet this requirement.

The impact assessment of the proposed project presented in this OPP has been aligned to meet the requirements of an OPP regulated under the Commonwealth Offshore Petroleum and Greenhouse Gas Storage (Environment) Regulations 2009 (OPGGS (E) Regulations) and administered by the National Offshore Petroleum Safety and Environmental Management Authority (NOPSEMA).

An assessment of the proposed Crux project has been progressed, in accordance with the Shell Health, Security, Safety, Environment and Social Performance (HSSE & SP) Control Framework, to *'identify and assess the potential environmental, social and health impacts of a project, and to implement measures so that negative impacts are minimised, and positive impacts are optimised.'*

The purpose of the OPP is to describe:

- the project area, the proposed activities and its expected timeframe
- the environmental management framework for the proposal, including legislation and other requirements
- the existing natural, social and economic environments of the local and regional setting, including issues or sensitivities particular to the proposal
- the possible impacts and risks to the environment from both planned (normal) and unplanned (emergency) operations
- Shell's HSSE & SP Commitment and Policy and the environmental performance objectives that derive from the Policy, and
- a framework for the forward environmental management and performance, including definition of key management controls and Environmental Performance Outcomes (EPOs), from which environmental performance will be measured and monitored throughout the life of the project.

The OPP is designed as an early stage, whole-of-project assessment. Subject to NOPSEMA's acceptance of the OPP, it will form the basis of future activity-specific Environment Plans (EPs) that will be submitted to NOPSEMA for acceptance as part of subsequent staged development and permitting.

Policy, Legal and Administrative Framework

As the Crux project is located in Commonwealth waters, the key legislation of relevance to the Crux project include:

- *Offshore Petroleum and Greenhouse Gas Storage Act 2006* (OPGGS Act) – the OPGGS Act, and subsidiary Offshore Petroleum and OPGGS (E) Regulations, ensures

that all offshore petroleum and greenhouse gas storage activities are undertaken in a manner where impacts and risks on the environment are of an acceptable level and reduced to as low as reasonably practicable (ALARP). This includes risks to Matters of National Environmental Significance (MNES) protected under Part 3 of the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act). The OPGGS Act requires that all activities are consistent with the principles of ecologically sustainable development (ESD), as defined in the EPBC Act.

- *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) – The EPBC Act and supporting regulations provides for the protection of the environment and conservation of biodiversity in Australia (including Australian waters) by the Commonwealth Government. Amendments to the OPGGS Act and OPGGS (E) Regulations in February 2014, undertaken as part of the Commonwealth streamlining environmental approvals process, require MNES to be addressed in assessments of offshore petroleum development approvals. Therefore, the OPP process under the OPGGS (E) Regulations supersedes the Commonwealth referral process under the EPBC Act and replaces the requirement to prepare environmental approvals for submission to the Department of the Environment and Energy (DoEE) for petroleum development activities in Commonwealth waters. As such, this OPP addresses the EPBC Act requirements for the Crux project, including those outlined in the EPBC Act Management Plans, Recovery Plans and Conservation Advices.

The administration of petroleum activities in Commonwealth waters is subject to a number of requirements administered by the National Offshore Petroleum Titles Administrator (NOPTA) and NOPSEMA. These requirements include:

- Environment Plans – all petroleum activities within the scope of this OPP must be undertaken in accordance with an EP accepted by NOPSEMA. EPs must describe the activity, the receiving environment, and provide a detailed evaluation of environmental impacts and risks associated with the activity. The EP is also required to outline appropriate EPOs, performance standards and measurement criteria for determining whether the outcomes and standards are met. In addition, an implementation strategy is provided to demonstrate how the impacts and risks will be managed to ALARP and acceptable levels, how performance outcomes and standards are met, and detail the arrangements in place to respond to and monitor oil pollution emergencies. A series of EPs will be developed by Shell for specific activities throughout the project life cycle.
- Safety Cases – NOPSEMA requires an accepted Safety Case be in place for the Crux platform and pipeline. The Safety Case identifies the hazards and risks for a facility, describes the measures in place to control these hazards and risks, and outlines the safety management systems that will be applied.
- Well Operations Management Plans (WOMPs) – all wells for the Crux project will be drilled, operated and abandoned in accordance with the requirements of an accepted WOMP.

Shell Health, Security, Safety, Environment and Social Performance Management Framework

The Shell HSSE & SP applies across the Shell Group and is designed to protect people and the environment. The policy illustrates the commitment made by the senior management and all staff of Shell to achieve not only compliance with environmental standards set by the

Australian Government and the Company, but also to seek continual improvements in performance.

Key features of the policy are:

- systematic approach to HSSE & SP management designed to ensure compliance with the law and to achieve continuous performance improvement
- targets for improvement and measurement, appraisal and performance reporting
- requirement for contractors to manage HSSE and SP in line with this policy, and
- effective engagement with neighbours and impacted communities.

All Shell's operations are conducted in accordance with Shell's HSSE & SP Control Framework, a comprehensive corporate management framework. This Framework defines a set of mandatory requirements that define minimum HSSE & SP principles and expectations.

Stakeholder Consultation

Stakeholder engagement and consultation is an integral part of Shell's social performance, impact assessment and project development process, helping to both inform business decisions and identify issues that require action.
Shell is committed to:

- inform stakeholders of the proposed Crux project
- maximise the level of accurate and accessible information about the project
- provide stakeholders with the opportunity to engage in meaningful dialogue
- listen to feedback from stakeholders and respond to them honestly and responsibly
- use stakeholder feedback to inform and improve business decisions, and
- deliver a net benefit to local communities.

A Stakeholder Engagement Plan specific to the Crux project has been developed and includes a stakeholder matrix, an engagement strategy and a feedback mechanism.

As part of Shell's commitment to early engagement, a Crux project website has been established and initial factsheets published, providing an overview of the project and the OPP process. The Crux project website is located at:

https://www.shell.com.au/about-us/projects-and-locations/the-crux-project.html

An initial industry briefing has been held, and Shell has commenced targeted engagement with a range of relevant stakeholders, including Government agencies, commercial fishing associations and other interested stakeholders, to discuss the project's status and facilitate the opportunity for feedback.

A core element of the OPP process is to facilitate a public comment period. The OPP will be published on NOPSEMA's website and made available on Shell's website. The length of the public comment period is subject to determination by NOPSEMA, ranging from 4 to 12 weeks duration.

Upon acceptance of the OPP, Shell will uphold its commitments to ensuring relevant persons continue to be consulted throughout the development of the Crux project. These consultations will be planned, tracked and recorded as part of the Crux Stakeholder Engagement Plan.

Description of the Project and Alternatives Analysis

Key Components

The Crux project has been identified as the primary source of backfill gas supply to the Prelude FLNG facility. The current project concept is shown in **Figure ES-2** and comprises:

- an NNM platform, which includes dry trees, processing facilities and associated utility systems
- five production wells with subsea wellhead system tied back through rigid concentric tubulars to the NNM platform and completed with dry trees
- a 26-inch export pipeline, approximately 165 km long, which ties the platform back to the Prelude FLNG facility, and
- subsea integration system connecting the export pipeline system with Crux platform and the Prelude FLNG facility, comprising risers, subsea isolation facilities, Pipeline Inspection Gauge (PIG) receiver and associated control systems.

There is also a potential for future subsea developments that will provide hydrocarbons to the Crux platform. These developments are expected to comprise subsea production wells, completed with subsea trees, and associated subsea tie-back to the platform (e.g. flowlines, risers and manifolds).

Project Area

The Crux in-field development area and export pipeline corridor define the geographic extent of the project area that is applicable for planned activities, which are considered and risk assessed in this OPP. For the purposes of this OPP, the extent of the in-field development area (approximately 282,000 ha) and export pipeline corridor (approximately 32,000 ha) (collectively referred to as the 'project area') is considered to comprise the area outlined in **Figure ES-3** and **Figure ES-4**, respectively.

The in-field development area incorporates the development of the Crux field and associated reservoirs that may be developed as future staged developments. The outer radius of potential backfills from the proposed Crux platform location will be 30 km from the current proposed platform location, excluding a 1 km buffer from around shoals within this area in order to avoid impacts to these features from potential future tie-backs. The preferred Crux platform location shown in **Figure ES-3** will be located within an approximate 1 km radius of this location.

The in-field development area also encompasses the marine environment that may be affected by planned discharges, as identified from modelling which is presented in the OPP.

The export pipeline route connecting the Crux platform to the Prelude FLNG facility includes a 1 km buffer either side of the proposed route where minor deviations in the final pipeline route may occur, as shown in **Figure ES-4**. A slightly larger buffer (approximately 2 km) has been allowed at the Prelude end of the pipeline to allow for tie-in to the most appropriate quadrant of the FLNG turret.

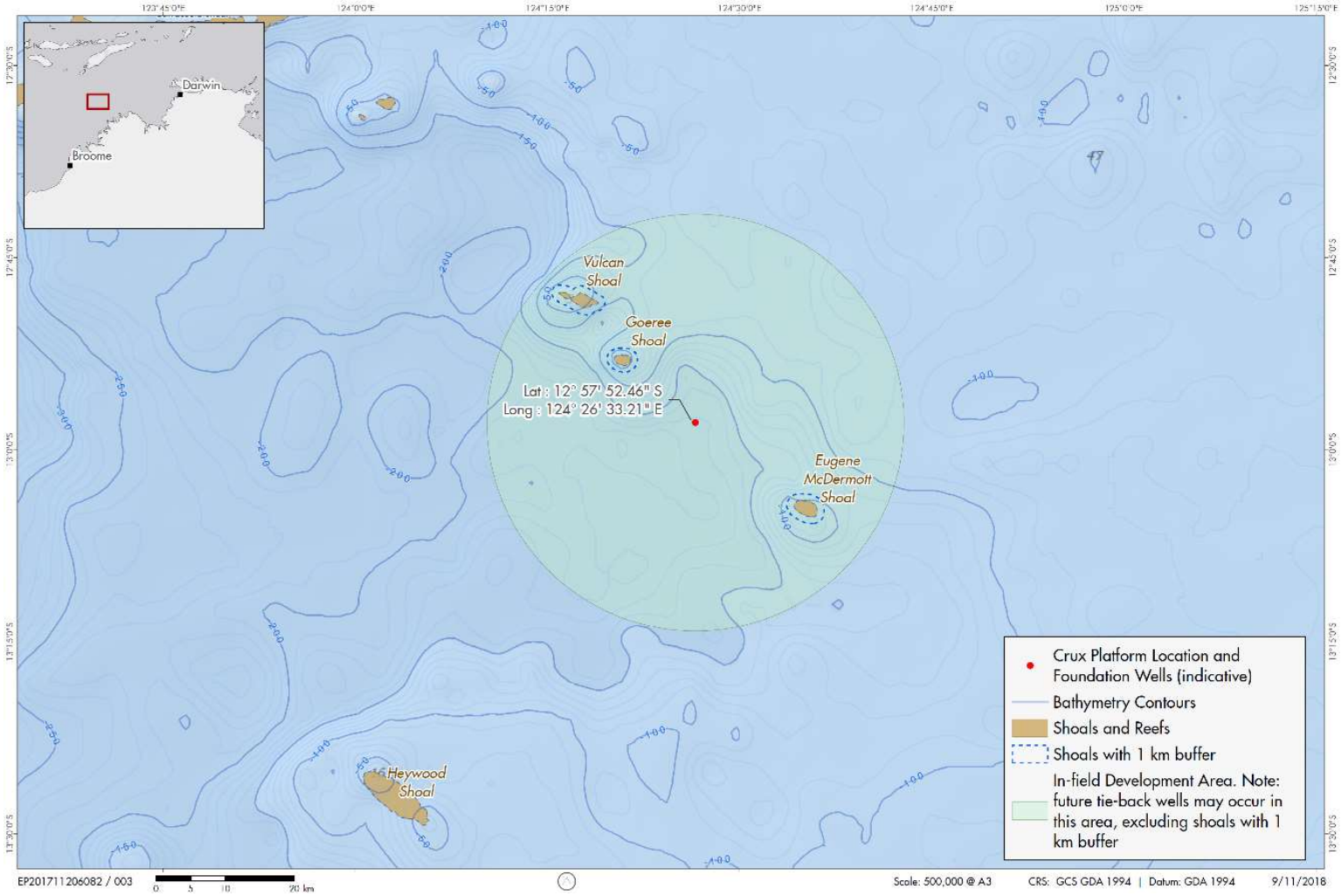


Figure ES-3: In-field Development Area



Figure ES-4: Export Pipeline Corridor

Project Schedule

It is expected that Front End Engineering Design (FEED) engineering for the project is expected to commence in 2019 with the Financial Investment Decision (FID) currently anticipated to occur in 2020. From FID it will take approximately 4 to 5 years for the platform to be fully designed, constructed off-site and towed to location. Whilst the platform is being built, the subsea production wells would be drilled and suspended until installation of the platform facilities, after which the wells would be completed, hooked-up to the platform and brought online.

The Crux platform will have a design life of 20 years. However, subject to the future investment decisions, operations may extend project life.

Decommissioning will be undertaken at the end of field operations.

Project Stages

The key execution stages of the project are:

- development drilling, including tie-back and dry tree completion
- installation of the platform jacket and topsides
- installation and hook up of export pipeline and subsea integration system to the platform facilities
- commissioning
- operations and maintenance (note, this includes any future subsea tie-back developments within the in-field development area), and
- decommissioning.

The key activities within these project stages are summarised in Table ES-1.

Additional gas reservoirs within the in-field development area may be tied back to the Crux platform. The development of these reservoirs will broadly involve the same key stages and activities as those used in the development of the Crux field, with the exception of completion with subsea trees.

Table ES-1: Crux Project Stages and Key Activities

Project Stage	Key Activities
Development drilling – including well tie-back to the platform and well completion	• Drilling and temporary suspension of production wells • Foundation wells tied-back and completed with dry tree using a Modular Platform Rig temporarily installed on the Crux platform • Wells perforated and unloaded with a coiled tubing unit and a temporary test package
Installation and hook-up of platform, export pipeline and subsea integration system	• Transport, installation and piling of jacket • Transport and installation of platform topsides • Installation and pre-commissioning (e.g. hydrotesting and dewatering) of export pipeline • Installation of subsea integration system, including Crux pipeline end termination, Prelude pipeline end manifold and risers.
Commissioning	• Commissioning testing and monitoring topside equipment on the platform and the export pipeline

Project Stage	Key Activities

Operations and maintenance	• Well, flowline and riser operations
	• Remote production and processing operations
	• Planned maintenance and shutdown campaigns
	• During operations, additional fields within the in-field development area may be developed. Key activities associated with the development of these fields may include:
	  ○ Installation and commissioning of subsea facilities to support future subsea tie-backs
	  ○ Installation and commissioning of future compression module

Decommissioning	• Well abandonment • Decommissioning of the platform • Decommissioning of subsea facilities and export pipeline

Key Project Aspects

Key aspects associated with project activities that can interact with the environment are summarised below:

- **Physical presence** – The physical presence of the project will arise from the installation of physical features, such as wells, well tie-back infrastructure, subsea facilities and the export pipeline, and from the presence of the Crux platform and project vessels.
- **Vessel movements** – A number of vessels will be required throughout the project to undertake specific activities. Vessel movements within the project area are expected to be highest during the installation phase of the project.
- **Light emissions** – Artificial light from activities associated with the project will result in light spill to the surrounding marine environment. Light emissions are anticipated to be highest primarily during commissioning and start-up and upset conditions due to the increased presence of vessels and requirement for flaring during commissioning activities. Lighting of the platform will be reduced to a minimum during periods when the facility is not occupied.
- **Underwater noise** – Underwater noise will be produced during all stages of the project from development drilling, installation activities, vessel and helicopter movements, and decommissioning activities. The main sources of noise will be from pile driving activities for the installation of the platform foundations, and from vessel engines and machinery.
- **Atmospheric emissions** – Atmospheric emissions associated with the project will be generated by a number of sources, including combustion emissions from power generation and processing facilities, periodic flaring of gas during development drilling, commissioning/start-up and shutdown activities, operation of a pilot flame on the flare during operations for safety reasons, disposal of TEG regeneration off gas stream to flare, transportation emissions, and fugitive emissions.

  As the Crux project development concept is premised on providing a supply of back-fill gas for the continued operation of the Prelude FLNG facility, the majority of the emissions are accounted for in the design and operation of the Prelude FLNG facility and have been subject to prior assessment and approval through the Prelude FLNG EIS and subsequent EPs. This OPP addresses emissions specific to the Crux project.

- **Invasive marine species** – The drilling rig, vessels and equipment sourced from outside Australian waters have the potential to introduce or transport invasive marine species (IMS) to the project area, or potentially to other areas through activities such as support vessel interaction with the project area.
- **Liquid discharges** – Liquid discharges will be released to the marine environment throughout the life of the project. Key discharge streams include Produced Formation Water (PFW), wastewater (domestic sewage, greywater, bilge and deck drainage) and utility cooling water (vessels only), hydrotest water, and drill fluids/cuttings discharge.
- **Waste management** – Hazardous and non-hazardous solid wastes (except drilling cuttings and fluids, sewage and putrescible waste) and recyclable materials will be removed from the project area and returned to shore for processing.
- **Emergency events** – Emergency events are incidents that have the potential to trigger impacts that would otherwise not be anticipated during the normal and planned activities. In this OPP, this covers the potential for unplanned events (i.e. accidents or emergencies) resulting in potential large-scale releases of hydrocarbons. While of low probability of occurrence, the consequence has been assessed, and a proposed management framework defined for future implementation.

Assessment of Alternatives

The potential for tie-back of Crux and other nearby reservoirs to Prelude FLNG was flagged as part of the Prelude environmental approvals. Concept Select studies have focused on the backfill opportunities presented for the Prelude FLNG host.

In progressing the Crux project, Shell has undertaken a range of alternative options to inform Concept Select. The Fixed Platform concept was identified as the optimal host type for Crux. It provides inherently lower HSSE exposure and a higher capital efficiency than Floating Production Storage and Offloading (FPSO) concepts.

The decision for the selection of the manning philosophy for the Crux platform gave consideration to the optimum combination of capital efficiency and personnel risk exposure, with NNM platform identified to be optimal to achieve these objectives. The processing facilities required for the platform-based concept are significantly reduced compared to an FPSO concept. Simplification of the topsides facilities and associated reduction in maintenance requirements and manhours provides the opportunity to operate the platform remotely while maintaining the facilities on a campaign maintenance basis.

Shell has also evaluated other alternatives in design that have been key to informing the Crux project, including options for PFW management, carbon dioxide (CO_2) management and power generation. These are presented in the OPP.

Description of the Existing Environment

The OPP describes the key physical, biological, socio-economic and cultural characteristics of the existing environment relevant to the Crux project, including MNES as defined under the EPBC Act.

The existing environment has been described in the context of two areas:

- the **project area**, which consists of the in-field development area and export pipeline corridor (as shown in **Figure ES-3** and **Figure ES-4**), and

- the potential **area of influence** associated with the project. This is informed by the maximum extent of the exposure zone (i.e. low threshold) for hydrocarbons released to the marine environment from the maximum credible spill scenarios that may occur throughout the life of the project. This is a conservative outer estimate, based on a low probability potential for unplanned discharge.

Shell has commissioned a number of baseline studies to characterise the existing marine environment relevant to the project. These baseline studies built on the knowledge undertaken through the Applied Research Programme (ARP) in collaboration with the Australian Institute of Marine Science (AIMS) and industry partner INPEX. These studies included metocean monitoring, baseline studies for water quality, sediment and infauna, benthic habitats and seabed geotechnical conditions.

A summary of the existing environment relevant to the Crux project is provided below, with a full description provided in the OPP.

Physical Environment

Water depths at the in-field development area range between approximately 90 m and 180 m. The seabed is generally relatively flat with a gentle gradient falling from the north-east toward the deeper south-west corner. Along the export pipeline, the general bathymetric profile is characterised by an overall increase in depth in a south-westerly direction, reaching a maximum depth of approximately 280 m.

Climate, oceanography, bathymetry and seabed features, water and sediment quality, air quality and underwater noise are all typical of the region.

Ecosystems, Communities and Habitats

There are no known offshore reefs or islands within or in close proximity to the project area. However, there are a number of emergent oceanic reefs and islands offshore of northern Australia. The main offshore reefs and islands in the region include Ashmore Reef (155 km north-west of the Crux platform), Cartier Island (105 km north-west of the Crux platform), Hibernia Reef (160 km from the Crux platform), Browse Island (158 km south-west of the Crux platform), Seringapatam Reef (270 km south-west of the Crux platform), Scott Reef (290 km south-west of the Crux platform) and Adele Island (314 km to the south-west).

There are a large number of shoals and banks within the Browse Basin and open offshore waters off northern Australia. The shoals closest to the project area are:

- Goeree Shoal – located within the in-field development area with a 1 km exclusion buffer around the shoal, approximately 13 km north-west of the Crux platform
- Eugene McDermott Shoals – located within the in-field development area with a 1 km buffer, approximately 18 km south-east of the Crux platform,
- Vulcan Shoal – located within the in-field development area with a 1 km buffer, approximately 22 km north-west of the Crux platform
- Barracouta Shoals – located approximately 63 km north-west of the Crux platform
- Heywood Shoals – located approximately 67 km south-west of the Crux platform and approximately 21 km from of the export pipeline corridor at the closest point, and

- Echuca Shoals – located approximately 117 km south-west of the Crux platform and approximately 53 km north of the export pipeline corridor.

While the in-field development area has an outer radius of 30 km from the current proposed platform location, a 1 km exclusion buffer from around shoals within this area has been defined in order to avoid potential impacts to these features.

The Crux platform is located 190 km from the nearshore and coastal environments of the Kimberley on the WA coastline.

The OPP presents a review of the Key Ecological Features (KEFs) that occur within or adjacent to the project area and area of influence. Only one KEF is intersected by the Crux project, with the export pipeline intersecting a small portion of the continental slope demersal fish communities. The other KEFs are only relevant in the context of the area of influence and are assessed in the OPP as relevant to unplanned discharges.

Threatened Species and Ecological Communities

An online EPBC Protected Matters Database Search was conducted for the in-field development area, export pipeline corridor and area of influence. A summary of the results is presented below:

- in-field development area – the search identified 20 listed threatened fauna species and 33 listed migratory species (17 of which are also listed as threatened) that may occur or have habitat in the area,
- export pipeline corridor – the search identified 20 listed threatened fauna species and 33 listed migratory species (17 of which are also listed as threatened) that may occur or have habitat in the area. All listed threatened and migratory species in the in-field development area were also identified as occurring in the export pipeline corridor.
- area of influence – the search identified 41 listed threatened fauna species and 89 listed migratory species (27 of which are also listed as threatened) that may occur or have habitat in the area.

A review of the DoEE National Conservation Values Atlas determined that the in-field development area is located within a biologically important foraging area for whale sharks although the published Conservation Advice and tagging studies indicate this is more likely to be a migration corridor than a significant foraging area. No other Biologically Important Areas are intersected or overlapped by the project area.

Socio-economic and Cultural Environment

Given the remote distance of the proposed Crux platform (approximately 190 km offshore north-west Australia and 620 km north-north-east of Broome), there are limited socio-economic interactions, and expected to be primarily related to other marine users (specifically other marine traffic, oil and gas facilities and commercial fishing).

It is expected that the Crux project will utilise the onshore facilities (Broome and Darwin) used to service the Prelude FLNG facility, and leveraging the established supply chain, logistics and community partnerships that have been embraced by Shell and its supply chain partners to date.

There are no World Heritage properties in, or in the immediate surrounds of, the project area. Similarly, there are no National Heritage properties or Ramsar wetlands in, or in the immediate surrounds of, the project area.

The project area does not overlap with any Australian Marine Parks (AMPs). However, there are a number of AMPs within the area of influence, which are assessed in the OPP as relevant to unplanned discharges.

The project area overlaps with a variety of Commonwealth and WA State commercial fishing management areas, and the OPP identifies fisheries interests within the broader area of influence. Commercial fishing is typically concentrated mostly in coastal waters and minimum fishing effort is known to occur within the vicinity of the project area, given its remoteness offshore.

There are no major shipping routes traversing the in-field development area or export pipeline corridor. The nearest major shipping channel is approximately 560 km to the west of the proposed Crux platform.

The petroleum exploration and production industry is a significant user of offshore waters in northern WA, particularly within and adjacent to the Browse and Northern Bonaparte basins. The closest facility to the proposed Crux platform is the Montara production FPSO facility, which is located approximately 36 km north. The Ichthys project offshore facilities are located approximately 164 km to the south-west of the proposed Crux platform, and the Prelude FLNG facility is approximately 165 km to the south-west of the Crux platform, representing the location where the export pipeline will feed into.

Definition of Acceptable Levels for the Crux Project

The OPGGS (E) Regulations require the proponent to include an evaluation of all the impacts and risks, that reaches a conclusion on whether the impacts and risks will be of an ‘acceptable’ or ‘unacceptable’ level. To this end, Shell has determined acceptable levels of impact to the environmental receptors that may credibly be impacted by the Crux project.

The following were considered when establishing the acceptable levels of impacts and risks outlined in the impact evaluation:

- the principles of ecologically sustainable development (ESD).
- other requirements applicable to the Crux project (e.g. laws, policies, standards, conventions etc.), including significant impacts to MNES. In this context, specific reference to the Significant Impact Criteria under EPBC Act guidance has been defined.
- internal context, including Shell’s environment policy, environmental risk management framework, technical guidance material and opinions of internal stakeholders, and
- external context, including any available information provided by stakeholders during the preparation of the Crux OPP.

Evaluation of Project Environmental Impacts and Risks

The OPP documents the process that identifies and evaluates potential environmental impacts and risks and develops means of mitigating the impacts of the proposed Crux project on the environment, including socio-economic, cultural and human health impacts.

It describes the approach undertaken to evaluate the magnitude of impact to environmental and social receptors from activities associated with the Crux project. This description includes the identification of potential impacts and benefits, and the evaluation of their significance.

The risk and impact assessment approach is based on Shell's standardised Hazards and Effects Management Process, which is consistent with the principles outlined in the Australian Standard AS/NZS ISO 31000:2009 Risk Management and Handbook 203:2006 Environmental Risk Management.

A summary of the relevant environmental impacts and risks presented in the OPP is provided in **Table ES-2**.

The acceptability of the impacts and risks associated with each of the aspects of the Crux project was assessed. Shell applies the following process to demonstrate acceptability of residual impacts and risks (i.e. taking into account management measures):

- residual planned impacts that are ranked as minor or less (i.e. minor, slight, no effect or positive effect) and residual risks for unplanned events ranked negligible and minor, are inherently 'acceptable', if they meet legislative and Shell requirements and the established acceptable levels of impacts and risks.
- moderate residual impacts, and moderate and major residual risks, are 'acceptable' if good industry practice can be demonstrated. In this acceptability evaluation, in addition to the considerations above, the following points are also considered:
    - internal context – the proposed controls are consistent with Shell policies, procedures and standards
    - external context – consideration of stakeholder expectations, objections and claims, and
    - other requirements – the proposed controls are consistent with national and international standards, laws and policies.
- major and massive magnitude effects from planned impact, and massive residual risks from unplanned risks, are 'unacceptable'.

The residual impacts and risks for each aspect of the Crux project were determined to be acceptable following implementation of the key management controls, as outlined in **Table ES-2**.

Table ES-2: Summary of Environmental Impacts and Risks Relevant to the Crux Project

Aspect	Project Component/Activity	Residual Impact/ Risk	Key Management Controls	Environmental Performance Outcomes
Physical presence and vessel movements	Planned impacts resulting from the physical presence of the Crux project, including: • drilling of the foundation wells with a moored semi-submersible drilling rig • physical presence of the Crux platform, export pipeline and subsea integration system, • presence of project vessels and vessel movements, and • seabed disturbance from project footprint.	Minor	All project vessels operating within the project area will adhere to the navigation safety requirements contained within the International Regulations for Preventing Collisions at Sea 1972 (COLREGS), Chapter 5 of The International Convention for the Safety of Life at Sea 1974 (SOLAS Convention), International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW Convention), the *Navigation Act 2012* and any subsequent Marine Orders, which specify standards for crew training and competency, navigation, communication, and safety measures. Maintenance of a minimum 1 km buffer from shoals within the in-field development area. Vessels will adhere to the requirements of the EPBC Regulations Part 8.1 – Interacting with cetaceans, (except in emergency conditions or when manoeuvring is not possible, such as in the case of pipelay activities), which include: • implement a caution zone of 150 m for dolphins and 300 m for whales • vessels will not knowingly approach closer than 100 m to a whale and 50 m for a dolphin (i.e. no approach zone) • make sure a vessel does not drift or approach within 50 m of a dolphin or 100 m of a whale • vessels will not knowingly travel > 6 knots within the caution zone of a whale or dolphin, and • there will not knowingly be no more than three vessels within 300 m of a whale (i.e. caution zone). All areas of the seabed disturbed by installation activities will be surveyed prior to installation (the Crux NNM platform location and export pipeline corridor have been surveyed as part of the baseline environmental studies for the Crux project). Validate that the Crux platform, export pipeline and subsea integration system facilities are laid according to planned locations within allowable tolerances.	***Physical and Biological Environment*** Direct impacts to benthic habitats from the Crux project will be limited to < 5% of the total project area. Impacts to the Continental slope demersal fish communities KEF will not exceed the Commonwealth marine environment significant impact criteria. No direct impacts to the biological communities at Goeree Shoal, Eugene McDermott Shoal and Vulcan Shoal will occur as a result of the Crux project. ***Threatened Species and Ecological Communities*** No collisions between project vessels and marine fauna listed as threatened or migratory under the EPBC Act will occur within the Crux project area. ***Socio-economic Environment*** No adverse interactions between Shell's activities within the Crux project area and other marine users.
	Unplanned risks resulting from the physical presence of the Crux project, including: • presence of project vessels and vessel movements – collision with marine fauna.	Minor		

Aspect	Project Component/Activity	Residual Impact/ Risk	Key Management Controls	Environmental Performance Outcomes
			An anchoring plan will identify suitable areas for anchors to be placed within the in-field development area and will confirm no anchoring on shoals. Australian Hydrographic Service will be advised of project activities and installed infrastructure to facilitate issuing Notices to Mariners. *Decommissioning* Development and implementation of a project decommissioning plan which considers environmental impacts and risks. Prior to the end of operating life, a comparative assessment of potential decommissioning options will be undertaken to inform the development of a Decommissioning EP that will be submitted to NOPSEMA. The comparative assessment will consider the merits of each option in the context of health, safety and environmental protection, technological feasibility, local capacity, regulatory compliance, public participation and economic stewardship within a broader ALARP framework to inform selection of the preferred decommissioning strategy. The Decommissioning EP will present the outcomes of the comparative assessment and include an ALARP and acceptability assessment of the preferred option. The acceptability assessment will consider ESD, industry standard at the time and stakeholder expectations. The Decommissioning EP will be implemented for the duration of the decommissioning activities.	Displacement of other marine users within the Crux project area restricted to: • temporary displacement from project activities, and • exclusion from gazetted Petroleum Safety Zones. Other marine users will be provided with information on the timing, nature and scale of aspects of the Crux project through Shell's consultation program.
Light emissions	Planned impacts resulting from light emissions arising from the Crux project.	Minor	External lighting on offshore facilities/infrastructure will be minimised through design to that required for navigation, and safety of deck operations, except in the case of an emergency. Flaring during operations is optimised to enable the safe and economically efficient operation of the facility.	***Biological Environment*** No mortality of, or significant impacts to, threatened and migratory MNES species as a result of artificial light emissions from the Crux project.
Underwater noise	Planned impacts resulting from underwater noise generated during the Crux project, including: • piling	Minor	Any VSP activities conducted at the development well will comply with 'Standard Management Procedures' set out in EPBC Act Policy Statement 2.1 – Interaction between Offshore Seismic Exploration and Whales: Industry Guidelines (or the contemporary requirements at the time of the activity), specifically:	***Threatened Species and Ecological Communities*** No mortality of, or significant impacts to, threatened and migratory MNES species as a

Aspect	Project Component/Activity	Residual Impact/ Risk	Key Management Controls	Environmental Performance Outcomes
	• Vertical Seismic Profiling (VSP) • operations, and • vessels.		• pre-start-up visual observations. Visual observations for the presence of whales by a suitably trained crew member will be carried out at least 30 minutes before the commencement of VSP. • start-up and normal operating procedures, including a process for delayed start-up, should whales be sighted. Visual observations by trained crew should be maintained continuously. • night time and low visibility procedures. Pile driving activities will follow standard industry controls for offshore piling which include: • safety zones – observation and shutdown zones • standard management and mitigation procedures, including pre-start, soft start, normal operation, stand-by and shut-down procedures • trained crew members as observers. Maintenance of a minimum 1 km buffer from shoals within the in-field development area.	result of underwater noise from the Crux project.
Atmospheric emissions	Planned impacts resulting from atmospheric emissions arising from the Crux project, including: • decline in local or regional air quality, and • contribution to the incremental build-up of greenhouse gas in the atmosphere.	Minor	All drilling rigs, vessels and Crux platform (as appropriate to vessel class) will comply with International Convention for the Prevention of Pollution from Ships (MARPOL) Annex VI (Prevention of air pollution from ships), the *Navigation Act 2012*, the *Protection of the Sea (Prevention of Pollution from Ships) Act 1983* and subsequent Marine Orders. which requires vessels to have a valid IAPP Certificate (for vessels > 400 tonnage) and use of low sulphur fuel, when possible. Complete and submit annual National Greenhouse and Energy Reporting (NGER) reports during the operations stage of the project for the Kyoto Protocol listed (or applicable post-Kyoto agreement at the time of operations) Greenhouse Gas (GHG) emissions on a CO_2 equivalency basis for each facility (as defined in Section 9 of the *National Greenhouse and Energy Reporting Act 2007* and National Greenhouse and Energy Reporting Regulations 2008) by fuel type, and the relevant requirements of the National Greenhouse and Energy Reporting (Safeguard Mechanism) Rule 2015.	***Physical Environment*** No significant impacts to air quality as a result of atmospheric emissions during the Crux project.

Aspect	Project Component/Activity	Residual Impact/ Risk	Key Management Controls	Environmental Performance Outcomes
			GHG and National Pollutant Inventory reporting records (or contemporary requirements at the time of the activities) will be complied with during the project. Flaring during operations is optimised to enable the safe and economically efficient operation of the facility. Selection of gas turbine generators during design process considers energy efficient (i.e. low emission) equipment. Tri-ethylene glycol off gas will not be vented but sent to the flare for combustion as long as the flare is ignited.	
Invasive marine species	Unplanned risks associated with the introduction of invasive marine species (IMS) as a result of the Crux project.	Moderate	Ballast water exchange operations will comply with the International Maritime Organisation (IMO) International Convention for the Control and Management of Ships' Ballast Water and Sediments 2004 (as appropriate to vessel class), Australian Ballast Water Management Requirements, *Protection of the Sea (Harmful Anti-fouling Systems) Act 2006* and *Biosecurity Act 2015*, including: • all ballast water exchanges conducted > 12 nautical miles from land • vessel Ballast Water Management Plan stipulating that ballast water exchange records will be maintained, and • completion of Department of Agriculture and Water Resources Ballast Water Management Summary sheet for any ballast water discharge in Australian waters). Biofouling management for vessels in accordance to the IMO Guidelines for the Control and Management of Ships Biofouling to Minimise the Transfer of Invasive Aquatic Species. The International Convention on the Control of Harmful Anti-fouling Systems on Ships will be complied with, including vessels (of appropriate class) having a valid International Anti-Fouling System Certificate. Compliance with the Commonwealth *Biosecurity Act 2015,* WA *Fish Resources Management Act 1994* and *Aquatic Resources Management Act 2016*, NT *Fisheries Act* and associated regulations. Alignment with the *National biofouling management guidance for the petroleum production and exploration industry*, and the WA	***Ecosystems, Communities and Habitats*** No IMS of concern established in the natural environment (beyond the installed project infrastructure) as a result of the Crux project.

Aspect	Project Component/Activity	Residual Impact/ Risk	Key Management Controls	Environmental Performance Outcomes
			Department of Primary Industries and Regional Development *Biofouling Biosecurity Policy*. Maintenance of a minimum 1 km buffer from shoals within the in-field development area.	
Waste management	Unplanned risks resulting from an accidental release of hazardous or non-hazardous solid waste to the marine environment.	Slight	All discharge of waste from vessels will comply with relevant MARPOL 73/78, *Navigation Act 2012* and *Protection of the Sea (Prevention of Pollution) Act 1983* and subsequent Marine Order requirements (as appropriate for vessel classification). Waste management procedures will be implemented for the Crux project that: • provide for waste segregation and storage • safe handling and transport of waste, and • appropriate waste classification and disposal, recycling and landfill. The disposal of non-hazardous and hazardous wastes will be tracked to confirm they are disposed of at an appropriately licensed waste facility.	***Threatened Species and Ecological Communities*** No mortality of, or significant impacts to, threatened and migratory MNES species as a result of unplanned waste discharge to sea during the Crux project.
Liquid discharges	Planned impacts resulting from planned liquid discharges from the Crux project, including: • PFW (including non-routine discharges of off-specification PFW) • wastewater • hydrotest water, and • drilling fluids and cuttings.	Minor	*Utility Discharges* All planned discharges from vessels will comply with relevant requirements of MARPOL 73/78, the *Navigation Act 2012*, *Protection of the Sea (Prevention of Pollution from Ships) Act 1983* and any subsequent Marine Orders requirements (as appropriate for vessel classification). The Crux platform deck drainage shall be managed to reduce impacts on the environment. Oily bilge water from machinery space drainage is treated to a maximum concentration of 15 ppm oil-in-water prior to discharge from vessels, as specified in MARPOL 73/78 (Annex I). Offshore discharge of sewage from vessels will be in accordance with Marine Order 96.	***Physical and Biological Environment*** No significant impacts to sediment quality or water quality from liquid discharges during the Crux project. Substantial impacts to sediment quality and water quality from the Crux project restricted to within < 1,000 m from the discharge source at least 95% of the time. Direct impacts to benthic habitats from the Crux project will be limited to < 5% of the total project area.
	Unplanned risks resulting from accidental liquid discharges during the Crux project, including: • minor accidental releases of chemicals/hydrocarbons to the environment.	Moderate		

Aspect	Project Component/Activity	Residual Impact/ Risk	Key Management Controls	Environmental Performance Outcomes
			Food wastes will be macerated to < 25 mm particle size whilst operational prior to discharge to sea, in accordance with Marine Order 95. Bunding around hydrocarbon contaminated areas to reduce the potential for minor accidental releases of chemicals/hydrocarbons to the environment. *Chemical Discharges* For chemicals planned to be used in production and process (including in the subsea facilities and well) and for hydrotesting, and which will be discharged to the marine environment, will be selected in accordance with the Chemical Management Process for chemical selection and assessment of effects on the environment. *Produced Water Discharges* An environmental monitoring program and adaptive management framework will be developed for PFW. The oil-in-water concentration of PFW will be continuously monitored by an online analyser, while available, which will be fitted with an alarm that activates if the oil-in-water concentration is > 30 mg/L. *Drilling Fluid and Mud Discharges* No planned discharge of whole SBM will occur during development drilling. When using SBM, the solids control equipment will reduce the residual base fluid on cuttings content prior to discharge overboard. Residual SBM on cuttings will be less than 10% by weight (w/w), averaged over all well sections using SBM.	No mortality of, or significant impacts to, threatened and migratory MNES species as a result of liquid discharges during the Crux project. Impacts from liquid discharges from the Crux project on the Continental slope demersal fish communities KEF will not exceed the Commonwealth marine environment significant impact criteria. No direct impacts to the biological communities at Goeree Shoal, Eugene McDermott Shoal and Vulcan Shoal will occur as a result of liquid discharges from the Crux project.

Aspect	Project Component/Activity	Residual Impact/ Risk	Key Management Controls	Environmental Performance Outcomes
Unplanned spills	Unplanned risks resulting from a worst-case credible spill scenario from: • loss of well control • loss of process storage tank containment • loss of containment from export pipeline, and • loss of fuel from vessel.	Major	Vessel specific controls will align with MARPOL 73/78, the *Navigation Act 2012,* the *Protection of the Sea (Prevention of Pollution from Ships Act 1983* and subsequent Marine Orders (as appropriate for vessel classification), which includes managing spills aboard, emergency drills and waste management requirements. All vessels involved in the project will have a valid Shipboard Oil Pollution Emergency Plan or Shipboard Marine Pollution Emergency Plan (as appropriate for vessel classification) which is maintained including: Spill Kit – Pollution Control Equipment container/ box is located at a strategic location, containing adequate equipment/material (minimum as per the Shipboard Oil Pollution Emergency Plan) to control spills of pollutants on board. All project vessels operating within the project area will adhere to the navigation safety requirements contained within the COLREGS, Chapter 5 of the SOLAS Convention, STCW Convention, the *Navigation Act 2012* and any subsequent Marine Orders, which specify standards for crew training and competency, navigation, communication, and safety measures. Offshore Vessel Inspection Database or equivalent reviewed prior to mobilisation of project vessels. Australian Hydrographic Service notified of location of installed infrastructure to facilitate inclusion on nautical charts. Australian Hydrographic Service advised of project activities and installed infrastructure to facilitate issuing Notices to Mariners. Accepted WOMP in place for all wells, in accordance with the OPGGS Act requirements, including: • installation of a Blowout Preventer (BOP) during drilling operations, and • regular testing of BOP. Accepted EPs and Oil Pollution Emergency Plans (OPEPs) in place for all petroleum activities appropriate to the nature and scale of the credible hydrocarbon spill risks. The OPEP include an Operational and Scientific Monitoring Program will be initiated and implemented as appropriate to the nature and scale of the spill and the existing environment, as informed by a net environmental benefit assessment. The OPEP shall consider:	No emergency events associated with the unplanned release of Crux condensate or vessel fuel to the marine environment during the Crux project.

Aspect	Project Component/Activity	Residual Impact/ Risk	Key Management Controls	Environmental Performance Outcomes
			• relief well planning and preparedness • interim source control (e.g. capping stacks) • oiled wildlife response, and • operational and scientific monitoring. Stakeholder consultation throughout the Crux project, including consultation consistent with the requirements of the OPGGS (E) Regulations for all subsequent petroleum activities and associated EPs. Where vessel dynamic positioning systems are required, they shall be in working order whilst within the Crux platform safety zone at all times. Development and implementation of a maintenance management system for the Crux platform, export pipeline and subsea infrastructure. Development of simultaneous operations (SIMOPS) plans where interactions with other activities (e.g. Prelude operations, backfill installations) may credibly occur. Concrete coating of the pipeline reduces the risk of a dropped object damaging the pipeline.	

Cumulative Impacts

The potential for cumulative impacts and risks resulting from the Crux project were considered from two perspectives:

- How might aspects from the Crux project compound with aspects of existing activities within the Timor Sea region?
- How might an environmental receptor be affected by multiple aspects of the Crux project and other activities?

Given the low likelihood of unplanned events that may arise during the Crux project (e.g. large hydrocarbon spills), unplanned events have not been considered in the assessment of cumulative impacts.

The aspects-based cumulative impact assessment considered how the aspects from the Crux project, and the associated environmental impacts and risks, may interact with aspects from other activities in the region to result in increased environmental risks and impacts. Other activities identified included:

- the Prelude FLNG facility
- the Montara production facility
- Ichthys offshore production facility, and
- commercial shipping.

The planned aspects identified that were common to these activities and the Crux project were:

- physical presence and vessel movements
- light emissions
- atmospheric emissions, and
- liquid discharges.

The receptor-based assessment of cumulative impacts considered how multiple aspects of the Crux project may compound to increase the impacts for a given receptor. Receptors at susceptible to cumulative impacts include:

- water quality
- sediment quality
- benthic communities
- shoals and banks, and
- threatened species and ecological communities.

The Crux project will not result in any material cumulative impacts to the marine environment at a local scale as there is no significant overlap with other existing facilities. No cumulative impacts to key values and sensitivities are expected. The receptor-based cumulative impact assessment concluded that the potential for cumulative impacts from different aspects of the Crux project is low and confined to the waters, sediment and benthic habitats and communities in the immediate vicinity of the Crux platform. Therefore, the residual impact and risk rankings detailed in the previous aspect assessments remain unchanged.

Regional cumulative impacts may occur in terms of incremental increases in vessel movements and CO_2 emissions. However, these have been assessed as minor and do

not change the residual risk rankings for any of the potential impacts assessed in this OPP.

The potential cumulative impacts to environmental receptors are low and will be largely restricted to the waters, sediment and benthic habitats and communities in the immediate vicinity of the Crux platform. Potential cumulative impacts, both aspect- and receptor-based, were all determined to be within the acceptable levels defined for the Crux OPP.

Health Impacts

The anticipated health impacts associated with the Crux project with potential to affect any onshore communities, in particular the onshore logistics bases of Broome and Darwin, are expected to be very minor with due consideration of:

- the remote offshore context for this project. The majority of construction and operation activities are well offshore, 620 km from Broome and approximately 700 km from Darwin
- the logistical arrangements for transiting workers aim to minimise overnight stays in onshore locations, and seeking to utilise existing established supply chain logistics now in place for Prelude FLNG, and
- existing industrial areas will be utilised for bases in Broome and/or Darwin.

Given the offshore nature of the Crux project, the effects of Crux project on community health (e.g. community health services or workforce influx pressures) are expected to be very minor, even during high-activity periods such as construction.

Shell is committed to reducing the potential impacts of the Crux project on Australian communities, and intends to implement the following measures:

- an ongoing stakeholder engagement program will be undertaken as the project progresses through future phases of development planning and implementation.
- emergency planning will include early discussions with local health authorities on local community arrangements to provide appropriate support in the scenario of medical response.
- the Crux platform is designed to operate under a NNM concept, which will deliver benefits of minimal workforce requirements and commensurate minimal disturbance to onshore communities
- scheduling of flights in accordance with the Broome International Airport Fly Neighbourly Policy.
- Shell will aim to replicate Prelude planned flight considerations (flight plans/times), which are designed to minimise local disturbance:
    - no flights on Sundays
    - reduced number of flights on Saturday, and
    - flying route to avoid Roebuck Bay and local Aboriginal community (Mallingbar).
- Shell is considering local content and progressing an AIP plan as part of the development of the Crux project.

Based on the points discussed above, Shell considered the impacts and risks from health impacts relevant to the Crux project to be acceptable.

Environmental Performance Framework

Shell will develop a health, security, safety and environmental management system (HSSE-MS) that encompass all stages of the Crux project. The HSSE-MS will provide the means that environmental risks and impacts from the Crux project are managed to a level that is acceptable and the EPOs described in this OPP achieved. Shell will draw on existing corporate policies, environmental systems and processes, which have been developed and improved continuously throughout Shell's considerable operational history. Elements of the implementation of the HSSE-MS include:

- contractor HSSE management process,
- competency requirements and assurance,
- environmental audits and assurance,
- management of incidents and non-conformances,
- emergency preparedness, including:
  - OPEPs, and
  - OSMPs.
- monitoring and measurement of emissions, discharges and environmental quality, including:
  - marine discharges, and
  - atmospheric emissions.

Given the intent of an OPP as an early stage, 'whole-of-project' approvals document, the EPOs defined for the Crux project are appropriately high-level, with a focus on the key environmental outcomes to be achieved commensurate to the impact/risk conclusions. Consequently, the environmental performance framework is also a high-level, and will be developed and refined as the design of the Crux project progresses.

Activity-specific EPs will be developed for all petroleum activities within the scope of the Crux EP, which will contain detailed EPOs, environmental performance standards, measurement criterial and detailed implementation strategy. The EPOs in the EPs will maintain an equivalent, or better, level of environmental performance.

1. Introduction

1.1. Introduction to the Crux Project

Shell Australia Pty Ltd (Shell), together with Joint Venture Participants Seven Group Holdings (SGH) Energy and Osaka Gas, is progressing planning for the prospective development of the Crux gas field, located approximately 160 km north-east of the Prelude field in the northern Browse Basin, offshore the Kimberley coast, Western Australia (WA) (**Figure 1-1**).

The Crux field is located in Commonwealth marine waters in the northern Browse Basin, 190 km offshore north-west Australia and 620 km north-north-east of Broome.

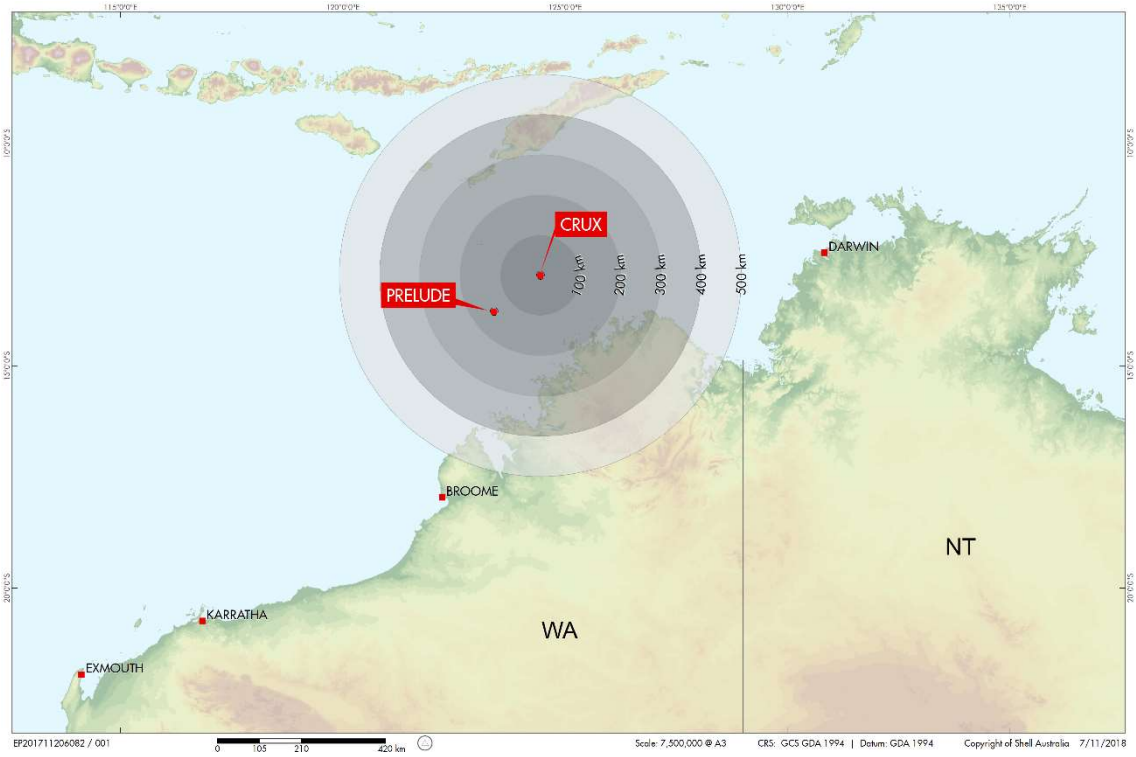


Figure 1-1: Location of the Crux Project

The Crux project has been identified as the primary source of backfill gas supply to the Prelude Floating Liquefied Natural Gas (FLNG) facility, previously approved under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), through decision EPBC 2008/4146. The Crux project will not result in any increase in production capacity of the Prelude FLNG facility. Rather, Crux will provide backfill capacity for the Prelude FLNG facility. In summary, the proposed Crux project consists of a Not Normally Manned (NNM) platform in 165 m water depth; with five production wells, minimal processing and utility systems, tied back to the existing Prelude FLNG facility via a 165 km 26-inch export pipeline. Crux will be operated remotely from the Prelude FLNG facility.

The current Crux project concept, shown in **Figure 1-2**, comprises:

- a NNM platform, which includes dry trees, processing facilities and associated utility systems
- five production wells with subsea wellhead system tied back through rigid concentric tubulars to the NNM platform and completed with dry trees

- a 26-inch export pipeline, approximately 165 km long, which ties the platform back to the Prelude FLNG facility, and
- subsea integration system connecting the export pipeline system with Crux platform and the Prelude FLNG facility, comprising risers, subsea isolation facilities, pipeline inspection gauge (PIG) receiver and associated control systems.

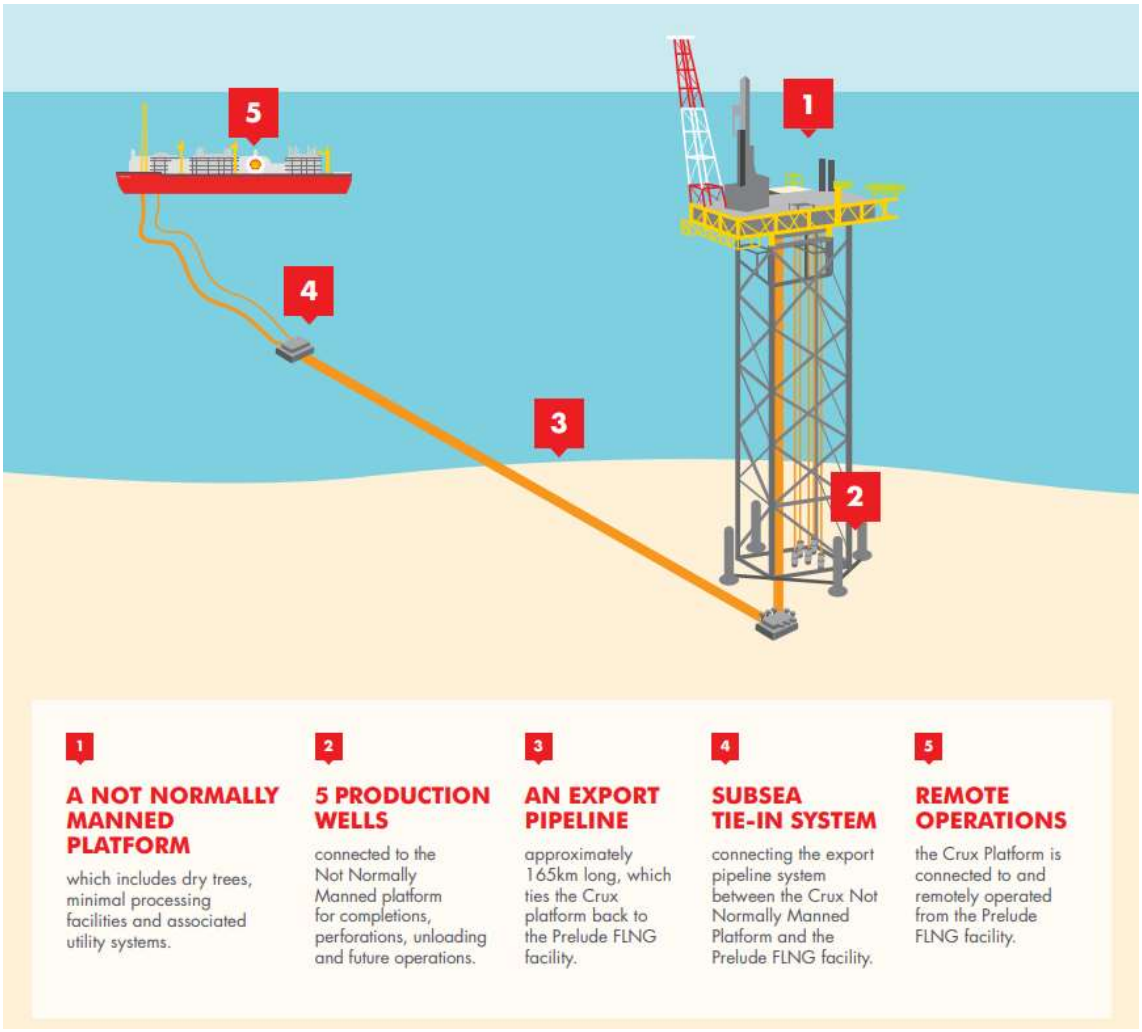


Figure 1-2: Crux Project Concept

A summary of the key project stages and development activities for the Crux project is presented in **Table 1-1**. Front-End Engineering and Design (FEED) for the project is expected to commence in 2019 with the Financial Investment Decision (FID) currently scheduled to occur in 2020. The project is anticipated to have a 20-year design life. However, subject to future investment decisions, the project may be extended.

Table 1-1: Key Project Stages and Development Activities

Project Stage	Key Activities
Development drilling – including well tie-back to the platform and well completion	• Drilling of production wells • Foundation wells tied-back and completed with dry tree using a Modular Platform Rig (MPR) temporarily installed on the Crux platform • Wells perforated and unloaded with a coiled tubing unit and a temporary test package
Installation and hook-up of platform, export pipeline and	• Transport, installation and piling of jacket • Transport and installation of platform topsides

Project Stage	Key Activities
subsea integration system	• Installation and pre-commissioning (e.g. hydrotesting and dewatering) of export pipeline • Installation of subsea integration system, including Crux pipeline end termination, Prelude pipeline end manifold and risers
Commissioning	• Commissioning testing and monitoring topside equipment on the platform and the export pipeline
Operations and maintenance	• Well, flowline and riser operations • Remote production and processing operations • Planned maintenance and shutdown campaigns • During operations, additional fields within the in-field development area may be developed. Key activities associated with the development of these fields may include: o Installation and commissioning of subsea facilities to support future subsea tie-backs, and o Installation and commissioning of future compression module
Decommissioning	• Well abandonment • Decommissioning of the platform • Decommissioning of subsea facilities and export pipeline

The in-field development area, as defined in this OPP, incorporates the development of the Crux field and associated gas reservoirs that may be developed as future staged developments and tied back to the Crux platform.

1.2. Development Objectives

The objectives of the proposed project are to:

- commercialise the hydrocarbon resources of the Crux project and optimise recovery of these resources
- manage all environmental, health, security and safety issues in accordance with recognised industry standards and Shell's requirements
- provide an acceptable return on investment, and
- provide for a commercial means to unlock the stranded gas reserves and backfill the Prelude field.

Shell is confident that the project can be developed and operated in an environmentally sustainable manner and that environmental impacts and risks can be managed to an acceptable level.

1.3. OPP Purpose and Scope

The impact assessment of the proposed project has been aligned to meet the requirements of an Offshore Project Proposal (OPP) regulated under the Commonwealth Offshore Petroleum and Greenhouse Gas Storage (Environment) Regulations 2009 (OPGGS (E) Regulations) and administered by the National Offshore Petroleum Safety and Environmental Management Authority (NOPSEMA).

An assessment of the proposed Crux project has been progressed, in accordance with the Shell Health, Security, Safety, Environment and Social Performance (HSSE & SP) Control Framework, to *'identify and assess the potential environmental, social and health impacts of a project, and to implement measures so that negative impacts are minimised, and positive impacts are optimised.'*

The purpose of the OPP is to describe:

- the project area, the proposed activities and its expected timeframe

- the environmental management framework for the proposal, including legislation and other requirements
- the existing natural, social and economic environments of the local and regional setting, including issues or sensitivities particular to the proposal
- the possible impacts and risks to the environment from both planned (normal) and unplanned (emergency) operations
- Shell's Health, Security, Safety and Environment and Social Performance (HSSE & SP) Commitment and Policy and the environmental performance objectives that derive from the Policy, and
- a framework for the forward environmental management and performance, including definition of key management controls and Environmental Performance Outcomes (EPOs), from which environmental performance will be measured and monitored throughout the life of the project.

The OPP is designed as an early stage, whole-of-project assessment. Subject to NOPSEMA's acceptance of the OPP, it will form the basis of future activity-specific Environment Plans (EPs) that will be submitted to NOPSEMA for acceptance as part of subsequent staged development and permitting.

The structure of the OPP and the relevant sections of the OPGGS (E) Regulations are shown in **Table 1-2**. This OPP has been prepared in alignment with current published guidance on OPP content requirements (NOPSEMA 2018a), and related Policy for OPP Assessment (NOPSEMA 2018b).

Table 1-2: OPP Structure, Content and Relationship to the OPGGS (E) Regulations

OPPGS (E) Regulation	Requirements	Section
Regulation 5A Submission of an Offshore Project Proposal		
5A (5) (a)	Include the proponent's name and contact details.	Section 1.4
5A (5) (b)	Include a summary of the project, including the following: (i) a description of each activity that is part of the project; (ii) the location or locations of each activity; (iii) a proposed timetable for carrying out the project; (iv) a description of the facilities that are proposed to be used to undertake each activity; and (v) (v) a description of the actions proposed to be taken, following completion of the project, in relation to those facilities.	Section 5
5A (5) (c)	Describe the existing environment that may be affected by the project.	Section 6
5A (5) (d)	Include details of the particular relevant values and sensitivities (if any) of that environment.	Section 6.7
5A (5) (e)	Set out the environmental performance outcomes for the project.	Section 8, Section 9
5A (5) (f)	Describe any feasible alternative to the project, or an activity that is part of the project, including: (i) a comparison of the environmental impacts and risks arising from the project or activity and the alternative; and (ii) an explanation, in adequate detail, of why the alternative was not preferred.	Section 5.8
5A (6)	Requirement to address particular relevant values and sensitivities [as defined in the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act)].	Section 6, Section 7, Section 8
5A (7)	The proposal must:	Section 2

	a) describe the requirements, including legislative requirements, that apply to the project and are relevant to the environmental management of the project; and b) describe how those requirements will be met.	
5A (8)	The proposal must include: a) details of the environmental impacts and risks for the project; and b) an evaluation of all the impacts and risks, appropriate to the nature and scale of each impact or risk.	Section 8
Regulation 11A Consultation with relevant authorities, persons and organisations, etc.		
11A	Consultation with relevant authorities, persons and organisations. [Note while this Regulation relates specifically to consultation required for an EP, the general intent can be applied to an OPP]	Section 4

1.4. Proponent

The project proponent for the Crux project is Shell Australia Pty Ltd (Shell). The Shell Group of companies is the largest equity LNG producer among international energy companies and has the most diverse LNG supply portfolio in the world. The Shell Group has been in Australia since 1901 and has continued to evolve to meet the changing needs of the Australian and international markets. Today, Shell is focused on the exploration, development and production of Liquefied Natural Gas (LNG), domestic gas and associated products such as LPG and condensate. Shell is a major investor in key Australian LNG projects, including the Shell-operated Prelude FLNG Facility.

Shell's Joint Venture Participants for the Crux project are SGH Energy and Osaka Gas. SGH Energy, a subsidiary of SGH, is an Australian oil and gas company with a portfolio of high quality assets and a resources base in the offshore Gippsland Basin in Victoria, and in the Browse Basin in northern WA. Osaka Gas has over 110 years of experience in the energy sector and has grown into a diversified energy company, across the entire natural gas value chain. The Crux Joint Venture Participants bring collective expertise and support for the sustainable commercialisation of the gas fields, in support of backfill to the Prelude FLNG facility.

Contact details for the proponent are:

Shell Australia Pty Ltd

Address: 562 Wellington Street

Perth 6000

Western Australia

Shell Community Hotline:

1800 059 152

https://www.shell.com.au/about-us/projects-and-locations/the-crux-project/crux-community-hotline.html

1.5. Organisation of this OPP

This OPP is prefaced by an Executive Summary and the remainder of the document structure is summarised as follows:

- ***Section 1*** provides an overview of the Crux project, summary of Shell's organisational profile, and outlines the purpose and structure of the OPP.
- ***Section 2*** establishes the policy, legal and administrative framework for the Crux project. It provides an overview of the legislation, standards, guidelines and key publications released by the Department of the Environment and Energy (DoEE) that are considered applicable to the Crux project.
- ***Section 3*** describes the management framework and management system that Shell implements to incorporate the commitments made for the Crux project into its daily business and operations.
- ***Section 4*** provides a summary of Shell's approach to stakeholder engagement, as it relates to the Crux project. It describes the engagement methodology and the outcomes of engagement feedback leading up to the OPP public comment period, as well as Shell's commitment to maintain open ongoing communication with relevant stakeholders.
- ***Section 5*** describes the Crux project and provides details on the key project phases (from development drilling through to decommissioning) and associated activities within the project area as relevant to the assessment of potential environmental impacts and risks. This section also provides an assessment of the alternative development concepts and activities considered early in the project development process.
- ***Section 6*** provides a detailed description of the key physical, biological, socio-economic and cultural values and sensitivities of the existing environment in which the Crux project will be located. It also provides a summary of the Crux baseline environmental studies undertaken to inform the project.
- ***Section 7*** describes the considerations in defining acceptable levels of impact and risk, in the context of the receiving environment relevant to the Crux project.
- ***Section 8*** provides a detailed evaluation of all impacts and risks associated with the project, from both planned activities and unplanned/emergency events, and from a cumulative impact perspective.
- ***Section 9*** outlines the environmental performance framework for the project, and details Shell's overarching delivery mechanism for implementing the commitments made in the OPP. The section also outlines environmental monitoring that will be undertaken throughout operations.
- ***Section 10*** provides a comprehensive summary of all citations and references of supporting literature relevant to the content of the OPP. A list of acronyms used in this document is also included.

2. Policy, Legal and Administrative Framework

2.1. Overview

This section provides an overview of the legislation, standards and guidelines which are applicable to the project, including the following:

- Australian policy, legislation and regulations
- relevant international and/or industry policies, guidelines, standards and technical guidance
- relevant provisions contained within international conventions and protocols to which Australia is a signatory, and
- applicable Shell Standards and Guidelines.

2.2. Commonwealth Policy Framework

The Crux project is located wholly in Commonwealth waters and is therefore subject to Commonwealth legislation. The following are Commonwealth Government policies regarding petroleum development and marine protection that are relevant to the Crux project.

2.2.1 Australian Offshore Petroleum Regime

The Australian Government is responsible for petroleum rights and activities beyond coastal waters (seaward of the first three nautical miles of the territorial sea) to the outer limits of Australia's Exclusive Economic Zone, with title decisions carried out jointly with the relevant regional State or Territory Government (Department of Industry, Innovation and Science (DIIS) 2018).

Onshore and in coastal waters (the first three nautical miles from the coastline), the States and the Northern Territory (NT) allocate petroleum rights, administer petroleum operations and collect royalties on petroleum produced (DIIS 2018). Titles are issued to the private sector by Commonwealth and State Government agencies to facilitate and encourage exploration and development of petroleum reserves within Australia.

2.2.2 Commonwealth National Oceans Policy

Australia's Oceans Policy was introduced in 1998. The policy has a number of aims, including:

- exercising and protecting Australia's rights over its marine jurisdictions
- meeting its obligations under the United Nations Conventions on the Law of the Sea 1982, which was ratified in 1994
- understanding and protecting the marine environment, and
- promoting ecologically sustainable economic development and establishing integrated planning and management.

Under the Oceans Policy, a Nationally Representative System of Australian Marine Parks (AMPs) has been established. These are based on the principles of multiple-use and Ecologically Sustainable Development (ESD). This policy has been implemented through the EPBC Act, as outlined in the Strategic Plan of Action for the National Representative System of Marine Protected Areas (ANZECC 1998).

The Crux project is not located within any AMPs. The closest AMPs to the Crux project are the Kimberley Marine Park and Cartier Island Marine Park, which are located

approximately 95 km south and 100 km north-west of the proposed Crux NNM platform, respectively.

2.3 Legislative Framework

This section describes legislation of relevance to the project. Key legislation is described in **Section 2.3.1**, with other relevant legislation outlined in **Section 2.3.2**.

2.3.1 Key Legislation

2.3.1.1 *Offshore Petroleum and Greenhouse Gas Storage Act 2006*

In order to provide protection of the environment in Commonwealth waters, the *Offshore Petroleum and Greenhouse Gas Storage Act 2006* (OPPGS Act) ensures that all offshore petroleum and greenhouse gas (GHG) storage activities are undertaken in a manner where impacts and risks on the environment are of an acceptable level and reduced to as low as reasonably practicable (ALARP). This includes risks to Matters of National Environmental Significance (MNES) protected under Part 3 of the EPBC Act. The OPGGS Act requires that all activities are consistent with the principles of ESD, as defined in the EPBC Act (Section 3A):

- *"decision-making processes should effectively integrate both long-term and short-term economic, environmental, social and equitable considerations;*
- *If there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation;*
- *The principle of inter-generational equity: that the present generation should ensure that the health, diversity and productivity of the environment is maintained for the benefit of future generations;*
- *The conservation of biological diversity and ecological integrity should be a fundamental consideration in decision-making;*
- *Improved valuation, pricing and incentive mechanisms should be promoted."*

The OPGGS Act and supporting regulations are administered by NOPSEMA. Particularly relevant subordinate regulations of the OPGGS Act are the:

- OPGGS (E) Regulations, which provide further definition and guidance on the environmental management of offshore petroleum and GHG storage activities
- OPGGS (Safety) Regulations, which ensure that facilities are designed, constructed, installed, operated, modified and decommissioned in Commonwealth waters only in accordance with Safety Cases that have been accepted by NOPSEMA, and
- OPGGS (Resource Management and Administration) Regulations, which requires that a Well Operations Management Plan (WOMP) are assessed and accepted by NOPSEMA for existing or proposed offshore facilities.

2.3.1.2 *Environment Protection and Biodiversity Conservation Act 1999*

The EPBC Act and supporting regulations provides for the protection of the environment and conservation of biodiversity in Australia (including Australian waters) by the Commonwealth Government. The EPBC Act is administered by the Commonwealth Minister for the Environment and Energy, with departmental responsibility provided to the DoEE.

Amendments to the OPGGS Act and OPGGS (E) Regulations in February 2014, undertaken as part of the Commonwealth streamlining environmental approvals process,

require MNES to be addressed in assessments of offshore petroleum development approvals. Therefore, the OPP process under the OPGGS (E) Regulations supersedes the Commonwealth referral process under the EPBC Act and replaces the requirement to prepare environmental approvals for submission to DoEE for petroleum development activities in Commonwealth waters. As such, this OPP addresses the EPBC Act requirements for the Crux project.

MNES of relevance to the Crux project OPP are discussed in **Section 6**.

2.3.2 Other Legislation

A detailed listing of other relevant Commonwealth legislation is outlined in **Table 2-1**.

Table 2-1: Commonwealth Legislation Relevant to the Crux Project

Commonwealth Legislation/ Regulation	Summary	Relevance to the Project
Navigation Act 2012	The Act regulates and manages health, safety and environmental (HSE) aspects of legislation for marine vessels in Australian waters. It gives effect to the relevant international conventions relating to maritime issues to which Australia is a signatory, such as the International Convention for the Prevention of Pollution from Ships (MARPOL 73/78). The Act also has subordinate legislation contained in Regulations and Marine Orders.	The project will adhere to MARPOL and the various Marine Orders (as appropriate to vessel class) enacted under this Act.
Protection of the Sea (Prevention of Pollution from Ships) Act 1983 (POTS Act) and Protection of the Sea (Prevention of Pollution from Ships) (Orders) Regulations 1994	The Act regulates discharges from ships to protect the sea from pollution. This includes a prohibition against discharges of oil or oily mixtures, noxious liquid substances, packaged harmful substances, sewage and garbage to the sea. The Act imposes a duty to report certain incidents involving prohibited discharges and to maintain record books and management plans. The Act also enacts MARPOL 73/78 requirements and implements the Marine Orders.	Vessels within the project area are subject to this Act and will adhere to the requirements for discharges and waste management outlined in the relevant MARPOL and Marine Orders (as appropriate to vessel class). The MARPOL annexes and Marine Orders of relevance to the Crux platform include: • Annex I: Marine Order 91 – Marine pollution prevention – oil • Annex III: Marine Order 94 – Marine pollution prevention – packaged harmful substances • Annex V: Marine Order – Marine pollution prevention – garbage, and • Annex VI: Marine Order 97 – Marine pollution – air pollution.
Fisheries Management Act 1994 and related legislation	The Act defines the Australian Fishing Zone (AFZ) and establishes the legislative basis for management plans for Commonwealth fisheries. As a related WA statute, the *Aquatic Resources Management Act 2016*, when it comes into force in January 2019, will become the primary legislation used to manage fishing, aquaculture, pearling and aquatic resources in WA.	The project will be developed with regard to relevant interactions with Commonwealth and State fisheries interests.

Commonwealth Legislation/ Regulation	Summary	Relevance to the Project
Environmental Protection (Sea Dumping) Act 1981	This Act provides for the protection of the environment by regulating dumping into the sea, incineration at sea and artificial reef placements.	The project may result in the release of wastes into the sea. Shell recognises the importance of minimising waste disposal to the marine environment and will adhere to the requirements of this Act. This Act may also be relevant in the context of future decommissioning activities, subject to the decommissioning strategy identified at the time.
National Greenhouse and Energy Reporting Act 2007 National Greenhouse and Energy Reporting (Safeguard Mechanism) Rule 2015	The Act provides a single, national framework for the reporting and distribution of information related to GHG emissions, GHG projects, energy production and energy consumption. Reporting obligations are imposed upon corporations that meet particular emissions/energy thresholds. The Act includes National Greenhouse and Energy Reporting (NGER) requirements and the Safeguard Mechanism requirements.	Shell will report as a corporate group under the Act and emissions from the Crux NNM platform will be incorporated into the total emission reporting by Shell, once the project facility becomes operational. The Safeguard Mechanism will be applied, as relevant to the project context.
Australian Heritage Council Act 2003	This Act identifies areas of heritage value, including those listed on the World Heritage List, National Heritage List and the Commonwealth Heritage List.	The project will take into consideration any heritage values (see **Section 6.6** for details).
Historic Shipwrecks Act 1976 and Historic Shipwrecks Regulations 1978	This Act protects shipwrecks and associated relics In Commonwealth waters that are more than 75 years old. The Act aims to ensure that historic shipwrecks are protected for their heritage values and maintained for recreational, scientific and educational purposes. It is an offence to disturb any shipwreck protected under this Act.	Planned project operations will not interfere with any historical shipwrecks (see **Section 6.6.11** for details).
National Environment Protection Council Act 1994	This Act establishes the National Environment Protection Council (NEPC). The primary functions of the NEPC are to: define National Environment Protection Measures (NEPMs) to ensure that Australians have equivalent protection from air, water, soil and noise pollution, and assess and report the implementation and effectiveness of NEPMs. This Act is mirrored in all States and Territories. For example, in WA the equivalent Act is the *National Environment Protection Council (Western Australia) Act 1996*.	The project will comply with the requirements of the relevant NEPMs.

Commonwealth Legislation/ Regulation	Summary	Relevance to the Project
National Environment Protection (National Pollutant Inventory) Measure 1998 (established under the *National Environment Protection Council Act 1994*)	This measure provides the framework for the development and establishment of the National Pollutant Inventory (NPI), which provides publicly available information on the types and amounts of 93 toxic substances being emitted into the Australian environment. These substances have been identified as important due to their possible effect on human health and the environment. Implementation of the NPI NEPM is the responsibility of each participating jurisdiction.	The project will comply with the NPI NEPM through the reporting of relevant NPI substances.
Ozone Protection and Synthetic Greenhouse Gas Management Act 1989 and Regulations 1995	The Act protects the environment by reducing emissions of ozone depleting substances (ODSs) and synthetic greenhouse gases (SGGs). It controls the manufacture, import and export of ODSs and SGGs and products containing these gases.	The project will adhere to restrictions on import and use of ODSs/SGGs through implementing appropriate measures that control procuring of products which contain these gases.
Biosecurity Act 2015	The Act and its supporting legislation are the primary legislative means for managing risk of pests and diseases entering Australian territory. The Act includes requirements for pre-arrival reporting, ballast water management plans and certificates.	The project will comply with biosecurity requirements, specifically in relation to biofouling and ballast water requirements.
Hazardous Waste (Regulation of Exports and Imports) Act 1989	This Act regulates the export, import and transport of hazardous waste to ensure that hazardous waste is managed appropriately so that human health and the environment are protected from the harmful effects of the waste.	The project will comply with the export, import and transport requirements for hazardous waste.
Telecommunications Act 1997	This Act regulates the telecommunications industry in Australia, including carriers and carriage service providers.	Secondary approvals required for the fibre optic cable (see **Section 5.6.3.4** for details) will consider the requirements of this Act, while noting that the fibre optic cable is not in its own right a petroleum activity under the OPGGS Act and related Regulations.
Australian Jobs Act 2013	The Act details Australian industry participation requirements for major projects valued at A$500 million or more. The Act ensures that information about opportunities to bid for work on major projects is provided by all levels of the project's supply chain.	Shell is preparing an Australian Industry Participation Plan for the project. Refer to **Section 2.5** for further details.

2.4 Administrative Framework

This section outlines the additional administrative approvals required under Commonwealth legislation.

2.4.1 Production Licence

A petroleum production licence is required for offshore petroleum production facilities under the OPGGS Act. A production licence provides the legal right to recover petroleum from an area, subject to meeting conditions specified by the licence.

2.4.2 Infrastructure Licence

An infrastructure licence is required prior to construction or operation of an infrastructure facility in an offshore area under the OPGGS Act. An infrastructure facility includes a facility engaged in petroleum activities that either rests on the seabed or is fixed or connected to the seabed (whether or not the facility is floating).

Shell has not yet applied for an infrastructure licence. The infrastructure licence will be issued by the National Offshore Petroleum Titles Administrator (NOPTA).

2.4.3 Pipeline Licence

A pipeline licence is required for the construction and operation of offshore pipelines, such as the export pipeline, under the OPGGS Act. As per the infrastructure licence, the pipeline licence will be issued by NOPTA.

2.4.4 Environment Plans

Under the OPGGS (E) Regulations, the titleholder is required to submit an EP before commencing an activity and the activity cannot take place until NOPSEMA accepts the EP. EPs must describe the activity, the receiving environment, and provide a detailed evaluation of environmental impacts and risks associated with the activity. The EP is also required to outline appropriate performance outcomes (i.e. EPOs), performance standards and measurement criteria for determining whether the outcomes and standards are met. In addition, an implementation strategy is provided to demonstrate how the impacts and risks will be managed to ALARP and acceptable levels, how performance outcomes and standards are met, and detail the arrangements in place to respond to and monitor oil pollution emergencies.

A series of EPs will be developed by Shell for specific activities throughout the project life-cycle.

Under the OPGGS (E) Regulations, an Oil Pollution Emergency Plan (OPEP) is required as part of the implementation strategy for the activity-specific EP. The OPEP must include comprehensive and adaptable arrangements for responding to and monitoring oil pollution. The OPEP will be supported by an Operational and Scientific Monitoring Program (OSMP) that provides a detailed strategy for responding to large-scale releases to the marine environment.

2.4.5 Safety Case and Well Operations Management Plan

As mentioned in **Section 2.3.1.1**, the OPGGS (Safety) Regulations and OPGGS (Resource Management and Administration) Regulations also require that a Safety Case and a WOMP are assessed and accepted by NOPSEMA for existing or proposed facilities.

Shell will prepare and submit the required Safety Cases to NOPSEMA as the Crux project is developed to ensure timely approvals prior to construction, installation and start-up. A WOMP will be developed for all activities in the life of the well. These

approvals assist in environmental protection as they ensure the integrity of the production wells throughout their life, drilling rig, Crux platform and project vessels.

2.5 Australian Industry Participation Plan

An Australian Industry Participation (AIP) Plan is a requirement of the *Australian Jobs Act 2013*. The requirement for an AIP Plan is triggered by any major construction project of over $500 million investment. The overarching aim of the Plan is to ensure investment and project delivery is contained within Australia; and that offshore spend is limited as much as possible.

The key objective of the Act is to ensure Australian entities have full, fair and reasonable opportunity to bid for the supply of key goods or services for the project and, if applicable, the initial operations of the facility.

The AIP Plan assists Shell in achieving this objective.

It is a requirement of the Act that an AIP Plan is lodged before detailed design and major procurement decisions are undertaken. In June 2018, Shell notified the AIP Authority that it will submit an AIP Plan for the Crux project in Q4 2018. Approval for the AIP Plan is expected in Q1 2019.

2.6 Relevant State/Territory Legislation

The Crux project, including its associated infrastructure and planned operations, is located in Commonwealth waters. Some planned activities, such as vessel transfers, and unplanned activities, however, have the potential to interact with values and sensitivities within both the jurisdiction of WA and NT (refer to **Section 6** for discussion of sensitivities). Onshore support facilities required during construction, commissioning and operation will be located in existing ports and associated industrial areas.

Any future supporting activities for the Crux project in State/Territory jurisdiction will be undertaken in accordance with relevant State/Territory legislation prevailing at the time.

2.7 Industry Good Practice Standards

In addition to the offshore environmental management procedures and reporting required under legislation, there are voluntary industry codes that are relevant to the project, as discussed in this section.

In Australia, the petroleum exploration and production industry operates within an industry code of environmental practice developed by the Australian Petroleum Production and Exploration Association (APPEA) (APPEA 2008). This code provides guidelines for activities and has evolved from the collective knowledge and experience of the oil and gas industry both nationally and internationally. The code also provides the Australian petroleum industry with clear guidance on management practices and measures to protect the environment during exploration, production and decommissioning phases. Shell is a signatory to the APPEA guidelines and will align with their intent in the implementation of the project.

The following Australian guidelines are also applicable to the project:

- National Biofouling Management Guidance for the Petroleum Production and Exploration Industry 2009 (Commonwealth of Australia 2009a)
- Australian Offshore Support Vessel Code of Safe Working Practice (Australian Maritime Safety Authority (AMSA) 1997)

- Technical Guideline for the Preparation of Marine Pollution Contingency Plans for Marine and Coastal Facilities (AMSA 2015a)
- Advisory Note for Offshore Petroleum Industry Consultation with Respect of Oil Spill Contingency Plans (AMSA 2017), and the corresponding WA Offshore Petroleum Industry Guidance Note – Marine Oil Pollution: Response and Consultation Arrangements (Department of Transport (DoT) 2017), and
- Australian Ballast Water Management Requirements (Department of Agriculture and Water Resources (DAWR) 2017).

The following international guidelines are also applicable to the project:

- Improving Social and Environmental Performance: Good Practice Guidance for the Oil and Gas Industry 2017 International Petroleum Industry Environmental Conservation Association (IPIECA 2017)
- The Oil and Gas Industry: Operating in Sensitive Environments 2003 (IPIECA 2003), and
- Environmental Management in Oil and Gas Exploration and Production 1997 – United Nations Environment Program Industry and Environment (UNEP IE) and the Oil Industry International Exploration and Production Forum.

2.8 International Standards and Guidelines

Shell refers to World Bank (WB)/International Finance Corporation (IFC) guidelines as the basis for many of its operation guidelines, as aligned with the Shell HSSE & SP Control Framework. The WB/IFC guidelines are the minimum environmental, social and health standards for WB funded projects, unless the standards of the host country are more stringent. Shell will adhere to Australian legislation and guidelines in the first instance unless international standards are more stringent.

The WB/IFC guidelines of primary relevance to the project include:

- IFC Performance Standards on Environmental and Social Sustainability (2012)
- General Environmental, Health, and Safety (EHS) Guidelines (2007, currently under review, with progressive updates expected in 2018-2019) – to provide general guidance on Good International Industry Practice, and
- EHS Guidelines for Offshore Oil and Gas Development (2015).

2.9 International Agreements and Conventions

Australia is signatory to numerous international conventions and agreements that obligate the Commonwealth Government to prevent pollution and protect specified habitats, flora and fauna. A number of these conventions are specifically designed to protect MNES, including:

- Convention on the Conservation of Migratory Species of Wild Animals 1979 (Bonn Convention), which aims to improve the status of all threatened migratory species through national action and international agreements between range states of particular groups of species.
- Agreement between the Government of Australia and the Government of Japan for the Protection of Migratory Birds in Danger of Extinction and their Environment 1974 (commonly referred to as JAMBA), which recognises the special international concern for the protection of migratory birds and birds in danger of extinction that migrate between Australia and Japan.

- Agreement between the Government of Australia and the Government of the People's Republic of China for the Protection of Migratory Birds and their Environment 1986 (commonly referred to as CAMBA), which recognises the special international concern for the protection of migratory birds and birds in danger of extinction that migrate between Australia and China.
- Agreement between the Government of Australia and the Government of the Republic for Korea for the Protection of Migratory Birds and their Environment 2002 (commonly referred to as ROKAMBA), which recognises the special international concern for the protection of migratory birds and birds in danger of extinction that migrate between Australia and Korea.
- International Convention on Wetlands of International Importance (Ramsar), which encourages the designation of sites containing representative rare or unique wetlands, or wetlands that are important for conserving biological diversity and their management for conservation purposes.
- The Minamata Convention on Mercury requires Parties to address mercury throughout its lifecycle, including its production, its intentional use in products and processes, its unintentional release from industrial activity, though to end-of-life aspects including waste, contaminated sites, and long-term storage. The Convention entered into force on 16 August 2017. Australia is a signatory to the Minamata Convention, however has yet to ratify.

2.10 EPBC Management Plans, Recovery Plans and Conservation Advices

Under the streamlining arrangements for the assessment of petroleum proposals in Commonwealth waters under the OPGGS (E) Regulations, this requires explicit consideration of MNES protected under Part 3 of the EPBC Act.

The requirements of the relevant species management/recovery plans and conservation advices have been considered to identify any requirements that may be applicable. Recovery plans are enacted under the EPBC Act and remain in force until the species is removed from the threatened list. Recovery plans set out the research and management actions necessary to stop the decline of, and support the recovery of, listed threatened species or threatened ecological communities. Conservation advices provide guidance on immediate recovery and threat abatement activities that can be undertaken to facilitate the conservation of a listed species or ecological community.

The management/recovery plans and conservation advices relevant to those species identified as potentially occurring or having habitat within the Crux project area and area of influence (i.e. the existing environment that may be affected from unplanned events) are further detailed in the applicable sections within **Section 6** as part of the description of the existing environment. Relevant management measures from these plans are also considered in relevant parts of **Section 8** as they apply to the project. The management/recovery plans and conservation advices have been taken into consideration in assessing the impacts and risks associated with the project, to demonstrate alignment with the EPBC publications, and will be further incorporated into implementation planning as the project progresses.

3. Shell Health, Security, Safety, Environment and Social Performance Management Framework

3.1 Introduction

The Shell Group operates under a common set of business principles, supported by policies, standards and business controls which are implemented throughout the organisation structure. In support of the business principles, there is a Group Health, Security, Safety, Environment and Social Performance Policy which requires every Shell Company to manage HSSE and SP in a systematic manner.

The HSSE and SP Control Framework is a corporate management framework which applies to every Shell Group company, contractor and joint venture under Shell's operational control.

3.2 HSSE & SP Policy

The Shell Commitment and Policy on HSSE & SP applies across the Shell Group and is designed to protect people and the environment. The policy, endorsed and adopted by Shell, is presented in **Figure 3-1**. The policy illustrates the commitment made by the senior management and all staff of Shell to achieve not only compliance with environmental standards set by the Australian Government and the Company, but also to seek continual improvements in performance.

Key features of the policy are:

- systematic approach to HSSE and SP management designed to ensure compliance with the law and to achieve continuous performance improvement
- targets for improvement and measurement, appraisal and performance reporting
- requirement for contractors to manage HSSE and SP in line with this policy, and
- effective engagement with neighbours and impacted communities.

SHELL COMMITMENT AND POLICY ON HEALTH, SECURITY, SAFETY, THE ENVIRONMENT AND SOCIAL PERFORMANCE

COMMITMENT

In Shell we are all committed to:

- Pursue the goal of no harm to people;
- Protect the environment;
- Use material and energy efficiently to provide our products and services;
- Respect our neighbours and contribute to the societies in which we operate;
- Develop energy resources, products and services consistent with these aims;
- Publicly report on our performance;
- Play a leading role in promoting best practice in our industries;
- Manage HSSE & SP matters as any other critical business activity; and
- Promote a culture in which all Shell employees share this commitment.

In this way we aim to have an HSSE & SP performance we can be proud of, to earn the confidence of customers, shareholders and society at large, to be a good neighbour and to contribute to sustainable development.

POLICY

Every Shell Company:

- Has a systematic approach to HSSE & SP management designed to ensure compliance with the law and to achieve continuous performance improvement;
- Sets targets for improvement and measures, appraises and reports performance;
- Requires contractors to manage HSSE & SP in line with this policy;
- Requires joint ventures under its operational control to apply this policy, and uses its influence to promote it in its other ventures;
- Engages effectively with neighbours and impacted communities; and
- Includes HSSE & SP performance in the appraisal of staff and rewards accordingly.

Ben van Beurden
Chief Executive Officer

Zoe Yujnovich
EVP Australia and New Zealand

Originally published in March 1997 and updated by the Executive Committee December 2009.

General Disclaimer: The companies in which Royal Dutch Shell plc directly and indirectly owns investments are separate entities. In this Policy the expression "Shell" is sometimes used for convenience where references are made to companies within the Shell group or to the group in general. Likewise, the words "we", "us" and "our" are also used to refer to Shell companies in general or those who work for them. These expressions are also used where no useful purpose is served by identifying specific companies.

Figure 3-1: Shell Australia's HSSE & SP Policy

3.3 HSSE & SP Control Framework

All Shell's operations are conducted in accordance with Shell's HSSE & SP Control Framework, a comprehensive corporate management framework. This Framework defines a set of mandatory requirements that define minimum HSSE & SP principles and expectations, which are documented in a set of manuals. **Figure 3-2** outlines the various control framework manuals applicable to the Crux project.

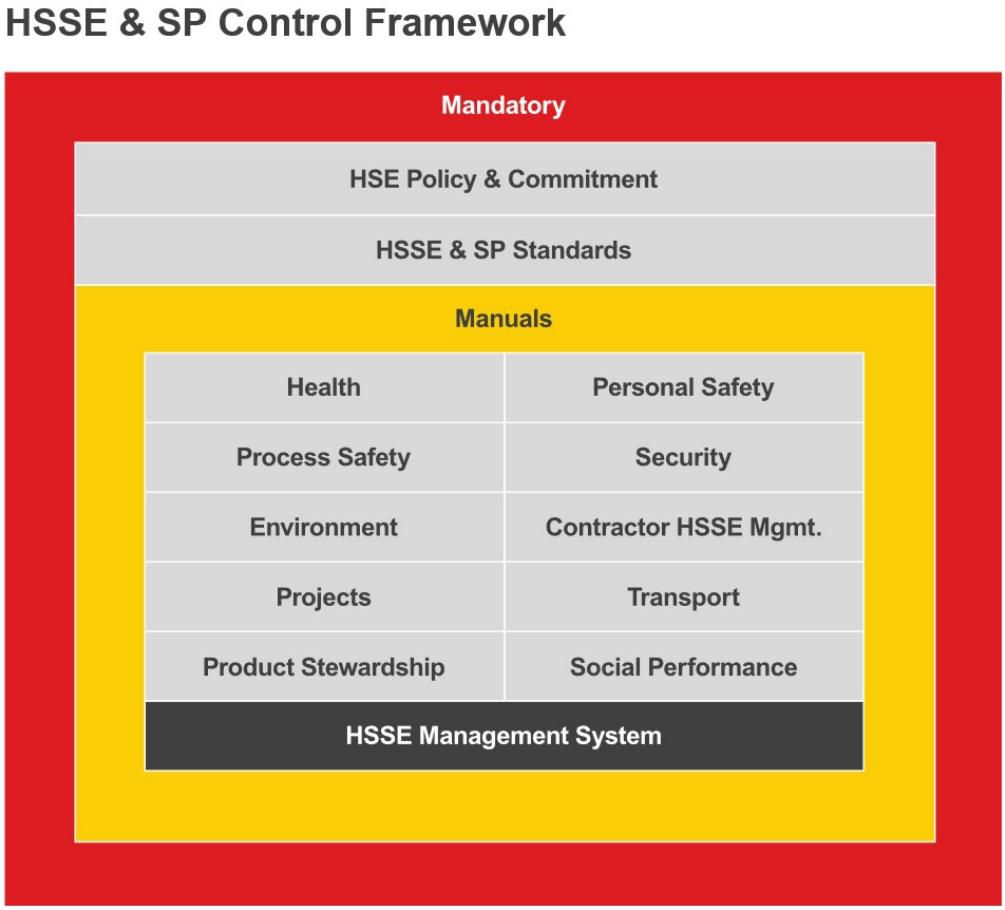


Figure 3-2: Shell HSSE & SP Control Framework

HSSE & SP Management System

The Shell Australia HSSE &SP-MS provides a structured and documented framework for the effective management of HSSE & SP risks and demonstrates how the requirements of the Shell Group HSSE & SP Control Framework are implemented throughout Shell. The Shell Australia HSSE & SP-MS Manual consists of the following sections:

- Leadership and Commitment
- Policy and Objectives
- Organisation, Responsibility and Resources, Standard and Documents
- Risk Management
- Planning and Procedures
- Implementation, Monitoring and Reporting
- Assurance, and
- Management Review.

The HSSE & SP-MS is subject to a continuous improvement 'plan, do, check, review' loop, with eight components as outlined in **Table 3-1**. There are numerous, specific ongoing (typically annual) assurance activities against each of the eight components in this HSSE & SP-MS Manual as detailed below. The audit and review function of the HSSE-MS seeks to ensure that the system is being implemented, is effective and to identify areas for improvement. Examples of elements that demonstrate continuous improvement are highlighted under each section.

Table 3-1: HSSE & SP-MS Elements, Implementation and Improvement

Management System Element	Implementation and Improvement
Leadership and Commitment *Creating and sustaining a culture that drives Shell's commitment of no harm to people or the environment*	Seek ongoing feedback on how others perceive HSSE & SP leadership (performance reviews, HSE Culture Survey (Shell People Survey), 360 feedback).
Policy and Objectives *Supporting the implementation of Shell HSSE & SP Commitment and policy*	Set annual HSSE & SP targets to drive continuous performance. Annually review and approve HSSE & SP objectives.
Organisation, Responsibilities and Resources *Establishing and maintaining an organisation that enables the compliance with the HSSE & SP Control Framework*	When there are changes in the business or organisation, identify the positions that require competence assurance. HSSE & SP Critical Position Register, Shell People Competency Profiles.
Risk Management *Identifying the HSSE & SP hazards and establishing the controls to reduce the risks to ALARP*	Ongoing review of hazards and risks. Regular review of risk registers.
Planning and Procedures *To integrate the requirements of the HSSE & SP Control Framework into business plan and procedures: Emergency & Crisis Response, Spill Preparedness and Response, Management of Change, Permit to Work*	Establish and maintain a programme of testing of emergency response plans and procedures at least once a year or more frequently based on the level of risk. Shell Australia Emergency Response Plan, records of emergency response drills, exercises and After Action Reports.
Implementation, Monitoring and Reporting *Implement the HSSE & SP requirements embedded in plans and procedures and take corrective action when necessary*	Report all Incidents, including near misses, to the supervisor of the work activity. Learn from significant incidents and high potential incidents through communication and implementation of required actions.
Assurance *Providing assurance that the HSSE & SP Control Framework requirements are implemented and effective*	Establish, maintain and execute HSSE & SP Self-Assessments in support of the Business HSSE & SP Assurance Plan, self-assessment, Control Framework Gap Analysis, HSSE & SP Management Review. Management Review – documents demonstrating how Shell Australia reviews the effectiveness, adequacy and fitness for purpose of the HSSE & SP Management System and acts to improve. Review the HSSE & SP-MS and its individual elements at least once a year and document the results.
Management Review *Reviewing the effectiveness, adequacy and fitness for purpose of the HSSE & SP-MS and taking actions for improvement*	Assess the effectiveness and adequacy of the management system in delivering the policy and objectives and in driving continual improvement.

Shell Australia's HSSE & SP-MS covers all operations within its business, including the planning, development and operations of the Crux platform.

Management of HSSE for the Crux project is through the implementation of the Shell Australia HSSE & SP-MS, supplemented by facility/asset specific HSSE systems/procedures (e.g. Shell Permit to Work system and associated procedures such as Confined Space Entry, Isolations, etc. as appropriately developed at the stage of project implementation).

Shell implements specific pre- and post-contract award processes and activities aimed at ensuring that contracts consistently and effectively cover the management of HSSE & SP risks and deliver effective management of HSSE & SP risks for contracted activities. Contractor HSSE & SP Management is governed by the Shell HSSE & SP Control Framework.

As a minimum, all relevant field active contractors' HSSE & SP-MS will be assessed to ensure they meet materially equivalent outcomes to Shell Australia's HSSE & SP-MS.

4 Stakeholder Consultation

4.1 Introduction

Stakeholder engagement and consultation is an integral part of Shell's social performance, impact assessment and project development process, helping to both inform business decisions and identify issues that require action. Shell has internal policies and processes which outline the requirements of stakeholder engagement. These are underpinned by Shell's General Business Principles (**Section 4.2**), which govern how the Shell companies that make up the Shell Group conduct their affairs.

Stakeholder engagement is a systematic process, starting with developing an understanding of the issues, identifying stakeholders, developing a Stakeholder Engagement Plan and then creating and maintaining stakeholder relationships and partnerships using a variety of engagement methods. Stakeholder engagement is seen as a two-way process, designed to ensure stakeholders can understand, absorb, respond and interact with sufficient information within appropriate timeframes.

Shell is committed to:

- inform stakeholders of the proposed Crux project
- maximise the level of accurate and accessible information about the project
- provide stakeholders with the opportunity to engage in meaningful dialogue
- listen to feedback from stakeholders and respond to them honestly and responsibly
- use stakeholder feedback to inform and improve business decisions, and
- deliver a net benefit to local communities.

A wide range of stakeholders have been identified for the project, comprising individuals and organisations from stakeholder groups including Federal government, State government, non-government organisations, industry and the local community.

Consultation with the Crux project's identified stakeholders will continue throughout the project's lifespan, ensuring that queries and concerns raised are addressed and, where feasible, appropriate responses are built into the design and/or future activity-specific EPs.

4.2 Shell General Business Principles and Stakeholder Engagement

Shell's consultation with stakeholders is undertaken in line with the Shell General Business Principles. Key to these principles is that Shell employees share a set of core values – honesty, integrity and respect for people. Key principles for stakeholder engagement:

- Local communities – Shell aims to be a good neighbour by continuously improving the ways in which we contribute directly or indirectly to the general wellbeing of the communities within which we work. We manage the social impacts of our business activities carefully and work with others to enhance the benefits to local communities, and to mitigate any negative impacts from our activities. In addition, Shell companies take a constructive interest in societal matters, directly or indirectly related to our business.
- Communication and engagement – Shell recognises that regular dialogue and engagement with our stakeholders is essential. In our interactions with local communities, we seek to listen and respond to them honestly and responsibly. Part

of this commitment is ensuring those people and organisations that are impacted by our activities are engaged, and that their concerns are heard and responded to.

4.2.1 Stakeholder Engagement Process

In supporting Shell's adherence to the Shell Business Principles, from the initial discovery of the resource, is a comprehensive stakeholder strategy which ensures that:

- the external context is monitored and understood
- stakeholder needs, interests, concerns and expectations understood, and shared outcomes defined
- a clear and direct link between impacts and risks/opportunities and stakeholders
- stakeholder engagement protocols established and consistent, and
- explicit inclusion of external perspectives in business decisions.

4.2.2 Crux Stakeholder Engagement Plan

A Stakeholder Engagement Plan specific to the Crux project has been developed and includes a stakeholder matrix, an engagement strategy and a feedback mechanism.

Shell's approach to stakeholder engagement on the Crux project, as is the case for all of Shell's assets, has always been "a no surprises approach" which has driven proactive engagements with a range of stakeholders from a very early stage. Shell has developed long term working relationships with those who may be impacted by the Crux project or who may have an interest in it.

4.2.3 OPP Consultation Strategy

The Crux Stakeholder Engagement Plan, as well as information gathered from ongoing engagement historically undertaken for the Prelude FLNG project, was used to develop an OPP consultation strategy.

Subject matter experts were engaged as required throughout the process, to inform the development of the plan and ensure that Shell staff undertaking consultation have an integrated understanding of the Crux environmental risks and mitigations.

4.2.3.1 Stakeholder Identification

Shell has an internal process to identify, prioritise and understand stakeholders. The process includes the following steps:

1. Identify stakeholders against specific business objectives
2. Prioritise stakeholders based on stakeholder views/concerns
3. Analyse value drivers and views on our activities
4. Define desired shared outcomes
5. Early engagements with stakeholders to understand views of impacts, risks and opportunities.

This process was used to develop the Crux Stakeholder Matrix and formed the foundation for the Stakeholder Identification Workshop. The workshop was held in February 2018 and was attended by External and Government Relations representatives as well as Shell Health, Safety and Environment subject matter experts.

At the workshop, each potential stakeholder was assessed based on how the proposed Crux project activities could impact their functions, interests or activity.

The workshop was informed by:

- historic information gathered as part of the Shell Prelude stakeholder engagement process, and
- desktop research to identify the specific functions, interests and activities of each relevant person.

Once stakeholders were identified, Shell determined the most appropriate consultation approach and associated information to communicate based on the:

- functions, interests and activities of the person
- prior feedback and information from relevant persons on their perspectives and how they prefer to be engaged gathered as part of the Crux stakeholder engagement process, and
- information gathered during prior engagement activities and/or ongoing communication with stakeholders.

4.2.3.2 Stakeholders and Consultation

Stakeholders identified consist of pre-existing stakeholders, engaged through the Prelude FLNG project, as well as others identified through initial engagements with Government agencies, desktop research and regional contacts. The stakeholders can be broadly grouped as follows:

- Federal Government
- State Government
- community (individuals or groups)
- local indigenous representative groups and Traditional Owners
- commercial fishing operators
- local government organisations
- non-government organisations
- industry representative organisations
- tourist operators and tourists, and
- academia.

Table 4-1 presents a summary of all the stakeholders that have been consulted to date by Shell.

Table 4-1: Crux Project Stakeholders

Stakeholder Group	Stakeholder
Primary Regulatory Bodies	National Offshore Petroleum Safety and Environmental Management Authority (NOPSEMA) National Offshore Petroleum Titles Administrator (NOPTA)
Commonwealth Government	Australian Border Force (Department of Immigration and Border Protection) Clean Energy Regulator Commonwealth Department of Industry, Innovation and Science (DIIS) Department of Agriculture and Water Resources Department of the Environment and Energy (DoEE) Department of Communications Parks Australia RAN Australian Hydrographic Service Australian Fisheries Management Authority (AFMA) Australian Marine Safety Authority (AMSA) Federal Member for Kimberley
State/Territory Government	Department of Mines, Industry Regulation and Safety (DMIRS) Department of Primary Industries and Regional Development (DPIRD) – Fisheries Division Department of Jobs, Tourism, Science and Innovation (formerly Department of State Development) Department of Water and Environmental Regulation (DWER) Department of Biodiversity, Conservation and Attractions (DBCA) Department of Transport (DoT) NT Department of Fisheries Department of Fire and Emergency Services (DFES) Office of Emergency Management (as a sub-department of DFES) State Member for Kimberley
Marine Organisations	Australian Institute of Marine Science (AIMS) Australian Marine Oil Spill Centre (AMOSC)
Fisheries and Representative Organisations	Commonwealth Fishing Association Kimberley Professional Fishermen's Association Mackerel Managed Fishery North Coast Shark Fishery North West Slope Fishery Northern Demersal Scalefish Fishery (represented by the Kimberley Professional Fishermen's Association) Pearl Oyster Fishery (represented by Pearl Producers Association) Pearl Producers Association RecFish West Southern Bluefin Tuna Fishery WA Fishing Industry Council (WAFIC) West Coast Deep Sea Fishery Western Tuna and Billfish Fishery
Community/Contractor	Australian Broadcasting Corporation Broome Advertiser Broome International Airport Broome Port Authority Broome Visitors Centre Cable Beach Club Canadian Helicopter Company Djarindjin Aboriginal Corporation (DAC) Goolarabooloo Aboriginal Corporation Goolarri Media

Stakeholder Group	Stakeholder
	GWN7 Broome James Brown (Cygnet Bay) Kimberley Development Commission Kimberley Institute Kimberley Land Council Kimberley Police Lombadina Aboriginal Corporation Maximus Pearls Nirrumbuck Aboriginal Corporation North West Tourism Board Nugurrara Rangers Nyamba Buru Yawuru One Arm Point Aboriginal Corporation Qantas Roebuck Bay Working Group Shire of Broome Toll Energy Wunan Bardi Jawi Prescribed Corporate Body Broome Chamber of Commerce Dambimangarri Aboriginal Corporation
Environmental Non-Government Organisations	Australian Conservation Foundation Australian Marine Conservation Society Conservation Council of WA Environmental Defenders Office WA Greenpeace Save the Kimberley Wilderness Society World Wildlife Fund

4.2.4 Early Consultation

As part of Shell's commitment to early engagement, a Crux project website has been established and initial factsheets published, providing an overview of the project and the OPP process. The Crux project website is located at:

https://www.shell.com.au/about-us/projects-and-locations/the-crux-project.html

Shell held an industry briefing in June 2018, which was attended by representatives from Commonwealth Government (including NOPSEMA and NOPTA), State Government (including DPIRD – Fisheries; Department of Jobs, Tourism, Science and Innovation; and Department of Industry, Department of Commerce), marine organisations (including AIMS), and representative industry bodies (including APPEA, Chamber of Minerals and Energy, and AMOSC). In a follow-up to the briefing, Shell has commenced targeted engagement with a range of relevant stakeholders, including Government agencies, commercial fishing associations and other interested stakeholders, to discuss the project's status and facilitate the opportunity for feedback.

4.2.5 OPP Public Consultation

A core element of the OPP process is to facilitate a public comment period. The OPP will be published on NOPSEMA's website and made available on Shell's website. The length of the public comment period is subject to determination by NOPSEMA, ranging from 4 to 12 weeks duration. NOPSEMA has published guidance information to support this public comment engagement process (NOPSEMA, 2018c).

The outcomes of consultation will be planned, tracked and recorded as part of the Crux Stakeholder Engagement Plan, supported by an Action Register to support the tracking of committed actions.

4.2.6 Ongoing Consultation

Upon acceptance of the OPP, Shell will uphold its commitments to ensuring relevant persons continue to be consulted throughout the development of the Crux project.

Shell has determined that the most effective way to manage ongoing consultation in line with the OPP and subsequent activity-specific EPs will be undertaking consultation around the key project milestones of installation, commissioning, start up and operations. Consultations will be tailored to the specific functions, interests or activities of the stakeholders relevant to the stage of the project.

The assessment is dynamic and could change, for example changes to scope or schedule, in which case the plan would be updated. As each key project milestone is reached, an assessment will occur to ensure that all relevant persons are engaged appropriately.

Stakeholders can and have identified their preferred ongoing engagements for the Crux project. In such cases, that suggestion is considered and if appropriate, implemented.

These consultations will be planned, tracked and recorded as part of the Crux Stakeholder Engagement Plan.

Shell's 'management of change' process will also ensure that any material changes to the activity scope will trigger engagement with those who may be impacted, with periodic internal compliance/assurance checks in place in line with good industry practice.

Shell will ensure any claims or objections, or feedback, from the ongoing consultation is processed as per Shell's internal claims process, and any required follow-up action will be managed appropriately.

5 Description of the Project and Alternatives Analysis

5.1 Overview

This section of the OPP provides a comprehensive description of the key stages and activities associated with the development and operation of the Crux project, as relevant to the assessment of environmental impacts and risks, such as the key discharge and emission sources. It defines the nature and scale of the Crux project to facilitate an appropriate description of the existing marine environment (**Section 6**). Understanding both the project and the existing marine environment allows the sources of impacts and risks to be appropriately evaluated (**Section 7**).

5.2 Project Concept and Design

The Crux project has been identified as the primary source of backfill gas supply to the Prelude FLNG facility. The Crux project will not increase the production capacity of the Prelude FLNG facility. The scope of the existing Prelude FLNG facility environmental approvals include backfill projects. The current project concept is shown in **Figure 5-1** and comprises:

- a NNM platform, which includes dry trees, processing facilities and associated utility systems
- five production wells with subsea wellhead system tied back through rigid concentric tubulars to the NNM platform and completed with dry trees
- a 26-inch export pipeline, approximately 165 km long, which ties the platform back to the Prelude FLNG facility, and
- subsea integration system connecting the export pipeline system with Crux platform and the Prelude FLNG facility, comprising risers, subsea isolation facilities, PIG receiver and associated control systems.

There is also a potential for future subsea developments that will provide hydrocarbons to the Crux platform. These developments are expected to comprise subsea production wells, completed with subsea trees, and associated subsea tie-back to the platform (e.g. flowlines, risers and manifolds).

Shell have undertaken concept engineering to support the selection of these facilities. During this process, all reasonable alternative development options/activities were considered in order to fully evaluate the environmental acceptability of the project.

A high-level evaluation and comparison of environmental impacts and risks for key development option/activity alternatives is discussed in **Section 5.8**.

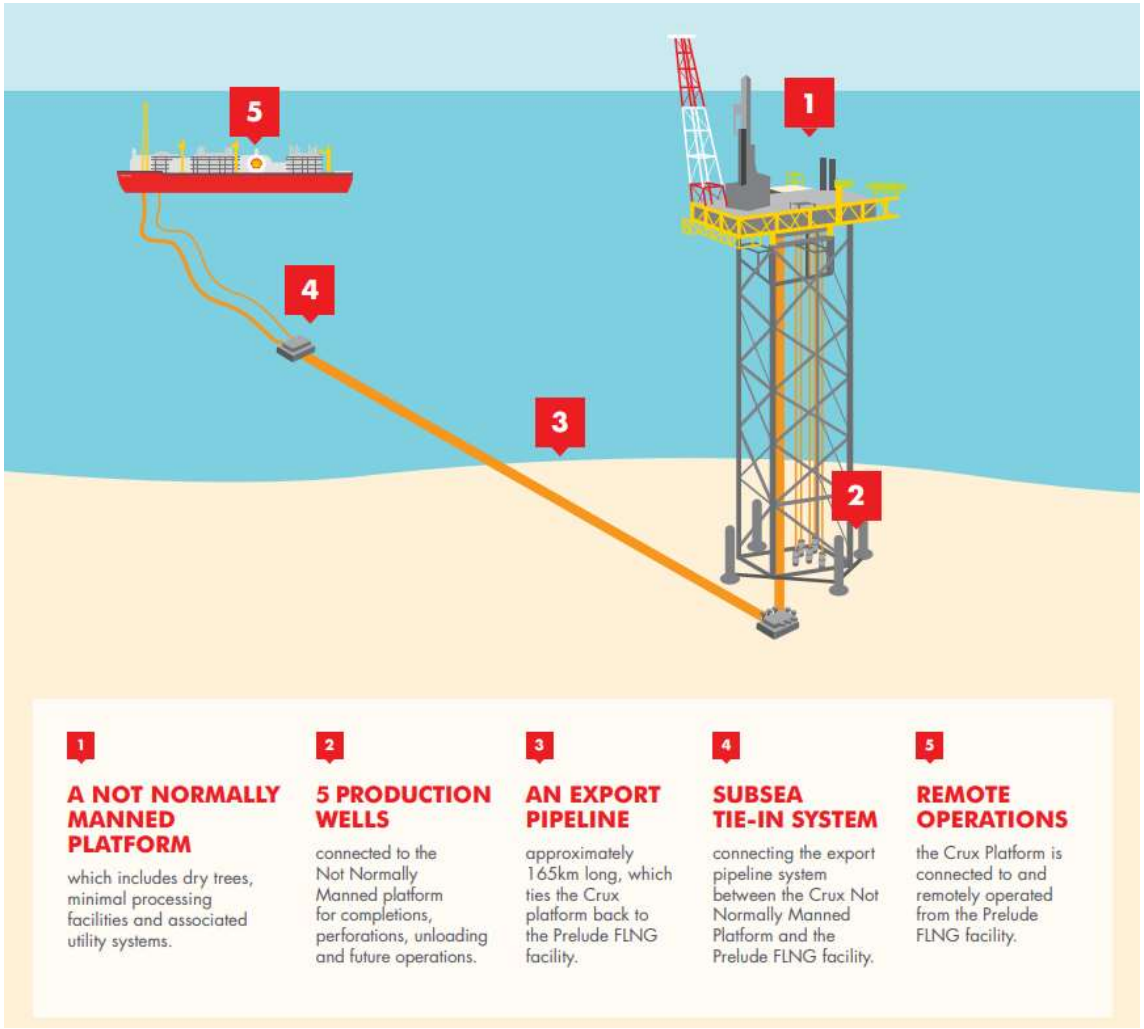


Figure 5-1: Concept Schematic of the Crux Project

5.3 Project Location

The Crux project is located in the northern Browse Basin in offshore Commonwealth marine waters approximately 160 km offshore north-west Australia and 620 km north-north-east of Broome, the nearest regional centre. The location of the Crux project is presented in **Figure 5-2**.

The proposed export pipeline spans between the Crux platform and the Prelude FLNG facility in Commonwealth marine waters. The pipeline is approximately 190 km offshore north-west Australia at its closest point and water depths range from approximately 170 m to 280 m.

The Crux project area (as defined in **Section 5.3.1**) does not contain any emergent reefs/islands. The nearest reef/island to the Crux platform is Cartier Island, which is approximately 105 km to the north-west. The nearest shoal/bank is Goeree Shoal, which is approximately 13 km to the north-west of the Crux platform location.

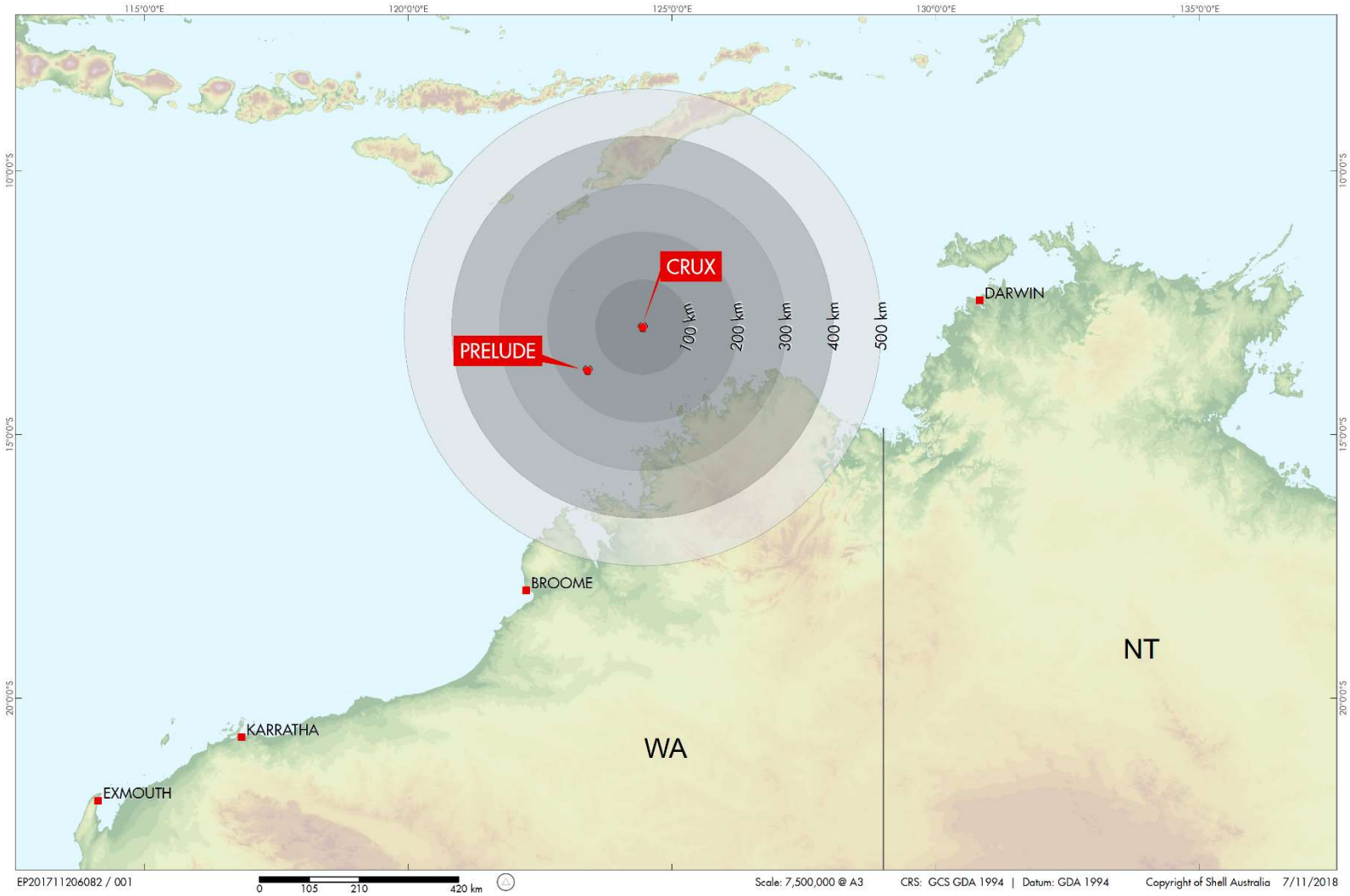


Figure 5-2: Crux Project Location

5.3.1 Project Area Definition

The Crux in-field development area and export pipeline corridor define the geographic extent of the project area that is applicable for planned activities, which are considered and risk assessed in this OPP. For the purposes of this OPP, the extent of the in-field development area and export pipeline corridor (collectively referred to as the 'project area') is considered to comprise the area outlined in **Figure 5-3** and **Figure 5-4**, respectively.

The in-field development area incorporates the development of the Crux field and associated reservoirs that may be developed as future staged developments. The outer radius of potential backfills from the proposed Crux platform location will be 30 km from the current proposed platform location, excluding a 1 km buffer from around shoals within this area in order to avoid impacts to these features from potential future tie-backs. The preferred Crux platform location shown in **Figure 5-3** will be located within an approximate 1 km radius of this location.

The in-field development area also encompasses the marine environment that may be affected by planned discharges, as identified from modelling which is presented in **Section 7.**

The export pipeline route connecting the Crux platform to the Prelude FLNG facility includes a 1 km buffer either side of the proposed route where minor deviations in the final pipeline route may occur, as shown in **Figure 5-4**. A slightly larger buffer (approximately 2 km) has been allowed at the Prelude end of the pipeline to allow for tie-in to the most appropriate quadrant of the FLNG turret.

The OPP is only required to assess petroleum activities, as defined in Regulation 5A(5) of the OPGGS (E) Regulations. The project area also covers the area that project vessels, carrying out petroleum activities, may be moving, such as installation vessels and pipelay vessels when they are installing subsea facilities. This OPP does not include the general transit of vessels to or from the project area. These activities will be undertaken in accordance with relevant maritime legislation, such as the Commonwealth *Navigation Act 2012*, and are within the jurisdiction of AMSA. In addition, helicopter activities outside of a petroleum safety zone are not defined as petroleum activities. Further, the fibre optic cable installation and operation is not considered a petroleum activity. Therefore, activities undertaken by the vessels and helicopters which are not carrying out petroleum activities are not considered in this OPP. Therefore, any assessment outside of these activities are provided for Shell internal Environmental, Social and Health Impacts (ESHIA) purposes, outside of the formal OPP process, to support the transparent, whole-of-project impact assessment process.

Onshore support facilities required during construction, commissioning and operation will be located in existing ports and associated industrial areas. It is expected that the Crux project will utilise the onshore supply base facilities (Kimberley and NT) that are used to service the Prelude FLNG facility. In general, the Crux project will seek to utilise existing support facilities and services used for the Prelude FLNG project. Given the nature of the Crux project, is not expected to significantly increase the demand on these facilities/services. Where required, the operation of these onshore support facilities is subject to relevant State and Territory Government approvals processes and is therefore outside the scope of this OPP.

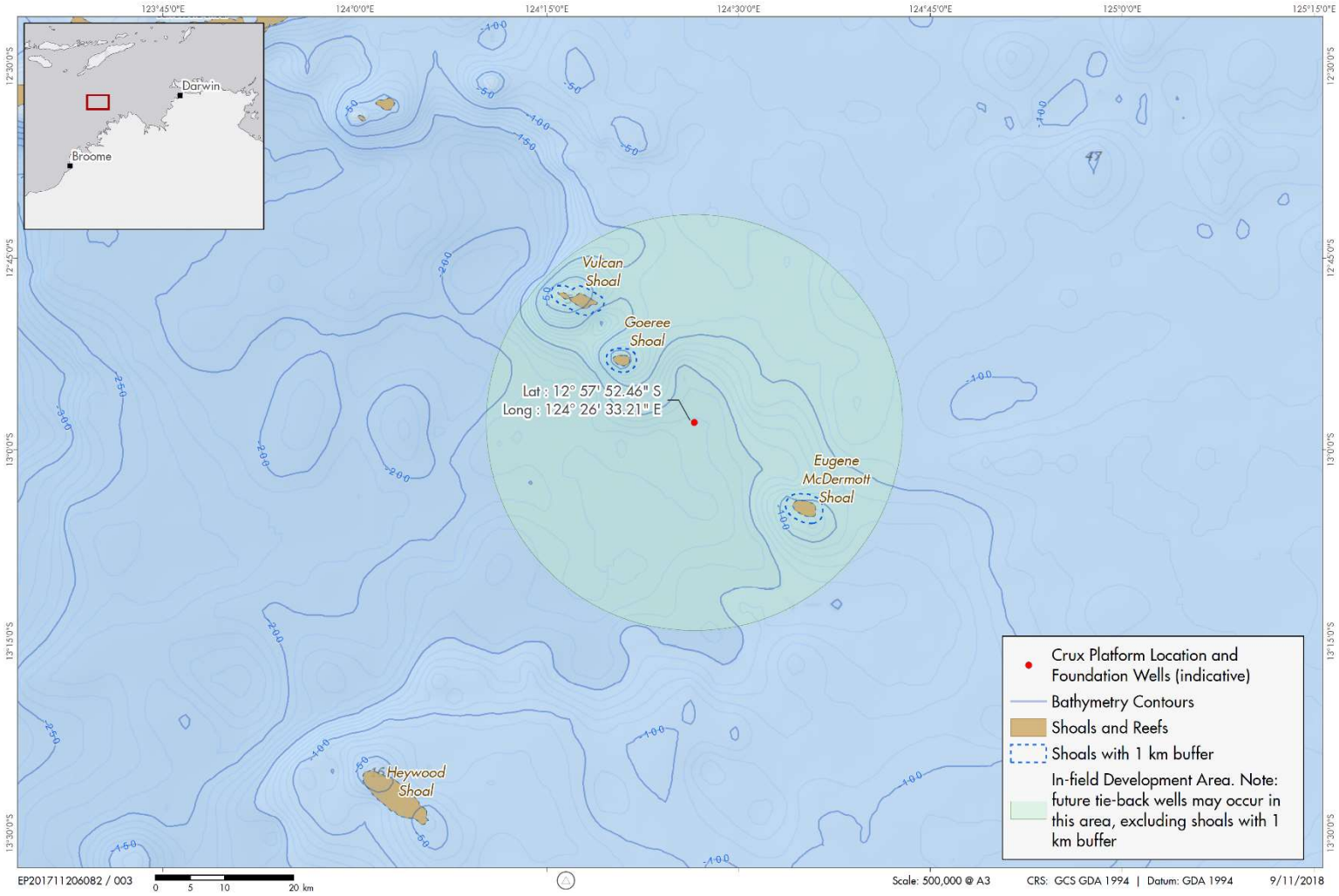


Figure 5-3: In-field Development Area

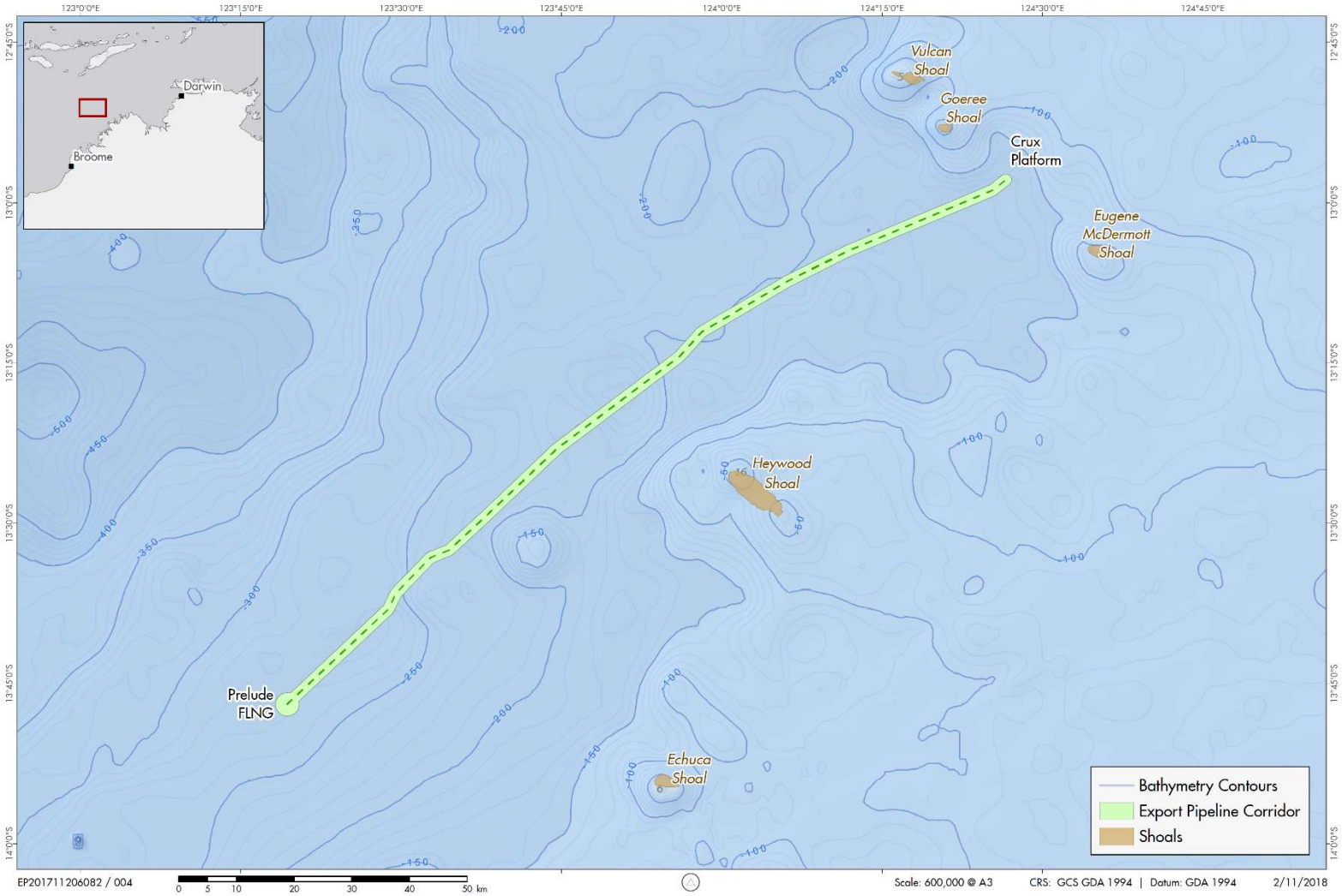


Figure 5-4: Export Pipeline Corridor

5.4 Project Schedule

As outlined in **Section 1.1**, it is expected that FEED engineering for the project is expected to commence in 2019 with the FID currently anticipated to occur in 2020. From FID it will take approximately 4 to 5 years for the platform to be fully designed, constructed off-site and towed to location. Whilst the platform is being built, the subsea production wells would be drilled and suspended until installation of the platform facilities, after which the wells would be completed, hooked-up to the platform and brought online.

The indicative timeframes and development schedule of key project activities are presented in **Table 5-1**.

Table 5-1: Indicative Project Timeline

Project Stage	Target Date/Timeframe
Foundation development drilling – including well tie-back to the platform and well completion	Between approximately 2–4 years post-FID
Subsea installation and hook-up – platform, export pipeline and subsea integration system	
Commissioning	Approximately 4–5 years post-FID. However, timing will be influenced by completion of the foundation development drilling and subsea installation and hook-up activities.
Operations – including potential future subsea tie-backs to the platform	The Crux platform and pipeline will have a design life of 20 years. However, subject to future investment decisions, operations may extend platform and pipeline life. The installation of any subsea infrastructure required to support future subsea developments (i.e. flowlines, risers and manifolds) within the in-field development area may be undertaken during operations.
Decommissioning	Decommissioning activities will be undertaken at the end of the operational life of the Crux project.

5.5 Crux Project Description

The Crux project, inclusive of any potential future subsea tie-backs, will comprise:

- platform (fixed jacket) and topsides processing facilities
- production wells with dry tree completion)
- export pipeline and associated subsea integration system, and
- subsea facilities (e.g. flowlines, risers and manifolds) associated with any future subsea tie-backs.

5.5.1 Crux NNM Platform

5.5.1.1 Platform Sub-structure

The fixed jacket platform will be held in position by piled foundations, based on current sub-structure engineering definition. To support the weight of the platform topsides, each of the four peripheral jacket legs will be secured to the seabed via piles installed through a skirt pile. The foundations are required to be piled to ensure a rigid connection is maintained between the jacket and the seabed during all weather and sea conditions.

5.5.1.2 Platform Topsides

Production Facilities

The topside facilities for each foundation well will comprise a wellhead system, accommodating the production tubing, tie-back strings and dry trees. The individual wellhead systems will be connected into a common production manifold. Space and tie-in points will be installed to accommodate future tie-back tubulars/risers.

Process Facilities

The platform topside facilities consist of a single processing train with approximately 2.9 million tonnes per annum (tpa) capacity, which dehydrates the gas and condensate streams for export to the Prelude FLNG facility as a co-mingled stream in the export pipeline.

The facilities comprise air cooling, separation, gas dehydration, condensate coalescer/filter, produced formation water (PFW) treatment and disposal overboard, chemical storage and injection facilities, plus the required power and utility systems. A process flow diagram for the platform is shown in **Figure 5-5**. There is a potential that a compression module could be installed in the future if required to support the development of future fields within the in-field development area.

The air cooler will cool the raw gas arriving at the platform before it passes into an inlet separator that separates gas from the hydrocarbon/PFW fluids. Gas exiting the inlet separator will be dehydrated via a triethylene glycol (TEG) system. The hydrocarbon/PFW fluids from the inlet separator will be cooled and passed to a liquid separator where the PFW will be separated from the condensate. The PFW stream will then be routed to the PFW treatment system while the condensate stream will be routed to the condensate filter/coalescer to remove any residual free water before it is recombined with the dehydrated gas for transfer through the export pipeline to the Prelude FLNG facility.

The PFW will be treated in a system comprising a liquid separator, low shear control valve and degasser vessel. Additional space will also be provided to allow further treatment options, such as hydrocyclones, if issues with the PFW treatment occurs. PFW will be disposed of overboard to the marine environment. Further context on the nature and scale of PFW discharge is covered in **Section 5.7.7**, and the evaluation of potential impacts/risks is covered in **Section 8**.

The platform design has allowed for future field development tie-ins through inclusion of future provisions for subsea tie-backs with flowline approach, riser and connection to the existing topsides manifold.

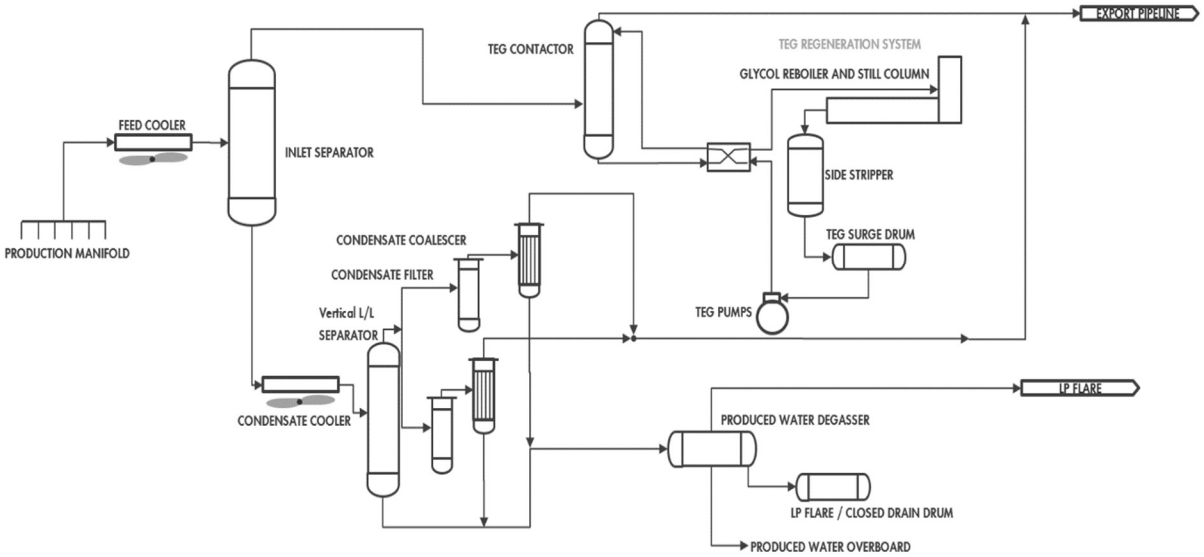


Figure 5-5: Process Flow Diagram for the Crux Platform

Utilities

To provide a reliable power supply for the platform process facilities, power will be generated from gas turbine generators installed on the platform topsides.

The platform will include a flare system. The purpose of the flare system is to collect and safely dispose of hydrocarbon-containing vapour that are released during start-up, operations, shutdown and maintenance. During start-up and shutdown, controlled flaring will be necessary.

Potable water will be provided by a lift-on tank for maintenance visits and is proposed to be used for ablutions and maintenance activities, as required. A sewage treatment system may also be installed should accommodation be provided on the platform.

Chemical storage and injection facilities will also be provided on the platform to maintain optimum production. Typical chemicals that may be stored in relatively small volumes (5 m^3–100 m^3) include corrosion and wax inhibitors, and TEG.

Operations and Accommodation

As a NNM platform, the intent is that the Crux platform will be operated remotely from the Prelude FLNG facility. The operations team will utilise existing procedures, method statements and proactive condition monitoring techniques, to monitor and analyse instrumentation and equipment health.

Upon achieving steady state operations, the current concept is to accommodate the workforce for campaign and turnaround maintenance via a 'Walk to Work Vessel' strategy from the Prelude FLNG facility. However, the platform design is under consideration and the feasibility of the strategy is still being assessed. Therefore, there is potential that it may include accommodation for a small number of personnel.

In the event that a remote operations workforce via a 'Walk to Work Vessel' unmanned philosophy for the Crux facility is not deemed feasible due to unforeseen circumstances, the space and option will be allowed to install accommodation facilities supporting approximately 50 people.

Temporary accommodation will be provided on vessels, for periods of peak workforce support, such as that expected during installation, commissioning and campaign maintenance/planned shutdowns.

Maintenance and Sparing

Maintenance of the platform will consist of campaign maintenance and planned shutdowns for major scheduled maintenance. Planned maintenance will be executed campaign-style for both normal operations and during maintenance shutdowns, with teams attending the platform or onshore workshops where equipment has been transported for overhaul.

5.5.2 Production Wells

The current design is for a total of five production dry tree wells. The wells will be drilled and suspended with a semi-submersible rig. Following installation of the Crux platform, the wells will be tied back with rigid concentric tubulars and completed with dry trees using a MPR on the Crux platform.

The deviated wells will be drilled from a single drill centre, which lies within the platform footprint. The location of the drill centre has been selected to optimise for well length and reservoir penetration, and avoidance of any potential subsurface hazards.

The wells for the foundation development are proposed to be drilled in a single campaign. Any future wells will be contained within the in-field development area shown in **Figure 5-3**, and will be conventional subsea wells with subsea trees, tied-back to the platform through subsea infrastructure. This is described further in **Section 5.6.2**.

5.5.3 Export Pipeline and Subsea Integration System

The export pipeline system is designed to carry gas and condensate from the Crux platform to the Prelude FLNG facility, through an approximately 165 km long 26-inch export pipeline.

The export pipeline route is relatively straight, as shown in **Figure 5-4**, and there are no seabed obstructions. The route slopes downwards towards the Prelude FLNG facility, going from a water depth of approximately 170 m at the Crux platform end to approximately 250 m at the Prelude FLNG facility location.

At the Crux end, a rigid tie-in spool connects the rigid riser on the Crux platform to the export pipeline end termination (Crux PLET). At the Prelude end, the export pipeline will terminate into a Crux dedicated pipeline end manifold (Prelude PLEM), which is proposed to be located approximately 550 m from the FLNG turret centre. A single large bore dynamic, flexible riser will connect the FLNG topsides facilities to the Prelude PLEM. Electrohydraulic control to the isolation valves will be provided via the existing Prelude control system or from a dedicated umbilical from the FLNG turret to the Prelude PLEM.

A schematic of the export pipeline and subsea integration system in shown in **Figure 5-6.**

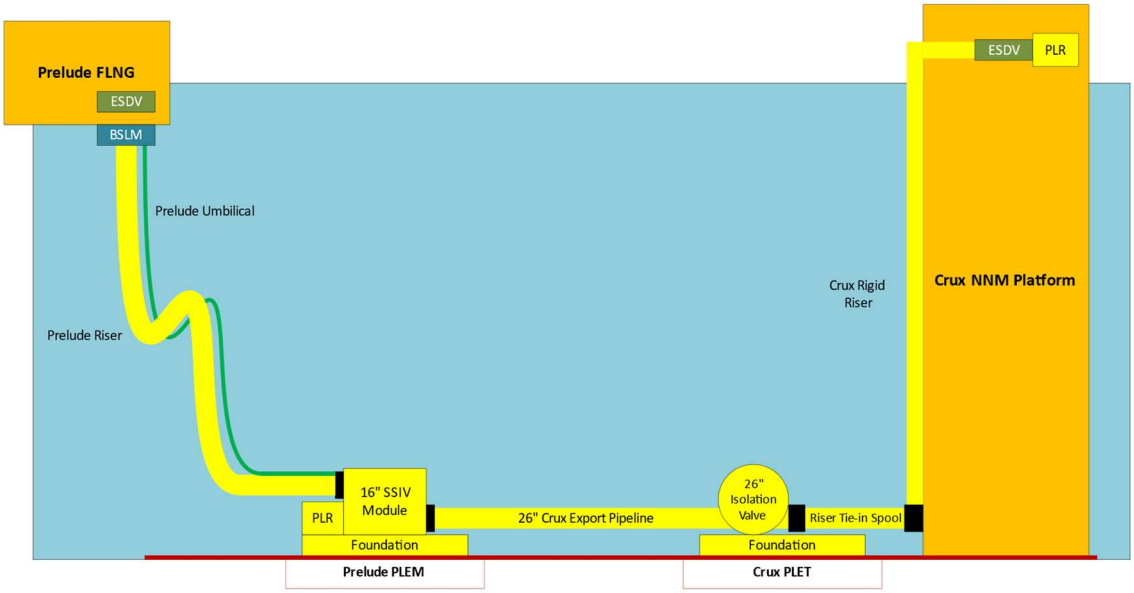


Figure 5-6: Export Pipeline and Subsea Integration System

5.5.4 Future Subsea Tie-Backs

As outlined in **Section 5.2**, the project incorporates provisions for future tie-back of subsea developments within the in-field development area to supplement production from the Crux field.

Space allowances will be included in the Crux platform to enable subsea control systems and risers to be retrofitted if required. In addition to space allowances, the platform structure will be designed to enable a future cantilevered module. This module will be used for hydrocarbon processing, including potentially compression.

Additional facilities and infrastructure associated with subsea tie-backs would also need to be installed for up to three separate subsea manifolds, subsea tree systems, flowlines and risers. The manifolds would collect and transfer reservoir fluids from the subsea wellheads into the platform. While details will be further considered as staged development progresses, it is possible that subsea compression may be utilised to minimise the size of a future module that may need to be added to the platform.

5.6 Project Stages

5.6.1 Overview

The key execution stages of the project are:

- development drilling, including tie-back and dry tree completion
- installation of the platform jacket and topsides
- installation and hook up of export pipeline and subsea integration system to the platform facilities
- commissioning
- operations and maintenance (note, this includes any future subsea tie-back developments within the in-field development area), and
- decommissioning.

The key activities within these project stages are summarised in **Table 5-2**.

As outlined in **Section 5.3.1**, additional gas reservoirs within the in-field development area may be tied back to the Crux platform. The development of these reservoirs will broadly involve the same key stages and activities as those used in the development of the Crux field, with the exception of completion with subsea trees.

Table 5-2: Crux Project Stages and Key Activities

Project Stage	Key Activities
Development drilling – including well tie-back to the platform and well completion	• Drilling and temporary suspension of production wells • Foundation wells tied-back and completed with dry tree using a MPR temporarily installed on the Crux platform • Wells perforated and unloaded with a coiled tubing unit and a temporary test package
Installation and hook-up of platform, export pipeline and subsea integration system	• Transport, installation and piling of jacket • Transport and installation of platform topsides • Installation and pre-commissioning (e.g. hydrotesting and dewatering) of export pipeline • Installation of subsea integration system, including Crux PLET, Prelude PLEM and risers
Commissioning	• Commissioning testing and monitoring topside equipment on the platform and the export pipeline

Operations and maintenance	• Well, flowline and riser operations
	• Remote production and processing operations
	• Planned maintenance and shutdown campaigns
	• During operations, additional fields within the in-field development area may be developed. Key activities associated with the development of these fields may include:
	  ○ installation and commissioning of subsea facilities to support future subsea tie-backs
	  ○ installation and commissioning of future compression module

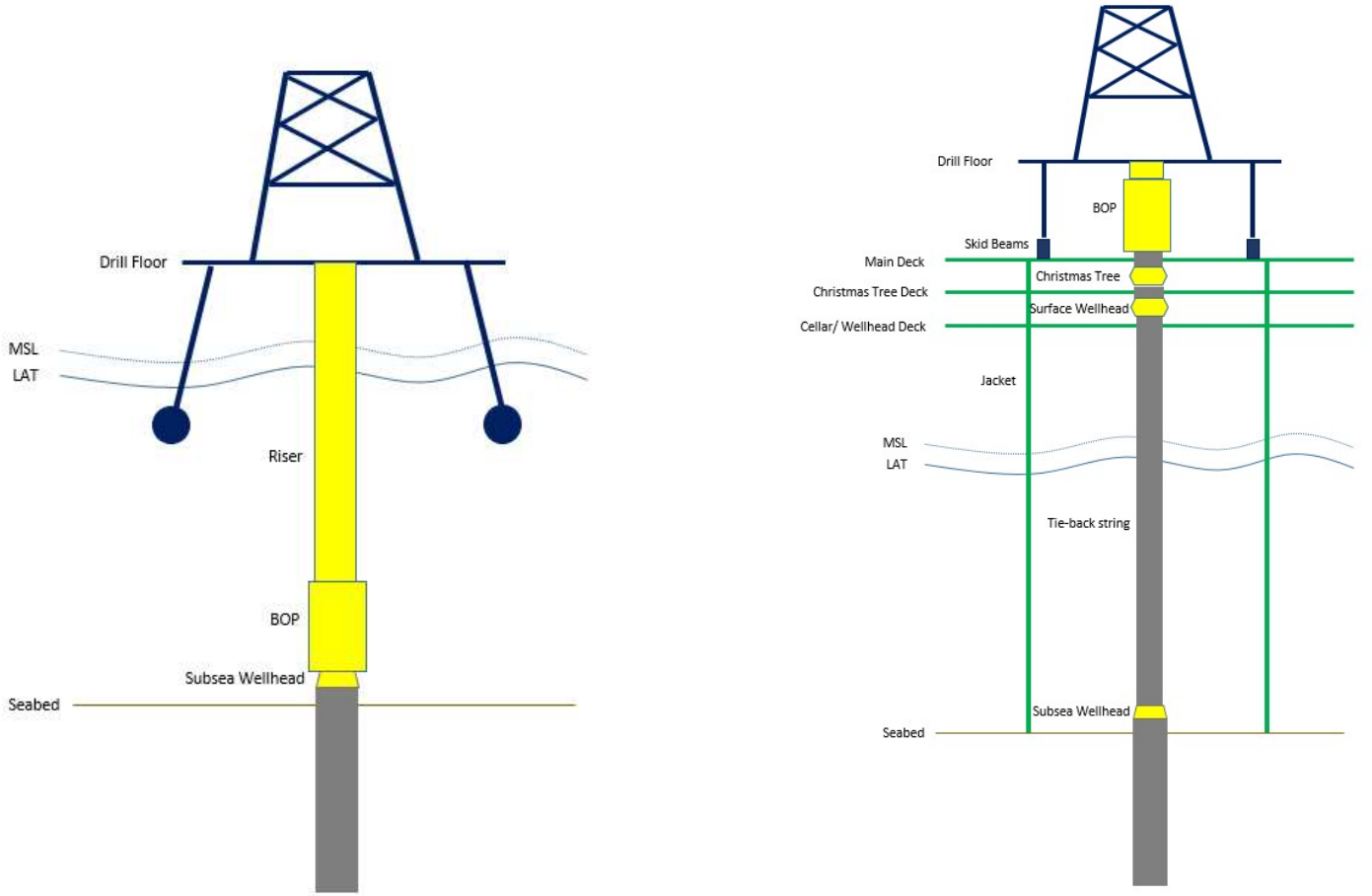
Decommissioning	• Well abandonment • Decommissioning of the platform • Decommissioning of subsea facilities and export pipeline

5.6.2 Development Drilling

The initial Crux production wells are proposed to be drilled with a semi-submersible drilling rig and later completed from the Crux platform using a temporary MPR. As the semi-submersible rig will drill (but not complete) the wells prior to the installation of the platform, the wells will be temporarily suspended until the Crux platform installation. Following the platform installation, a MPR will tie-back the wells to the platform through rigid concentric tubulars, production tubing run and wells completed with dry trees. The MPR will then be removed from the Crux platform. Subsequently, it is anticipated that the wells will be perforated with a coiled tubing unit and unloaded to a temporary test package. The drilling strategy is conceptualised in **Figure 5-7**. Any future wells will be subsea wells, drilled and completed with subsea trees using a semi-submersible drilling rig, and tied back to the platform through subsea infrastructure.

Drilling conducted from a semi-submersible drilling rig will use standard offshore drilling methods. Five production wells are proposed and are anticipated to be drilled within an approximate two-year period. Three additional spaces will be provided on the platform as contingency slots for the five foundation wells.

During drilling the rig will require supply vessels to visit every two or three days to replenish materials and equipment, and refuelling (diesel) once every 2–3 weeks.



a) Semi-submersible Drilling Rig

b) Tie-back and Completion using an MPR

Figure 5-7: Conceptual Development Drilling Strategy

5.6.2.1 Drilling Method

The wells will be drilled through a subsea drilling template, which may be installed with the semi-submersible drilling rig or as part of a dedicated campaign. The drilling template ensures correct positioning of the wells and alignment with future platform facilities. It is anticipated that dedicated docking piles will be installed, to facilitate installation of the platform substructure over the drilling template. Docking piles and the subsea template will remain in place for the producing life of the NNM platform.

The wells will be drilled in sections which decrease in diameter at increasing depths until the target reservoir is reached. Protective steel casing is inserted into the wells and cemented in place to isolate each section from the subsequent sections and provide structural support and stability to the well.

In the process of drilling, drilling muds (also known as drilling fluids) will be used to lubricate and cool the drill bit, maintain well bore stability, and remove drill cuttings (i.e. rock fragments) from the well sections as they are drilled. Two types of drilling muds will be used to drill the wells; water-based mud (WBM) and synthetic based mud (SBM). SBM will be used on the deeper and more challenging well sections where improved wellbore stability and suitability of the mud system for higher temperatures is required. WBM will be discharged to sea at the end of their useful life or at the end of the drilling program, whereas SBM is recovered and returned onshore for recycling or disposal.

Table 5-3 presents the types of drilling fluids, and their typical components, proposed to be used for the different well sections. The final selection of drilling fluids will be undertaken once detailed well design information is available to ensure that drilling fluids are appropriate for the drilling conditions. Based on the current well design and information from previous drilling campaigns undertaken by Shell for Prelude and the Auriga West-1 well, it is expected that the volume of drilling fluid discharged will be < 5,000 m^3 per well.

Drilling fluids and cuttings will be discharged at the seabed during drilling of the upper well sections as a riser connecting the drilling rig to the wellhead will not yet be installed. An alternate option of a riserless mud recovery system is being considered and may be used for the riserless well sections. This system allows cuttings to be recovered at the surface (i.e. drilling rig); however, the cuttings would still be discharged to seabed (if drilled with WBM), but not immediately above the well location.

On installing the riser system, the drilling fluids and cuttings will be circulated to the drilling rig prior to discharge overboard. Based on available information, it is estimated that the volume of drill cuttings discharged during conventional operations is not anticipated to exceed 1,000 m^3 per well. Cuttings from sections drilled with SBM are passed through a treatment system onboard the drilling rig prior to discharge overboard to reduce the volume of synthetic mud coating the rock. Previous experience from Prelude suggests that the residual SBM base fluid on cuttings content will be less than 10% weight per weight (w/w), averaged over all sections using SBM, prior to discharge overboard.

A subsea blowout preventer (BOP) will be installed prior to drilling the lower well sections for well control purposes during drilling. The BOP is removed once drilling is complete. Function and pressure tests of the BOP will be conducted regularly throughout drilling to ensure the system reliability is maintained. Each function or pressure test of the BOP will result in approximately 300 L of BOP hydraulic fluid (i.e. hydraulic fluid chemical diluted in water), depending on the BOP specifications, being discharged to the marine environment.

Once all sections of the well have been drilled, cased and cemented, the well will be temporarily suspended with suspension plugs, inflow tested and monitored until the Crux platform is installed.

Following installation of the platform, a MPR will be used to tie the initial production wells back to the platform via one or more tubulars. This requires the use of a surface wellhead system. Subsequently, a BOP will be installed, well suspension plugs recovered, and the production tubing will be run. Following well completion, the BOP will be removed, and the dry trees installed. The dry trees control the flow of the well, allow for pressure and temperature monitoring, and also provide a means of access for well intervention in the event down hole (well) checks or modifications are required.

The section of the well within the target reservoir (i.e. the production liner) will be perforated to allow the reservoir fluids to flow into the well. Prior to production, the wells will be cleaned up to remove any remaining drilling fluids, solids and debris. During clean-up, gas and condensate will be flared using temporary burner booms. Any water from the clean-up operations will be discharged overboard, provided it meets oil-in-water specifications, or shipped and treated onshore. It is anticipated that this will be part of a rigless campaign. The wells are then ready for production.

The persons on board (POB) required for well completion, perforating and unloading operations on the NNM platform will be accommodated on a floating accommodation support vessel.

Table 5-3: Drilling Fluid Types and Typical Components

Well Section Diameter (inches)	Drilling Fluid Type and Typical Main Components
Tophole (size yet to be confirmed – notionally 42" and 32")	WBM – seawater and high-viscosity gel sweeps
17.5	WBM – generally consists of seawater base fluid with bentonite clay, barite, brine and gellents (e.g. guar gum or xanthum gum)
12.25	Detailed SBM formulation is still to be determined but the drilling fluid may include synthetic base fluid with bentonite clay, barite, fluid loss control agents, lime, aqueous chloride, bridging agents and emulsifiers
8.5	

5.6.2.2 Vertical Seismic Profiling

While vertical seismic profiling (VSP) is not expected to be required for the development drilling of the initial Crux production wells, VSP may be performed at some stage in the Crux project, such as during future drilling campaigns within the in-field development area for backfills to the Crux platform. VSP may also be performed on a targeted basis during operations as part of well flow management. The use of VSP in these instances will be through deployment of a single small sound source from the drilling rig or Crux platform in the water column while receivers are positioned at specific depths downhole within the well. VSP provides a seismic image of the geology in the immediate vicinity of the well, with the survey taking approximately eight to 24 hours per well.

5.6.3 Installation and Hook-up of Facilities

5.6.3.1 Crux NNM Platform

The platform jacket and Crux rigid riser will be constructed off-site and transported to the Crux location by an offshore installation vessel(s). On arrival, the platform jacket will then be installed at location and fixed to the seabed by piled foundations using a construction vessel. Drilling is likely to be undertaken to assist in the installation of the piled foundations. The platform topsides will be installed via a floatover.

5.6.3.2 Export Pipeline and Subsea Integration System

The export pipeline system will be installed in several phased campaigns, these being:

- Prelude FLNG facility integration
- export pipeline installation, and
- Crux platform integration.

The Prelude FLNG facility integration scope, consisting of the large bore flexible riser and associated dynamic umbilical, will be installed using a specialised flexlay vessel. The flexible riser and dynamic umbilical will be designed to allow for extended wetparking while the rest of the export system is installed.

The rigid export pipeline and associated Crux PLET and Prelude PLEM will be installed in a separate campaign, utilising specialised large bore rigid pipeline vessels with heavy lift capability. Prior to laying of the export pipeline, the Crux PLET and Prelude PLEM will be installed on the seabed using installation vessels with heavy lift capability.

The export pipeline will be installed by a pipelay vessel. An S-lay method of installation will be used and involves lengths of steel pipe (joints) being continuously welded, inspected and coated with (anti-corrosion and concrete coating) in a horizontal working plane (firing line) on board the pipelay vessel. As the pipelay vessel moves forward along the pipeline route, the pipe gradually exits the firing line, curving downward through the water until it reaches the seabed. The stability of the pipeline on the seabed is achieved through the addition of concrete weight-coating. No trenching or rock stabilisation of the export pipeline is envisaged.

Crux integration will be achieved by the installation of the rigid tie-in, connecting the Crux PLET to the Crux rigid riser. Integration at the Prelude FLNG facility is completed by connecting the large bore flexible riser and dynamic umbilical to the Prelude PLEM. It is expected that an installation vessel/multi-purpose support vessel will be used to install the Crux PLET and Prelude PLEM.

Pre-commissioning of the export pipeline will likely include the following activities:

- flooding, cleaning and gauging
- process/pressure testing using treated seawater to confirm structural integrity
- dewatering and drying, and
- pipeline inerting using nitrogen purge.

The pre-commissioning activities will require the use of PIGs. The pressure test fluid will be discharged to the marine environment from the Crux platform or Prelude FLNG facility end

of the pipeline. Further context on the nature and scale of hydrotest discharge is covered in **Section 5.7.7**, and potential impacts/risks covered in **Section 8**.

5.6.3.3 Future Subsea Facilities

Subsea facilities required for any future developments will be installed and connected to the platform using a combination of specialised offshore installation vessels, such as crane vessels and subsea construction vessels.

While trenching of the flowlines/risers will not be required, some secondary stabilisation may be needed in some areas to ensure the stability and long-term integrity of the subsea facilities.

5.6.3.4 Supporting Infrastructure - Fibre Optic Cable

A fibre optic cable will be installed to connect the Crux platform to the existing North-West Cable System, which connects both the Prelude and Ichthys projects to Port Hedland and Darwin. The cable will provide the project with reliable and high-speed data communications that allows efficient and responsive operation of the Crux platform topside facilities remotely. The fibre optic cable will branch off the existing North-West Cable System (operated by NEXTGEN) and is anticipated to be approximately 50 km in length. There is also another option that the cable may be laid along the export pipeline route from Prelude to the Crux platform. The cable route has not been determined given the early stage of the project.

The cable is anticipated to be around 10 mm–40 mm in diameter and will be installed using a specialised vessel. The cable is expected to the buried along the majority of the route to provide extra protection and stabilisation. A combination of standard techniques may be used to bury the cable, including ploughing/trenching concurrently with the laying of the cable and post lay burial via jetting techniques through use of a remotely operated vehicle.

The forward approvals process for the installation and connection of the cable is subject to financial and commercial arrangements, and the timing of other customer negotiations and connections.

5.6.4 Commissioning

It is anticipated that the majority of the commissioning activities of the Crux platform will take place at the construction yard, with only limited commissioning activities of the platform occurring within the in-field development area. Key steps in the offshore commissioning process of the platform are expected include:

- cold venting to clear nitrogen from the equipment and piping systems
- lighting the pilots for the flare system
- sequential pressurisation of topsides systems and final leak checks
- fuel gas system commissioning to start main power generation
- commissioning of condensate and gas dehydration systems, and
- when export specifications have been met, the gas production rates will be slowly increased to system capacity.

Supply vessels will ship materials, equipment and other supplies, such as food, in support of commissioning and start-up activities. During commissioning, there will be temporary

support requirements, including temporary power generation (diesel), temporary offices and services (for water, nitrogen etc).

5.6.5 Operations and Maintenance

The platform will require a medium sized operational team in early production life, following commissioning and start-up activities. It is likely this will be provided via floating accommodation such as vessels to accommodate personnel. The facility will be designed such that it can employ a Walk To Work vessel as means of accommodation. The Walk to Work vessel will be equipped with heave compensated gangway allowing transfer of personnel on and off the facility. Remote, NNM operations, are expected to be in place after approximately 12 months from the wells commencing production.

The following operational activities are anticipated to occur throughout the life of the facility:

- start-up, ramp-up and shut-in of individual wells
- remote chemical injection into the well-streams
- remotely monitoring and control of the platform
- well-testing
- well, flowline and export pipeline integrity management
- well intervention works, including water shut-off, valve installation, suspension plug installation for tree replacement, re-perforation or upper completion (e.g. tubing, subsea isolation valves) replacements
- campaign and shutdown maintenance execution along with unplanned interventions, and
- intelligent pigging of export pipeline.

Inspection and intervention on the subsea facilities will be undertaken when required using specialised intervention vessels.

Integrity and inspection through pigging of the export pipeline may be undertaken throughout operations to ensure structural integrity of the pipeline is maintained and remove any residual materials, such as deposited wax, that may have accumulated in the pipeline. Pigging refers to the practice of using PIGs to inspect or clean the pipeline without stopping the flow of the product in the pipeline. Pigging will be performed from the PIG launcher/receiver located on the Crux platform to the Prelude facilities. Pigging frequency will be determined based on a risk-based inspection process and ongoing monitoring of corrosion controls. Small volumes of liquids or solids may be released to the marine environment during operational pigging activities.

A flow assurance management strategy has been defined for the project to ensure efficient and sustained operability of the production facilities. While the risk of hydrate formation and plugs building up in the export pipeline is low, a hydrate surveillance and remediation strategy will be implemented throughout operations to monitor for the formation of hydrate plugs.

There is a low likelihood of wax deposition occurring in the export pipeline and provision for continuous paraffin inhibitor injection has been assumed throughout the field life in case this occurs. A fluid sample surveillance program will also be in place for wax deposition analysis

during initial production and new wells coming online. If required, pigging of the export pipeline will be undertaken.

Transition to a NNM platform personnel manning philosophy is expected to take approximately one year from start-up. The manning philosophy during this period comprises several phases:

- early operations phase (manned) – following commissioning and start-up activities, personnel will be maintained to provide operational and maintenance support until the platform facilities are operating satisfactorily. During this phase the operations model will be a typical offshore rotational model. This team will operate and maintain the platform until reliability is such that operations numbers onboard can be reduced. The early operations phase is anticipated to be approximately 3 months.
- interim operations model – following early operations and once steady state operations are achieved, the number of personnel will be reduced to a sufficient number to undertake field operations and maintenance. A minimum operations crew is retained until reliable remote operation has been demonstrated. This phase is anticipated to be approximately 6 to 9 months.
- NNM phase – it is anticipated that the facility will move to a NNM operating model within the first year of operation. At this time the facility will be periodically visited during planned campaign and other maintenance activities.

5.6.6 Decommissioning

The project will be decommissioned at the end of its operating life when production from the reservoirs ceases to be economically viable. The project will be decommissioned in accordance with the prevailing legislation at that time. Decommissioning is a petroleum activity and requires approval under the OPGGS Act, including acceptance of the Decommissioning EP and Safety Case prior to decommissioning activities commencing.

The overarching objective of decommissioning will be to ensure that activities do not cause unacceptable environmental impacts and are the most appropriate for the circumstances at the time in which decommissioning option is undertaken.

The complete removal of infrastructure and the plugging and abandonment of wells is the default decommissioning requirement under the OPGGS Act and is consistent with Australia's international obligations to remove disused installations and structures. However, this requirement is subject to other provisions of the OPGGS Act and regulations, directions given by NOPSEMA or the responsible Commonwealth Minister, and other applicable laws such as the *Environmental Protection (Sea Dumping) Act 1981*. Therefore, alternative options other than complete removal can be undertaken if the titleholder can demonstrate that the alternative approach delivers equal or better environmental, safety and well integrity outcomes (DIIS 2018). The OPGGS Act allows titleholders to make alternative arrangements for the treatment of equipment (e.g. partial removal or abandonment in situ) through the submission of an EP that includes decommissioning activities, provided that these arrangements and that impacts and risks are acceptable and ALARP (NOPSEMA 2017).

Infield decommissioning activities are expected to take several years to complete. Prior to decommissioning, an EP will be submitted to NOPSEMA for acceptance after considering a range of decommissioning options, including but not limited to those outlined below for

project infrastructure, and will present an ALARP assessment of the appropriate strategy at that time:

- plugging and abandonment of production wells
- NNM platform – options may include cutting off at the base and total removal of topsides for onshore disposal, leave in situ, jacket toppling or offshore reefing
- subsea infrastructure (e.g. risers, Crux PLET, Prelude PLEM, manifold, jacket/foundation) – options may include removal and onshore disposal, leave in situ, jacket toppling, or offshore reefing, and
- export pipeline, flowlines and fibre optic cable – options may include total removal, leave in situ after flushing to remove hydrocarbons, or partial removal.

After the successful completion of decommissioning activities, Shell will apply to surrender the Crux production and infrastructure licences. Once satisfied that Shell has complied with all requirements for the surrender of these licences, the Designated Authority can give consent to the surrender of the licences. It is likely that decommissioning and surrender of the licences, from approval of the Decommissioning EP through to the Designated Authority's consent to the surrender of the licences, will take about 12 months.

It is widely acknowledged that there are a variety of factors that may affect titleholders' consideration of the most suitable decommissioning option, including site-specific environmental and safety risks, type of infrastructure, costs and available technology. An ALARP and acceptability assessment of the decommissioning options proposed for the project will provide transparency in decision making where environmental benefits and impacts are clearly presented in the context of a broader framework of decision criteria.

Given the early stage of the project, and the expected operational life of the project, it is premature to define a decommissioning strategy that aims to address environmental impacts in detail in this OPP. Key decommissioning risks have been broadly addressed through the evaluation of project impacts and risks in **Section 8**. Further detailed information of the nature and scale of the activity, potential environmental impacts and risks, and the control measures that will be implemented will be provided in the activity-specific Decommissioning EP. As such, this OPP only outlines broad EPOs relating to decommissioning activities, as aligned with the intent for this to be an 'early stage, whole-of-project' assessment.

5.7 Key Project Aspects

Key aspects associated with project activities that can interact with the environment are described in **Section 5.7.1** to **Section 5.7.9**.

5.7.1 Physical Presence

The physical presence of the project will arise from the installation of physical features, such as wells, well tie-back infrastructure, subsea facilities and the export pipeline, and from the presence of the Crux platform and project vessels. These offshore facilities/infrastructure and equipment will be present both at the sea surface (e.g. platform and project vessels), within the water column (e.g. platform jacket and risers) and on the seabed (e.g. flowlines, manifold, PLET/PLEM and the export pipeline). The presence of project vessels is considered in detail within the vessel movements aspect, as discussed in **Section 5.7.2**.

Installation and other works, such as anchoring, associated with the following components of the project will disturb areas of the seabed:

- Crux platform (jacket structure)
- drilling and installation of wells
- export pipeline and subsea integration system (e.g. Crux PLET and Prelude PLEM), and
- potential future subsea facilities associated with well and tie-back infrastructure.

During drilling and installation stages of the project, the semi-submersible drilling rig and some installation vessels will be held in place using anchors. The exact anchoring configuration will vary for each installation vessel. Physical disturbance of the seabed will mainly be associated with laying and retrieval of anchors and chains.

The expected approximate area extent of direct seabed disturbance is provided in **Table 5-4**.

Table 5-4: Proposed Direct Seabed Disturbance

Facility	Approximate Area of Disturbance (m^2)
Crux Field	
Semi-submersible drilling rig – anchors and mooring lines	10,000
Wells (5)	45
Vessel anchoring	200
Platform jacket	10,000
Export pipeline (1)	165,000
Subsea integration system (e.g. Crux PLET, Prelude PLEM, isolation facilities)	9,000
Fibre optic cable	45
Additional Future Backfills	
Semi-submersible drilling rig – anchors and mooring lines	30,000
Wells (10)	90
Subsea integration system (e.g. flowlines and associated umbilicals, manifolds, isolation facilities, PLET)	90,600
Flowline stabilisations and supports ((e.g. buckling structures, mattresses, rock stabilisation)	1,000
Total	**315,980 (approximately 32 hectares (ha))**

Indirect seabed disturbance may occur as a result of localised sedimentation and turbidity generated from activities associated with the controlled placement of infrastructure on the seabed, such as the drilling template, docking piles, riser base manifold, Crux PLET, Prelude PLEM and export pipeline. In addition, the planned discharge of drilling cuttings and fluids during development drilling will also result in a temporary increase in sedimentation and turbidity levels.

5.7.2 Vessel Movements

A number of vessels will be required throughout the project to undertake specific activities, as indicated by the summary of the key vessels provided in **Table 5-5**.

Vessel movements within the project area are expected to be highest during the installation phase of the project. Although a number of different vessel types will be used during installation, they will not all be in the field at the same time.

During steady state operations, it is expected that supply vessels will visit the platform during operational maintenance campaigns or planned shutdown to replenish key consumables (e.g. food, water), chemicals and equipment specifically required for scheduled maintenance.

In-field vessels operating within the project area will typically travel at speeds slower than those operating in offshore waters, and therefore exhibit a lower risk profile in terms of interactions with other marine users and marine fauna.

Table 5-5: Key Project Vessels

Vessel	Project Stage				
	Development Drilling	Subsea Installation and Hook-up	Commissioning	Operations and Maintenance	Decommissioning
Supply vessel	✓	✓	✓	✓	✓
Walk to Work vessel	✓	✓	✓	✓	✓
Offshore support vessels (e.g. drill rig support vessel, well testing vessel, inspection, monitoring, maintenance and repair vessel, survey vessel, infield support vessel, remotely operated vehicle inspection vessel)	✓	✓	✓	✓	✓
Offshore installation/construction/heavy lift vessel		✓			✓
Pipelay vessel		✓			✓
Pipelay barge		✓			✓
Line pipe supply vessel		✓			
Cable lay vessel (for fibre optic cable)		✓			

5.7.3 Light Emissions

Artificial light from activities associated with the project will result in light spill to the surrounding marine environment. Existing sources of light in the vicinity of the project area are limited to vessel movements and oil and gas development activities, with these resulting in temporary illumination. Therefore, the baseline illumination of the project area is predominantly from starlight and the lunar phase and cycle.

All offshore facilities and vessels must meet maritime and operational safety lighting requirements, as specified by Safety Case assessments under the OPGGS Act and relevant legislation, such as the *Navigation Act 2012*. As project activities are conducted 24 hours a day, lighting is required for safety and navigational purposes. Therefore, the Crux platform and project vessels will be constantly lit. The amount of light spill generated in the project area will be dependent on the number of light sources, the wavelength and intensity of the light sources, the location and/or placement of light fittings and the method of light switching.

Light emissions are anticipated to be highest primarily during commissioning and start-up and upset conditions due to the increased presence of vessels and requirement for flaring during commissioning activities. During operations, light from the platform will be predominantly from the pilot flare, which is for process safety requirements, and navigational beacons. Lighting of the platform will be reduced to a minimum during periods when the facility is not occupied. Light emissions from upset flare events will be intermittent and varied in duration.

There will be no permanent lighting within the export pipeline corridor. Project vessels involved in the installation and operational maintenance campaigns will be the only light sources within this area.

5.7.4 Underwater Noise

Underwater noise will be produced during all stages of the project from development drilling, installation activities, vessel and helicopter movements, and decommissioning activities. The main sources of noise will be from pile driving activities for the installation of the platform foundations (approximately four piles for each of the four foundations, therefore total of 16 piles) and from vessel engines and machinery. Vessel movements are expected to be higher during the installation and commissioning stages of the project due to the increased number of vessels required (**Section 5.7.2**).

Underwater noise emissions during operations will be relatively limited with noise generating activities expected to be associated with vessel movements only during scheduled maintenance campaigns at the Crux platform. Therefore, the presence of vessels in the project area will be intermittent during the operational life of the project.

Primary access to the Crux platform during operation is expected to be via vessels from Prelude. Helicopters/vessels will transport personnel to/from the platform during commissioning, operational maintenance campaigns and planned shutdowns. It is anticipated that only a single vessel transfer will be required to/from the platform during these periods.

It is expected that helicopters will be used in support of installation phase activities. During operation, helicopters would only be used in the event of an urgent operational need, medical emergency or evacuation. Helicopters have the potential to result in localised underwater noise emissions when landing on/taking off from the platform.

5.7.5 Atmospheric Emissions

Atmospheric emissions associated with the project will be generated by a number of sources:

- combustion emissions from power generation and processing facilities
- periodic flaring of gas during development drilling, commissioning/start-up and shutdown activities. A continuous small pilot flame will be necessary on the flare during operations for safety reasons. This will comprise a continuous flow of small quantities of purge gas and off gas from gas dehydration.
- disposal of TEG regeneration off gas stream to flare
- transportation, such as vessel and helicopter movements, and
- fugitive emissions.

As the Crux project development concept is premised on providing a supply of back-fill gas for the continued operation of the Prelude FLNG facility, the majority of the emissions are accounted for in the design and operation of the Prelude FLNG facility and have been subject to prior assessment and approval through the Prelude FLNG Environmental Impact Statement (EIS) and subsequent EPs. The above-mentioned emissions include the venting of Crux reservoir CO_2 (11.6%vol) at the Prelude FLNG acid gas removal unit (AGRU). Alternative options have been considered through the evaluation of the implementation of carbon capture and storage (CCS) at Crux and/or allowances in the design for future implementation of CCS at Crux. It was deemed not viable to implement CCS at Crux (for more detail see **Section 5.8**).

The Crux NNM platform process and utilities design is lean, therefore the emission at the platform will be relatively limited. Primary atmospheric emissions include carbon dioxide (CO_2), methane (CH_4), oxides of nitrogen (NO_X), sulphur and volatile organic compounds (VOCs) including benzene, toluene, ethylbenzene and xylene (BTEX).

There is no planned cold venting of hydrocarbons at the Crux platform during operations. There may be unanticipated release of hydrocarbon emissions by venting in the unplanned scenario that the flare pilot flame is not lit, arising from flare tip failure. This is an unlikely scenario, and venting will be of short duration while the flare tip is not operational. There may also be minor fugitive emissions from vents in the onboard diesel storage tanks, or flanges/valves.

5.7.5.1 Emissions

CO_2

Table 5-6 provides a summary of estimated CO_2 emissions during plateau production levels. The main source of CO_2 is that produced from combustion of fuel gas in the platform topsides for preliminary processing of the gas and condensate and power generation. The emissions inventory provided in **Table 5-6** accommodates a potential for future compression emissions on the Crux platform. While this is not within the current foundation development concept, an estimation of emissions is provided for completeness.

The Crux platform process and utilities design will be optimised through the project to minimise GHG emissions.

Table 5-6: Summary of CO_2 Emissions specific to the Crux Project

Source	$CO_{2\text{-}e}$ Tonnes Per Annum (tpa) At peak production rates
Combustion at Crux platform	75,000
Flaring at Crux platform – foundation development during normal operations	100,000[1]
Future compression emissions	282,000

[1] This value assumes flaring associated with trips, restarts and blowdown equates to approximately 20 hours of peak rate raw feed gas per year.

NO_X

NO_X emissions will be produced from combustion and flaring operations on the Crux platform and are expected to be approximately 2.5 tpa for foundation scope, and 9 tpa if future compression is added. Relatively minor emissions are expected to arise from products of combustion during other development phases including development drilling and associated vessel activities

Sulphur

The hydrogen sulphide (H_2S) in the feed gas is almost completely removed in the Prelude FLNG facility acid gas regeneration unit and vented. It is expected that approximately 65 tpa of H_2S will be vented with the Crux reservoir CO_2. Minor emissions of H_2S or SO_X will be released from the Crux platform as part of the flare gas stream, which will be intermittent and variable over the life of the project.

VOCs

VOCs arise from fugitive emissions that are defined as releases not confined to a stack, duct or vent. These emissions generally include equipment leaks, emissions from bulk handling of products and a number of other industrial operations. Fugitive emissions sources can include connectors and flanges, valves, seals, pumps and compressors.

Flaring

Flaring will be required on the Crux platform for commissioning start-up, shutdown, emergency depressurisation and for the disposal of low volume low pressure off gas streams such as TEG regeneration off gas. Apart from the pilot flare, the following flaring events may occur:

- emergency depressurisation – in certain circumstances, this represents the maximum flaring rate required to ensure the topside facilities of the platform are brought to controlled condition as soon as possible. This case results mainly from an emergency shutdown and depressurisation in the topsides. This involves mainly opening of emergency depressurisation valves and is expected to be infrequent.
- operational flaring – operational flaring results from a controlled operational event such as start-up, normal shutdown, system upset, manual controlled blowdown, purging, and draining of equipment in preparation for maintenance. During start-up, there is periodic flaring until the process reaches steady state and stable operations.
- off gas stream disposal – low pressure off gas streams such as off gas from the TEG regeneration system and flash gas from water treatment system will be routed to flare.

5.7.5.2 Summary of Greenhouse Gas Emissions

As described previously, the majority of emissions are to be transferred and processed at the existing Prelude FLNG facility, which have already been subject to prior approval. The NNM platform process and utilities design is lean, accounting for a small proportion of the Crux upstream emissions (approximately 9-10% for the foundation project). Consequently, there are limited opportunities to further reduce combustion and flaring emissions. However, process and utilities design will continue to be optimised as the project design progresses.

The major sources of GHG emissions at the Crux platform are:

- combustion associated with providing electrical power for Crux processing and personnel facilities, and
- flaring.

The major sources of GHG emissions for the overall system are from the Prelude FLNG facility and are:

- venting of acid gases (primarily CO_2), and
- combustion associated with liquefaction compression, providing electrical power for Prelude FLNG facility processing and personnel facilities.

Any changes in GHG emissions from the Prelude FLNG facility will be addressed through future revisions of the Prelude FLNG Operations EP, which will be submitted to NOPSEMA for acceptance.

5.7.6 Invasive Marine Species

Invasive marine species (IMS) are non-indigenous marine fauna or flora that have been introduced into an area beyond their natural geographical range, and may have the ability to survive, reproduce and establish a population such that they threaten native species through increased competition for resources and/or increased predation.

The drilling rig, vessels and equipment sourced from outside Australian waters have the potential to introduce or transport IMS to the project area, or potentially to other areas through activities such as support vessel interaction with the project area. There are two primary mechanisms which may cause the inadvertent introduction and spread of IMS; hull fouling (biofouling) and ballast water discharges.

The project will be managed in accordance with all relevant Australian and international regulations, requirements and guidelines.

5.7.7 Liquid Discharges

Liquid discharges will be released to the marine environment throughout the life of the project. The key discharge streams are discussed in further detail below and are considered to represent the largest planned discharges associated with the project. The full range of potential planned liquid discharge sources that may be released at different stages of the project will be assessed and defined as the engineering design progresses.

Produced Formation Water

PFW is water that occurs naturally within the same rock strata as the hydrocarbons and flows to the surface with hydrocarbon from the production wells. It comprises condensed water and saline formation water.

The characteristics of the PFW discharge will transition during the life of the project. The water production profiles for the project during early operations predict condensed water during which there is minimal formation water produced. During later operations, the water produced will transition to a mixture of condensed water and formation water. The amount of formation water is expected to comprise a greater proportion of the discharge as the field nears end of life.

PFWs are saline and contain a mixture of dissolved inorganic salts, dispersed oil, dissolved organic compounds, treatment and workover chemicals, dissolved gases, and dispersed solid particles. The elements of the PFW discharge stream that may represent an environmental risk include:

- BTEX compounds – benzene, toluene, ethylbenzene, xylene
- NPD compounds – naphthalene, phenanthrene, dibenzothiophene
- PAH compounds – polycyclic aromatic hydrocarbon compounds, which include acenaphthylene, fluoranthrene and chrysene
- metals – cadmium, chromium, copper, lead, nickel, zinc, iron, barium, mercury and strontium, and
- production chemicals.

Data from the investigation of the Crux field formations has shown the volume of PFW produced from the gas reservoir will increase towards the end of field life. A maximum water flow rate of approximately 238 m^3/day is expected during early operations.

After this time, there is a potential for wells to start producing formation water. Reservoir modelling shows water breakthrough may result in water flow rate increasing to the maximum water flow rate that can be produced from a well. The produced water system on the Crux facility has been designed to handle one well at peak formation water rate after approximately 8 years of production and two wells towards the end of field life (3,180 m^3/day formation water).

The modelling and assessment of the potential environmental impact associated with PFW has taken into consideration early field life maximum and maximum peak PFW flow rates, as described in **Section 8**.

Non-routine events resulting in off-specification oil-in-water discharge of PFW could occur. Such events are expected to be infrequent and will be rectified as soon as is practicable and does not represent a typical discharge concentration during routine operations. During commissioning or process upsets, such events are considered more likely. Shell has taken this into account in the project concept engineering and evaluation of alternatives (refer **Section 5.8**) and the assessment of relevant impacts and risks with this discharge stream (**Section 8**).

Wastewater

Wastewater will be discharged to the marine environment from the drilling rig, vessels and platform when manned during commissioning/start up, operational maintenance and planned shutdown activities. Wastewater consists of domestic sewage, greywater, bilge and deck drainage from open, un-contaminated drainage areas. The volume of treated sewage discharged is influenced by the number of personnel onboard the platform/vessel. In general, it is assumed that 0.5 m^3–1 m^3 per person per day will be released to the marine environment. When taking into consideration the typical POB of the platform (when manned) and project vessels, the sewage volume discharged is expected to range between approximately 14 m^3–120 m^3 per day.

Cooling Water

Cooling water discharges will not occur from the Crux platform. Air cooling has been selected as the medium for the NNM platform concept, therefore no continuous release of cooling water during operations will occur.

It may be expected that small volumes of cooling water (typically characterised as utility discharges) will be discharged from vessels, with volumes expected to be in the order of approximately 5,000 m^3–10,000 m^3 per day per vessel, depending on the type of vessel.

Hydrotest Water

Pressure-testing (or flood, clean, gauge and testing) is required to assess the structural integrity of subsea facilities, including flowlines, riser, spools and the export pipeline. Pressure-testing is undertaken by using treated seawater and internal pressures monitored to detect any leaks. Hydrotest water may consist of seawater containing combinations of the following constituents; biocides, corrosion inhibitor, scale inhibitor, dye, oxygen scavengers, monoethylene glycol (MEG) and gel slugs. Chemicals are required to avoid metal corrosion, prevent bacterial growth and the accumulation of scale on internal surfaces, all aimed at maintaining pipeline integrity.

The majority of the hydrotest water discharged will be associated with testing of the export pipeline. The export pipeline will be flooded with approximately 48,000 m^3 of treated seawater which will be released near the seabed at either the Crux platform or Prelude FLNG facility end of the export pipeline once pressure-testing activities are complete. The volumes of hydrotest water required for the rigid riser will be significantly smaller than that required for the export pipeline and are expected to be in the order of approximately 100 m^3. The volumes of hydrotest water required for all future subsea tie-backs would be expected to be an order of magnitude less than the Crux export pipeline volumes.

The topside facilities associated with the platform will be hydrotested to ensure structural integrity, with the activity occurring in either the overseas construction yard or proposed Crux platform location. However, if hydrotesting of the topside facilities is undertaken in the in-field development area, the volume of hydrotest water that would be discharged is expected to be in the order of approximately 500 m^3–1,000 m^3.

Drill Fluids/Cuttings

As summarised previously in **Section 5.6.2.1**, there will be small volumes of drilling fluids and cuttings discharged during drilling of the production wells.

If drilling is used to support the installation of the Crux platform foundations, drill cuttings will be discharged overboard from the platform. It is estimated that in the order of 1,130 m^3 of drill cuttings per hole will be discharged during this activity. Up to 16 holes may be drilled for the platform foundations. Drill fluids will not be used for any drilling associated with the installation of the Crux platform foundations.

5.7.8 Waste Management

Hazardous and non-hazardous solid wastes (except drilling cuttings and fluids, sewage and putrescible waste) and recyclable materials will be removed from the project area and returned to shore for processing.

The waste management strategy for the project will be designed to optimise segregation of waste in the offshore location and to minimise contamination of recovered waste destined for recycling or disposal. All non-hazardous and hazardous solid waste will be managed in accordance with the relevant Waste Management Procedure and the vessels' Waste Management Plan/Procedure, and as detailed in activity-specific EPs.

5.7.9 Emergency Events

Emergency events are incidents that have the potential to trigger impacts that would otherwise not be anticipated during the normal and planned activities. The magnitude of impact from emergency events can be greater than the magnitude of potential impacts associated with routine operations, however the probability of an emergency event occurring is significantly lower.

A detailed discussion of the potential low probability spill scenarios that may occur during the project, and the potential impacts and risks, are provided in **Section 8.**

The project will implement a number of stringent measures to mitigate the risk and potential impacts associated with the unlikely event of an unplanned discharge to the marine environment, including elimination controls (wherever possible), engineering controls, planned maintenance, operational procedures and spill response preparedness measures.

5.8 Assessment of Alternatives

The potential for tie-back of Crux and other nearby reservoirs to Prelude FLNG was flagged as part of the Prelude environmental approvals (Shell 2009):

> *'When the Prelude field pressure eventually does start to reduce, the decline in production rate is likely to be backfilled by tiebacks from other gas sources so that the FLNG facility can continue to operate efficiently at full throughput. Exploration is still underway but potential gas sources include the nearby Concerto field, the Crux field and the Libra field. Sufficient spare tie-in points have been allowed for potential future gas tiebacks. Such tiebacks are not included in the scope of this draft EIS and will be the subject of a separate environmental approvals process to cover their field development and connecting pipelines.'*

Following the grant of a retention lease for the in-field development area in 2013, feasibility assessments were commenced in 2014. After the completion of the Auriga West-1 exploration well in the in-field development area in 2015, Concept Select studies have focused on the backfill opportunities presented for the Prelude FLNG host.

These studies focused on selecting an option from a range of alternative for key decisions underpinning the overall development concept. The decision-making process was informed by a number of criteria across the Technical, Economical, Commercial, Organisational and Political spectrum.

The concept selection process used for the Crux project follows the competitive scoping framework developed within Shell. Competitive scoping calls for the identification and development of the minimum technical requirements and hence scope for a development concept. Whilst this minimum scoped concept is able to meet technical requirements, it is

possible that additional scope elements may enhance value by mitigating operational or execution risks.

Using this framework, the potential value trade-offs for the Crux project were identified and grouped into decisions. These were ranked according to estimated impact and/or risk mitigation on the overall Crux project.

The decision quality of individual key concept decisions, as well as the integration across inter-dependent concept decisions are documented and form part or the overall integrated concept select decision. Review and challenge from appropriate stakeholders are a key part of this process.

A key consideration in the decision-making process are HSSE requirements. The overall Crux HSSE management strategy can be summarised as follows:

- a Crux HSSE Management Plan has been developed for the project. This sets out goals, strategies and roles/responsibility for the Crux team
- a Crux HSSE & SP Premises document has been developed which capture a minimum set of standards for the design of the project. These Premises will be refined or extended as a result of the formal Hazards and Effects Management Process (HEMP) to ensure risks to people, assets, community and the environment are tolerable and ALARP. This includes Contractor HSSE
- design standards have been used in concept development, including Shell design requirements. The Shell HSSE control framework guides the minimum, mandatory requirements for the project, and
- HAZID workshops have been conducted involving multidiscipline teams. The sessions have focused on key differentiators between the various concepts and findings incorporated in the project Hazard and Effects register.

A large proportion of HSSE risk management, inclusive of all critical HSSE risks identified, has been integrated into the decision-making process by assessment during the decision quality process. If the decision being taken may have an impact on high potential impact HSSE risks, the NOPSEMA Decision Framework is used to determine the decision context. In addition to safety studies, an initial assessment of the potential ESHIA was undertaken at an early stage. This preliminary evaluation helped to inform the scope and focus of key issues to be further assessed in this OPP.

A summary of the key alternative development concepts evaluated as part of Concept Select, is provided in the following sub-sections.

5.8.1 Host Type

The host type decision focused on the selection of the host type at the Crux location. The following host types were considered during the study:

- subsea tieback to Prelude FLNG facility
- greenfield FLNG facility
- fixed host types, including:
  - Platform, and
  - Tension Leg Platform (TLP)/Spar.
- floating host types, including:
  - Floating Production Storage and Offloading (FPSO), and
  - Semi-submersible.

The subsea tieback option and greenfield FLNG option were reviewed early during screening and determined to not be commercially or economically viable. A summary of this decision process is provided below:

Subsea Tieback

Several studies were conducted investigating the feasibility of a direct subsea tieback to the Prelude FLNG facility which would avoid the requirement for an offshore host at Crux. This is schematically shown in **Figure 5-8**.

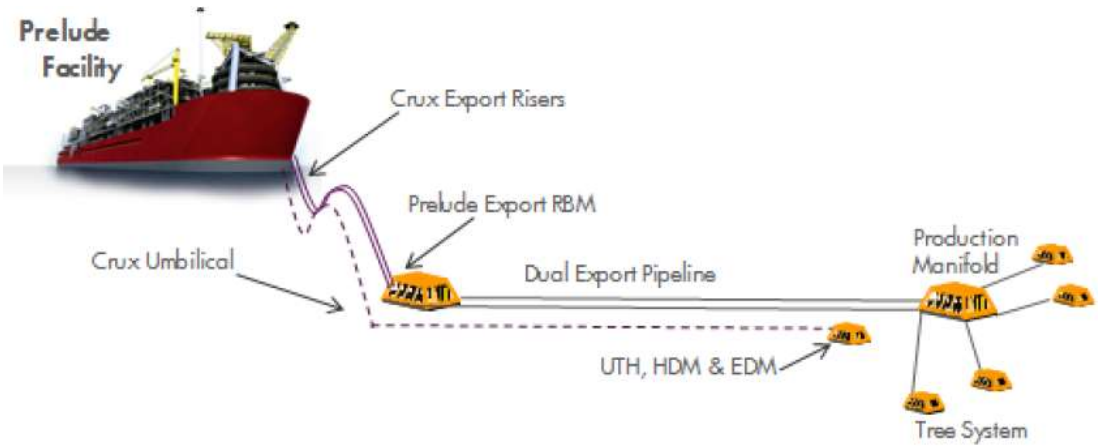


Figure 5-8: Crux Long Subsea Tieback Development Concept Evaluated during Early Screening

The concepts considered require a combination of novel technologies to mitigate several flow assurance issues. Although several novel technologies and other risk mitigation measures were possible within the subsea system, there remained a high overall technical and operational risk profile and at a non-competitive capital expenditure (CAPEX) position.

Of the decisions considered as part of the evaluation, the technical key showstopper for the overall concept was the issue of hydrate management. A range of management strategies were investigated but a feasible option could not be found:

- continuous MEG injection – would require replacement of an existing batch MEG Regeneration module with a continuous system at Prelude. The potential Prelude FLNG shutdown required for this project concluded it economically unattractive compared to alternative host type concepts.
- kinetic hydrate inhibitor – would require depressurisation of export pipeline after shut-in (approximately 150 million standard cubic feet of gas, > 24 hours flaring at the Prelude FLNG facility). Re-pressurisation of the pipeline for re-start is an issue. Limitations of water production would significantly impact gas recovery, impacting the overall economics of this option.
- green anti-agglomerate – requires technology development with timing uncertainty and low probability of success, and
- subsea water removal/dehydration – requires technology development with timing uncertainty and low probability of success.

Given a viable flow assurance strategy is not available for the subsea tieback concept, it was de-selected which confirmed the requirement for a Crux offshore host to, as a minimum, remove water for hydrate management.

Greenfield FLNG Facility Option

The greenfield FLNG facility development option showed there is insufficient resource base in the greater Crux area to support a standalone FLNG development given the capital expenditure requirements to pursue this option. Therefore, this was de-selected at an early stage and not carried further.

Fixed and Floating Host Options

A range of offshore host types are available that were identified to be deployable at the Crux location. An initial screening was performed to narrow the host types to be focused on for the Crux opportunity. An outline of the key host types considered for Crux are shown in **Figure 5-9** (fixed) and **Figure 5-10** (floating), respectively. All host types are technically feasible but have inherent constraints highlighted in yellow.

The Fixed Platform concept was identified as the optimal host type for Crux. It provides inherently lower HSSE exposure and a higher capital efficiency than floating FPSO concepts.

Although a number of technical risks (such as soil uncertainty and drill execution) may be higher than FPSO concepts, mitigation plans have been identified and are in place.

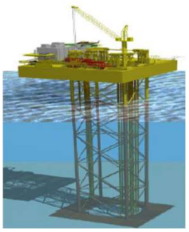
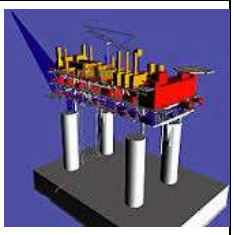
	TLP	Platform		
		Jacket	Shallow	Storage
				
Dry Tree Well	Potential	Yes	No	Yes
Liquid Storage	No	No	No	Yes
CAPEX	High	Low	Medium	High

Figure 5-9: Fixed Host Types Screened for Crux

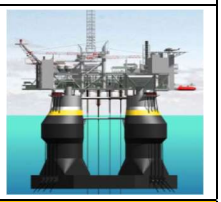
	FPSO		Semi-sub	
	Ship-Shaped	Sevan	Conventional	Ultra-Draft
				
Dry Tree Well	No	No	No	Potential
Liquid Storage	Yes	Yes	No	No
CAPEX	Low	Low	High	Medium

Figure 5-10: Floating Host Types Screened for Crux

In the context of relative environmental impact and risk, the following is concluded:

- all options present materially the same environmental impacts and risks with minimal differentiation between them
- the options which require the smallest physical host type (fixed jacket and shallow platforms) present the least overall footprint in terms of material use to build the facilities
- the fixed jacket platform has enabled a substantial reduction (approximately 80%) in upstream combustion GHG intensity, compared to a floating FPSO concept, with limited onboard atmospheric emissions at the platform
- the fixed jacket platform (unmanned) has a limited ability to carry out complex water treatment, and

- the NNM platform provides a simple concept with minimal vessel movements once operational, and no requirement for cooling water discharge from the platform.

To provide a broad comparison of the merit of the different host types that were determined to be feasible for the Crux project, a qualitative assessment is presented in Table 5-7.

This reflects key considerations across safety, environment, technical, commercial and stakeholder/society expectations, which are taken into account by Shell as part the decision-making process in identifying the optimal host type concept appropriate to the field development.

Table 5-7: Qualitative Comparison of Feasible Host Types for the Crux Project

Key Evaluation Criteria	Fixed Host Options				Floating Host Options			
	Platform (premise case of NNM)		TLP		FPSO		Semi-sub	
	Relative Evaluation	Rationale	Relative Evaluation	Rationale	Relative Evaluation	Rationale	Relative Evaluation	Rationale
Safety								
- HSSE exposure risk	5	Fixed platform has relatively lower HSSE exposure risk. NNM platform has lowest HSSE risk, over operational lifetime. Individual Risk Per Annum and Potential Loss of Life are 50% lower for a NNM platform as compared to a manned platform	4	Fixed platform (TLP) has relatively lower HSSE exposure risk. Marginally higher HSSE exposure risk with a manned TLP philosophy.	2	Higher HSSE exposure risk relative to fixed platform options.	2	Higher HSSE exposure risk relative to fixed platform options.
Environment								
- Physical presence	3	Seabed disturbance anticipated to be broadly similar across host types - variable depending on seabed layout and configuration. Platform requires piled foundations, but no anchoring. All options require a subsea pipeline to facilitate Crux to be backfill to Prelude FLNG, therefore not a differentiating feature.	3	Seabed disturbance anticipated to be broadly similar across host types - variable depending on seabed layout and configuration. TLP requires the platform to be tethered to the seabed. All options require a subsea pipeline to facilitate Crux to be backfill to Prelude FLNG, therefore not a differentiating feature.	3	Seabed disturbance anticipated to be broadly similar across host types - variable depending on seabed layout and configuration. FPSO host type requires a mooring system supported by anchoring. All options require a subsea pipeline to facilitate Crux to be backfill to Prelude FLNG, therefore not a differentiating feature.	3	Seabed disturbance anticipated to be broadly similar across host types - variable depending on seabed layout and configuration. Semi-sub host type requires a mooring system supported by anchoring. All options require a subsea pipeline to facilitate Crux to be backfill to Prelude FLNG, therefore not a differentiating feature.
- Vessel movements	4	NNM platform provides a simple host type concept with minimal vessel movements once operational, with limited maintenance visits.	3	Fixed platform (TLP) likely to have comparable vessel movements, although dependent on manned vs unmanned.	2	FPSO has potential for higher vessel movements, with offtake tankers (if offtake of condensate) and service support vessels.	3	Semi-sub likely to have comparable vessel movements, although dependent on manned vs unmanned.
- Light emissions	5	All offshore facilities and vessels must meet maritime and operational safety lighting requirements, regardless of host type. NNM platform requires minimal lighting during operational lifetime, relative to other host type options. This is to reflect the not-normally manned status with the exception of maintenance visits.	4	All offshore facilities and vessels must meet maritime and operational safety lighting requirements, regardless of host type. Fixed platform (TLP) likely to have comparable light emissions, although dependent on manned vs unmanned.	3	All offshore facilities and vessels must meet maritime and operational safety lighting requirements, regardless of host type. FPSO likely to have greater light emissions compared to platform for a larger concept layout, but dependent on the lighting philosophy to meet functional requirements.	3	All offshore facilities and vessels must meet maritime and operational safety lighting requirements, regardless of host type. Semi-sub likely to have greater light emissions compared to platform for a larger concept layout, but dependent on the lighting philosophy to meet functional requirements.
- Underwater noise	4	Underwater noise is anticipated to be broadly similar across host types - depending on the nature of primary sources. Short-term contribution from piling expected to be primary source, short-term and intermittent. A NNM platform has relatively lower vessels during operations, therefore vessel-related noise is expected to be lower over the operational lifetime.	3	Underwater noise is anticipated to be broadly similar across host types - depending on the nature of primary sources.	3	FPSO host type likely to have higher vessel-related noise as a result of additional offtake tankers and service support vessels. However, unlikely to represent a material differentiator given the low contribution of vessel-related noise.	3	Underwater noise is anticipated to be broadly similar across host types - depending on the nature of primary sources.
- Atmospheric emissions	5	Fixed jacket platform has a significantly lower emissions intensity, compared to a floating concept, with limited onboard atmospheric emissions at the platform.	4	TLP has a lower emissions intensity, compared to a floating concept, with limited onboard atmospheric emissions at the platform.	2	FPSO has higher emissions intensity, requiring additional onboard power generation and compression utilities, compared to fixed host types.	2	Semi-sub has higher emissions intensity, requiring additional onboard power generation and compression utilities, compared to fixed host types.

Key Evaluation Criteria	Fixed Host Options				Floating Host Options			
	Platform (premise case of NNM)		TLP		FPSO		Semi-sub	
	Relative Evaluation	Rationale	Relative Evaluation	Rationale	Relative Evaluation	Rationale	Relative Evaluation	Rationale
- Invasive marine species	3	Risk of invasive marine species anticipated to be broadly similar across host types.	3	Risk of invasive marine species anticipated to be broadly similar across host types.	3	Risk of invasive marine species anticipated to be broadly similar across host types. Potential for slightly higher IMS risk from higher vessel movements. However, given standard industry controls, these are unlikely to differ significantly between host types.	3	Risk of invasive marine species anticipated to be broadly similar across host types. Potential for slightly higher IMS risk from higher vessel movements. However, given standard industry controls, these are unlikely to differ significantly between host types.
- Liquid discharges	2	Fixed jacket platform (NNM) has a limited ability to carry out complex water treatment, with space restrictions. Additional equipment would be required, which increases complexity and maintenance requirements; this is not aligned with the NNM platform concept. No requirement for cooling water discharge from the platform. PFW discharge is dependent on the reservoir characteristics over the field life. Remote monitoring and response to off-specification PFW is a key consideration for a NNM platform concept, given the platform will be unmanned between maintenance shifts. NNM platform has minimal sewage and greywater wastes during operation, with limited personnel on board relative to manned host type options. Other liquid discharges (deck drainage, hydrotest, drilling fluids and cuttings, etc), not significantly influenced by host type.	3	Comparable liquid discharges, relative to other host types. PFW discharge treatment options are more available in a larger manned facility, where space restrictions are less. Other liquid discharges (deck drainage, hydrotest, drilling fluids and cuttings, etc), not significantly influenced by host type.	3	Comparable liquid discharges, relative to other host types. PFW discharge treatment options are more available in a larger manned facility, where space restrictions are less. Other liquid discharges (deck drainage, hydrotest, drilling fluids and cuttings, etc), not significantly influenced by host type.	3	Comparable liquid discharges, relative to other host types. PFW discharge treatment options are more available in a larger manned facility, where space restrictions are less. Other liquid discharges (deck drainage, hydrotest, drilling fluids and cuttings, etc), not significantly influenced by host type.
- Waste management	4	Fixed jacket platform (NNM) has minimal waste, including very low/negligible domestic wastes during operations.	4	Fixed platform (TLP) likely to have comparable waste management, although dependent on manned vs unmanned.	3	Waste management requirements typically expected to be greater for a floating FPSO concept, with greater volumes of hazardous and non-hazardous wastes to be handled, segregated and transferred.	3	Waste management requirements typically expected to be greater for a floating host concept, with greater volumes of hazardous and non-hazardous wastes to be handled, segregated and transferred.
- Emergency events	3	The nature and extent of emergency (unplanned) events, and the preventative control and response framework appropriate to the risk, are expected to be broadly similar across host types. Credible spill volumes are influenced by the project-specific inventories and risk of release. Not expected to be a major differentiating factor across host types, on the basis that a multi-phase export pipeline from a NNM platform is transferring comparable volumes of gas and condensate, as alternative host types. Physical space restrictions on platform may limit the volume of liquids onboard, however the risk of uncontrolled release remains irrespective of host type.	3	The nature and extent of emergency (unplanned) events, and the preventative control and response framework appropriate to the risk, are expected to be broadly similar across host types. Credible spill volumes are influenced by the project-specific inventories and risk of release. Not expected to be a major differentiating factor across host types.	3	The nature and extent of emergency (unplanned) events, and the preventative control and response framework appropriate to the risk, are expected to be broadly similar across host types. Credible spill volumes are influenced by the project-specific inventories and risk of release. Not expected to be a major differentiating factor across host types.	3	The nature and extent of emergency (unplanned) events, and the preventative control and response framework appropriate to the risk, are expected to be broadly similar across host types. Credible spill volumes are influenced by the project-specific inventories and risk of release. Not expected to be a major differentiating factor across host types.
Technical								

Key Evaluation Criteria	Fixed Host Options				Floating Host Options			
	Platform (premise case of NNM)		TLP		FPSO		Semi-sub	
	Relative Evaluation	Rationale	Relative Evaluation	Rationale	Relative Evaluation	Rationale	Relative Evaluation	Rationale
- Soil stability	3	A platform concept is more dependent on suitable soil conditions than a floating host type, for the platform foundation design. Suitability informed by geotechnical studies.	3	A platform concept is more dependent on suitable soil conditions than a floating host type.	4	Floating concept less dependent on suitable soil conditions, though important for anchoring system.	4	Floating concept less dependent on suitable soil conditions, though important for anchoring system.
- Drill execution strategy (dry tree wells)	4	A fixed jacket platform concept can accommodate the intended drill execution strategy for dry tree wells.	3	A fixed jacket platform concept can accommodate the intended drill execution strategy for dry tree wells. TLP platform has technical complexities, relative to a fixed jacket platform.	2	Drilling execution strategy for dry tree wells cannot be readily accommodated in an FPSO concept.	2	Drilling execution strategy for dry tree wells cannot be readily accommodated in a semi-sub concept.
- Liquid storage	2	Liquid storage requirements are constrained with a platform concept, with physical space restrictions compared to FPSO host type.	2	Liquid storage requirements are constrained with a platform concept, with physical space restrictions compared to FPSO host type.	4	Liquid storage requirements can be readily accommodated with an FPSO concept, with typically larger offtake and storage capacity.	2	Liquid storage requirements are constrained with a semi-sub concept.
Commercial								
- CAPEX	4	Low-medium CAPEX relative to other host type options – variable depending on platform type. NNM platform provides a cost-competitive option for the field development. Higher capital efficiency than FPSO host type.	2	High CAPEX relative to other host type options.	3	Low-medium CAPEX relative to other host type options. Lower capital efficiency than NNM platform host type.	2	Medium-high CAPEX relative to other host type options.
Society/Stakeholder								
- Societal expectations	3	Societal expectations for the safe, responsible commercialisation of gas resource, with HSSE&SP commitments, expected to be the same, irrespective of host type.	3	Societal expectations for the safe, responsible commercialisation of gas resource, with HSSE&SP commitments, expected to be the same, irrespective of host type.	3	Societal expectations for the safe, responsible commercialisation of gas resource, with HSSE&SP commitments, expected to be the same, irrespective of host type.	3	Societal expectations for the safe, responsible commercialisation of gas resource, with HSSE&SP commitments, expected to be the same, irrespective of host type.

Relative Evaluation	Descriptor
1	Significantly worse outcome
2	Marginally worse outcome
3	No difference
4	Marginally better outcome
5	Significantly better outcome

Export Pipeline Configuration

The hydrocarbon export system configuration decision focused on selecting the products to be exported and hence the processing requirements on the Crux platform. The following alternatives were considered:

- multiphase – gas and condensate exported in a single pipeline
- rich gas and condensate – non-hydrocarbon dewpointed gas in a pipeline and stabilised condensate in a separate pipeline. This option was found to have no appreciable benefits to the multiphase pipeline behaviour and as such was discounted
- dry gas and condensate – hydrocarbon dewpointed gas in a pipeline and stabilised condensate in a separate pipeline
- dry gas – hydrocarbon dewpointed gas in a pipeline, no liquid pipeline. This option requires liquid storage at the Crux platform and as such has been discounted due to the capital-intensive nature of introducing storage for the platform concept, and
- supercritical – high pressure multiphase pipeline that enables a single, dense phase stream. Discounted due to impractical high pressures required and consequences on compression at Crux, pipeline design pressure, safeguarding and low temperature issues at Prelude.

A comparison of the topsides processing systems required to support the options considered for the platform are shown in **Table 5-8**.

Table 5-8: Comparison of Topsides Processing Systems Required to Support Export Pipeline Options Evaluated for Concept Select

Export Pipeline System Configuration	Gas Dehydration	Gas Hydrocarbon Dewpointing	Export Compression	Condensate Pump	Pipeline(s)
Multiphase	TEG dehydration	None	None	None	1x26" Multiphase
Dry gas and condensate	TEG dehydration	Valve and cold separator	Export compressor at Crux	Booster pump required	1x26" Dry Gas and 1x8" Condensate

The risks associated with multiphase flow and the impact it has on the Prelude FLNG facility were assessed using Dynamic Flow Assurance and Dynamic Process simulation tools. These concluded that the risks are manageable.

Minor modifications to the Prelude FLNG facility high pressure separator to increase the liquid surge capacity and liquid drain rate are able to be readily implemented, to provide an additional margin to handle liquid surges from the multiphase pipeline.

The dry gas and condensate export configuration eliminates the risk associated with liquid management at the Prelude FLNG facility in regard to liquid surges. However, this option introduces significant scope to the Crux platform topsides. These are both capital intensive and it puts greater demand on maintenance and increases the risk that the NNM philosophy for the platform could not be achieved.

As the risks associated with the multiphase pipeline are manageable and the associated downtime with liquid management not material compared to the CAPEX associated with

the dry gas and condensate export configuration it was decided that the platform will have a single multiphase export configuration.

In the context of relative environmental impact and risk, the following is concluded:

- a single multiphase pipeline provides for a smaller seabed disturbance footprint
- inherently low risk of emergency events through preventative controls and integrity maintenance regime, and
- provides best pipeline integrity outcome compared with other options.

Manned versus Unmanned Platform Concept

The decision for the selection of the manning philosophy for the Crux platform gave consideration to the optimum combination of capital efficiency and personnel risk exposure.

The processing facilities required for the platform-based concept are significantly reduced compared to the FPSO concept. Simplification of the topsides facilities and associated reduction in maintenance requirements and manhours provides the opportunity to operate the platform remotely while maintaining the facilities on a campaign maintenance basis.

The following manning philosophies were considered:

- NNM platform operated remotely from the Prelude FLNG facility or Perth with campaign maintenance one week in every six weeks and up to 12 weeks with 14 POB. Reduced facility NNM living quarters and no kitchen facilities
- lighthouse manning platform operated remotely from the Prelude FLNG facility or Perth with a minimum permanent maintenance crew of around nine personnel. Provision of full living quarters and permanent kitchen facilities
- permanently manned and operated platform with a permanent operations/maintenance crew of 14 personnel. Provision of full living quarters with permanent kitchen facilities
- NNM manning-ready platform operated remotely from the Prelude FLNG facility or Perth with campaign maintenance one week in six weeks with 14 POB, but with capability to be permanently manned/operated in future if required. Provision of contingent space for expansion of the living quarters (kitchen, common areas)
- NNM with no permanent accommodation and vessel transfer of personnel (walk-to-work only), and
- fully unmanned with minimum frequency campaign maintenance (approximately once per year).

In order to confirm feasibility for NNM operations, an assessment of the feasibility of remote operations has been carried out and a maximum no-touch-time of 3 months is achievable for the equipment.

From a personnel risk perspective, it was demonstrated that Individual Risk Per Annum and Potential Loss of Life are 50% higher for a manned platform as compared to a NNM platform. A significant overall value benefit for the NNM platform versus manned was also derived. This fact, in conjunction with the significant reduction in personnel risk, justified the selection of the NNM Platform option. It was recognised that full definition during FEED and Detailed Design phases of the project is required to ensure the platform

design, equipment specification and selection and platform operability (remote start of wells, gas turbine generators, produced water treatment adaptive management response, etc.) meets the more stringent requirements for a NNM platform.

In the context of relative environmental impact and risk, the following is concluded:

- NNM platform brings the benefit of very low/negligible sewage and domestic wastes
- low frequency of maintenance visits with resultingly lower vessel and helicopter interactions during operations
- minimal amount of infrastructure to be constructed and installed and the associated lifecycle footprint that these cause (CO_2 footprint, decommissioning infrastructure minimized, and
- ability to respond to upset conditions will be reduced compared to a manned platform but will be a focus to mitigate this risk during detailed design and execute phases.

5.8.2 PFW Treatment and Disposal Alternatives

For the Crux platform concept there will be a combination of initially condensed and, in later field life, condensed and formation water which is required to be disposed of. Shell identified a range of PFW treatment and disposal alternatives that are currently used in the offshore oil and gas industry. Alternatives were identified through reviewing existing PFW disposal options used within Shell and the offshore oil and gas industry more broadly.

The following list of PFW treatment and disposal alternatives were identified:

- reinjection at the Crux platform
- discharge to the sea via Prelude FLNG or Montara FPSO
- discharge to the sea at the Crux platform following treatment using a variety of potential processes:
    - primary treatment
    - secondary treatment
    - tertiary treatment
    - implementation of a buffer tank onboard the Crux platform for temporary storage of off specification PFW.
- post-treatment discharge to the sea at the Crux platform via:
    - above sea surface discharge from discharge pipe
    - below sea surface discharge from caisson

Each of these disposal options was examined to determine if it was feasible in the context of the Not-Normally Manned Operating Philosophy. This host type drives the need for simple, high reliability equipment, with the facility being unmanned apart from planned maintenance activities 3-4 times per year. Therefore, in the context of this evaluation of alternatives, feasibility is premised on the NNM basis of design. Disposal options that were determined not to be feasible were eliminated from further consideration. Descriptions and an assessment of the feasibility of each identified alternative are summarised in the **Option Feasibility Screening** section below.

Following the feasibility assessment, each of the feasible disposal options were then compared qualitatively using the following criteria:

- safety

- environmental
- technical feasibility, and
- cost (both capital and operational cost).

Considerations of each of these disposal options are summarised below in the **Feasible Option Comparison** section. Secondary treatment, of PFW with some treatment redundancies, and discharge above the surface at the Crux platform was determined to be the preferred disposal option when considering all the decision criteria.

5.8.2.1 Option Feasibility Screening

The feasibility of the identified PFW treatment and disposal alternatives considered the compatibility with the NNM platform operating philosophy. These considerations are summarised below.

Reinjection

Re-injection of PFW involved pumping PFW into a suitable geological reservoir using dedicated water injection wells. Re-injection typically significantly reduces the volume of PFW discharge to the environment. Discharges to the environment when implementing a re-injection system typically only occur when the system is not available (e.g. maintenance, equipment failure) or the rate of PFW production exceeds the injection capacity.

The environmental benefit of injection wells is somewhat negated by the fact they are notoriously unreliable. Contingency options, such as storage in buffer tanks or discharge to sea, are required to maintain production in the event the re-injection system is unavailable. Buffer tanks with sufficient volume to temporarily store PFW during outages is not feasible given the volumes of PFW that may be produced, the space constraints on the platform and the potential timeframes required to mobilise crew to the platform to reinstate the re-injection system.

In order to undertake re-injection, a suitable geological formation must be identified. This may include the reservoir that is producing hydrocarbons, or a non-producing formation that has the capacity to receive the PFW.

Re-injection into the production reservoir that is producing hydrocarbons may be an option, but this poses risks to reservoir integrity such as souring, scaling and formation damage. These may result in increased safety risks, increased chemical usage and reduced production. Injection into production reservoirs may be done to enhance hydrocarbon production (e.g. waterflooding for oil reservoirs); this method is not technically feasible for the Crux gas and condensate fields. PFW can be treated to improve its characteristics and reduce the risk to reservoir integrity, however these treatment systems require considerable space and maintenance, which is not consistent with the Crux NNM platform operating philosophy.

Non-producing geological formations were also considered which would reduce the risk to hydrocarbon reservoirs. Scaling and formation damage are still potential issues that typically require water processing at the platform topsides and chemical use to mitigate. Based on a review of the available subsurface data, no suitable non-hydrocarbon containing geological formation within the Crux area was identified that could be used to contain the re-injected PFW.

Considering these factors, a suitable geological formation with the capacity to receive PFW volumes generated during the Crux project has not identified.

Even if a formation was identified, re-injection requires additional dedicated injection wells. These impose further costs and environmental risks and impacts to drill, complete,

operate and decommission. Additional equipment, such as water treatment, injection pumps and chemical storage tanks, is required onboard production facilities that have re-injection systems. This increases complexity and maintenance requirements.

Based on the discussion above, re-injection of PFW for the Crux project is not considered feasible because:

- the Crux NNM platform basis of design significantly limits the space available for equipment required for re-injection, such as water treatment, pumps and chemical storage.
- the Crux NNM platform concept delivers significant operational safety benefits through reduced personnel time on the platform. Operation of a re-injection system would likely require the platform to be manned and would increase maintenance requirements.
- re-injection into the Crux production reservoir poses risks to reservoir integrity and hydrocarbon recovery. Methods to mitigate reservoir risks by increased treatment of the PFW are not consistent with the Crux NNM platform operating philosophy.
- no suitable geological formations for re-injection that do not hold potentially commercial hydrocarbons have been identified within the Crux in-field development area.

Disposal of PFW by re-injection is not feasible for the Crux project and has not been considered further.

Discharge via Prelude/Montara

Transporting PFW to either the Prelude or Montara production facilities was investigated, both of which discharge treated PFW to the sea. Transport of PFW to other facilities would require the installation of a dedicated subsea pipeline. Given both Prelude and Montara discharge treated PFW to the sea, discharge of PFW at either of these facilities would not eliminate the risk of PFW. However, both Prelude and Montara have the capacity to store off-specification (i.e. high oil content) PFW, which the NNM Crux platform does not have. Off-specification water may be recirculated through the PFW treatment systems prior to discharge or blended to relatively low oil content PFW to meet the required PFW discharge standards. Neither Prelude nor Montara have been designed to receive PFW from the Crux project; sending PFW form Crux to these facilities may reduce their production capacities.

The PFW treatment systems at Prelude include tertiary treatment which may be expected to exceed the environmental performance of secondary treatment systems that are the preferred PFW treatment options for the Crux NNM platform. The treatment system at Montara is similar to the most preferred system on the Crux NNM platform. Hence, it is not considered to provide any improvement in environmental performance over discharge at the Crux platform.

Transport of PFW to either Prelude or Montara imposes technical flow assurance issues, including pipeline corrosion and hydrate formation. Management of these issues would require additional equipment such as pumps and chemical storage/injection systems on the Crux platform. This equipment would require additional maintenance and space on the platform, which is not consistent with the Crux platform NNM basis of design.

Based on the above, disposal of PFW via another facility is not considered feasible because:

- the Crux NNM platform basis of design significantly limits the space available for equipment required for PFW flow assurance, such as pumps and chemical storage.

- the Crux NNM platform concept delivers significant operational safety benefits through reduced personnel time on the platform. Operation of a PFW transport pipeline may require the platform to be manned and would increase maintenance requirements.

Disposal of PFW at Prelude or Montara is not feasible for the Crux project and has not been considered further.

PFW Treatment at Crux Platform

Several PFW treatment options were considered for the Crux platform. These have been categorised into the following:

- Bulk separation – gravity separation of the bulk water and condensate streams. For the Crux NNM platform, a liquid/liquid separator will be used to remove floating oil and entrained oil droplets (> 30 µm) from the PFW. With the Crux operating conditions, this is expected to reduce the oil-in-water content to less than 300 mg/L.
- Primary treatment – primary water treatment is designed for the removal of large hydrocarbon droplets, large solid particles and hydrocarbon slugs from the water stream, and can be designed to provide a stable feed to the subsequent water treatment stages by absorbing flow surges. Typically primary water treatment can tolerate 1500 mg/l dispersed oil-in-water. The product stream of the primary water treatment step achieves typically <100 mg/l dispersed oil-in-water. Provided the droplet size distribution and other water characteristics are within the operating envelope of the equipment, primary water treatment can be sufficient to reduce the dispersed oil-in-water content to typical offshore discharge level of 30 mg/l.
- Secondary treatment – typically secondary water treatment can tolerate 100-300 mg/l dispersed oil-in-water and 50-100 mg/l TSS. The product stream of the secondary water treatment step achieves typically <50 mg/l dispersed oil-in-water and <25 mg/l TSS.
- Tertiary treatment – typically tertiary water treatment can tolerate 50 mg/l dispersed oil-in-water and 25 mg/l TSS. The product stream of the tertiary water treatment step achieves typically 10-20 mg/l dispersed oil-in-water and <10 mg/l TSS. Equipment used to remove dissolved hydrocarbons, guard applications and hydrogen sulphide removal also falls in this category.

Primary Treatment

Primary treatment removes floating oil and entrained oil droplets (> 30 µm) from the PFW. Primary treatment relies on physical separation via the difference in density between the hydrocarbon droplets and the PFW.

Primary treatment systems do not rely on chemicals to perform effectively and are mechanically simple, which reduces the space and maintenance requirements. Primary treatment systems also have a relatively low likelihood of mechanical failure compared to secondary and tertiary treatment systems, making them very reliable. These characteristics make them ideal for NNM platforms. This type of treatment is used at platforms considered analogous to the NNM Crux platform such as Woodside's Angel platform off Australia's Pilbara coast and the Maui-B platform off New Zealand's Taranaki region.

Primary treatment relies on gravity to provide the force that separates the less dense oil droplets from the PFW. Shell expects a primary treatment system on the Crux platform would effectively remove oil droplets down to approximately 30 µm diameter. Primary treatment systems enhance the separation via gravity by facilitating aggregation of oil

small oil droplets into larger ones. They are mechanically simple and have high reliability. Shell's preferred primary PFW treatment system is a Produced Water Degasser Vessel.

Primary treatment does not remove dissolved hydrocarbon fractions or dissolved metals, which are typically the most toxic components in PFW.

Primary treatment is considered feasible for the Crux NNM platform and is Shell's preferred PFW treatment option.

Secondary Treatment

Secondary treatment removes smaller entrained oil droplets than primary treatment (typically > 10 µm) from the PFW. Secondary treatment may rely on enhanced physical separation via the difference in density between the hydrocarbon droplets and the PFW (e.g. hydrocyclones) or the use of filter material. Secondary treatment can typically remove approximately 90% for oil droplets > 15 µm.

Secondary treatment enhances the physical separation of oil droplets from PFW. Shell expects a secondary treatment system would effectively remove oil droplets down to approximately 10 µm diameter. Hydrocyclones are an example of a secondary treatment system. Hydrocyclones enhance the separation of oil from PFW by spinning the PFW in a circular motion (i.e. hydrocyclones are centrifuges). The less dense oil droplets are forced towards the centre of the hydrocyclone by centripetal force, which enhances the separation of oil droplets from the PFW. Secondary treatment systems are typically mechanically more complex than primary treatment systems, although also have high reliability.

Secondary treatment systems typically require greater maintenance and space compared to primary treatment systems and are costlier to install and operate compared to primary treatment systems. For example, hydrocyclones are mechanically more complex than a Produced Water Degasser, increasing maintenance requirements and the potential for mechanical failures. Filters that use consumable filter elements must be regularly cleaned (e.g. back flushed) or replaced to maintain performance, increasing maintenance requirements. This increases the need to personnel to be onboard the platform.

Secondary treatment does not remove dissolved hydrocarbon fractions or dissolved metals, which are typically the most toxic components in PFW.

Secondary treatment is considered feasible for the Crux platform.

Tertiary Treatment

Tertiary treatment systems reduce residual oil droplets in the PFW to very low levels. Unlikely primary and secondary treatment, tertiary treatment may also reduce the concentrations of soluble hydrocarbons and metals in some cases. This results in improved environmental performance as the potential toxicity of the PFW stream is lower compared to other treatment systems.

Tertiary treatment systems that rely on adsorption, such as organoclays or granular activated carbon, become exhausted over time. The adsorption media require regular replacement, which increases the maintenance requirements for the facility. This is not consistent with the Crux platform NNM basis of design. The spent adsorption media waste stream requires storage, handling and disposal, which may lead to potential contaminants being translocated. Changing out of filters also requires personnel to be onboard the platform, which is not consistent with the Crux platform NNM basis of design.

The macro-porous polymer extraction (MPPE) tertiary treatment system used on the Prelude FLNG is large in size and requires more space and primary or secondary treatment systems. MPPE also require additional utility systems, such as demineralised

water supply, steam generation, cooling water and heat exchangers. Given the space constraints and 'unmanned' operations on the Crux platform, use of MPPE treatment is not feasible.

Based on the discussion above, tertiary treatment of PFW for the Crux project is not considered feasible because:

- tertiary treatment systems, particularly MPPE, will require additional space. These systems may not fit within the space constraints of the Crux NNM platform.
- tertiary treatment systems will require greater maintenance, increasing the frequency and duration of personnel visits to the Crux platform. This increases the safety risks for Shell personnel.

Tertiary treatment of PFW is not feasible for the Crux NNM platform and has not been considered further.

Buffer Tank

Buffer tanks provide storage capacity at production facilities. This may be used to temporarily store off specification (e.g. high oil in water concentrations) PFW in the event the treatment system is not meeting specified discharge requirements. Once the performance of the PFW treatment system has improved and meets discharge requirements, the off-specification water in the buffer tank is routed through the treatment system and discharged to sea. This option is commonly used onboard large production facilities with high volumes of available liquid storage, such as floating production storage and offtake (FPSO) platforms. Design studies have shown a storage volume of approximately 100 m^3 is the practical limit based on the layout of the Crux NNM platform.

The space constraints of the Crux platform NNM basis of design severely limits the volume of any buffer tank that may be installed on the platform. The capacity of a buffer tank that may be installed on the Crux platform is likely to be exceeded in a relatively short space of time (e.g. in the order of hours to days) if PFW is being directed to the tank. If the off specification PFW is the result of a fault that requires a visit to the platform to rectify, the capacity of the buffer tank is likely to be exceeded before such a visit may be conducted. This would result in off specification PFW being discharged to the sea once the buffer tank is filled.

Installation of a buffer tank onboard the Crux platform is considered feasible, although is unlikely to significantly improve environmental performance.

Discharge from Platform

Discharge of treated PFW above sea level from the Crux platform is the simplest method of disposing of PFW to the sea. This approach is commonly used onboard facilities that discharge PFW to the sea. The plunging of the PFW from height into the sea can increase near-field turbulent mixing, which can enhance the dilution of the PFW. This results in more rapid dilution of the PFW in the sea and consequently results in a smaller area that may be impacted by potentially harmful components of the PFW.

Discharging treated PFW directly from the Crux platform above sea level is considered feasible and is Shell's preferred treated PFW discharge option.

Discharge from Caisson

Discharge of treated PFW from a caisson below sea level is more complex than discharge above sea level but may have some advantages. Discharge below sea level from a caisson may enhance mixing of relatively buoyant PFW plumes.

In the event of high residual oil levels in the treated PFW (e.g. failure of the treatment system), the caisson will retain some floating hydrocarbons, preventing their discharge to the sea. These hydrocarbons may be recovered by the production facility.

Implementation of a caisson introduces some additional maintenance requirements as it is exposed to waves and seawater. These may be accommodated within the planned and unplanned maintenance allowances for the NNM Crux platform basis of design.

Discharging treated PFW from a caisson at the Crux NNM platform is considered feasible.

5.8.2.2 Feasible Option Comparison

Following the feasibility assessment of the identified PFW treatment and disposal alternatives, the following alternatives were identified as being feasibly implemented for the Crux project:

- treatment systems:
  - primary treatment of PFW
  - secondary treatment of PFW
- discharge locations:
  - above the sea surface via a pipe, and
  - below the sea surface via a caisson.

The treatment system and discharge location alternatives were compared using the criteria outlined.

Treatment Systems

Both primary and secondary PFW treatment systems were considers feasible for the Crux project. Both separate oil droplets from the PFW by physical processes driven by the difference in density between the oil and the PFW. Neither primary or secondary separation remove dissolved materials from the PFW, such as soluble hydrocarbons and metal ions. A comparison of primary and secondary treatment systems using the criteria outlined in **Section 5.8.2** is provided in **Table 5-9**.

Table 5-9: Pairwise Comparison of Primary and Secondary PFW Treatment Systems

Criterion	Primary Treatment	Secondary Treatment	Conclusion
Environment	Effective removal of oil droplets down to approximately 30 µm diameter results in higher volumes of oil discharged with PFW. Under steady state operations the difference in performance is expected to be negligible. Slightly larger mixing zone for total hydrocarbons compared to secondary treatment. Mixing zone for soluble hydrocarbons the same as secondary treatment (i.e. no difference); soluble hydrocarbons are generally the most toxic fraction. No removal of dissolved hydrocarbons or metals.	Effective removal of oil droplets down to approximately 10 µm diameter results in smaller volumes of oil discharged with PFW. Under steady state operations the difference in performance is expected to be negligible. Slightly smaller mixing zone for total hydrocarbons compared to primary treatment. Mixing zone for soluble hydrocarbons the same as secondary treatment (i.e. no difference); soluble hydrocarbons are generally the most toxic fraction. No removal of dissolved hydrocarbons or metals.	Secondary treatment is slightly preferred to primary treatment considering the environment criterion.
Safety	Mechanical simplicity results in lower maintenance requirements.	Secondary treatment systems are typically mechanically more	Primary treatment is

Criterion	Primary Treatment	Secondary Treatment	Conclusion
	This reduces the time personnel are required on the Crux platform, reducing their exposure to safety risks. Primary treatment option is slightly preferred to secondary treatment option.	complex than primary treatment systems and have greater maintenance requirements. This increases the time personnel are required on the Crux platform, potentially increasing their exposure to safety risks.	slightly preferred to secondary treatment considering the safety criterion.
Technical	Compared to secondary treatment systems, primary treatment systems: • are mechanically simpler • require less space • more reliable • remove less oil, although only marginally less during normal operations.	Compared to primary treatment systems, secondary treatment systems: • are mechanically more complex • require more space • less reliable • remove more oil, although provides little benefit during routine operations due to oil droplet sizes being too small for efficient separation.	Primary treatment is preferred to secondary treatment for the technical criterion.
Cost	Primary treatment systems require less space onboard the Crux platform and cost less to procure than secondary treatment systems. These factors reduce the capital expenditure to build the platform or replace the treatment system if required. Maintenance requirements for primary treatment systems are typically lower than secondary treatment systems. This reduces ongoing operational expenditure costs.	Secondary treatment systems require more space onboard the Crux platform and typically cost more to procure than primary treatment systems. Consequently, the capital expenditure to build the Crux platform would be higher if a secondary treatment system is used. Maintenance requirements for primary treatment systems are typically lower than secondary treatment systems. This reduces ongoing operational expenditure costs.	Primary treatment is preferred to secondary treatment for the cost criterion.

Shell has assessed the potential discharges of oil into the marine environment for early (low PFW discharge rates) and late (peak PFW discharge rates) field life operations for the Crux development using primary and secondary treatment options. Based on the stochastic modelling of PFW discharges (refer to **Section 8.4.7** for further detail), the worst-case dilution of the PFW discharge within 100 m is 1:73. Based on the worst-case residual oil concentrations during late-life operations, the dispersed oil concentration at 100 m from the discharge point would be approximately 0.3 parts per million (ppm) and 0.2 ppm for primary and secondary treatment respectively. These very low concentrations of residual oil (i.e. non-soluble hydrocarbons) have effectively the same potential for environmental impacts. Hence, there is effectively no difference in the environmental outcome at 100 m (i.e. once the discharged PFW plume has been diluted in the environment).

Note that primary and secondary treatment do not remove soluble hydrocarbons from the PFW; there is no difference in the environmental performance or primary and secondary treatment with respect to soluble hydrocarbon fractions.

Discharge Locations

Discharge of treated PFW from above the sea (i.e. from a pipe) and below the sea surface (i.e. from a caisson) were identified as feasible options. Based on operational experience, Shell expects the PFW to be slightly warmer and significantly saltier than the receiving tropical seawater. The PFW will be considerably denser than the receiving sea water and the PFW plume will initially be negatively buoyant. As the plume mixes

and become more dilute, its density will approach that of the receiving seawater. A comparison of primary and secondary treatment systems using the criteria outlined in **Section 5.8.2** is provided in **Table 5-10**.

Table 5-10: Pairwise Comparison of Above Sea Surface (pipe) and Below Sea Surface (caisson) Discharge of Treated PFW

Criterion	Above Sea Surface (Pipe)	Below Sea Surface (Caisson)	Conclusion
Environment	Studies based on late-life operations PFW discharge rates indicate that discharge from a pipe has slightly improved mixing compared to discharge from a caisson. This resulted from the fall of the negatively buoyant PFW from the platform plunging into the sea, which enhanced turbulent mixing in the immediate vicinity of the discharge. Discharge from a pipe will not contain any floating oil in the event that PFW treatment system is not functioning effectively (e.g. during mechanical failure).	Studies based on late-life operations PFW discharge rates indicate that discharge from a caisson has slightly worse mixing compared to discharge from a pipe. While the negatively buoyant PFW plume mixes turbulently when discharged from the caisson, it is not expected to mix as effectively as discharge from a pipe above the sea surface. A caisson may retain floating oil in the event that the PFW treatment system is not functioning effectively. However, this is considered to be an unlikely scenario. The capacity of a caisson to retain floating oil is likely to be exceeded before an unplanned maintenance visit to the platform can be scheduled.	Discharge from a pipe is slightly preferred to discharge from a caisson considering the environment criterion due to the enhanced mixing. This outweighs the ability for a caisson to retain floating oil if the treatment system is not functioning effective.
Safety	The discharge pipe will require relatively little maintenance, which can be conducted entirely from onboard the Crux platform.	The caisson is likely to require greater maintenance, resulting in increased safety exposure. The caisson may require unplanned maintenance visits.	Discharge from a pipe is preferred to discharge from a caisson considering the safety criteria.
Technical	Discharge from a pipe on the platform is mechanically simpler and requires less maintenance.	The caisson would be exposed to the sea and hence would need to be engineered to withstand waves and external corrosion. This makes the caisson more challenging to implement technically. Exposure to waves and corrosion will require greater maintenance during operations than discharge from a pipe on the platform.	Discharge from a pipe is preferred to discharge from a caisson considering the technical criterion.
Cost	Discharge from a pipe on the platform costs less to fabricate, install and operate than a caisson.	A caisson costs more to fabricate, install and operate than a pipe from the platform.	Discharge from a pipe is preferred to discharge from a caisson considering the cost criterion.

Discharge of treated PFW above the sea surface from a pipe on the Crux platform is preferred to discharge below the sea surface from a caisson for each of the criteria considered in **Table 5-10**. The only advantage identified by discharging from a caisson is that it would retain floating oil within the caisson in the event that the PFW treatment systems are not functioning effectively.

This advantage is only delivered during a failure of the PFW treatment system which is expected to be an uncommon event. The enhanced mixing of the treated PFW discharge above the sea surface is delivered continuously throughout the production life of the Crux platform. On this basis, discharge from above the sea surface was considered to deliver a better environmental outcome than discharge from the caisson.

If the treated PFW was positively buoyant, discharge from a caisson may result in enhanced mixing compared to discharge above the sea. However, the treated PFW from Crux is likely to be negatively buoyant and discharge above the sea will enhance mixing more than a caisson will.

5.8.2.3 Summary of Selected PFW Treatment Options

The following outlines a summary of the selected PFW treatment technologies during concept select, noting that further evaluation will continue during FEED to further optimise the PFW treatment technologies:

- liquid/liquid separator designed to remove 30 micrometre (µm) oil droplets from water (i.e. primary treatment). Analogue field performance has shown this enables an oil-in-water of acceptable performance under steady-state conditions.
- low-shear, liquid/liquid separator level control valve to maximise size of oil droplets in the produced water streams. Due to pressure drop, oil droplets of approximately 10 µm can be expected downstream of the valve.
- produced water degasser vessel designed to de-gas the produced water and collect any oil droplets separated. This vessel also enables any bulk condensate to be collected in case of upsets in upstream equipment. This vessel may be fitted with internals to promote gas floatation effects.
- space to allow for additional treatment technologies (e.g. secondary treatment such as hydrocyclones) to be installed as part of an adaptive management processes.
- disposal to ocean via piping terminated approximately +8 m above sea level.

5.8.3 CO_2 Management Alternatives

The project has evaluated a number of significant direct CO_2 management alternatives as part of the concept selection. These options included analysis of venting reservoir CO_2, implementing carbon capture and storage (CCS) at Prelude or Crux and making allowances in design for future implementation of CCS at Crux. Other direct CO_2 management alternatives will continue to be investigated throughout front end engineering and design.

Key factors influencing CO_2 management alternatives decisions include:

- technical feasibility of GHG mitigation options
- economic impact of the capital and operating costs associated with the various GHG mitigation options
- economic impact of potential future exposure to GHG related costs (e.g. emissions trading scheme, carbon tax) or operational restrictions (e.g. mandatory CCS)
- internal Shell CO_2 aspirations and performance standards, and

- impact to proposed NNM operation of the Crux facility, increase in safety risk and to project schedule.

The implementation of other GHG management options require a balance of emissions reduction benefits with the need to be technically and commercially viable.

FEED will be the next stage during which Shell will review practicable options to reduce atmospheric emissions, including alternatives to optimise the selected power generation system.

Implementing CCS

The existing Prelude FLNG facilities contain an AGRU, which is used to remove CO_2 from the process gas stream (reservoir CO_2) prior to liquefaction. CCS at Prelude would benefit from the use of this existing infrastructure. However, in 2010, as foreseen in the Prelude EIS, the Prelude facility selected venting as the acid gas disposal method, with CCS deselected on economic and technical grounds. Subsequently, the space associated with CCS facilities was reallocated to the MEG system. There is no space available to retrofit CO_2 compression onto Prelude FLNG, therefore it is not a technically feasible option.

The option exists to include reservoir CO_2 capture and compression on the Crux facility as part of the greenfield scope.

The inclusion of CO_2 capture and compression equipment on the Crux platform will substantially increase the operations and maintenance requirements and therefore would likely drive the project towards fully manned operations. Increased offshore manning will have a corresponding increase in worker exposure to process, occupational and structural hazards. The introduction of a high-pressure CO_2 process stream will also introduce additional process hazards to the platform. Process requirements are an AGRU for CO_2 removal, dehydration and compression.

In addition, the inclusion of the CCS facilities would represent a significant increase in project scope and associated on and offshore construction and commissioning manpower hazard exposure.

On the basis of economic, operational and safety grounds, the decision has been taken to not deploy CCS as a part of the Crux greenfield development.

5.8.3.1 Power Generation

The Crux platform will require a source of electrical power to operate the equipment onboard (e.g. process heaters, pumps, lighting etc.). Shell identified several alternatives by which power is supplied to facilities currently used in the offshore oil and gas industry. The following list of alternatives for the provision of power to the Crux platform were identified:

- powered remotely from Prelude FLNG by an umbilical
- powered by gas engines onboard Crux platform
- powered by gas turbine generators onboard Crux platform
- powered by photovoltaic (solar) onboard Crux platform, and
- power supply augmentation from battery energy storage system.

Each option was assessed to determine if it would be feasible for the Crux project.

5.8.3.2 Option Feasibility Assessment

Remote Power from Prelude FLNG

The option of powering the Crux platform via an umbilical from the Prelude FLNG running along the export pipeline was considered. The Prelude FLNG facility was not designed to generate nor export power for additional facilities and does not currently have excess power generating and transmission capacity to do so. Installing additional power generation and transmission facilities onboard Prelude FLNG is not possible due to the space limitations aboard the facility. On this basis, powering the Crux NNM platform from Prelude FLNG is not feasible.

Gas Powered Reciprocating Engines Onboard Crux Platform

Gas-powered reciprocating engines using gas produced by the Crux platform may be used to provide electrical power. The efficiency of the gas engines is not expected to be better than the gas turbines as although they have the potential to burn more efficiently at low load (compared to gas turbines) the Crux facility will operate at high loads over the life of the Asset. It is expected that gas engines utilised for Crux would have lower reliability and higher maintenance requirements than gas turbines, which does not align with the Crux NNM requirements. For this reason, they have not been selected for Crux.

Gas Turbine Generators Onboard the Crux Platform

Gas turbine generators are commonly used onboard offshore oil and gas facilities. Gas turbines are compact, have high reliability, require relatively little maintenance and can be run using fuel gas produced by the Crux platform. These characteristics often make this technology preferable for generating electrical power offshore. Gas turbines are considered feasible for use on the Crux NNM platform.

Photovoltaic Generation Onboard the Crux Platform

Photovoltaic generation on the Crux NNM platform was assessed however the space required for these panels would be an order of magnitude larger than that available on the platform and as such is not a feasible option.

Although photovoltaic power is not feasible for the main power supply on the Crux platform it may be considered as a supplementary power source during the FEED process.

Battery Energy Storage Onboard the Crux Platform

A battery energy storage system has been considered in conjunction with the main power generation system to better stabilise power loads and potentially increase efficiency of the system. Initial studies show limited benefits of utilising a battery system and the feasibility of such a system on a NNM facility has not been confirmed. The base case for Crux does not rely on a battery storage system, however the integration of battery system either for the main power supply or supplementary power will be considered in FEED.

5.8.3.3 Feasible Option Comparison

Of the power generation options identified by Shell for the Crux platform, gas turbine generators were identified as having the greatest overall benefits for Crux and provided suitable high efficiency options. Gas turbines are commonly used for power generation at offshore facilities and are suitable for use on unmanned platforms.

Shell continuously appraises the development of power generation technology, and options that are not feasible at this time may become so in future.

The FEED process for the Crux platform will consider the application of alternative energy systems for supplementary power loads on the Crux project and potential integration of battery systems.

5.8.4 Do Nothing Alternative

The project aligns with the Australian Government's broad mandate to develop offshore oil and gas resources. Specifically, the policy of the Australian Government in relation to the development of offshore oil and gas resources is to increase investment in petroleum development in offshore areas under Commonwealth jurisdiction. The Government recognises that investment in this area provides benefits to the Australian community through the following:

- taxation revenues
- employment
- regional development
- provision of back-fill gas for the continued operation of existing infrastructure such as the Prelude FLNG facility, and
- enhanced energy security.

In addition, to satisfy offshore permit retention lease requirements, Shell and its JV partners have an obligation to undertake exploration and develop any commercially viable hydrocarbon reserves. In this context, the 'no development' alternative is not consistent with the legal obligations and commercial objectives of Shell and was not considered further.

Shell is committed to supporting the energy transition in a responsible and sustainable manner. It is recognised that achieving net-zero emissions essentially involves re-wiring of the whole global economy, while at the same time meeting greater energy demand due to population growth, development, new energy services, and the extended use of existing services. There is yet no clear development pathway for an emerging economy that does not include traditional energy sources and the drive towards net-emissions is challenging due to the current lack of low-carbon substitutes for many emission intensive industries. Gas is recognised as an important fuel in the energy transition, especially for economies which are currently powered by coal and is key to reducing GHG intensity of the energy supply chain. The Crux project, therefore, contributes to this transition.

5.9 HSE Design Standards

The HSE requirements of the project start with compliance with the Australian Commonwealth and applicable state and territory legislation, and applicable internationally HSE codes, standards and guidelines, as specified in **Section 2** of this OPP. In addition, international agreements to which Australia is a party have been applied, as well as Shell Group Policies, Standards, Procedures and Guidelines including:

- Shell Design and Engineering Practices, and
- Shell HSSE & SP Control Framework.

The design mitigations, together with the management measures that will be developed, will ensure risks are acceptable at this stage of project evaluation.

6 Description of the Existing Environment

6.1 Introduction

This section describes the key physical, biological, socio-economic and cultural characteristics of the existing environment that may be affected by the project, both from planned activities and emergency events. The description of the environment is comprehensive and describes the environmental values and sensitivities, including MNES as defined under the Commonwealth EPBC Act, within two areas:

- the project area, which consists of the in-field development area and export pipeline corridor (as defined in **Section 5.3.1**), and
- the potential area of influence associated with the project (as defined in **Section 6.1.1**). The potential area of influence will be further refined as future detailed engineering information becomes available and will be presented in the activity-specific EPs.

The description provided in this section has informed a detailed evaluation of all impacts and risks associated with the project for the project, as presented in **Section 8**.

6.1.1 Project Area of Influence

As outlined above, this OPP considers the potential impacts and risks to the existing environment that may be affected from both planned activities within the project area (**Figure 5-3** and **Figure 5-4**) and emergency events.

The extent of the environment that may be affected from liquid discharges associated with the project was informed by discharge modelling studies, as discussed in **Section 8.4.7**.

The ‘area of influence’ defines the outer boundary of the existing environment that may be affected from emergency events, as shown in **Figure 6-1**. The area of influence was derived using the maximum spatial extent of the low exposure zone from the stochastic modelling studies of the worst-case credible hydrocarbon spill scenarios identified for the Crux project (**Section 8.4.8**). As such, the area of influence was created by merging all of the modelling results, although it is characterised by the entrained hydrocarbon fraction of loss of well control scenario. This scenario has the longest duration and releases the greatest volume of hydrocarbons of all the credible worst-case scenarios that may occur during the Crux project. The area of influence includes all areas where hydrocarbon levels exceed threshold concentrations. This approach has facilitated the assessment of all environmental values and sensitivities that could potentially be affected by the project and has formed the basis of the EPBC Protected Matters search. Refer to **Section 8.4.8** for further information on the worst-case credible hydrocarbon spills and associated modelling studies.

A low exposure threshold, which represents a visible oil (rainbow) sheen, has been used to provide an indication of the extent to which stakeholders may visually observe oil on the sea surface. This is considered to provide a conservative extent of potential impacts to socio-economic receptors associated with visual amenity. The description of the socio-economic environment in **Section 6.6** covers this wider area of influence.

It is important to note that biological impacts are not expected to occur within the entire area of influence. Refer to **Section 8.4.8** for discussion of the biological impact thresholds (i.e. moderate thresholds).

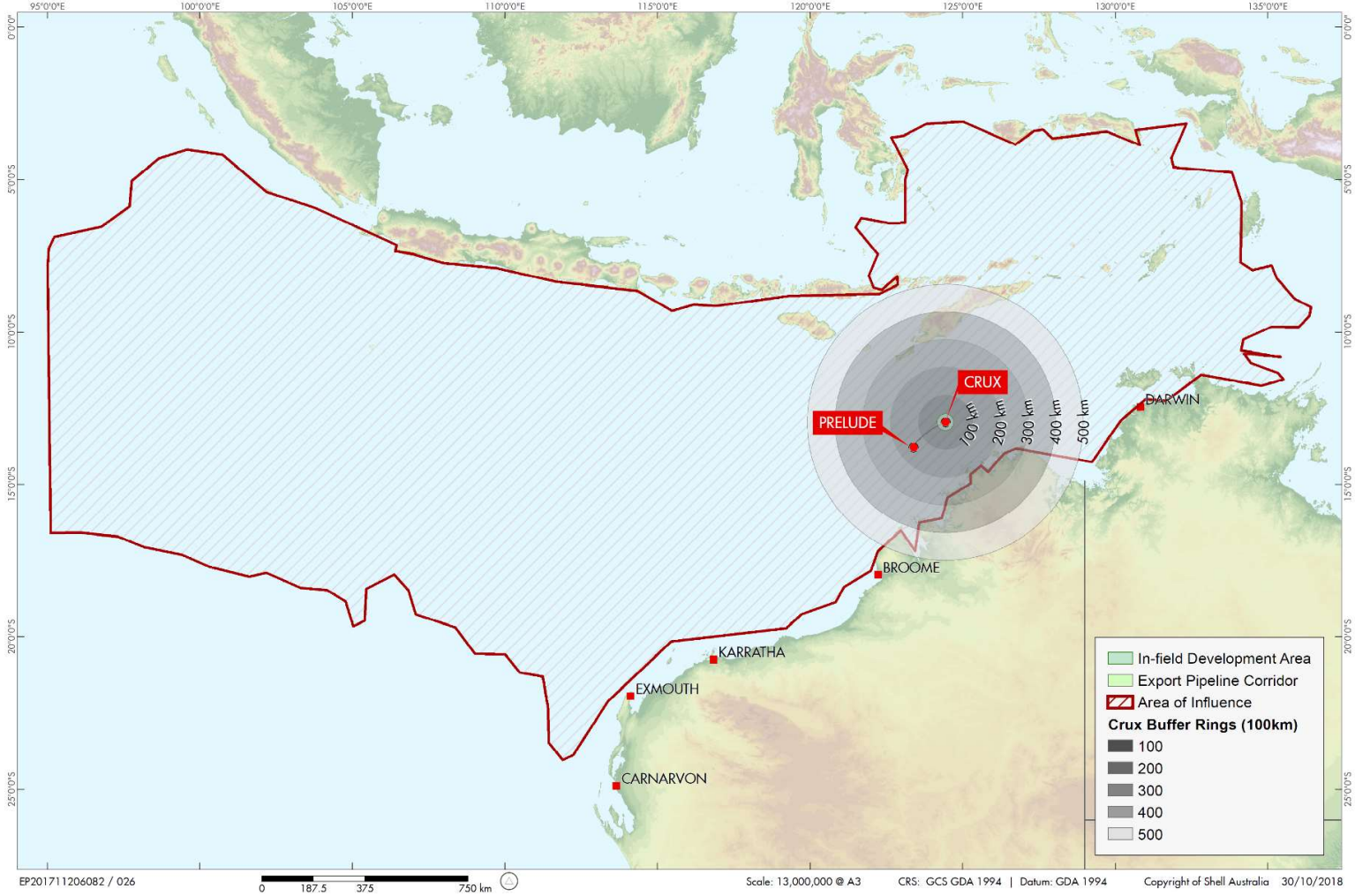


Figure 6-1: Area of Influence for the Crux Project

Note the western margin of the Area of influence is the edge of the model domain of the hydrocarbon spill modelling studies.

6.2 Data Sources

6.2.1 Desktop Study

A wide range of scientific literature were used to inform the detailed assessment of environmental values and sensitivities in this OPP. The key sources of information included:

- baseline marine studies program undertaken by Shell to inform the existing context of the in-field development area and pipeline corridor – these are summarised further in the following **Section 6.2.2**
- the Applied Research Program (ARP) undertaken by the Australian Institute of Marine Science (AIMS) and associated industry partners
- material published by the DoEE, including EPBC Protected Matters search tool, species profile and threats database, National Conservation Values Atlas, biologically important areas (BIAs) and internesting habitat critical to the survival of marine turtles, recovery/management plans and conservation advices, bioregional marine region plans, conservation value report cards, threat abatement plans, National strategies and Australian marine park management plans
- State and Territory Government publications, including material published by DBCA, Department of Planning, Lands and Heritage (DPLH) and DPIRD, such as marine park management plans, heritage databases and fisheries status reports
- recent Environment Plans of relevance to the Crux project and surrounds, including the AC/RL9 EP for the Auriga West-1 exploration drilling (Shell 2014), and the Prelude EPs for subsea installation (accepted 2014), operations (accepted 2016) and wellhead removal (accepted 2017)
- published EIS/offshore referral study reports to inform the regional environmental context, including:
    - Shell Prelude FLNG EIS (Shell 2009), and Supplement (Shell 2010), EPBC 2008/4146. As part of the Prelude EIS, a range of technical studies were undertaken to inform the existing environment and have been referenced where relevant in this OPP
    - Woodside. 2011. Browse LNG Development, Draft Upstream EIS EPBC Referral 2008/4111 (November 2011)
    - Woodside. 2013. Floating LNG EPBC referral 2013/7079 (December 2013), Draft EIS (November 2014) and EIS Supplement (May 2015)
    - INPEX. 2010. Ichthys Gas Field Development Project Draft EIS, and subsequent EIS Supplement (April 2011), and
- published literature on the regional environmental values and sensitivities, e.g. PTTEP surveys initiated in response to the Montara incident (Heyward et al. 2010; Heyward et al. 2012) and as published on the North West Atlas.

6.2.2 Crux Project Studies

Shell has commissioned a number of baseline studies to characterise the existing marine environment relevant to the project. These baseline studies built on the knowledge undertaken through the ARP in collaboration with AIMS and industry partner INPEX. A summary of the baseline studies is provided in **Table 6-1**. The locations of key baseline monitoring locations are shown in **Figure 6-2**.

The modelling studies undertaken to inform this OPP are also outlined in **Table 6-1**.

Table 6-1: Summary of Crux Baseline Studies

Study Type	Study Description/Objective	Reference
Field Studies		
Metocean study	Collection of metocean data (e.g. current, conductivity, wave and wind data) on the surface and through the water column for a full 12-month period from late April 2016 to early May 2017 within and in the vicinity of the Crux field and along the planned pipeline route to Prelude.	RPS Metocean (RPS) 2017
Water quality study	Collection of baseline data on physical and chemical components of water quality, along the proposed pipeline corridor and within the Crux field. The surveys were completed over two survey events in April/May 2016 and October/November 2016.	AECOM 2016 (**Appendix A**)
Sediment, water quality and infauna study	Collection of baseline data on sediment quality, water quality and infauna communities, along the proposed pipeline corridor and within the Crux field. The study was completed in October/November 2016.	AECOM 2017 (**Appendix B**)
Benthic habitat study	Collection of baseline data to characterise topographic features, benthic habitats and macrofaunal communities, along the proposed pipeline corridor and within the Crux field, through the use of underwater transects (towed video camera) and geophysical methods (multibeam, side-scan sonar, seismic reflection and sub-bottom profiling). This study was completed in April/May 2017, as part of a combined geophysical and environmental survey scope. The survey considered an alternative pipeline corridor near the Prelude FLNG facility end, as shown in **Figure 6-2**, to account for a previously identified seabed ridge traversing the south-western end of the proposed pipeline area. The area in the vicinity, which encompassed part of this ridge, were also surveyed. While this alternative route is no longer being carried forward into the OPP it has been presented for completeness.	Fugro 2017a (**Appendix C**)
AIMS Applied Research Program (ARP)	Shell is an industry partner, together with INPEX, in support of the AIMS ARP, to develop a comprehensive environmental baseline for waters in the Browse Basin. As part of this project, AIMS is leading a collaborative partnership of trusted research organisations including Commonwealth Scientific and Industrial Research Organisation (CSIRO), the University of WA, Curtin University, Monash University and the Western Australian ChemCentre. The ARP research programs of particular relevance to informing the regional baseline context are: ARP 2 – Baseline hydrocarbon surveying in the Browse Basin ARP 4 – Evaluating the effects of hydrocarbon exposure on non-avian marine wildlife ARP 6 – Investigating the breeding and foraging parameters of seabird species in the Browse Basin to determine their vulnerability to impacts associated with potential oil spills, and their ability to recover ARP 7 – Subtidal benthos: towards benthic baselines in the Browse Basin.	ARP 2: CSIRO 2017 ARP 7: Heyward et al. 2017a

Study Type	Study Description/Objective	Reference
	ARP 2 and ARP 7 are of particular relevance to this OPP. The other ARPs are of more relevance to informing the subsequent activity-specific EPs.	
Geotechnical study	An assessment of the geotechnical conditions of the seabed in the Crux field and along the proposed pipeline. This study was completed in 2016, with a further study completed in April 2018.	Fugro 2017b
Modelling Studies		
Drill cuttings and drilling muds dispersion modelling study	To calculate the fate of discharged drill cuttings and unrecoverable drilling muds, including the likely area of coverage, bottom deposition (thickness and accumulated load) and assess the risk to key values and sensitivities from contact with cuttings and muds discharged during development drilling operations.	RPS 2018a (**Appendix D**)
PFW modelling study	To quantify the extent of the mixing zones of the PFW discharge (based on the maximum pre and post PFW breakthrough flow rates) and assess the potential risk to key values and sensitivities under various seasonal conditions.	RPS 2018b (**Appendix E**)
Pipeline hydrotest discharge modelling study	To quantify the potential mixing zone from the release of chemicals within the hydrotest discharge (e.g. biocides) during commissioning activities.	RPS 2018c (**Appendix F**)
Hydrocarbon spill modelling study	To quantify the movement and fate of spilled hydrocarbons that would result from an accidental, uncontrolled release from four determined scenarios that are considered representative of the maximum credible worst-case spills that could result from project activities. The scenarios include a well blowout during development drilling, a significant rupture of the export pipeline during operations, a spill from the Crux platform and a pipelay vessel collision during installation of the export pipeline. The study assessed the potential risk to key values and sensitivities from these spill scenarios.	RPS 2018d (**Appendix G**)
Hydrodynamic model validation study	Data from the metocean study were used to validate the underlying hydrodynamic model used to develop the liquid discharge and oil spill models. The results of the study have been incorporated into RPS 2018a-d.	RPS 2018e
Light modelling study	To characterise the sources of light emissions from the operation of the Crux project and assess the predicted impact of light in the context of the nearest sensitive receptors.	Imbricata 2018 (**Appendix H**)
Underwater noise modelling study	To predict the effects of underwater noise emissions from the Crux project, specifically piling of the Crux platform footings and from vessel movements during operations, on key values and sensitivities.	SVT 2018 (**Appendix I**)

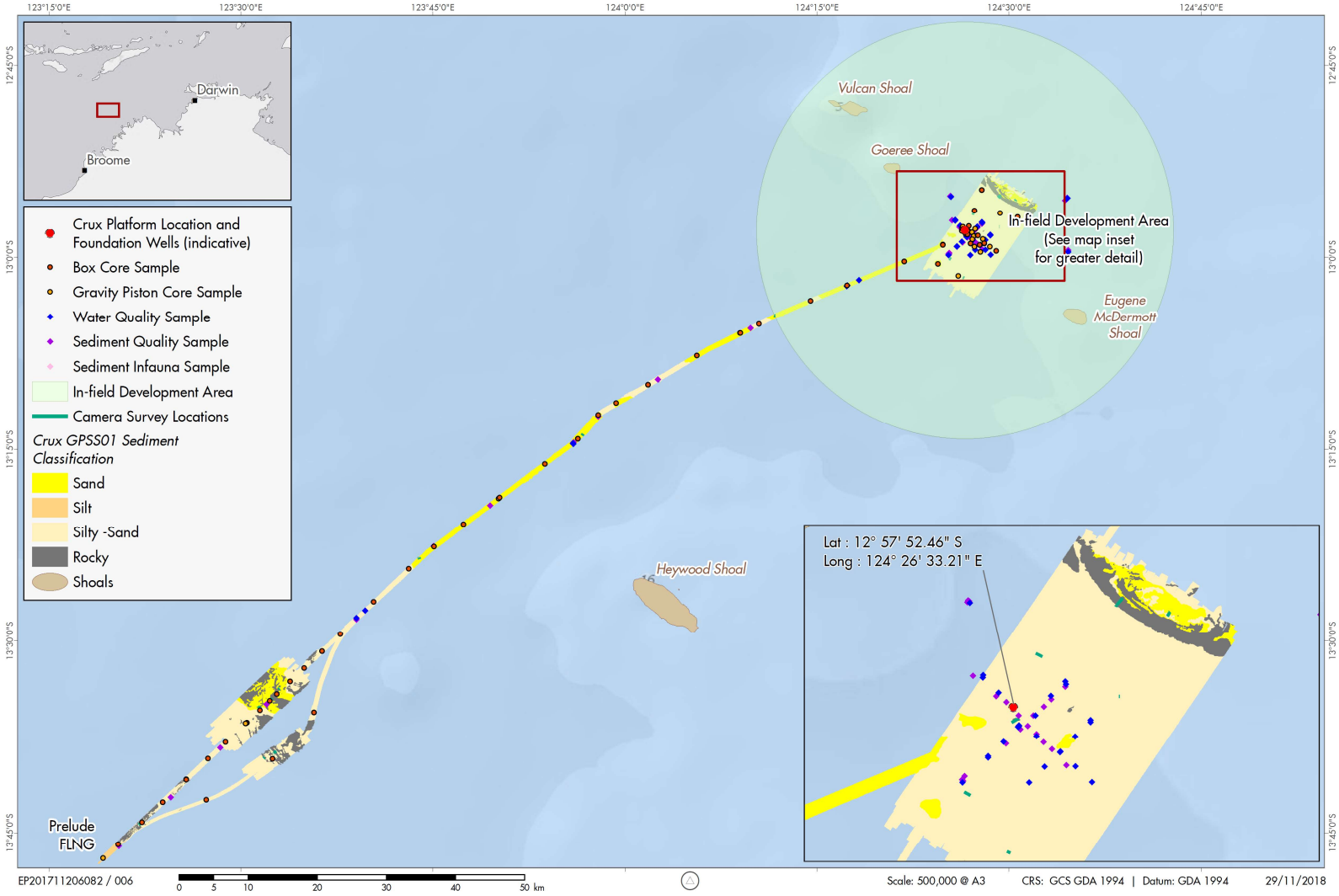


Figure 6-2: Crux Environmental Baseline Monitoring Locations

6.3 Physical Environment

6.3.1 Climate

The Browse Basin and Timor Sea region experience a tropical climate with two distinct monsoonal seasons, a winter or “dry” season from April to September and a summer or “wet” season from October to March (RPS 2017). This is a result of the two major atmospheric pressure systems of the region; a subtropical ridge of high pressure cells (highs or anticyclones) and a broad tropical low pressure region (the monsoon trough or inter-tropical convergence zone) (RPS 2017). The southeast trade winds originating over the mainland provide a steady easterly air flow to the region in the dry season. The monsoon trough is characterised by the reversal of these winds and brings high rainfall when it is in close proximity to, or over the mainland (RPS 2017).

Meteorological data collected from the Bureau of Meteorology (BoM) weather station located at Cygnet Bay, selected as a station closest to the project area with long term climatic data. While it is recognised this station is in a coastal location, the data is expected to be broadly representative of the region. Average air temperatures vary from 25.8 °C to 36.6 °C in the winter months, and 30.3 °C to 36.7 °C in summer (BoM 2018a). Average seasonal rainfall for the region ranges from 117 mm per month in summer to 19.5 mm per month in winter (BoM 2018b). Observations from the RPS (2017) metocean study, which comprised collection of 12 months of data in the offshore project area, noted that air temperatures remained relatively stable, with mean monthly temperatures ranging between 27 °C in August and 30 °C in December (RPS 2017).

6.3.2 Oceanography

The oceanography of the project area and the wider region is influenced by the large-scale ocean currents, monsoonal seasonality in wind and wave action, as well as storm and tropical cyclone events. A summary of these influencing factors is provided in the following sections.

As outlined in **Section 6.2.2**, a baseline metocean study conducted by RPS was undertaken from April 2016 to May 2017 in order to characterise the local current behaviour at the in-field development area and along the export pipeline corridor (RPS 2017). The study also captured meteorological and surface wave measurements within the project area. The key results from this study are discussed in the sections below.

6.3.2.1 Tides and Current

Regional

The project is located within the North West Marine Region (NWMR) which experiences semi-diurnal tides. Tidal ranges of between 3 m (neaps) and 10 m (springs) (Brewer et al. 2007), and 2 m (neaps) and 12 m (springs) (Ivey et al. 2016), for example, have been recorded as representative of the Kimberley region. These tides have been shown to strongly influence regional currents in the NWS due to their large tidal range (Brewer et al. 2007; Ivey et al. 2016; RPS 2017). Notably, tidal amplitudes seem to be retained at large distances offshore and travel initially in a north-east direction in the deeper waters of the region (RPS 2017).

A strong seasonal wind regime is closely associated with seasonality in surface currents in the region. **Figure 6-3** indicates the key regional currents influencing the NWMR and wider region (DEWHA 2008a). The Holloway current is the prevailing seasonal current, travelling south-west along the north West Australian coast in winter and north-east in summer (Brewer et al. 2007). The Indonesian Throughflow (ITF) and Holloway surface currents are the predominant currents affecting the North West Shelf (NWS) from February through to June. During this period the ITF produces flows of warm, low-salinity

water onto the NWS (Shell 2014). The reversal of these currents caused by strong south-westerly winds at other times of the year may cause anti-clockwise circulation and a northward movement of water and upwellings of cold water onto the NWS (DEWHA 2008a).

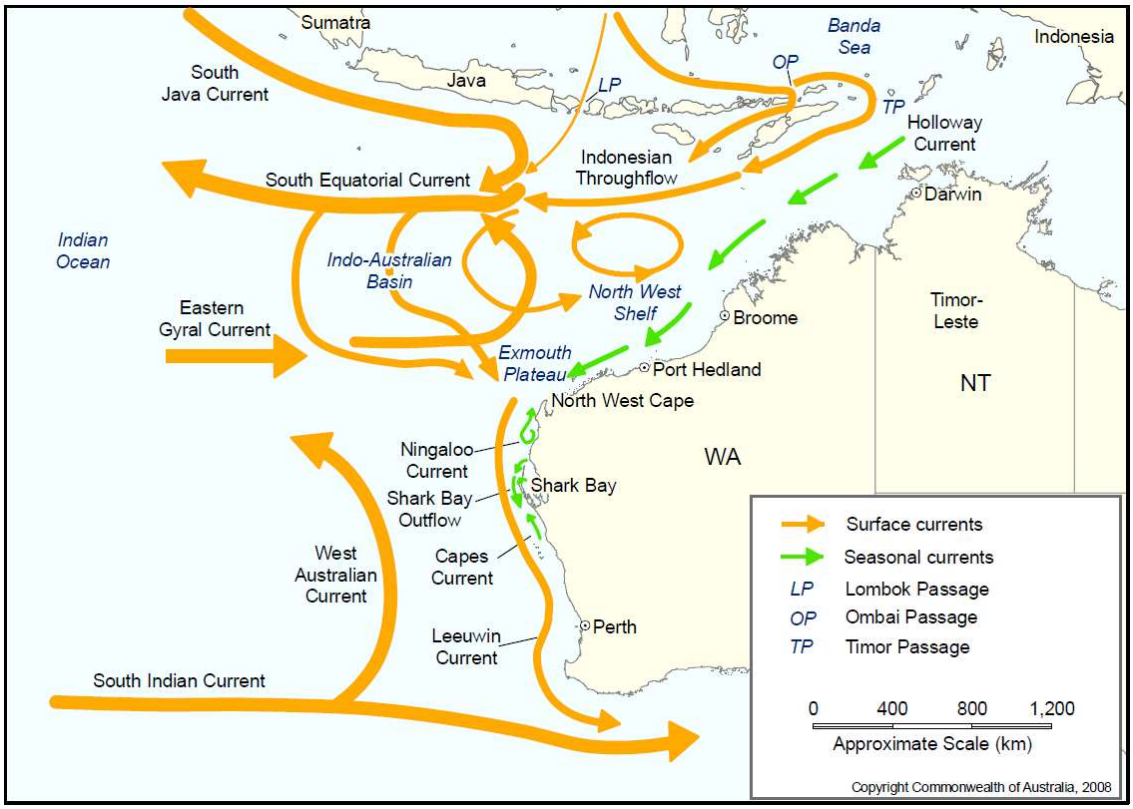


Figure 6-3: Key Regional Currents Influencing the Waters of North-west Australia

Crux Project Area

Currents within the project area are broadly typical of the region and predominantly affected by seasonality and driven by tidal variation. The RPS (2017) metocean study reported a mean tidal range between approximately 0.8 m (neaps) and 5 m (spring) within the project area. Prevailing tides in the project area generally flow along a north-west to south-east axis (RPS 2017). Barotropic tides are expected to be less powerful in the deeper waters of the project area and during neaps due to less tidally-induced friction (RPS 2017). Currents within the project area are also influenced by interactions with site-specific seafloor topography and water column stratification (RPS 2017). The occurrence of internal current-driven waves is dependent on variations in localised seafloor topography, such as a continental slopes or shelf breaks, interacting with water moving through the thermocline (DEWHA 2008a). Given the stratification, water depth and regional bathymetry at the in-field development area, it is a site of significant internal wave activity. Based on the metocean study, internal wave action at the in-field development area was typically in the form of well-developed soliton wave packets, whereas areas of the export pipeline corridor were influenced by large waves during spring tides and localised bathymetry (RPS 2017). High frequency currents generated by internal wave action were observed to be strongest in the project area toward the end of winter as this was when the upper mixed layer was at its deepest (RPS 2017).

6.3.2.2 Waves

Regional

Regional wave action consists of sea-waves, which are shorter period waves generated at a local level in response to wind conditions, and swell-waves, which result from larger scale ocean storm weather originating from the Southern Ocean or southern portion of the Indian Ocean. Wave action generated during tropical cyclones may be affected at distances of up to several hundred kilometres (RPS 2017).

Crux Project Area

Wave conditions in the project area are relatively consistent throughout the year with variations predominantly influenced by monsoonal seasonality in wind patterns and tropical cyclone events (Shell 2014). Persistent levels of swell originating from the Southern Ocean, moving in a west-south-west to westerly direction, are amplified by locally generated swell in summer. Conversely, easterly Trade Winds contribute an additional east-north-easterly swell to the local area in winter (RPS 2017). The summer months are associated with seas and swells from a west-north-west direction (RPS 2017).

6.3.2.3 Water Temperature

Regional

The ITF influences the sub-tropical water temperatures of the NWMR and the depth of the permanent regional thermocline (Brewer et al. 2007). Internal tides may also influence this thermocline and cause rapid changes in temperature at depths of 50 m–150 m. Mean regional sea-surface temperatures have been recorded at 28.5 °C with limited seasonal variation (Brewer et al. 2007).

Crux Project Area

The metocean study observed average surface water (<10 m) temperatures to be generally consistent within the project area, ranging from approximately 27 °C to 32 °C over a 12-month period (RPS 2017). Surface water temperatures were highest in November and December due to the calm conditions of the extended transition period between winter and summer (RPS 2017). Temperatures near the seabed and up to approximately 60 m above the seabed (ASB) clearly reflect the spring-neap tidal variation, whilst mid-waters of approximately 20 m–70 m ASB were stable (RPS 2017). The thermocline was typically located around mid-water depth (RPS 2017). Cyclonic events and storm activities were observed to result in increased mixing of the water column to depths of up to approximately 80 m before re-stratification occurred (RPS 2017).

6.3.2.4 Severe Weather Events

Tropical Cyclones

The NWMR is an area of high cyclone activity (Brewer et al. 2007). Tropical cyclones typically form in the Timor and Arafura Sea areas during an active monsoonal trough and are associated with torrential downpours and potentially destructive winds. While tropical cyclones commonly form during the summer season (October to March), they may also occur within transitional seasons. The average tropical cyclone frequency for the Timor and Arafura Seas region is one cyclone per year with cyclones most commonly occurring between November and April (BoM 2018c).

Tropical cyclone intensity and frequency in northern Australia is also influenced by the El Niño-Southern Oscillation (ENSO), a natural climate cycle that influences the year to

year variability of the Australian climate (BoM 2018d). The two phases of ENSO are termed El Niño and La Niña. La Niña occurs when the equatorial trade winds become stronger, bringing warmer surface waters to the western Pacific and northern Australia (BoM 2018d). This is associated with an increase in rainfall and risk of flooding in northern and eastern Australia, as well as an earlier monsoon onset and above average rainfall during the early summer months (BoM 2018d). The La Niña phase creates favourable conditions for tropical cyclone development to the North of Australia and, on average, twice as many tropical cyclones make landfall during La Niña phase (BoM 2018d).

Squalls

Associated with thunderstorms in the Timor Sea, squalls occur during summer and are caused by strong downdraft winds. Whilst typically short in duration (i.e. a matter of hours as opposed to days), squalls can often be accompanied by heavy rain and can produce strong currents and increased localised wave activity (RPS 2017).

Tsunamis

The project area is relatively exposed to tsunamis originating from the Sunda Arc, which is approximately 250 km north-of the Crux platform, where the Australian Plate is subducting beneath the Sunda Plate (Burbidge and Cummins 2007). However, the tsunami potential for the NWS and Browse Basin is considered moderate and tsunamis at water depths such as those within the project, pose few concerns as they remain relatively small (Geoscience Australia 2018).

6.3.3 Bathymetry and Seabed Features

A survey to characterise the benthic habitat at the project area was carried out in 2017 by Fugro and included mapping the bathymetry and seabed characteristics of the in-field development area and export pipeline corridor (Fugro 2017a).

Water depths at the in-field development area range between approximately 90 m and 180 m. The seabed is generally relatively flat with a gentle gradient falling from the north-east toward the deeper south-west corner. Along the export pipeline, the general bathymetric profile is characterised by an overall increase in depth in a south-westerly direction, reaching a maximum depth of approximately 280 m.

Seabed morphology across the project area is typically smooth and bare of hard substrates, with predominantly sandy sediments observed (Fugro 2017a). Muddy sand was more common at the Prelude end of the export pipeline corridor and gravelly sand with hard substrate identified in the shallower north-eastern zone of the in-field development area. Seabed features observed throughout the project area included clusters of pockmarks, sand waves, megaripples and some anchor drag scars (Fugro 2017a).

A large outcropping reef area was identified in the north-eastern section of the in-field development area. The reefal outcrop feature extended 10 m–20 m above the seabed over a distance of approximately 30 m (Fugro 2017a). The feature is characterised by a steep southern wall and irregular morphology due to smaller reef developments around the flanks and clusters of seabed depressions on the top of the outcropping area. It is thought that this reef structure is similar in origin to the many other shoals in the wider region (Fugro 2017a). The seabed around the feature comprises of a mixture of silt and sand. A study of the seafloor undertaken in the Browse Basin observed that small, but prominent, mounds were scattered throughout the study area. The mounds were similar to that recorded in the in-field development area in that they were generally steep-sided, rose to similar heights above the seabed (approximately 6 m–16 m) and comprised of

hard substrate (Howard et al. 2016). The mounds also extended up to diameters of more than 30 m.

A trench, whereby the seabed drops by up to 25 m over a distance of 50 m, and a platform of 20 m–30 m elevation in relation to the surrounding seabed, were observed within the wider area surveyed along the export pipeline corridor. While in the vicinity of the export pipeline corridor, the export pipeline will not intersect these features.

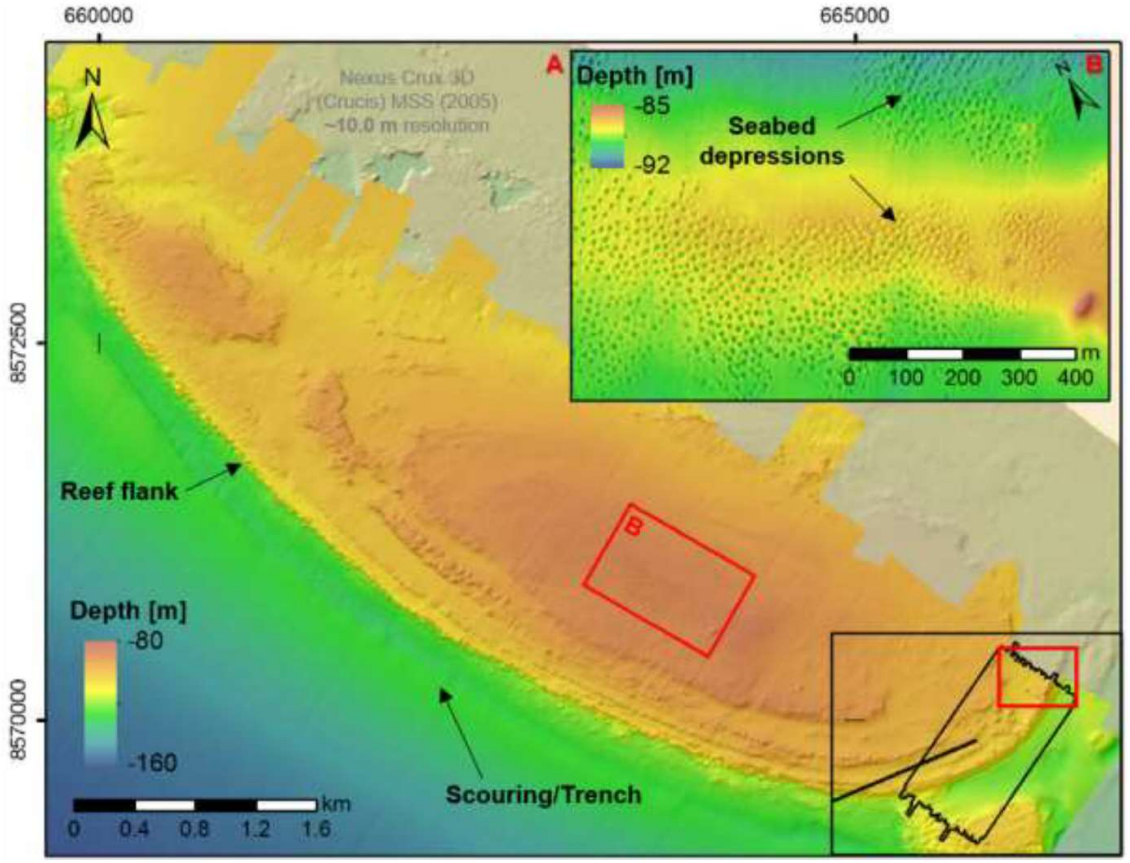


Figure 6-4: Outcropping Reef in the In-field Development Area

6.3.4 Water Quality

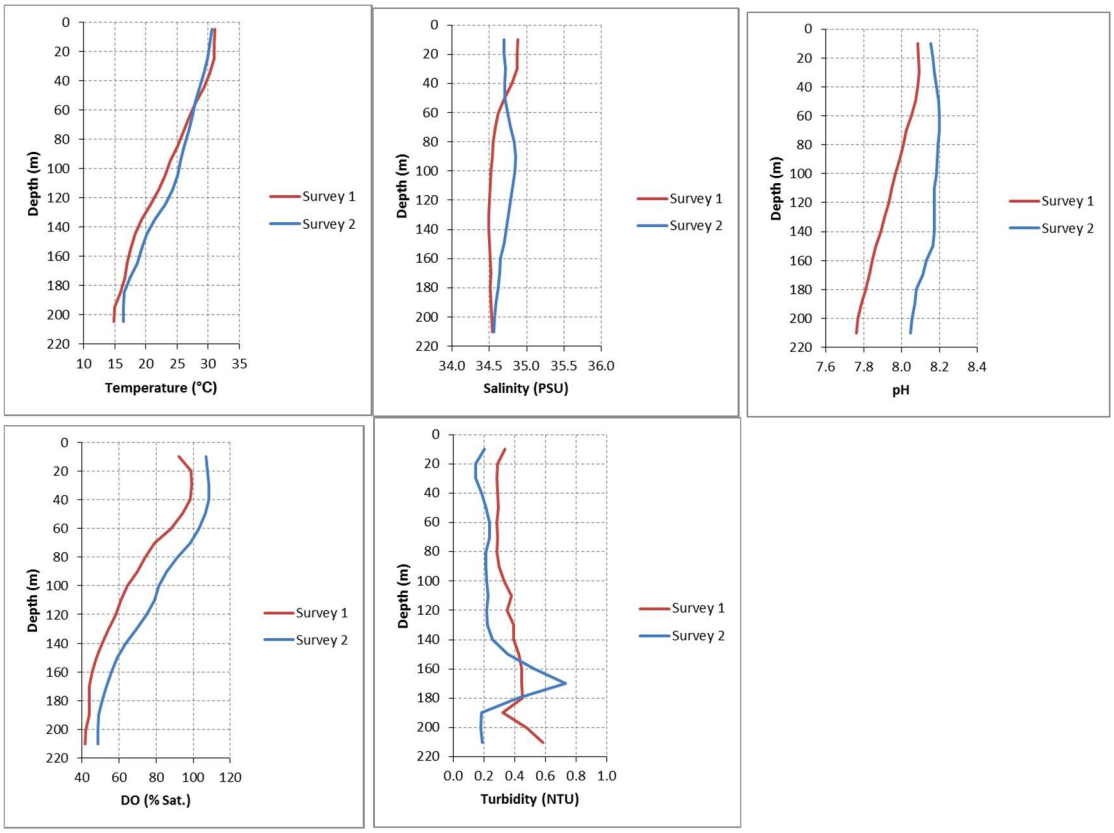
This section describes the water quality recorded within the project area during baseline environmental surveys. Two separate surveys were conducted over three days in April/May 2016 (the 'May survey') and October/November 2016 (the 'November survey') to reflect seasonality (AECOM 2016, 2017). In the May survey, a total of 24 sites were sampled, 21 sites were within the in-field development area and three were within the export pipeline corridor. In the November survey, ten of these sites were re-sampled, seven in the in-field development area and three within the export pipeline corridor. Vertical profiling, water sampling for nutrient and chemical analysis, and phytoplankton sampling were carried out at sample sites in both surveys.

Where appropriate, water quality data have been compared to the Australian and New Zealand Environment and Conservation Council and Agricultural and Resource Management Council of Australia and New Zealand (ANZECC & ARMCANZ) (2000) guidelines. Notably, the guidelines are intended to be modified to capture variabilities at regional, local and/or site-specific levels.

Overall, water quality in the project area was considered to be of high quality.

6.3.4.1 Physico-chemical Water Column Profiles

Temperature, salinity, pH and dissolved oxygen (DO) were relatively consistent across all sites and well within expected ranges when compared to previous studies in the region, such as Prelude (Shell 2009), Ichthys (INPEX 2010) and Barossa (ConocoPhillips 2018). Between the May and November surveys there were marginal consistent differences in DO and pH throughout the water column, as well as comparatively lower salinities in the upper water column for the November survey followed by a gradual increase then decrease in salinities on approaching the seabed (**Figure 6-5**). These physico-chemical variations in water quality between the two surveys suggest the existence of minor seasonal variation.



Key: Survey 1 – May survey; Survey 2 – November Survey

Figure 6-5: Water Column Profiles at Comparable Sites in the In-field Development Area

Surface temperatures (in the shallow profile up to 10 m depth) ranged between approximately 30 °C to 31 °C for both surveys (AECOM 2016, 2017). Temperatures dropped consistently throughout the water column with the thermocline being relatively indistinct (**Figure 6-5**). Temperatures near the seabed typically ranged between approximately 17 °C to 20 °C, however temperatures around 15 °C were recorded at the deeper depths within the export pipeline corridor.

Average surface salinities (0 m–10 m) were recorded between 34–35 Practical Salinity Unit (PSU). While there was some variation in the salinity profile within the water column (**Figure 6-5**) salinities were generally slightly lower near the seabed when compared to the surface waters.

Surface water pH was found to range between approximately 7.9 and 8.3 and pH was consistently higher in the November survey, excepting one site within the in-field development area where the pH was slightly lower (approximately 0.2). Average pH was generally uniform to approximately 20 m–30 m depth. There was then generally a constant decrease through the water column to the seabed where pH values were

observed to be slightly lower within the same survey at most sites. However, at some sites a slight increase in pH between 40 m and 60 m depth in the water column was observed. These readings are consistent with expectations for offshore marine environments as outlined in ANZECC & ARMCANZ (2000).

Average DO percent saturation was higher in the upper water column and decreased consistently with depth to the seabed. Average surface DO percent saturation ranged from approximately 86 –109%, with DO near the seabed ranging between approximately 41% to 56%. The high levels of DO in surface waters is consistent with mixing in the upper water column.

Turbidity was consistently low throughout the water column (<1 NTU) for both surveys, which can be expected for offshore marine environments.

6.3.4.2 Hydrocarbons and Metals

Water sample analyses found concentrations of total recoverable hydrocarbons (TRH) and benzene, toluene, ethylbenzene and xylene (BTEX) were not detectable above the Practical Quantification Limits (PQLs) or ANZECC & ARMCANZ (2000) guideline trigger values. The data indicates there was no detectable anthropogenic or natural contamination from neighbouring regional petroleum activities or natural seeps at the time of this study. Due to the open ocean context of the project, the occurrence of natural hydrocarbon seeps in the area (see **Section 6.3.4.4**) and the numerous petroleum activities in the NWS, it should be considered that temporal variation in background TRH and BTEX levels may occur within the project area.

Sample analyses for total metals typically returned concentrations below the PQLs. Exceptions to this were generally substantially below ANZECC & ARMCANZ (2000) guideline trigger values (99% species protection trigger values for marine waters) and/or within expected levels for offshore marine environments. An exception of note was zinc which was detected above the PQL (0.005 mg/L) and ANZECC & ARMCANZ (2000) guideline 99% species protection trigger value (0.007 mg/L) at one site within the in-field development area (0.021 mg/L) in the May survey only. The November survey subsequently detected zinc above the PQL and ANZECC & ARMCANZ (2000) guideline trigger values at all sites, with concentrations ranging from 0.01 mg/L–0.046 mg/L. The consistently elevated concentrations of zinc recorded suggest potential contamination from laboratory processes and/or sample contamination during collection. In light of this, measurements of zinc at sites in the November survey cannot be regarded as representative for the project area and should not be used in defining baseline trigger values for zinc in the area.

6.3.4.3 Nutrients and Photosynthetic Pigments

Nutrient concentrations, including nitrite and nitrate, total nitrogen and total phosphorus, were consistently low across sites for both surveys, as were levels of photosynthetic pigments indicating little seasonal variation in these properties and no obvious nutrient loads.

PQLs were exceeded for nitrite and nitrate concentrations at four sites (0.01 mg/L–0.05 mg/L) in the May survey. The PQL was lowered to 0.002 mg/L for the November survey, which is closer to the suggested guideline value of 0.001 mg/L (suggested to be typical of clear offshore waters). No detections above the lower PQL of 0.002 mg/L were detected.

Total nitrogen concentrations did not exceed the PQL of 0.2 mg/L at any of the sites sampled during the May survey. The PQL was lowered to 0.1 mg/L for the November survey to align with the ANZECC & ARMCANZ (2000) trigger level. No detections above the lower PQL of 0.1 mg/L were measured.

Concentrations of total phosphorous at sites in the May survey did not exceed the PQL or ANZECC & ARMCANZ (2000) guideline trigger value for north-west WA offshore marine environments of 0.01 mg/L. A reduced PQL of 0.005 mg/L for total phosphorous was applied in the November survey and was exceeded, with results still in an acceptable range of 0.01 mg/L–0.012 mg/L.

A summary of the photosynthetic pigment analysis, which is an indicator for plankton, from the surveys is provided in **Section 6.4.3**.

6.3.4.4 Natural Hydrocarbon Seeps

Natural hydrocarbon seep studies in offshore Australia have primarily been in the context of frontier basin exploration and are therefore highly localised and mostly focussed on the NWS region, as Australia's main offshore petroleum province. However, the Browse Basin has been described as the best known area of natural hydrocarbon seepage in the marine environment in Australia (Logan et al. 2010).

In the Browse Basin, within which the Crux project is located, hydrocarbon seeps have been observed at the Cornea oil field and Heywood Shoals on the northern Yampi Shelf, which is approximately 65 km south of the project (Jones et al. 2005; Rollet et al. 2006; Logan et al. 2010). Pockmark formations have been noted in a number of the sub-basins within the Browse Basin (Jones et al. 2007, 2009; Picard et al. 2014; Howard et al. 2016), and were detected during baseline surveys of the project area (as discussed in **Section 6.3.3**) (Fugro 2017a). Pockmarks have been attributed to the expulsion of seawater at the seabed, driven by tidal pumping through the shallow sub-surface and commonly indicate natural hydrocarbon seepage (DIIS 2017). Active expulsion of gas bubbles suggesting seep activity have been observed along the southern flank of the Ashmore Platform, which is approximately 70 km north of the project (Stalvies et al. 2017).

A desktop and field study was undertaken by CSIRO (2017) to characterise the hydrocarbon content of waters and sediments in the Browse Basin in order to identify evidence of hydrocarbon seepage. Sites were selected based on the indication of hydrocarbon seepage by previous studies, as well potential areas of influence relevant to the Prelude and Ichthys facilities. The study recorded evidence of equivocal hydrocarbon seepage in the Browse Basin. This conclusion was primarily based on the presence of hydroacoustic flares within the vicinity of Browse Island and Heywood Shoal. This is in keeping with a survey of the Caswell Sub-basin by Howard et al. (2017) which was unable to conclusively identify hydrocarbon or other fluid seepage, nor detect active seepage, within the sub-basin. Notably, Howard et al. (2017) identified strong currents in parts of the survey area as potentially impeding the detection of seepage in the water column.

6.3.5 Sediment Quality

This section provides an overview of the baseline sediment survey conducted within the project area in October/November 2016 (i.e. the 'November Survey', as referred in **Section 6.3.4**) (AECOM 2017). Twenty sample sites were chosen within the in-field development area, 16 which aligned with or were perpendicular to the prevailing tidal current axis and four reference sites located at each corner of AC/LR9 (**Figure 6-2**). Eleven sample sites were selected at 10 km–15 km intervals along the export pipeline corridor to account for existing sediment variability.

In summary, concentrations of metals, hydrocarbons and radionucleotides were generally consistent across all sites, indicating no obvious existing anthropogenic impacts on sediment quality in the area.

6.3.5.1 Metals

No obvious spatial trends were observed for sediment metal concentrations, with slightly elevated concentrations of metals being recorded at various sites within the in-field development area and the south-west end of the proposed export pipeline corridor.

Metal concentrations were detected above the laboratory PQLs for all metals at all sites, with the exception of one reference site in which lead and mercury were below the PQL. However, concentrations across all sites were well below the low levels defined in the Interim Sediment Quality Guideline (ISQG) (ANZECC & ARMCANZ 2000) and/or within values found at reference sites. One exception was nickel which exceeded the concentrations of reference sites at a number of sites along the proposed export pipeline corridor. However, only one site (near the Prelude end of the pipeline corridor) exceeded the ISGQ-Low level of 21 mg/kg with a concentration of 21.9 mg/kg.

6.3.5.2 Hydrocarbons

Detectable levels of petroleum hydrocarbons (TRH and total petroleum hydrocarbon (TPH)) were found at three sites, as well as one polycyclic aromatic hydrocarbon (PAH) (naphthalene) at one site which was detected at concentrations equal to the laboratory PQL. All were interpreted to be within acceptable levels based on currently accepted sediment quality guideline values by Simpson et al. (2013). Oil and grease were detected at all sites above the PQL with no evidence of spatial trends in concentrations.

6.3.5.3 Naturally Occurring Radioactive Material

National Assessment Guidelines for Dredging 2009 (Commonwealth of Australia 2009b) were used to determine acceptability of gross alpha and beta radionuclide concentrations due to the absence of ANZECC & ARMCANZ (2000) guideline trigger values. Whilst the PQL (500 Bg/kg) was exceeded at twenty sites within the in-field development area and export pipeline corridor for gross alpha (560 Bg/kg–1,860 Bg/kg) and one site within the export pipeline corridor for gross beta (640 Bg/kg), the NAGD value of 35,000 Bg/kg was not exceeded at any site.

6.3.5.4 Nutrients

Nitrogen was predominantly present across sites as total Kjeldahl nitrogen (TKN) with a small nitrate plus nitrite component at some sites. TKN concentrations ranged from 210 to 1,040 mg/kg. Concentrations of nitrogen in the form of NO_x across all sites did not exceed the PQL (0.1 mg/kg). There were no spatial patterns evident for nitrogen. Concentrations of phosphorous exceeded the PQL of 2 mg/kg at all sites, ranging from 816 mg/kg to 10,200 mg/kg. These concentrations fell within the ranges found at reference sites, with the exception of three sites located along the export pipeline corridor. There are no ANZECC & ARMCANZ (2000) guideline trigger values for nutrients in sediments.

6.3.5.5 Particle Size Distribution

Particle Size Distribution (PSD) was variable across sites, with an expected higher percentage of fine sediments found at sites in deeper waters. The in-field development area sediment samples were typically characterised by medium to fine sands with variable amounts of silt and clay (5% to 42%). Sediments in the shallower north-east portion of the in-field development area and at a number of sites along the export pipeline corridor were found to be notably coarser, having a higher coarse sand or gravel fraction.

The results of the AECOM (2017) survey broadly support the findings from the Fugro (2017a) survey.

6.3.6 Air Quality

No specific information concerning air quality in the project area is available. However, the Crux platform is approximately 190 km from the Kimberley coastline, which itself is a remote and unindustrialised area. Therefore, the air quality is unlikely to be subject to significant anthropogenic effects. Commercial shipping is likely to represent the main source of localised and temporary reductions in air quality. Production facilities in the broader region, such as the Montara FPSO facility (approximately 36 km from the Crux platform), and the Prelude and Ichthys facilities, are also expected to incrementally influence local and regional air quality.

In a regional context, the main contributors to particulate levels are ambient wind-borne dust and smoke from seasonal bush fires that are characteristic across the Kimberley regions. International contributors to reduced air quality in the project area may also include the likes of 'slash-and-burn' agricultural methods and other large forest fires in South-east Asian countries (Vadrevu et al. 2014; Kim Oanh et al. 2018).

6.3.7 Underwater Noise

Noise in the marine environment is generated by both natural and anthropogenic sources. Natural noise sources include those produced by wind, waves, currents, rain, earthquakes, echo-location and communication noises generated by cetaceans and fish. Natural background noise levels have been recorded as ranging between 90 decibel (dB) to 110 dB (re 1 micropascal (µPa)), representing the typical range for calm to windy conditions, though heavy rain can result in higher noise levels (Shell 2009). Baseline noise monitoring undertaken by INPEX for the Ichthys project, located approximately 164 km to the south-west of the Crux platform, recorded average ambient noise levels of 90 dB (re 1 µPa) under low sea states (INPEX 2010). Baseline noise monitoring for the proposed Barossa project, approximately 713 km north-east of the Crux platform, observed average ambient sound levels ranging between approximately 97 dB and 119 dB (re 1 µPa) (ConocoPhillips 2018). A number of cetacean species were also detected (as discussed in **Section 6.5.6.1**).

The Prelude underwater noise monitoring program, in the northern Browse Basin, also recorded the following natural and anthropogenic features of:

- several regular fish choruses (i.e. schooling fish calling en masse)
- several great whale calls including humpback song, a possible great whale signal, pygmy blue whale signals in late October 2006 and possible minke whale signals
- persistent vessel noise, and
- seismic survey noise, associated with marine seismic survey signals.

The biological noise sources recorded in the Ichthys field were similar and included regular fish choruses, infrequent calls from nearby fish and several whale calls from humpback whales, pygmy blue whales, minke whales and other unidentifiable species (INPEX 2010). Anthropogenic noise sources recorded included low frequency noise from vessels and that generated from seismic surveys being conducted in the region (INPEX 2010).

6.4 Ecosystems, Communities and Habitats

6.4.1 Marine Regions and Bioregions

The project area is located in the NWMR, on the boundary between the North-west Shelf Transition and Timor Province bioregions (**Figure 6-6**). The majority of the project lies in the Timor Province bioregion, with a small portion of the export pipeline corridor occurring in the Oceanic Shoals bioregion. The NWMR has a large area of continental shelf and

continental slope, with a range of bathymetric features such as canyons, plateaus, terraces, ridges, reefs, shoals and banks (Woodside 2014). The in-field development area and export pipeline corridor fall between the key bathymetric features of these two bioregions; the Bonaparte Depression (to the east) and the continental shelf slope (to the west) (DEWHA 2008a).

The project is distant from other significant features within the NWMR typically associated with reefs and islands, as described in **Section 6.4.5**. The NWMR also supports internationally significant breeding and feeding grounds for a number of threatened and migratory marine fauna species (DEWHA 2008a). Results of an EPBC Protected Matters Database search for the in-field development area and export pipeline corridor are presented in **Section 6.5**.

While the project area is located wholly within the NWMR, the area of influence extends into the North Marine Region (NMR). The NMR encompasses the entire NT coastline and the Queensland coastline west of the Cape York Peninsula. The region is typified by a wide continental shelf with shallow water depths typically less than 70 m (DSEWPaC 2012a). The seafloor of the NMR is characterised by canyons and terraces, and features the Pinnacles of the Bonaparte Basin and complex and morphology of the Van Diemen rise (as described in **Section 6.4.7**).

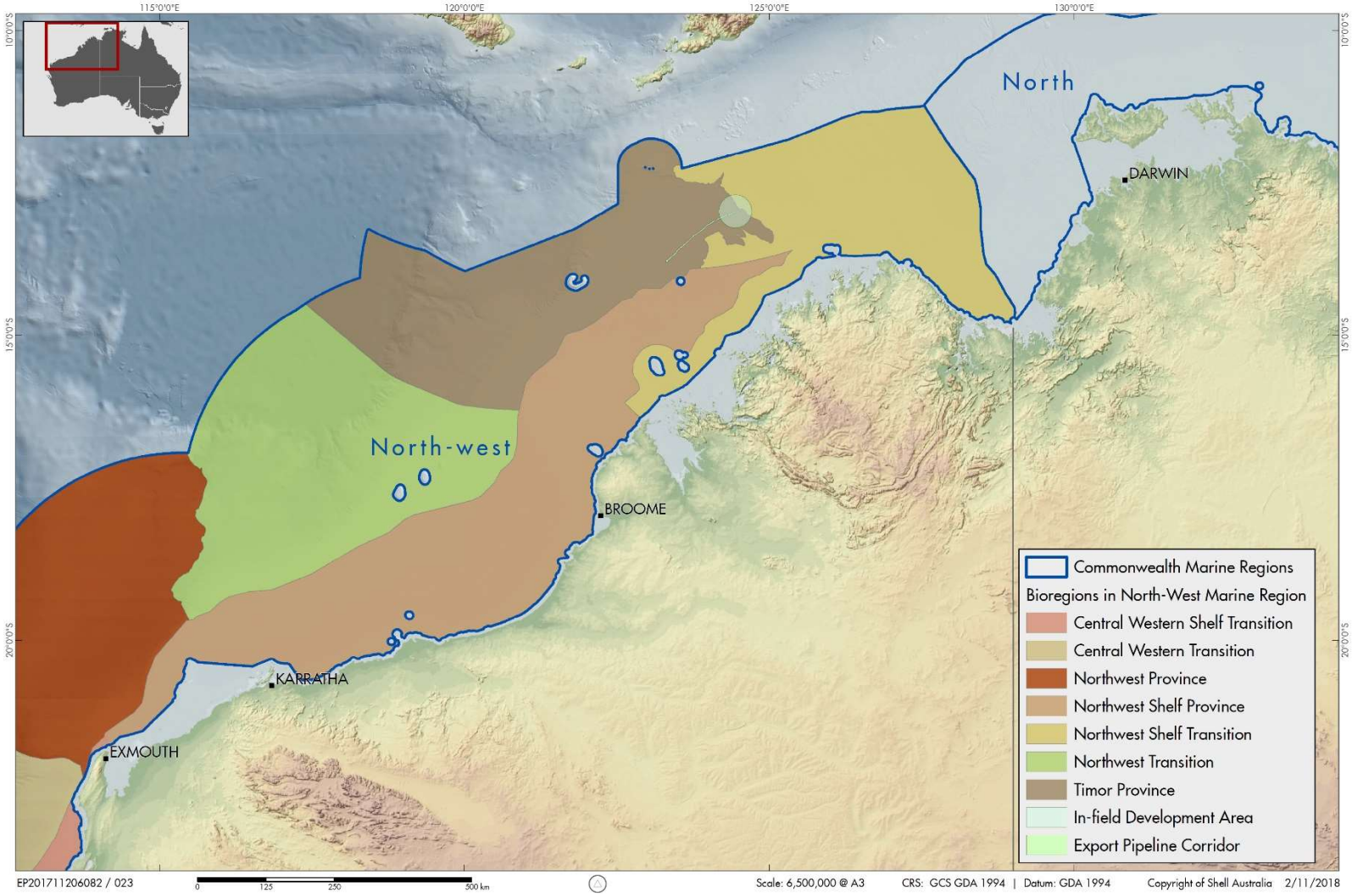


Figure 6-6: Marine Regions and Bioregions

6.4.2 Benthic Communities

6.4.2.1 Regional

Macrobenthos are organisms which live within (infauna) or on (epifauna) the seabed sediments. In the shallower coastal waters of the continental shelf, and on reefs and shoals/banks in less than 50 m water depth, communities of benthic epifauna are abundant and diverse. However, seafloor communities in deeper waters, such as those found within the project area, are generally expected to be less abundant and diverse. Notably, the absence of hard substrate at depth in areas of soft sediment is also considered a limiting factor for the recruitment of epifauna (Shell 2009).

A benthic habitat survey undertaken in the vicinity of Prelude provides an indication of the regional macrobenthos abundance and community composition. Macrobenthos composition was recorded as being similar across the survey area while abundance was found to be consistently low (an average of 7.9 individuals per sample grab) (Shell 2009). While individuals were identified from nine different Phyla, approximately 80% of individuals across the survey area were identified as Annelid worms (Shell 2009). Species from three classes of polychaete worm and mud shrimps (Crustacea) were also dominant.

Other surveys in the region include seabed habitat surveys for the Ichthys Gas Field Development Project, Montara Development Project, Browse Upstream Development and Bonaparte LNG Project. The seabed within the Ichthys field (235 m to 275 m), approximately 164 km south-west of the in-field development area, was characterised by bare substrates with heavily rippled sand, which is indicative of strong near-seabed currents and mobile sediments that are unfavourable towards the development of diverse epibenthic communities (INPEX 2010). Few epibenthic organisms were recorded within the Ichthys field. A low cover of epibenthic fauna, comprising filter feeding communities with sponges, gorgonians, soft corals, hydroids, bryozoans, fan worms and other polychaetes, was observed within the broader exploration permit area where the seabed comprised a pavement reef with a sand veneer (INPEX 2010). The infauna within the Ichthys field was dominated by polychaete worms and crustaceans, which accounted for approximately 70% of the infaunal assemblage (INPEX 2010).

The benthic habitats in the Montara development project area, approximately 36 km north-east of the Crux platform, were characterised by homogenous, flat, featureless soft sediment with low relief ripples displaying evidence of bioturbation (PTTEP 2017). The sparsely distributed epifauna assemblage supported hydroids, octocorals (soft corals, gorgonians and seapens), black corals and ascidians. The macrobenthic faunal assemblages were generally low and patchy in abundance, with the dominant species being polychaete bristleworms (abundance of approximately 40 to 60%) and crustaceans (e.g. shrimps, crabs) (approximately 13 to 19%) (PTTEP 2017).

The deep-sea seabed (400 m to 600 m) within the Browse development area, approximately 265 km south-west of the Crux platform, was observed as comprising fine sand and silt with epibenthic fauna limited to isolated individual bryozoan colonies, brittlestars and basketstars, and sea anemones (Woodside 2014). The most abundant infauna recorded were polychaete bristleworms, accounting for 53.4% of all infaunal assemblages (Woodside 2014).

Benthic habitat in the GDF Suez (now Engie/Neptune Energy) Bonaparte Basin retention lease areas (approximately 440 km east of the Crux platform, in water depths 80 m to 100 m) was recorded as soft sediments with epifauna and sessile benthos generally being sparse and characterised by a limited number of common and widespread taxa (GDF Suez 2011). Infaunal communities were also observed to be typical of soft sediment habitat and dominated by polychaete worms (GDF Suez 2011).

6.4.2.2 Crux Project Area

Camera observation and benthic grab surveys for benthic fauna and community characterisation were undertaken in the project area by Fugro (2017a) and AECOM (2017). The camera survey was conducted in April/May 2017 using a towed mounted camera and video camera system. A total of 25 camera transects were surveyed; 10 in the in-field development area, 12 along the export pipeline corridor, and an additional two along an alternative export pipeline route (**Figure 6-2**). Four additional transect sites were intended for inclusion but poor visibility at the seabed precluded the use of three of these. Visibility was typically poorer at the Prelude end of the export pipeline corridor due to finer sediments. Grab sampling sites for the sediment benthic fauna analysis by AECOM (2017) were the same 31 sites as for the sediment quality assessment summarised in **Section 6.3.5** (refer **Figure 6-2**) (AECOM 2017). Triplicate samples were made at reference sites resulting in a total of 39 samples being collected using the benthic grab.

In summary, the benthic surveys observed a very low macrobenthic fauna abundance in the project area (AECOM 2017). The dominant phyla were Annelida, Mollusca, Porifera and Arthropoda, as expected for the region.

Eight benthic habitats were identified within the project area based on a hierarchical benthic habitat classification scheme which considered geomorphological structure and comprising sediments (Fugro 2017a). **Figure 6-7** shows the distribution of the benthic habitats across the project area while **Figure 6-8** provides photographs representative of these habitat types. A detailed summary of the benthic habitats is provided in **Table 6-2** (Fugro 2017a). The amount of hard substrate present appeared to have the greatest effect on the composition of the benthic community present (Fugro 2017a).

Sediment types observed on the camera varied across the survey area. Muddy sand was observed on the video to the south of the survey area at the Prelude end of the export pipeline route, while gravelly sand with hard substrate was observed in the shallower areas of the in-field development area. This was broadly consistent with the geophysical data interpretation which identified the predominant sediment type as silty sand at the in-field development area, with sand being the predominant sediment type along the export pipeline route. Overall epifaunal abundance was low with some habitats having little to no visible fauna. Most habitats had low faunal abundance with a few characterising taxa.

Sampling of the benthic fauna within the sediments identified 457 individual infauna (AECOM 2017). Of the 457 individuals collected, 11 major phyla and sub-phyla were identified. The dominant phyla were Annelida (approximately 37%), Mollusca (approximately 24%) and Porifera (approximately 11%). A summary of the benthic fauna identified is shown in **Table 6-3**. There were no evident spatial trends in benthic infauna based on sediment physicochemical attributes. Replicate samples at reference sites, and comparisons between sites with similar sediments, indicated high variability between samples. The patchy distribution was described as typical of benthic infauna for soft sediment habitats (AECOM 2017).

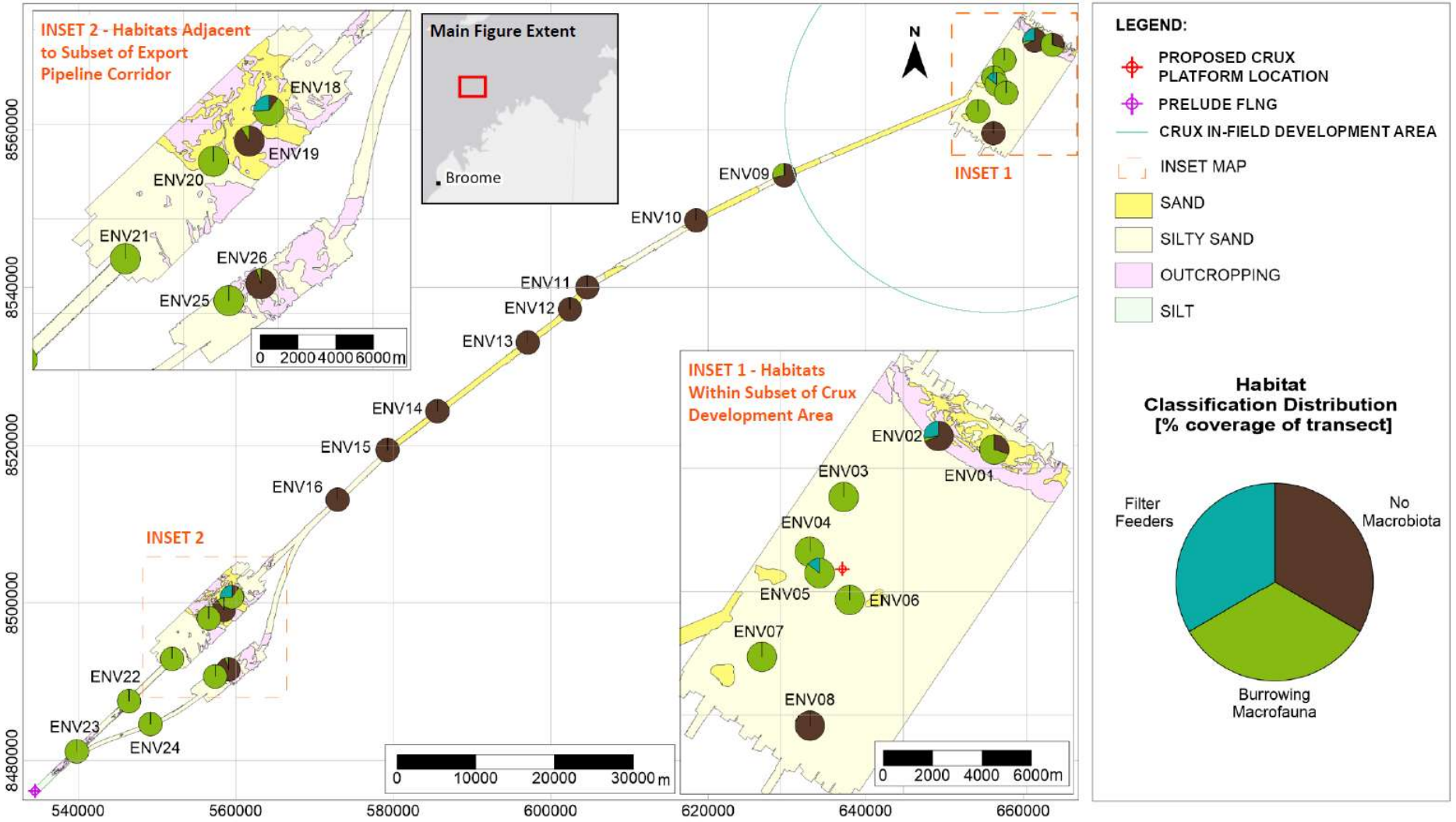
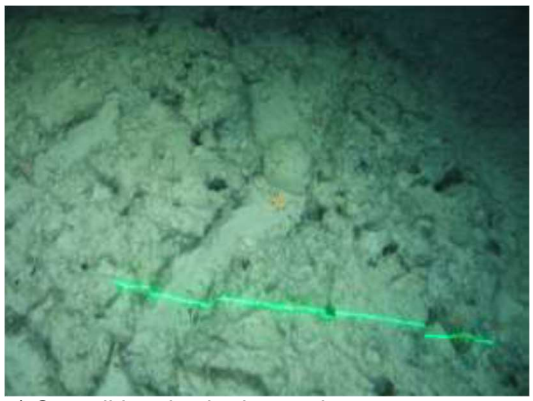
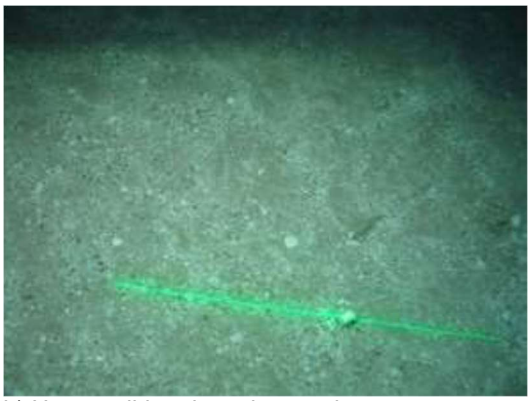


Figure 6-7: Benthic Habitat Classification and Fugro (2017a) Sample Sites within the Project Area



a) Consolidated unbroken rock



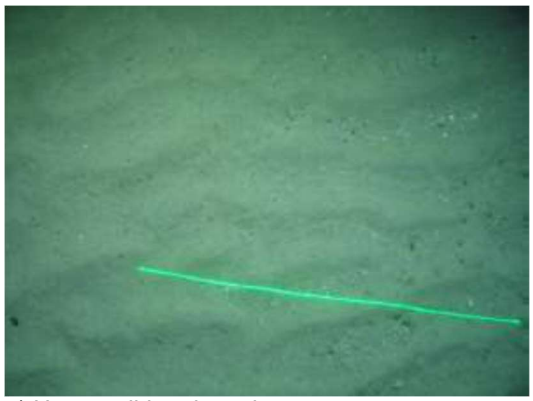
b) Unconsolidated sandy gravel



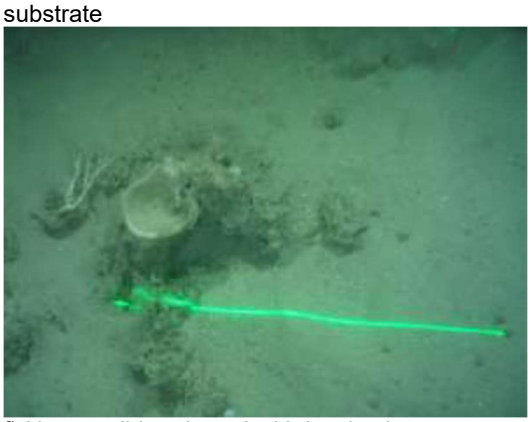
c) Unconsolidated gravelly sand



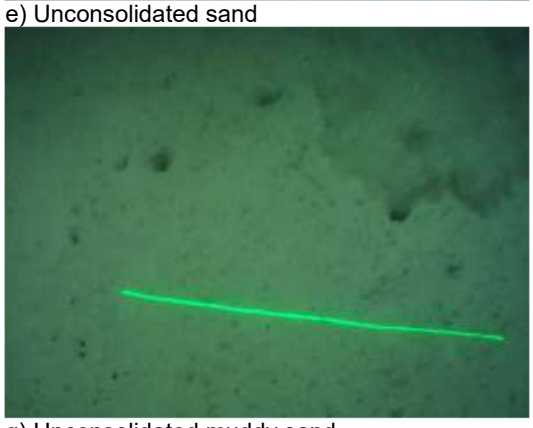
d) Unconsolidated gravelly sand over hard substrate



e) Unconsolidated sand



f) Unconsolidated sand with hard substrate



g) Unconsolidated muddy sand



h) Unconsolidated muddy sand with hard substrate

Figure 6-8: Photographs of the Benthic Habitats Identified in the Project Area

Table 6-2: Benthic Habitats within the Project Area

Level 1	Level 2	Level 3				Location
Substrate Type	**Particle Size**	**Sediment Particle Size**	**Sediment Description**	**Profile**	**Characterising Fauna**	
Consolidated	Rock	Rock (unbroken)	Reef with sand veneer, high relief	High	Burrows, soft coral (Alcyonaria), sponge (Porifera), sea anemone (Actiniaria), branching coral (Alcyonacea)	Export pipeline corridor
			Reef with sand veneer, medium relief	Medium	Sea whips (Alcyonacea), branching soft coral (Alcyonacea), sponge (Porifera)	In-field development area, export pipeline corridor
			Reef with veneer of sediment, low relief	Low	Hydroids (Hydrozoa), sponge (Porifera), branching coral (Alcyonacea)	In-field development area, export pipeline corridor
Unconsolidated	Gravel	Sandy gravel	Sandy gravel	Flat	Sparse to no fauna	Export pipeline corridor
		Gravelly sand	Gravelly sand	Flat to small ripples	Soft coral (Alcyonacea), hydroids (Hydrozoa)	In-field development area, export pipeline corridor (alternate route only)
					Faunal burrows	Export pipeline corridor
					Sparse to no fauna	Export pipeline corridor
		Gravelly sand over substrate	1 – 49% reef	Flat	Sea whips (Alcyonacea), hydroids (Hydrozoa), sponge (Porifera)	In-field development area, export pipeline corridor
	Sand	Sand	Sand	Flat to medium ripples	Faunal burrows	In-field development area, export pipeline corridor
					Sea anemone (Actiniaria), tubular glass sponges (Porifera), sea urchin (Echinoidea)	In-field development area
					Sparse to no fauna	Export pipeline corridor
		Sand with hard substrate	1 – 49% reef	Flat	Sponges (Porifera), crinoids (Crinoidea), faunal burrows	In-field development area, export pipeline corridor
			Volcanic rock	Small to medium waves	Sparse to no fauna	Export pipeline corridor
	Mud	Muddy sand	Muddy sand	Flat	Faunal burrows	In-field development area, export pipeline corridor
		Muddy sand with hard substrate	1 – 24% reef	Flat	Sponges (Porifera), faunal burrows	Export pipeline corridor

Table 6-3: Benthic Fauna Abundance from Sediment Grab Samples

Phylum	Number of Individuals	% Total	Number of Morphospecies	% Total
Porifera	50	11.0	8	5.2
Nemertea	8	1.8	2	1.3
Annelida (Echiura)	2	0.4	2	1.3
Annelida (Sipunculida)	31	6.8	10	6.5
Annelida (Polychaeta)	137	30.0	55	36.0
Mollusca	108	23.6	18	11.8
Bryozoa	5	1.1	3	2.0
Nematoda	16	3.5	4	2.6
Arthropoda (Crustacea)	70	15.3	37	24.2
Echinodermata	29	6.4	13	8.5
Chordata	1	0.2	1	0.7
Total	**457**	**100**	**153**	**100**

6.4.3 Plankton

Plankton refers to generally passively, mobile, single-celled organisms that are present within the water column. Forms include a highly diverse mix of phytoplankton and zooplankton, ranging in size from micrometres to centimetres that fulfil a diverse range of ecological roles.

Plankton distribution is often patchy and linked to localised and seasonal productivity that produces sporadic bursts in phytoplankton, zooplankton and tropical krill production (DEWHA 2008a). Fluctuations in abundance and distribution occur both horizontally and vertically in response to the tidal cycles, seasonal variation (light, water temperature and chemistry, rainfall, currents and nutrients) and cyclonic events. In general, the mixing of warm surface waters with deeper, more nutrient-rich waters (i.e. areas of upwelling) generates phytoplankton production and zooplankton blooms.

6.4.3.1 Regional

Previous surveys undertaken in offshore marine waters near the Prelude location concluded that phytoplankton was highly diverse but low in abundance (Shell 2009). However, phytoplankton abundance is likely to be seasonal with higher densities occurring during the spring and summer (Shell 2009). Key groups identified near Prelude included dinoflagellates (Dinophyceae), diatoms (Bacillariophyceae) and Prasinophyceae. The most abundant species included *Prasinophyte sp.* (Prasinophyceae); *Gyrodinium sp.* and *Heterocapsa sp.* (Dinophyceae); *Pseudonitzschia sp., Cylindrotheca closterium, Chaetoceros sp., Thalassionemafrauenfeldii* and *Nitzschia longissima* (Bacillariophyceae) (Shell 2009). The Prelude EIS also noted that phytoplankton in the wider NWS region is similar to that observed in the Prelude location with relatively high diversity in certain groups recorded such as diatoms, dinoflagellates and coccolithophorids (Hallegraeff and Jeffrey 1984; Hallegraeff 1984, cited in Shell 2009). Zooplankton assemblages within the Prelude location were primarily dominated by copepod species (Shell 2009). However, overall densities of crustacean assemblages were relatively low and typical of low nutrient open ocean environments in the region.

The phytoplankton and zooplankton assemblages in the Prelude location were consistent with the results of a survey in the Timor Sea for the proposed Sunrise Gas Project (approximately 550 km north-west of the Crux platform), which also found phytoplankton abundance to be low and zooplankton samples to be low in abundance but high in diversity of species (BBG 2002).

6.4.3.2 Crux Project Area

As part of the baseline water quality surveys undertaken for the Crux project (see **Section 6.3.4**), chlorophyll concentrations were measured as an index of phytoplankton biomass (AECOM 2016, 2017). Analysis was undertaken for total chlorophyll, chlorophylls 'a', 'b' and 'c', and phaeophytin. The ratio of the three forms of chlorophyll (‘a’, ‘b’ and ‘c’) is used as an indicator of the composition of the phytoplankton assemblages.

For the four parameters analysed (Chlorophyll a, b, c and phaeophytin), no sites registered a result above the laboratory PQL of 0.0001 mg/L (0.0002 mg/L for phaeophytin) in the November survey (AECOM 2016). This is marginally different to the May survey results, where concentrations of chlorophyll ‘a’ were measured above the PQL at seven sites within the in-field development area (AECOM 2017). All detections of total chlorophyll for both surveys were very low with the measured concentration of total chlorophyll at all sites being 0.0001 mg/L, with the exception of one site in the May survey which returned a value of 0.0002 mg/L. These results are below the ANZECC & ARMCANZ (2000) trigger levels for offshore marine waters of Northern Australia (0.0005 – 0.0009 mg/L). The lower of these two values is typical of clear coral dominated waters (e.g. Great Barrier Reef), while higher values are typical of turbid macrotidal systems (e.g. NWS of WA) (ANZECC & ARMCANZ 2000).

In conclusion, photosynthetic pigments in surface waters within the project area were generally low and typical of clear tropical open water environments. These results suggest very little seasonal variation in photosynthetic pigments in the surface waters between the two surveys.

6.4.4 Shoals and Banks

There are a large number of shoals and banks within the Browse Basin and open offshore waters off northern Australia, including those shown in **Figure 6-9**, that have recognised environmental value. An understanding of these features has been gained from the Big Bank Shoals study (Heyward et al. 1997), PTTEP surveys initiated in response to the Montara incident (Heyward et al. 2010; Heyward et al. 2012) and the regional shoals and shelf assessment undertaken by AIMS for the Barossa Area Development project (Heyward et al. 2017b). Other studies which have contributed to the scientific understanding of these features include the INPEX Ichthys surveys, those within the surrounds of the Barossa offshore development area and the baseline studies for the Crux project (as discussed further below).

6.4.4.1 Ecological Importance

The shoals and banks within the Crux project area, and the Timor Sea more broadly, are of recognised environmental value. The benthic habitats and associated fauna assemblages are highly diverse compared to the surrounding relatively deep and bare seabed which constitutes the majority of the outer continental shelf in the region. These isolated “islands” of biodiversity may act as important sources of larvae of important taxa such as fish and corals, which may be advected considerable distances. This supply of larvae may enhance recovery of banks, shoals and reefs following disturbances such as cyclones, fishing and coral bleaching events, and hence may play a role in regional ecosystem resilience (Wahab et al. 2018). The shoals/banks support many of the same

species found on emergent reef systems of the Indo West Pacific region such as Ashmore Reef, Cartier Island, Seringapatam Reef and Scott Reef (Heyward et al. 2017b). This indicates a high level of ecological connectivity among the reef systems and between the shoals/banks. This is further supported by an analysis undertaken by AIMS which compared benthic habitat community data from a number of shoals/banks within the Timor Sea and Bonaparte Gulf region. The analysis showed that neighbouring shoals and banks frequently share many attributes in terms of benthic community composition and species (Heyward et al. 2017a).

Environmental monitoring following the Montara oil spill has indicated some components of the biological communities of the banks and shoals in the Timor Sea are dynamic, with changes in habitats (e.g. seagrass distribution) and fish assemblages over time. The apparently healthy marine communities observed during the post-Montara monitoring may indicate these communities were not significantly exposed to spilled oil or were resilient to oil contamination; the lack of long-term monitoring data (including baseline data) makes interpretation of monitoring results difficult.

There is some evidence of fishing pressure (particularly illegal fishing such as shark finning) on the banks and shoals in the Timor Sea. Heyward et al. (2017) suggested that the low abundance of highly prized finfish and sharks, indicates banks and shoals are subject to some fishing pressure despite the long distances from ports. Fishing at banks and shoals may include both subsistence and commercial fishing, potentially providing food and income.

While the benthic communities on each shoal/bank reveal a degree of connectivity, it is acknowledged that they may vary in the abundance and diversity of dominant benthic species, with subsets of species featuring more prominently on some than others (Heyward et al. 2017b). This variability may reflect different disturbance events (e.g. cyclones, storm damage and coral bleaching) and recruitment histories, as well as potentially different ecosystem trajectories (Heyward et al. 2017b).

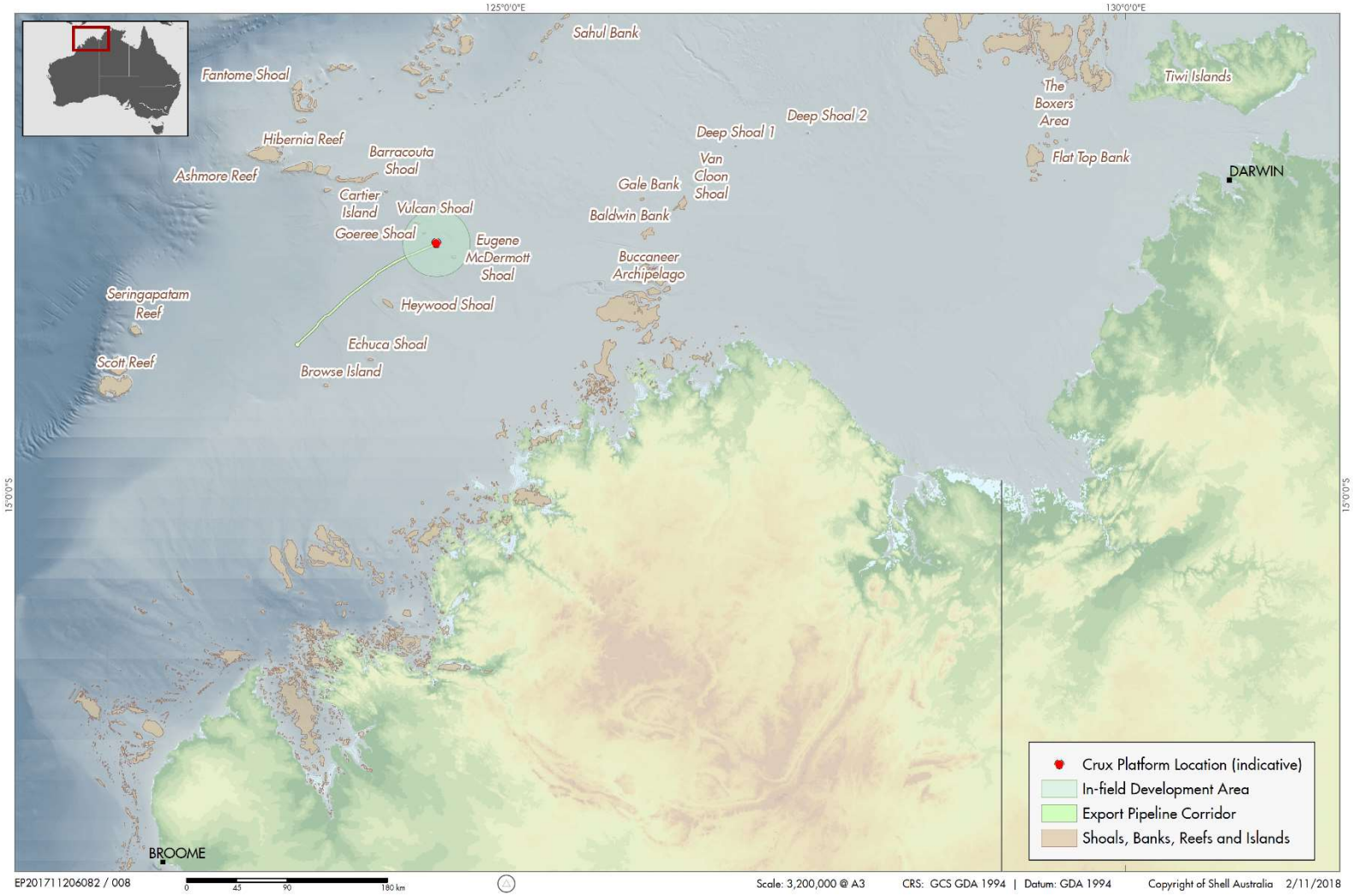


Figure 6-9: Shoals and Banks, and Offshore Islands/Reefs within the Area of Influence of the Crux Project

Shoals within the boundary of the Crux in-field development area are surrounded by a 1 km buffer within which no activities will take place. These shoals are described in more detail below and include (**Figure 5-3**):

- Goeree Shoal – located within the in-field development area with a 1 km exclusion buffer around the shoal, approximately 13 km north-west of the Crux platform,
- Eugene McDermott Shoals – located within the in-field development area with a 1 km buffer, approximately 18 km south-east of the Crux platform, and
- Vulcan Shoal – located within the in-field development area with a 1 km buffer, approximately 22 km north-west of the Crux platform.

Shoals in the region beyond the Crux in-field development area include:

- Barracouta Shoals – located approximately 63 km north-west of the Crux platform,
- Heywood Shoals – located approximately 67 km south-west of the Crux platform and approximately 21 km from of the export pipeline corridor at the closest point, and
- Echuca Shoals – located approximately 117 km south-west of the Crux platform and approximately 53 km north of the export pipeline corridor.

The shoals closest to the project area have been subject to comprehensive survey by AIMS following the 2009 Montara oil spill (Heyward et al. 2012). The survey involved multibeam swath mapping and towed video and digital stills along a number of transects across the shoals. Stereo Baited Remote Underwater Video Stations (BRUVs) were deployed at sample sites in order to provide a representation of the benthic and pelagic communities of the wider shoal area. Shell and INPEX also commissioned AIMS to undertake a detailed survey of the benthic habitats and fish communities at Heywood Shoal and Echuca Shoal (Heyward et al. 2017a). The survey adopted the same methods and sampling locations that were first applied on these shoals as part of a post-Montara impact assessment. The topography, characterising benthic habitats and pelagic communities of the shoals are described below.

6.4.4.2 Shoals within the Crux In-field Development Area

Goeree Shoal

Goeree Shoal is the closest bank or shoal to the Crux platform that has been named by the Australian Hydrographic Office, lying approximately 13 km north-west of the Crux platform. Goeree Shoal lies within the boundary of the Crux in-field development area, and Shell has applied a 1 km buffer around the shoal within which no activities will take place. The bathymetric features of Goeree Shoal are consistent with the patterns observed at other shoals and banks in the region, although Goeree Shoal is smaller than Vulcan and Eugene McDermott shoals, which also lie within the Crux in-field development area. Goeree Shoal rises abruptly from the surrounding seabed, with steep sides of the shoal rising from approximately 170 m to < 40 m (Figure 6-10). The top of the shoal forms a plateau ranging from approximately 20 to 40 m water depth. The western part of the plateau is relatively shallow (Figure 6-10) and is characterised by hard coral communities (Figure 6-11). Growth of these hard corals may account for the relatively shallow local bathymetry in this part of the shoal. At a coarse scale (> 500 m), the surface of Goeree Shoal is relatively smooth. At finer scales (10 m to 100 m) the bathymetry is rugose, which reflects the complexity of the benthic habitats found on Goeree Shoal.

Like other banks and shoals in the region, Goeree Shoal is understood to have been formed through in situ biogenic production of sediments, particularly calcareous green algae in the genus *Halimeda* spp. Coring in shoals and banks in the region has identified

extensive deposition of carbonates of biogenic origin (Heyward et al. 1997). Geological assessment by Saqab and Bourget (2015) indicates the banks and shoals features developed primarily in phase with repeated changes in sea level, providing further evidence for localised sediment production generating the banks and shoals.

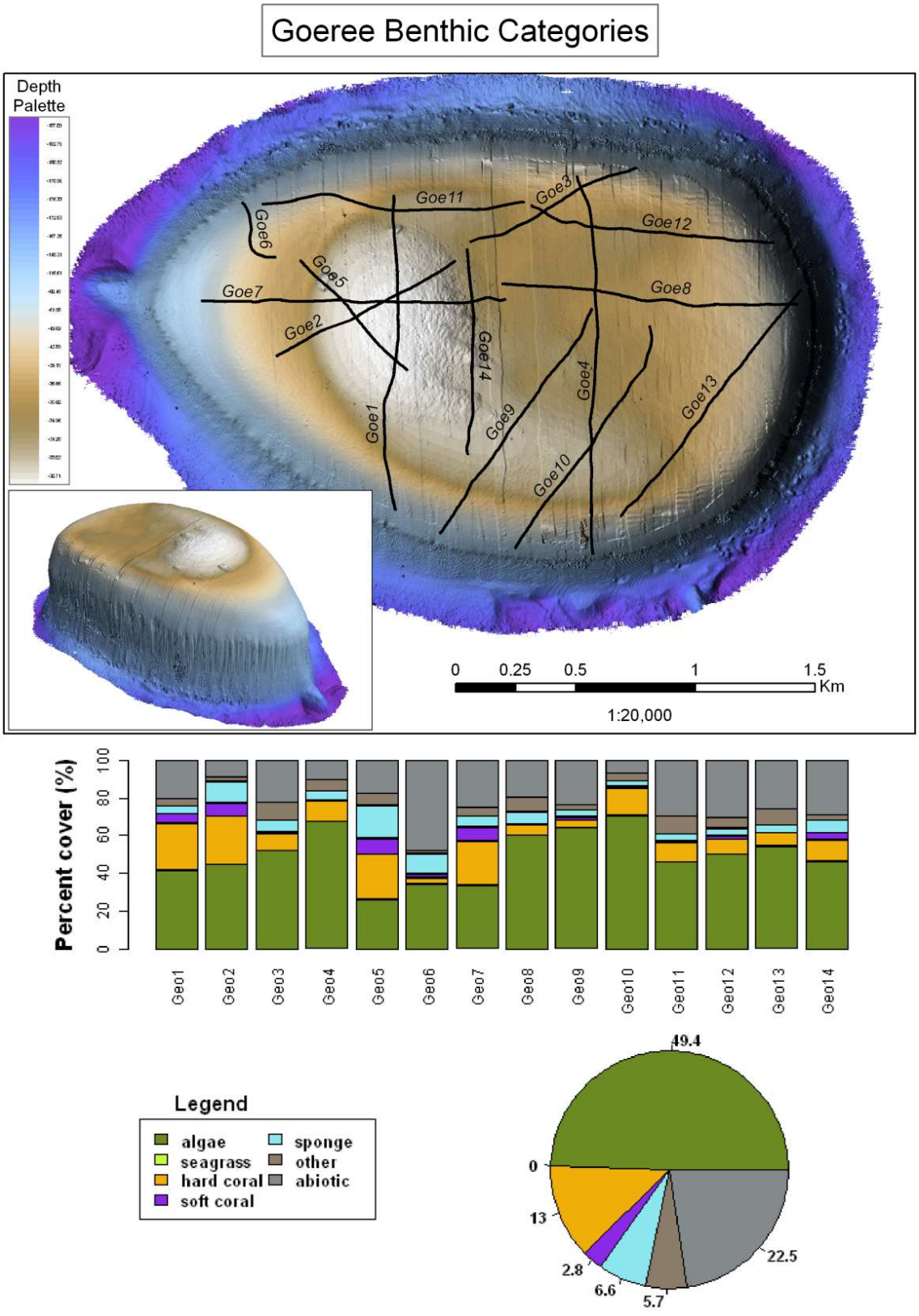


Figure 6-10: Goeree Shoal Morphology, Depth and Abundance of Major Benthic Groups derived from Multibeam Echo Sounder and Towed Video Surveys (from Heyward et al. 2012)

Sediments within and around Goeree Shoal are characterised by sand and gravel fractions, which is coarser than the silty sands around the Crux platform (Fugro 2017). The relatively coarse characteristics of the sediments may be the result of the relatively young geological age of locally produced biogenic sediments (e.g. hard coral rubble or calcareous *Halimeda* spp. fragments) and potential exposure to relatively fast surface currents that may re-suspend fine sediments. Data presented in Heyward et al. (2017) indicates sediments at Goeree Shoal are generally coarser than at Vulcan or Eugene McDermott shoals.

Benthic habitats at Goeree Shoal (Figure 6-11) are broadly similar to other shoals in a similar depth range in the region. Habitats in < 30 m of water are characterised by consolidated reef (and associated turfing algae), sand, hard coral, algae and unconsolidated reef (Heyward et al. 2017b). The relative abundances of these habitats change with increasing depth, with algae and hard corals decreasing in relative abundance in waters around Goeree Shoal between 30 and 60 m depth (Heyward et al. 2012, Heyward et al. 2017b). This is likely to be the result of photosynthetically active radiation decreasing as water depth increases, limiting the depth range of photosynthetic organisms such as algae, seagrass and zooxanthellate corals. Substrate types appear to be highly spatially correlated with habitats (Figure 6-12). Unconsolidated reef (such as rubble from *Halimeda* and hard coral) increases with water depth. Substrate types are correlated with habitat types (Figure 6-12).

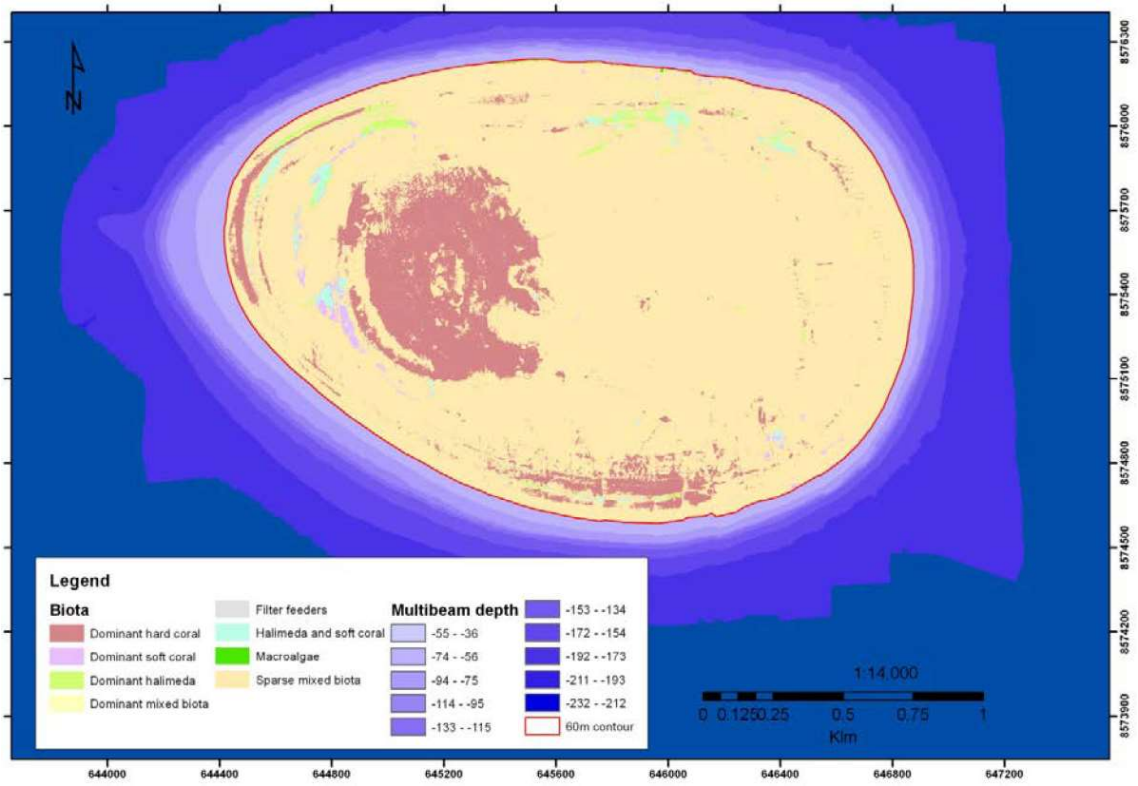


Figure 6-11: Composite Modelled Benthic Habitats of Goeree Shoal (from Heyward et al. 2012)

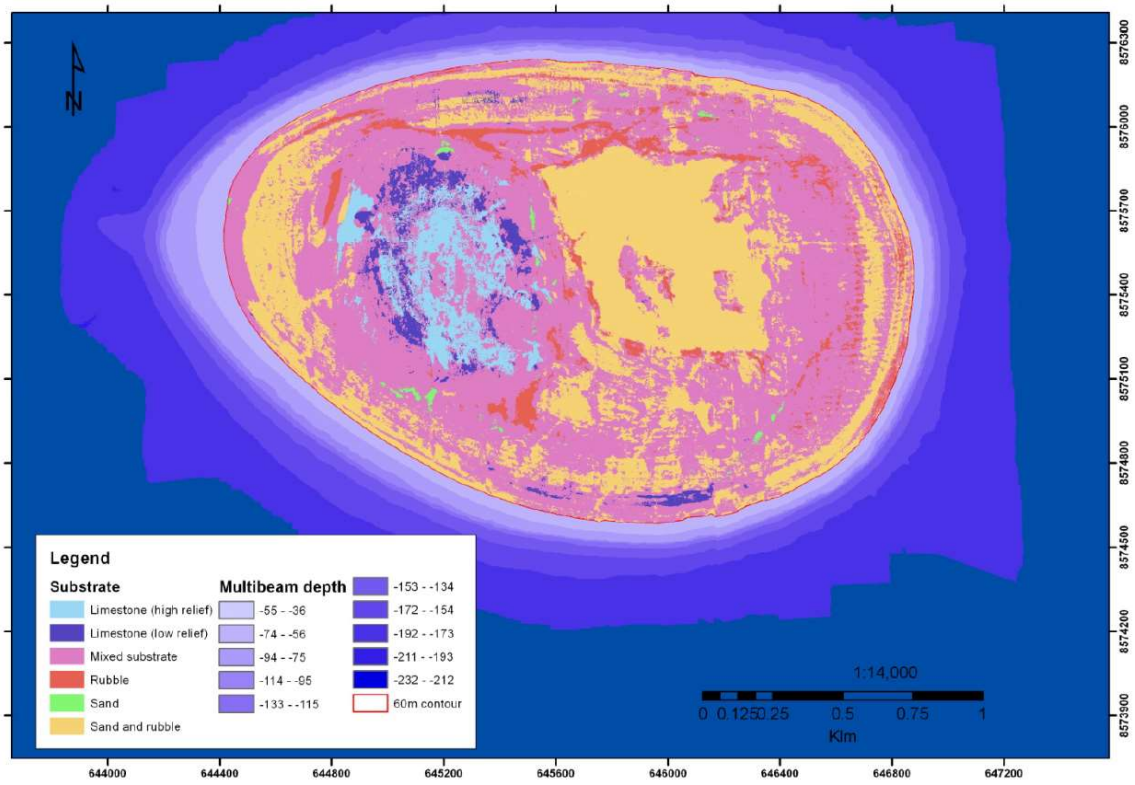


Figure 6-12: Composite Modelled Substrate Types of Goeree Shoal (from Heyward et al. 2012)

The relatively complex benthic habitats of Goeree Shoal support a diverse fish assemblage compared to the surrounding deeper seabed habitat surrounding the shoal. Sampling using BRUVs following the Montara oil spill indicated the fish assemblage at Goeree Shoal was diverse, with significantly greater fish abundance and diversity associated with the hard coral habitat found on the western part of the shoal (Heyward et al. 2012). The fish assemblage within this part of the shoal was characterised by species associated with coral habitat, including species of grouper (Serranidae), damselfish (Pomacentridae) and wrasses (Labridae) (Heyward et al. 2012). The deeper parts of the shoal classified as sparse mixed biota, where hard coral cover is low, were characterised by wrasses (Labridae), houndsharks (Triakidae) and dartfish (Ptereleotrinae) (Heyward et al. 2012). Sparse mixed biota was the most common habitat found on Goeree Shoal (Figure 6-11).

Analysis of repeated sampling using BRUVs at several of the banks and shoals in the Timor Sea indicated that the cumulative species curves typically do not reach an asymptote. This indicates that these assemblages are likely to be more diverse than has been observed to date (Heyward et al. 2012, Heyward et al. 2017).

Eugene McDermott Shoal

Eugene McDermott Shoal lies within the boundary of the Crux in-field development area, approximately 18 km south-east of the Crux platform. Shell has applied a 1 km buffer around Eugene McDermott Shoal within which no activities will take place. Like Goeree Shoal, Eugene McDermott Shoal rises abruptly from the seabed (Figure 6-13). The surface of the shoal reaches to approximately 20 m water depth in the shallowest part of the shoal. The plateaued surface of the shoal is somewhat more domed in shape than some other shoals in the region; the gradient from the shallowest part of the shoal to approximately 100 m water depth is less steep than similar shoals in the region. The sides of the shoal become steeper beyond approximately 100 m water depth, with a similar gradient from this depth to the surrounding continental shelf (< 150 m). The

relatively shallow domed part of the shoal is characterised by a high cover of hard coral habitat (Figure 6-14). Growth of hard coral on this part of the shoal over the Holocene period may account for the geological origin of this relatively shallow feature. Like Goeree Shoal, the surface of Eugene McDermott Shoal appears relatively smooth at a coarse scale (> 500 m) but is much more rugose at finer scales (10 m to 100 m).

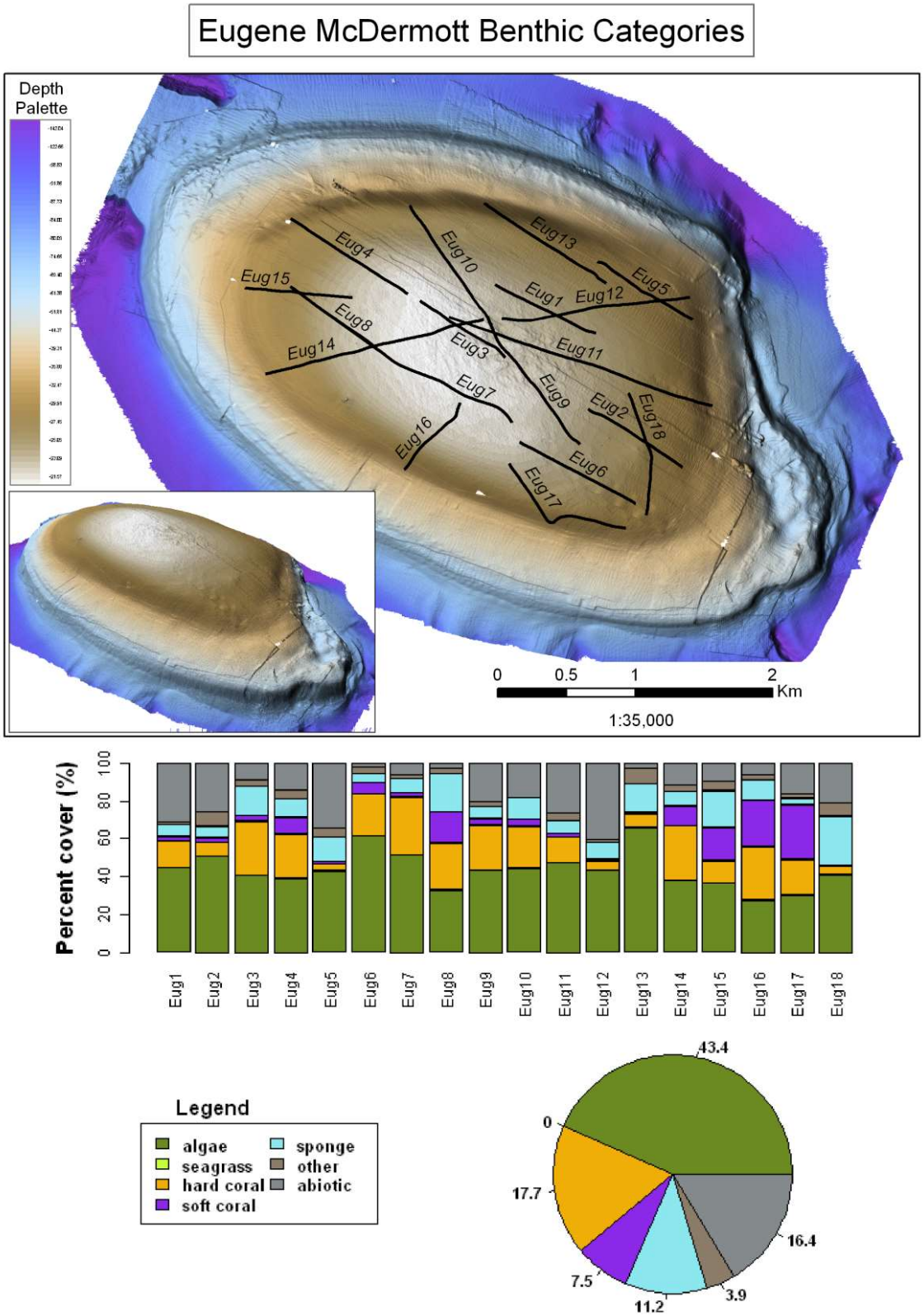


Figure 6-13: Eugene McDermott Shoal Morphology, Depth and Abundance of Major Benthic Groups derived from Multibeam Echo Sounder and Towed Video Surveys (from Heyward et al. 2012)

Eugene McDermott Shoal appears to have formed in a similar manner to other shoals and banks in the region, with the in-situ generation of biogenic sediment thought to account for the growth of the shoal.

Sampling results indicate sediments at Eugene McDermott Shoal have a higher portion of fine sediments than other shoals in the region (Heyward et al. 2017). This may be a consequence of the greater average depth of Eugene McDermott Shoal resulting in lower current velocities on the shoal plateau, with consequently reduced resuspension and transport of fine sediments.

Benthic habitats on the plateau of Eugene McDermott Shoal are characterised by mixed biota and hard corals interspersed with other habitat types (Figure 6-14), which is similar to other shoals in the region (Heyward et al. 2012). Habitats in < 30 m of water are characterised by consolidated reef (and associated turfing algae), hard coral, sand and algae (Heyward et al. 2017). The abundance of hard coral habitat at Eugene McDermott Shoal decreases with increasing water depth (Heyward et al. 2017). Modelled substrate types were closely correlated with habitat types (Figure 6-14).

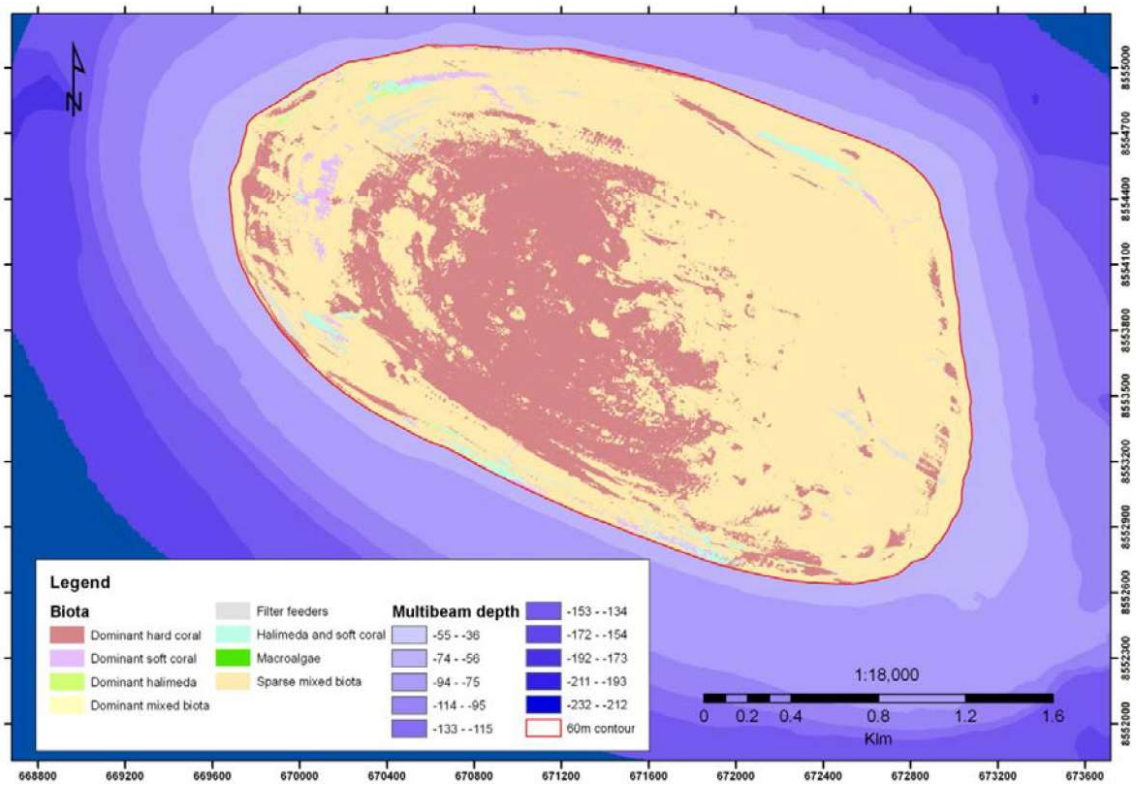


Figure 6-14: Composite Modelled Benthic Habitats of Eugene McDermott Shoal (from Heyward et al. 2012)

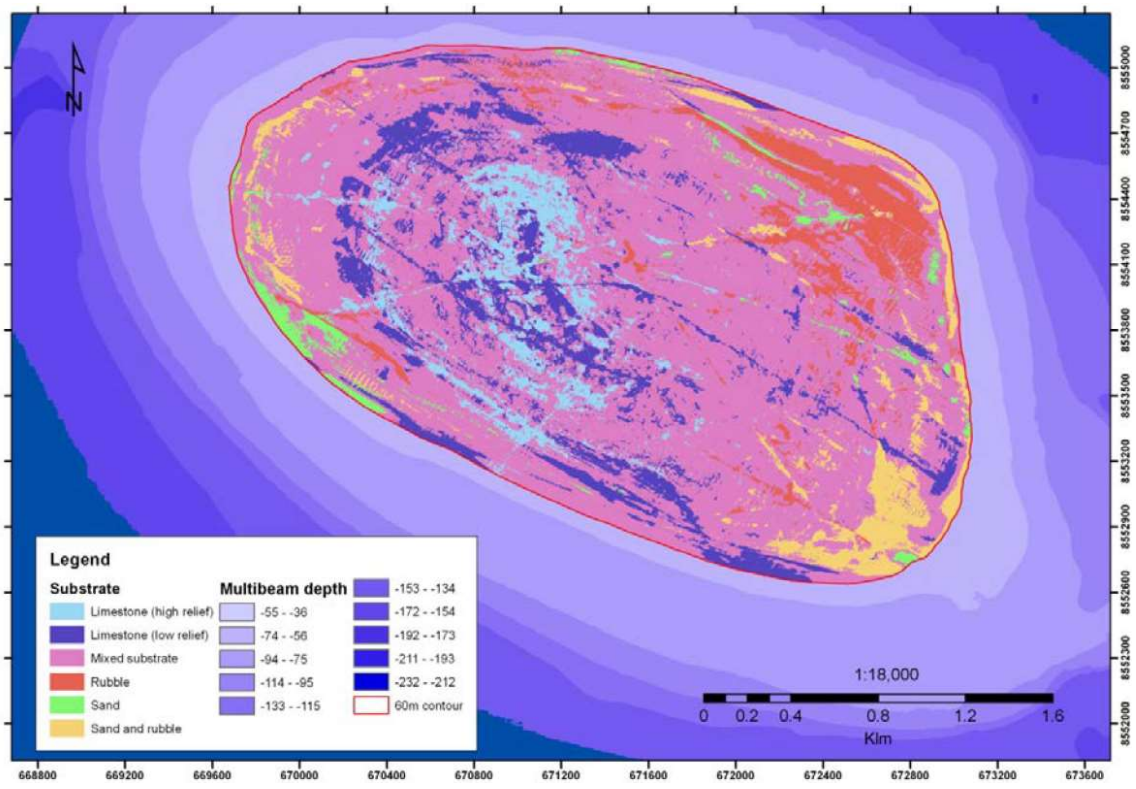


Figure 6-15: Composite Modelled Substrate Types of Eugene McDermott Shoal (from Heyward et al. 2012)

Like other shoals in the region, Eugene McDermott Shoal supports relatively diverse and abundant fish assemblages compared to the surrounding deeper continental shelf habitat. Higher fish assemblage diversity was identified by Heyward et al. (2012) at Eugene McDermott Shoal than the smaller nearby Goeree Shoal, which may be a consequence of the greater variation in benthic habitats. The coral habitat in the shallower part of the shoal hosted species such as grouper (Serranidae), damselfish (Pomacentridae) and wrasses (Labridae), which was similar to the assemblage in this habitat at Goeree Shoal (Heyward et al. 2012). Deeper parts of the shoal plateau with relatively high reef cover hosted angelfish (Pomacanthidae), groupers (Serranidae) and wrasses (Labridae) (Heyward et al. 2012). The relatively deep peripheral shoal hosted a less diverse assemblage hosting wrasses (Labridae), houndsharks (Triakidae) and dartfish (Ptereleotrinae) (Heyward et al. 2012).

Vulcan Shoal

Vulcan Shoal is the furthest named shoal from the Crux platform within the Crux in-field development area, lying approximately 22 km north-west of the Crux platform. As with other shoals within the Crux in-field development area, Shell has applied a 1 km buffer around this shoal within which no activities will take place. Vulcan Shoal rises steeply from the surrounding continental shelf, from around 180 m water depth to the plateau of the shoal at approximately 20-40 m water depth (Figure 6-16). The plateau of the shoal is relatively large compared to other shoals in the region. Shallower regions around the margin of the plateau host hard coral communities (Figure 6-17). As with Goeree Shoal, growth of hard corals may account for the geological origin of these relatively shallow parts of the plateau. The surface of Vulcan Shoal is relatively smooth at coarse scales (> 500 m), but rugose at finer scales (10 m to 100 m), creating complex habitat.

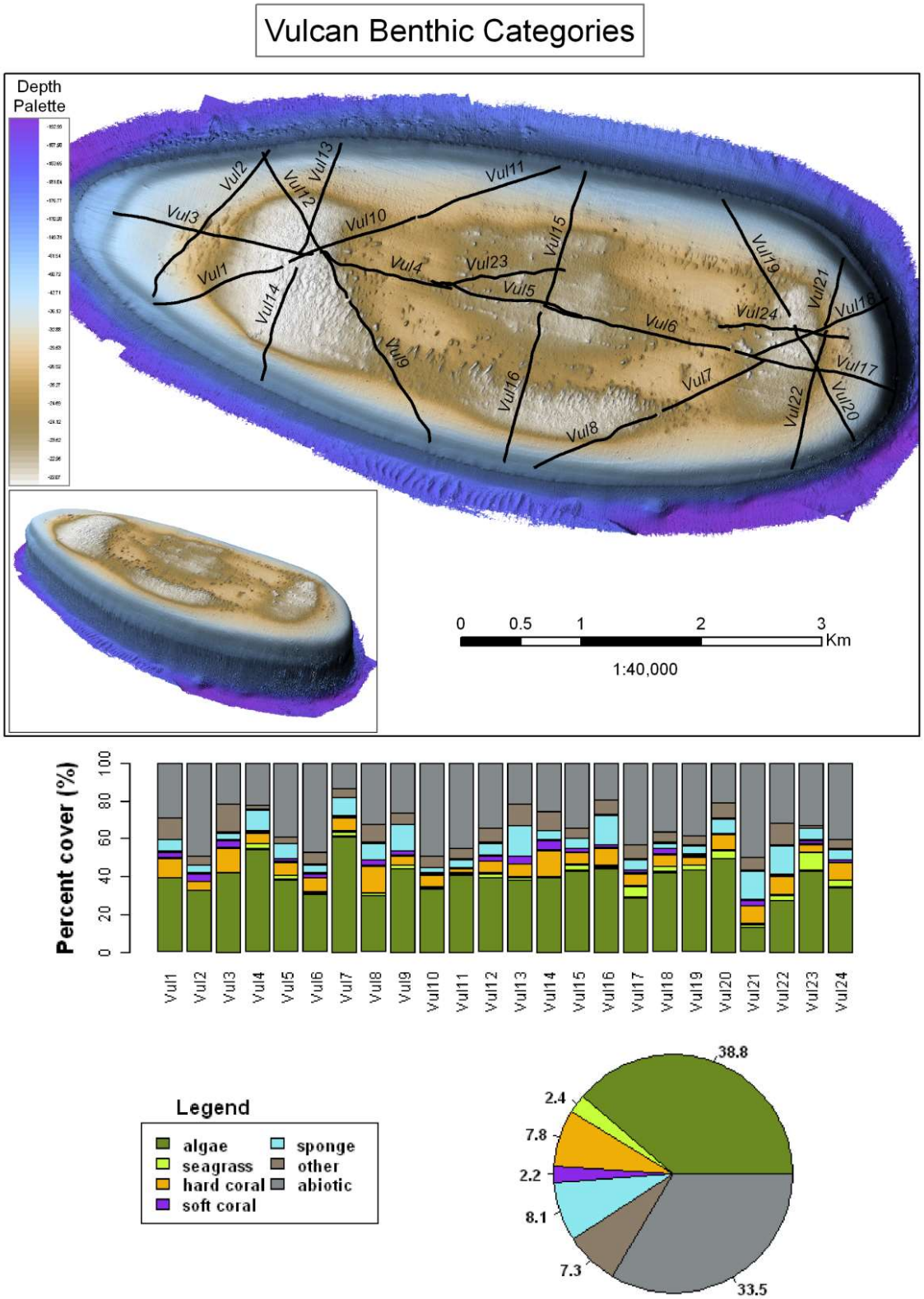


Figure 6-16: Vulcan Shoal Morphology, Depth and Abundance of Major Benthic Groups derived from Multibeam Echo Sounder and Towed Video Surveys (from Heyward et al. 2012)

The geological origin of Vulcan Shoal appears consistent with other shoals in the region, with in situ biogenic sediment production from *Halimeda* spp. and hard corals the likely sediment sources. Sediments from Vulcan Shoal are predominantly (> 80% by mass) sand-sized or smaller (i.e. < 2 mm). The grain size distribution is consistent with shoals of similar depth in the region (Heyward et al. 2017).

Benthic habitats on the plateau of Vulcan Shoal are characterised by mixed biota covering the central part of the shoal, with hard coral habitat concentrated around the margin of the shoal (**Figure 6-17**). Habitats in < 30 m were characterised by sand, algae and unconsolidated reef. Between 30 and 60 m the relative portion of sand increased, while photosynthetic taxa (algae and zooxanthellate corals) decreased. Of interest, seagrass meadows were observed at Vulcan Shoal in 2010 but had significantly declined by 2011 and had not recovered by 2013. Modelled substrate types were closely correlated with habitat types (**Figure 6-18**).

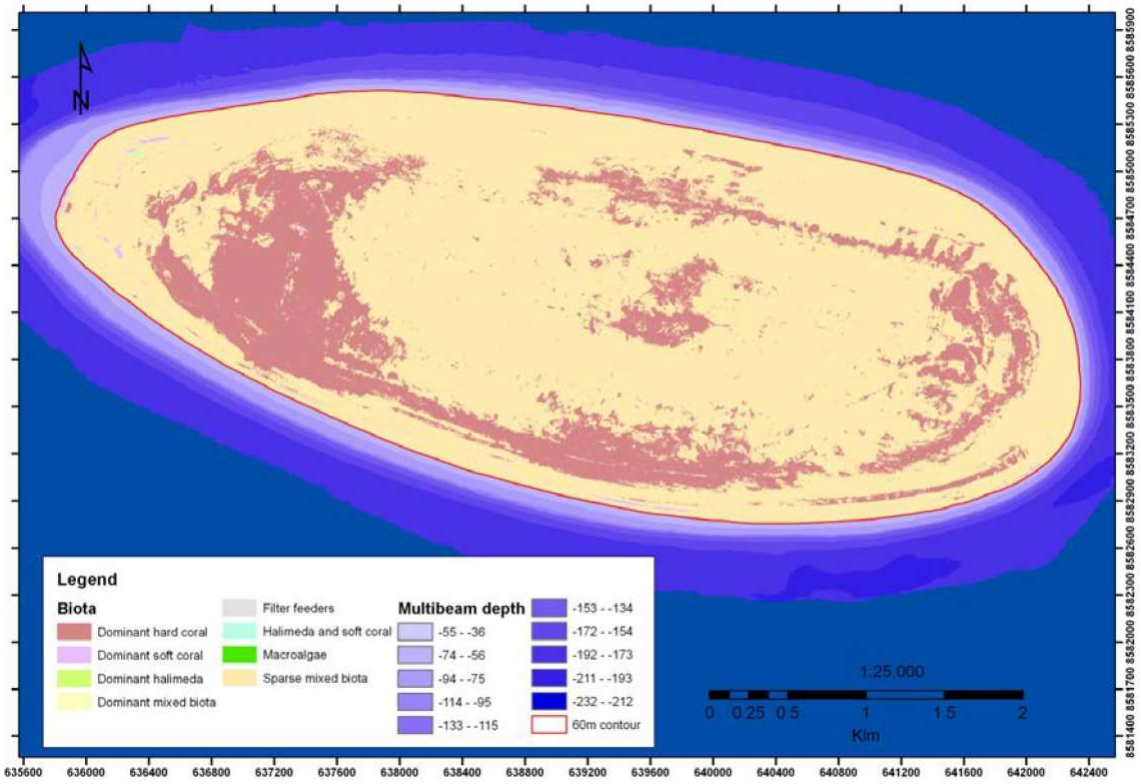


Figure 6-17: Composite Modelled Benthic Habitats of Vulcan Shoal (from Heyward et al. 2012)

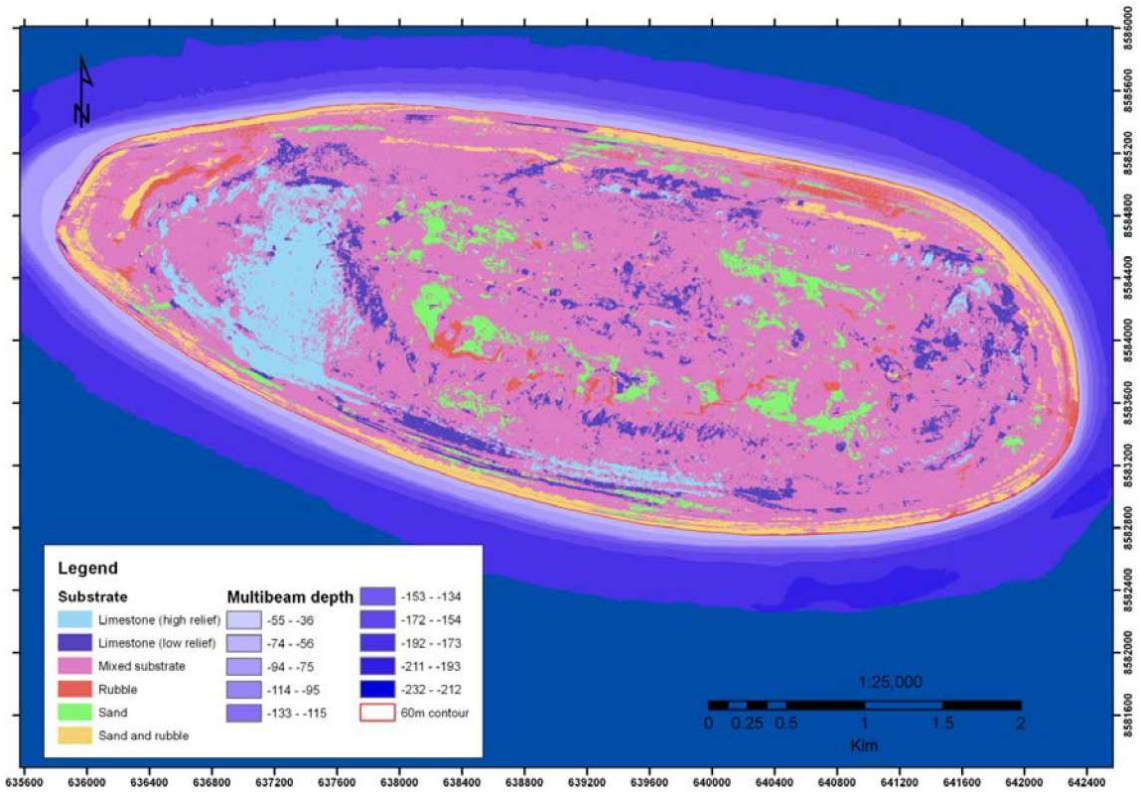


Figure 6-18: Composite Modelled Substrate Types of Vulcan Shoal (from Heyward et al. 2012)

While larger in size, the composition of benthic habitats at Vulcan Shoal was similar to other shoals within the boundary of the Crux in-field development area. The fish assemblage associated with the relatively shallow areas with high coral cover include angelfish (Chaetodontidae), butterfly fish (Pomacanthidae) and snapper (Lutjanidae) (Heyward et al. 2012). Shallower areas with less reef cover supported species that were less likely to be site-attached and included trevally (Carangidae), wrasses (Labridae) and scad (Carangidae) (Heyward et al. 2012). Deeper areas with low reef cover supported wrasses (Labridae), houndsharks (Triakidae) and dartfish (Ptereleotrinae) (Heyward et al. 2012).

6.4.5 Offshore Reefs and Islands

There are no known offshore reefs or islands within or in close proximity to the project area. However, there are a number of emergent oceanic reefs and islands offshore of northern Australia. The main offshore reefs and islands in the region include Ashmore Reef, Cartier Island, Hibernia Reef, Browse Island, Seringapatam Reef, Scott Reef and Adele Island (**Figure 6-9**). These reefs/islands occur within the area of influence and are discussed below. The Tiwi Islands, Christmas Island and Cocos (Keeling) Islands are also discussed as they occur within the area of influence; however, they are significantly more distant from the project area.

6.4.5.1 Ashmore Reef

Ashmore Reef lies approximately 155 km north-west of the Crux platform and is protected by the Ashmore Reef Marine Park (**Section 6.6.8**). Ashmore Reef is also a designated Ramsar wetland of international significance (**Section 6.6.7**).

Ashmore Reef is a large platform reef complex containing an atoll-like structure with two lagoons, large areas of drying flats that become exposed at low tide, shifting sand banks and three vegetated sandy cays: West Island (281,000 km^2), East Island (134,200 km^2),

and Middle Island (129,800 km^2) (ConocoPhillips 2018). The surrounding reef consists of a well-developed reef crest and a broad reef flat that can be up to 3 km across. Water depths in the lagoons vary from extremely shallow waters around the sand banks to up to 45 m deep. The three islands located within the lagoon are mostly flat, being composed of coarse sand with a few areas of exposed beach rock and limestone outcrops (ConocoPhillips 2018; Shell 2009).

6.4.5.2 Cartier Island

Cartier Island lies approximately 105 km north-west of the Crux platform and 45 km from Ashmore Reef. The island and surrounding reefs are protected by Cartier Island Marine Park (**Section 6.6.8**). Cartier Island is an un-vegetated sand cay surrounded by a wide platform, that rises steeply from the seabed, and fringing coral reef flats (ConocoPhillips 2018). The coarse sandy beaches of the island support large populations of nesting green turtles.

6.4.5.3 Hibernia Reef

Hibernia Reef is located approximately 160 km north-west of the Crux platform and is situated approximately 40 km north-east from Ashmore Reef and 60 km north-west of Cartier Island. The reef is less extensive than that at Ashmore Reef and Cartier Island and is roughly oval in shape, tapering to a point on the western side (ConocoPhillips 2018; Shell 2009). The reef complex contains a deep central lagoon and drying sand flats. There is no permanent land at Hibernia Reef, however, large areas of the reef are exposed at low tide.

6.4.5.4 Browse Island

Browse Island lies approximately 158 km south-west of the Crux platform. The island and surrounding waters within a distance of three nautical miles (nm) are WA State Territorial Waters. Browse Island is a sand and limestone cay situated on a limestone and coral reef, covering an area of 13 ha (0.13 km^2) (Shell 2009). The reef is a flat topped, oval shaped platform reef with a diameter of 2.2 km at its widest point (INPEX 2010). The reef complex rises from a depth of approximately 200 m. The intertidal habitats around the island include (INPEX 2010):

- sandy beaches or coarse coral sand, which is a known turtle nesting site for green turtles (*Chelonia mydas*)
- beach rock which supports invertebrate fauna
- a lagoon with sand and coral rubble substrates and live corals such as Acropora spp. and *Porites* spp.
- a reef platform, containing areas of sand and coral rubble, limestone supporting sparse algal turf and many barren shallow pools, which is exposed at low tide
- the reef crest, which supports a diverse range of molluscs and hard corals of the Faviidae family (such as *Goniastrea* spp.), and
- a wave swept seaward ramp which supports some algae and coral.

The shallow subtidal zone (< 20 m depth) of Browse Island ranges from 50 to 200 m wide and is comprised mainly of bare limestone, with the most diverse coral communities (including *Hydnophora rigida, Acropora* and to a lesser extent *Porites)* recorded in raised coral reefs in shallower areas around the island (INPEX 2010). The benthic habitats were noted as being characteristic of coral platform reefs throughout the Indo-West Pacific region and limited in their extent in the subtidal region.

6.4.5.5 Seringapatam Reef

Seringapatam Reef (approximately 270 km south-west of the Crux platform) is a remote atoll covering an area of approximately 55 km^2 and encloses a lagoon of relatively consistent depth of approximately 20 m (maximum depth of 30 m) (ConocoPhillips 2018). The lagoon is connected to the ocean by a narrow passage in the northeast part of the reef.

Seringapatam Reef is recognised as a Key Ecological Feature (KEF) (**Section 6.4.7**). The reef is a regionally important scleractinian coral reef as it has a high biodiversity. Results from the Western Australian Museum (WAM) survey in 2006 noted 159 species of scleractinian corals with a hard coral cover of approximately 16% (WAM 2009). The dominant benthic habitats of the reef have been observed to include turf algae, macroalgae, hard and soft corals, algae and filter feeders (e.g. sponges, gorgonians, hydroid, seapens) (ConocoPhillips 2018).

6.4.5.6 Scott Reef

Scott Reef (located approximately 290 km south-west of the Crux platform) is a large oceanic atoll platform which rises vertically from the seafloor in water depths between approximately 400 m and 700 m and comprises two lagoonal areas (North and South Scott Reef). North Scott Reef is approximately 17 km long and 16 km wide (Gilmour et al. 2013, Woodside 2014). South Scott Reef is approximately 20 km wide. Water depths within Scott Reef vary between 0 m and 80 m with areas of the reef flat being exposed at low tide. Sandy Islet, a small sandy cay, is the sole permanently emergent land and is approximately 700 m long and 60 m wide (Woodside 2012). Sandy Islet is a significant nesting site for green turtles, predominantly during the summer months (Gilmour et al. 2013), as well as being a foraging and breeding area for a number of seabird species (Woodside 2012).

Scott Reef is recognised as a KEF (**Section 6.4.7**). Corals communities at Scott Reef occur across shallow (< 30 m) and deep (> 30 m) habitats, with 306 species from 60 genera and 14 families having been identified (Gilmour et al. 2009). Coral communities varied from shallow to deep water with 295 species recorded from shallow water environments and 51 species from deep water. Eleven species were only found in deep water environments. None of the corals recorded were endemic to Scott Reef (Gilmour et al. 2009). Biodiversity at Scott Reef is similar to that of other offshore emergent reefs in the region (e.g. Seringapatam Reef, Ashmore Reef and Rowley Shoals), with the biological assemblages being a sub-set of Indo-Pacific reefs.

6.4.5.7 Adele Island

Adele Island is located off the central Kimberley coast and is approximately 314 km south-west of the in-field development area.

The fish-hook shaped island, measuring 2.9 km by 1.6 km with an area of 2.17 km^2, and its surrounding extensive sandbanks sit atop a shallow-water limestone platform (Ecosure 2009). The island is surrounded by extensive coral reefs and is an important site for breeding seabirds, with rookeries of the lesser frigate, brown booby, red-footed booby, lesser crested tern and masked booby (Ecosure 2009).

6.4.5.8 Tiwi Islands

The Tiwi Islands are comprised of two main islands (Bathurst and Melville Islands) and nine smaller uninhabited islands. The islands are located approximately 80 km north of Darwin and 624 km east of the Crux platform. The Tiwi Islands comprise a total area of approximately 8,320 km^2 with a coastline of 1,016 km, and are Aboriginal freehold land

owned by the Tiwi Aboriginal Land Trust (Natural Resources, Environment, the Arts and Sport (NRETAS) 2009a).

Due to the isolation of the Tiwi Islands from the Australian mainland, as well as climatic extremes (including high rainfall events), many species found on the islands are not present in the NT (NRETAS 2009a). The diverse array of coastal habitats on the Tiwi Islands includes mangroves, tidal mudflats, sandy beaches, seagrass meadows and fringing reef habitats, as well as eucalypt, paperbark and monsoon vine forests (Tiwi Islands Regional Council 2018). The islands support nesting habitat for marine turtles, internationally significant seabird rookeries, and some major aggregations of migratory shorebirds (NRETAS 2009a). The north coast of the islands is recognised as key areas for the conservation of dugongs and seagrass habitats (Parks and Wildlife Service Northern Territory (PWSNT) 2003).

6.4.5.9 Christmas Island

Christmas Island is located in the Indian Ocean and is approximately 2,061 km west-north-west of the Crux platform. A significant portion (approximately 66%) of the island comprises the Christmas Island National Park, which is managed by Parks Australia. The National Park protects the approximately 80,000 seabirds which nest on the island each year, as well as the abundant and species diverse land crabs, plants and tropical rainforest habitat, and two Ramsar wetlands (see **Section 6.6.7**) (Director of National Parks 2014). More than 100 migrant and vagrant seabird species have been recorded on Christmas Island, including nine resident breeding seabird species and 23 vagrant/nonbreeding seabirds (Director of National Parks 2014). The island supports a large number of endemic species (254 taxa) due to its isolated oceanic location. The marine environment supports fringing coral reefs, terrace and cave systems, and more than 600 species of fish (Director of National Parks 2014). The waters also support threatened green and hawksbill turtles.

6.4.5.10 Cocos (Keeling) Islands

The Cocos Islands, located approximately 2,990 km west of the Crux platform in the Indian Ocean, are an atoll consisting of 27 coral islands. North Keeling Island, the northern atoll island, and surrounding waters form the Pulu Keeling National Park, which is administered by Parks Australia. The North Keeling Island is characterised by a broken, irregular fringing coral reef, with the exception of the north-west corner. The marine component of the National Park comprises three major marine habitat types; the outer reef slope (subtidal), reef flats including sandy and rocky shores (predominantly intertidal) and lagoon (predominantly subtidal). The waters surrounding the island support a diverse array of marine fauna, including dolphins, turtles, fish (approximately 550 species), crustaceans, molluscs and corals (Director of National Parks 2015).

North Keeling Island supports an internationally significant seabird rookery as it provides a focal point for birds within a huge expanse of the central-eastern Indian Ocean (Director of National Parks 2015). Thirteen species of birds in the park are listed under international migratory bird agreements between Australia and Japan, China and the Republic of Korea (JAMBA, CAMBA and ROKAMBA). The island and surrounding atolls also provide habitat for land crabs and flora species (Director of National Parks 2015).

6.4.6 WA and NT Mainland Coastline

The WA and NT mainland coastlines are only of relevance in the context of the area of influence as areas of the coastline may be contacted in an unlikely emergency event resulting in a large-scale release of hydrocarbons (see **Section 8.4.8**).

The Crux platform is located 190 km from the nearshore and coastal environments of the Kimberley on the WA coastline. The Kimberley coastline supports a diverse array of marine habitats and communities including coral reefs, sandy beaches, rocky shores, seagrass meadows, mangroves, sponge gardens, wetlands, estuaries, creeks and rivers (Department of Environment and Conservation (DEC) 2009a). These environments in turn support a number of fauna, including EPBC listed seabirds and migratory shorebirds, turtles, sea snakes, dugongs, cetaceans, fish, sharks and rays (DEC 2009a). The values and sensitivities of the Kimberley coastline are considered representative of those for the extended northern WA coastal area.

The NT coastline, located 539 km from the Crux platform, supports a variety of marine habitats including coral reefs, seagrass meadows, mangroves and sand or mudflats (NT Government 2018a). These coastal habitats in turn provide important areas for breeding, nursery and foraging for numerous marine species such as fish, marine turtles, cetaceans, dugongs and sharks (NT Government 2018a).

Threatened marine species that occur within the area of influence where it is predicted to contact the WA/NT mainland coastline are described in **Section 6.5.**

The WA/NT nearshore and coastal areas provide Indigenous and European heritage value, as well as cultural, social and economic values such as local tourism and recreation. The nearshore and coastal habitats also support a number of culturally and commercially significant marine fauna species such as marine turtles, dugongs, fish and prawns (DEC 2009a).

6.4.7 Key Ecological Features

KEF are elements of the Commonwealth marine environment that are considered to be of regional importance for either the marine region's biodiversity or its ecosystem function and integrity. KEFs are not listed as MNES and have no legal status in their own right.

A search of the DoEE National Conservation Values Atlas identified a number of KEFs that occur within or adjacent to the project area and area of influence (**Figure 6-19**). A summary of the KEFs is provided in **Table 6-4** (DSEWPaC 2012a; 2012b). Only one KEF is intersected by the Crux project, with the export pipeline intersecting a small portion of the continental slope demersal fish communities.

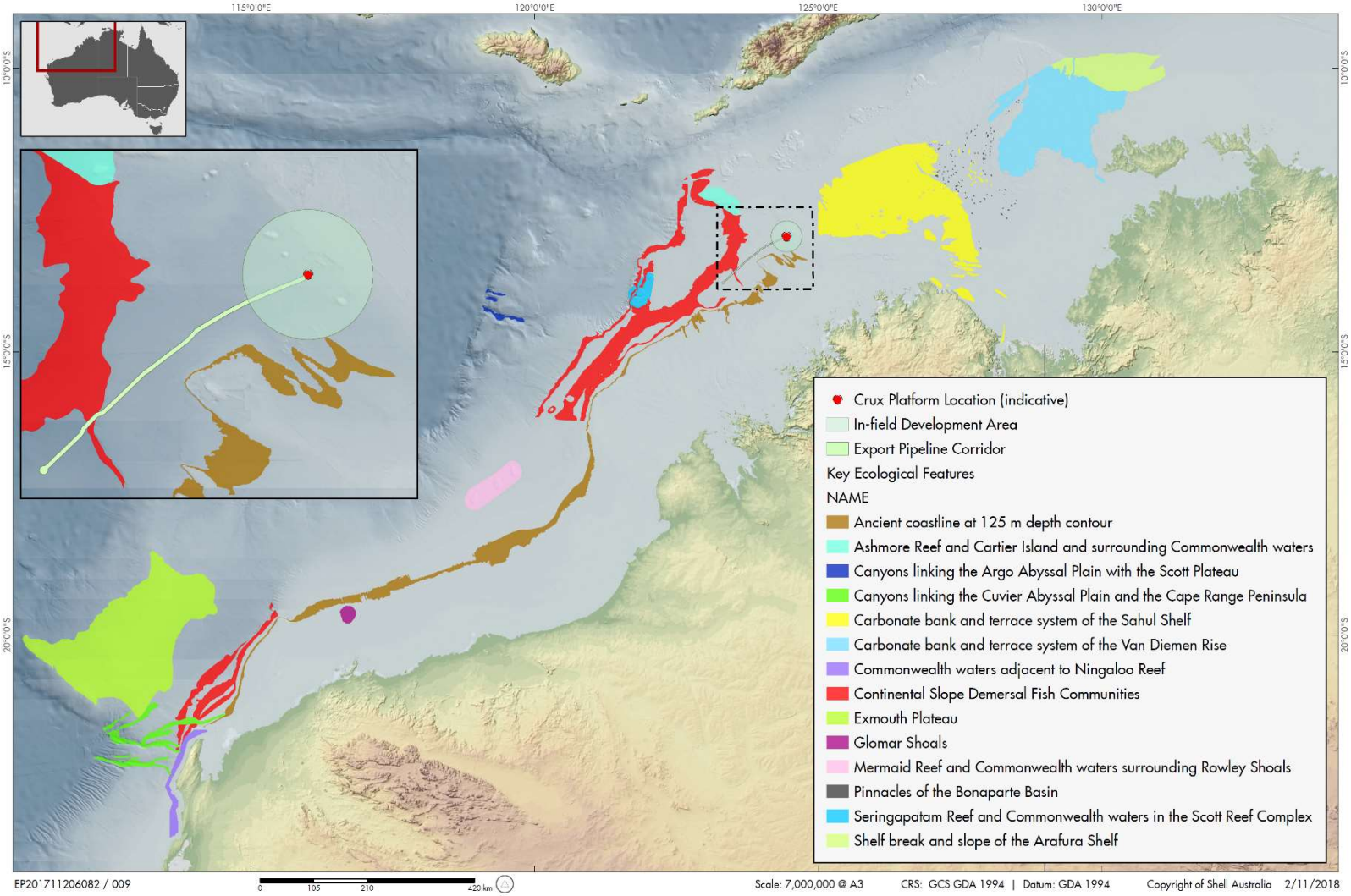


Figure 6-19: Key Ecological Features

Table 6-4: KEFs Relevant to the Project

KEF	Relevance to Crux Project	Summary of Key Values
Ancient coastline at 125 m depth contour	Located 30 km south of the Crux platform and is therefore directly adjacent to the in-field development area	*Unique seafloor feature with ecological properties of regional significance* The areas of hard substrate along this ancient coastline, which follows the 125 m depth contour, are thought to provide biologically important habitats in areas otherwise dominated by soft sediments; thereby providing for higher species diversity and richness relative to the wider region. The topographic complexity of these escarpments may also facilitate vertical mixing of the water column providing a relatively nutrient-rich environment for species present on the escarpment. The KEF encompasses an area of approximately 16,190 km^2.
Ashmore Reef and Cartier Islands and surrounding Commonwealth waters	Located 100 km north-west of the Crux platform and occurs within the area of influence	*High productivity and aggregations of marine life* Ashmore Reef is the largest of only three emergent oceanic reefs present within the north-eastern Indian Ocean and is the only oceanic reef in the region with vegetated islands. The emergent reefs are known to provide areas of enhanced primary productivity in otherwise oligotrophic environments. Ashmore Reef and Cartier Islands and the surrounding Commonwealth waters are regionally important for feeding and breeding aggregations of seabirds and shorebirds, and other marine life. Ashmore Reef regularly supports more than 40,000 waterbirds (those ecologically dependant on wetlands) and is estimated to support as many as 100,000 seabirds in a twelve month period (Hale 2013). The marine habitats supported by the reefs are nationally and internationally significant, providing habitat for diverse and abundant marine reptile (including feeding, nesting and internesting areas for green, hawksbill and loggerhead turtles) and marine mammal populations, including dugongs. Species at Ashmore and Cartier include more than 225 reef-building corals, 433 molluscs, 286 crustaceans, 192 echinoderms, and 709 species of fish. Thirteen species of sea snakes occur in high numbers at Ashmore and Cartier reefs but are in decline. Additionally, Ashmore Reef supports the highest number of coral species of any reef off the WA coast and plays a primary role in the maintenance of the biodiversity of reef systems in the region.
Canyons linking the Argo Abyssal Plain with Scott Plateau	Located 525 km south-west of the Crux platform and occurs within the area of influence	*High productivity and aggregations of marine life* Canyons linking the Argo Abyssal Plain with Scott Plateau covers an area of approximately 836 km^2. The Bowers and Oats canyons are major canyons on the slope between the Argo Abyssal Plain and Scott Plateau and deeply cut into the Scott Plateau at depths of approximately 2,000 m – 3,000 m. The ocean area above the canyons is thought to be an area of moderately enhanced productivity, attracting aggregations of fish, sharks, toothed whales and dolphins.
Carbonate bank and terrace system of the Sahul Shelf	Located 60 km north-east of the Crux platform and occurs within the area of influence	*Unique seafloor feature with ecological properties of regional significance* While little is known about this KEF, the carbonate banks and terrace system of the Sahul Shelf is considered regionally important because of their role in enhancing biodiversity and local productivity relative to their surrounds, largely due to the presence of elevated hard substrates. The seabed features are thought to create enhanced productivity and biodiversity as a result of upwellings of cold nutrient-rich water at the heads of the channels.

KEF	Relevance to Crux Project	Summary of Key Values
		The KEF covers an area of approximately 41,158 km^2. The banks rise to depths of 150 m – 300 m and are separated from each other by narrow meandering channels which are up to 150 m deep. The hard substrates of the banks are thought to support a high diversity of organisms including reef-fish, sponges, soft and hard corals, gorgonians, bryozoans, ascidians and other sessile filter feeders.
Continental slope demersal fish communities	Located 73 km south-west of the Crux platform, is intersected by a small portion of the Crux export pipeline corridor (0.04%) and occurs within the area of influence	*Communities with high species biodiversity and endemism* There is a high diversity of demersal fish assemblages on the Australian continental slope from the North West Cape to the edge of the NMR. Specifically, the continental slope between North West Cape and the Montebello Trough has more than 500 fish species, 76 of which are endemic, which makes it the most diverse slope bioregion in the whole of Australia (DEHWA 2008). The Timor Province and Northwest Transition bioregions, in which the Crux project is located, are the second-richest areas for demersal fish across the entire continental slope. The KEF covers a vast area of approximately 33,182 km^2.
Glomar Shoals	Located 1,090 km south-west of the Crux platform and occurs within the area of influence	*High productivity and aggregations of marine life* The Glomar Shoals (approximately 786 km^2) are a submerged littoral feature located approximately 150 km north of Dampier on the Rowley shelf at depths of 33 m – 77 m. While biological data is limited, the fish of Glomar Shoals are believed to be a subset of reef-dependent species. The shoals are known to be an important area for a number of commercial and recreational fish species such as rankin cod, brown-striped snapper, red emperor, crimson snapper, bream and yellow-spotted triggerfish.
Mermaid Reef and Commonwealth waters surrounding Rowley Shoals	Located 674 km south-west of the Crux platform and occurs within the area of influence	*High productivity and aggregations of marine life* The Rowley Shoals consist of three atoll reefs; Clerke, Imperieuse and Mermaid Reef which support 214 coral species and around 530 species of fish. The steep changes in slope around the reef also attract a range of migratory pelagic species such as dolphins, tuna, billfish and sharks. The coral communities of Mermaid Reef are also an important feature. The enhanced productivity at the shoals is thought to be facilitated by the breaking of internal waves in the waters surrounding the reefs, causing mixing and re-suspension of nutrients from water depths of 500–700 m into the photic zone.
Pinnacles of the Bonaparte Basin	Located 310 km from the Crux platform and occurs within the area of influence	*Unique seafloor feature with ecological properties of regional significance* The limestone pinnacles in the western Bonaparte Depression are expected to support a diverse community in an otherwise oligotrophic system. More than 110 pinnacles occur in the Bonaparte Depression, covering a total area of more than 520 km^2. The pinnacles are thought to be the eroded remnants of underlying strata and can be up to 50 m high and 50 km–100 km long.

KEF	Relevance to Crux Project	Summary of Key Values
Seringapatam Reef and Commonwealth waters in the Scott Reef complex	Located 265 km from the Crux platform and occurs within the area of influence	*High productivity and aggregations of marine life* The coral communities at Seringapatam and Scott Reefs play a key role in maintaining species richness and aggregations of marine life. The reefs and the waters surrounding them attract aggregations of marine life including humpback whales on their northerly migration, Bryde's whales, pygmy blue whales, Antarctic minke whales, dwarf minke whales, minke whales, dwarf sperm whales, spinner dolphins and whale sharks. Green and hawksbill turtles nest during the summer months on Sandy Islet on South Scott Reef. These species also internest and forage in the surrounding waters. Scott Reef is a particularly biologically diverse system and includes more than 300 species of reef-building corals, approximately 400 mollusc species, 118 crustacean species, 117 echinoderm species, around 720 fish species and several species of sea snakes.
Exmouth Plateau	Located 1,276 km from the Crux platform and occurs within the area of influence	*Unique seafloor feature with ecological properties of regional significance* Due to its large size (approximately 49,310 km^2), the plateau is thought to modify deepwater flow and be associated with the generation of internal tides in the Exmouth region. These oceanic processes may contribute to the upwelling of nutrients, which result in areas of increased productivity. The plateau ranges in depth between 800 m to 4,000 m and features valleys and channels that support a range of benthic environments. These features are also thought to provide conduits for the transport of sediment and other materials from the plateau surface to deeper areas. While the Exmouth Plateau has low habitat heterogeneity, it is likely to be an important area of biodiversity as it provides an extended area for communities adapted to depths of around 1,000 m.
Shelf break and slope of the Arafura Shelf	Located 626 km from the Crux platform and occurs within the area of influence	*Unique seafloor feature with ecological properties of regional significance* The shelf break and slope of the Arafura Shelf is described as a biogeographic crossroad of biota from the Timor-Indonesian-Malay region. Whilst there is limited information about the ecosystem processes of the area, it is thought that the ITF current and surface wind-driven circulation from the north-west monsoon are a strong influence. These oceanic processes are likely to drive pelagic dispersal of nutrients, species and biological productivity and, in turn, the long term patterns in transport and dispersal of larvae juvenile and migrating adult organisms through the area. Demersal fish communities are diverse and the area is likely to support whale sharks, sharks and marine turtles.
Carbonate bank and terrace system of the Van Diemen Rise	Located 430 km from the Crux platform and occurs within the area of influence	*Unique seafloor feature with ecological properties of regional significance* The bank and terrace system of the Van Diemen Rise covers approximately 31,278 km^2 and forms part of the larger system associated with the Sahul Banks to the north and Londonderry Rise to the east. The complex topographic features of the area consist largely of raised geomorphic features (e.g. terraces and banks) with relatively high proportions of hard substrate, supporting sponge and octocoral gardens. These sponge and coral communities in turn provide habitat for epifauna. Infauna, including polychaetes and ascidians, are also scattered throughout the KEF. Variability in water depth and substrate composition is thought to contribute to the richness in benthic epifauna and the

KEF	Relevance to Crux Project	Summary of Key Values
		unique ecosystems found in the area. The carbonate banks and shoals found within the Van Diemen Rise make up 80% of the banks and shoals, 79% of the channels and valleys, and 63% of the terrace found across the NMR. The carbonate banks and shoals rise from depths of 100 m–200 m to within 10 m–40 m of the sea surface (Anderson et al. 2011).
Canyons linking the Cuvier Abyssal Plain and the Cape Range Peninsula	Located 1,404 km from the Crux platform and occurs within the area of influence	*Unique seafloor features with ecological properties of regional significance* The nutrient-rich and high productivity waters of the KEF are associated with aggregations of whale sharks, manta rays and sharks, humpback whales, sea snakes, sharks, large predatory fish and seabirds. The canyons are thought to connect to the Commonwealth waters adjacent to Ningaloo Reef, as well as the Exmouth Plateau. The KEF also supports unique seafloor features of a regional significance with regards to both benthic and pelagic ecological habitats.
Commonwealth waters adjacent to Ningaloo Reef	Located 1,451 km from the Crux platform and occurs within the area of influence	*High productivity and aggregations of marine life* Ningaloo Reef is of global significance as it is the only coral reef in the world that fringes the west coast of a continent and is a seasonal aggregation site for the whale shark. The high degree of interconnectivity with regional canyons and plateau contributes to high levels of productivity and species richness of the Ningaloo Reef. The reef supports aggregations and migration pathways of whale sharks, manta rays, humpback whales, sea snakes, sharks, large predatory fish and seabirds. The deepwater biodiversity includes unique assemblages of sponge and filter-feeder communities (compared with the Dampier Archipelago and Abrolhos Islands) which are indicative of areas of potentially high and unique sponge biodiversity.

6.4.7.1 Anthropogenic Pressures

The DoEE Commonwealth Marine Report Cards for the North and North-west Marine Regions (DSEWPaC 2012a, 2012b) provide a high-level analysis of the anthropogenic pressures on the KEFs. The analysis defines five categories in which each pressure impacts on the designated KEF including 'of concern', 'of potential concern', 'of less concern', 'not of concern' and 'data deficient or not assessed'. For the purposes of this OPP only pressures applicable to the project activities outlined in **Section 5** have been considered. A summary of the pressure analysis is detailed in Table 6-5, with further description provided below for the pressures 'of potential concern' and where there is a credible risk of interaction with project activities.

Table 6-5: KEFs Anthropogenic Pressure Analysis

Pressure	Physical Habitat Modification	Invasive Species	Noise Pollution		Light Pollution[1]	Marine Debris	Oil Pollution	
	Offshore Construction	Vessels	Vessels	Offshore Construction	Vessels and Oil and Gas Infrastructure	Vessels	Oil Rigs	Shipping
Ancient coastline at 125 m depth contour								
Ashmore Reef and Cartier Islands and surrounding Commonwealth waters								
Canyons linking the Argo Abyssal Plain with Scott Plateau								
Carbonate bank and terrace system of the Sahul Shelf								
Continental slope demersal fish communities								
Glomar Shoals								
Mermaid Reef and Commonwealth waters surrounding Rowley Shoals								
Pinnacles of the Bonaparte Basin								
Seringapatam Reef and Commonwealth waters in the Scott Reef complex								
Exmouth Plateau								
Shelf break and slope of the Arafura Shelf								
Carbonate bank and terrace system of the Van Diemen Rise								

Canyons linking the Cuvier Abyssal Plain and the Cape Range Peninsula								
Commonwealth waters adjacent to Ningaloo Reef								

Key	
	Of concern
	Of potential concern
	Of less concern
	Not of concern
	Data deficient or not assessed

[1] The pressure analysis for light pollution was sourced from marine bioregional plans (DSEWPaC 2012a, 2012b) as it was not detailed in the Commonwealth Marine Report Cards.

6.4.7.2 Marine Debris

The KEFs of Ashmore Reef and Cartier islands and surrounding Commonwealth waters and Seringapatam Reef and Commonwealth waters in the Scott Reef complex are of potential concern from marine debris. While there is limited region-specific information available on marine debris, key contributing factors for the introduction and spread of debris in the region are present. These include high levels of commercial shipping, increasing use of recreational vessels, active fisheries (recreational and commercial), and significant coastal urban and industrial development (DSEWPaC 2012a). Threats to the marine fauna aggregations associated with the KEFs include the ingestion or entanglement of marine biota which aggregate within these areas (DSEWPaC 2012a).

Marine debris and dropped objects resulting from project related activities are unlikely to materially affect these KEFs given they are located > 100 km from the Crux platform.

6.4.7.3 Oil Pollution

Oil pollution resulting from oil rigs is of potential concern to Ashmore Reef and Cartier Islands and surrounding Commonwealth waters, Mermaid Reef and Commonwealth waters surrounding Rowley Shoals, Seringapatam Reef and Commonwealth waters in the Scott Reef complex, and Commonwealth waters adjacent to Ningaloo Reef. Petroleum exploration, development and production in the North and North-west marine region is increasing and shipping is also likely to continue to expand in the region in relation to increasing resource development (DSEWPaC 2012a).

A detailed assessment of the potential impact to these KEFs from oil pollution is provided in **Section 8.4.8**.

6.5 Threatened Species and Ecological Communities

6.5.1 EPBC Listed Threatened and Migratory Species

An online EPBC Protected Matters Database Search was conducted for the in-field development area, export pipeline corridor and area of influence (**Table 6-6**; DoEE 2018a). A summary of the results is presented below:

- in-field development area – the search identified 20 listed threatened fauna species and 33 listed migratory species (17 of which are also listed as threatened) that may occur or have habitat in the area (DoEE 2018b),
- export pipeline corridor – the search identified 20 listed threatened fauna species and 33 listed migratory species (17 of which are also listed as threatened) that may occur or have habitat in the area (DoEE 2018c). All listed threatened and migratory species in the in-field development area were also identified as occurring in the export pipeline corridor, and
- Area of influence – the search identified 41 listed threatened fauna species and 89 listed migratory species (27 of which are also listed as threatened) that may occur or have habitat in the area (DoEE 2018d).

Forty-three species were excluded from **Table 6-6** as they are not considered relevant to the project, given they are commonly associated with terrestrial habitats that are generally not present on shorelines (e.g. wetlands, forests).

The EPBC Protected Matters results also lists a number of marine and other cetacean species, which are not listed as MNES under the EPBC Act. Refer to **Appendix J** for further details. With regards to marine mammals, a sub-set of these species, and an additional cetacean species (pantropical spotted dolphin; *Stenella attenuata*), have been observed in the NWMR region through surveys and opportunistic observations (pers. comm. R. Clarke, Monash University, 2018). An additional four marine bird species are also known to breed at Ashmore Reef; the eastern great egret (*Ardea modesta*), little egret (*Egretta garzetta*), eastern reef egret (*Egretta sacra*) and nankeen night-heron (*Nycticorax caledonicus*) (Clarke et al. 2011).

A further seven listed migratory species have been noted as potentially transiting the Barossa project area (approximately 713 km north-east of the Crux platform) on an annual basis as part of their migration, and therefore may also transit the project area; wedge-tailed shearwater (*Ardenna pacifica*), Bulwer's petrel (*Bulweria bulwerii*), Matsudaira's storm-petrel (*Hydrobates matsudairae*), Swinhoe's storm-petrel (*Hydrobates monorhis*), Wilson's storm-petrel (*Oceanites oceanicus*), red-tailed tropicbird (*Phaethon rubricauda*), white-winged black tern (*Chlidonias leucopterus*), bridled tern (*Onychoprion anaethetus*) and common tern (*Sterna hirundo*) (ConocoPhillips 2018).

Table 6-6: EPBC Listed Threatened and Migratory Species of Potentially Occurring in the Project Area or Area of Influence

Species	Threatened Status	Listed as Migratory	Search Area		
			In-field Development Area	Export Pipeline Corridor	Area of Influence
Marine Mammals					
Sei whale (*Balaenoptera borealis*)	Vulnerable	X	X	X	X
Blue whale (*Balaenoptera musculus*)	Endangered	X	X	X	X
Fin whale (*Balaenoptera physalus*)	Vulnerable	X	X	X	X
Southern right whale (*Eubalaena australis*)	Endangered	X			X
Humpback whale (*Megaptera novaeangliae*)	Vulnerable	X	X	X	X
Antarctic minke whale (*Balaenoptera bonaerensis*)		X			X
Bryde's whale (*Balaenoptera edeni*)		X	X	X	X
Killer whale (*Orcinus orca*)		X	X	X	X
Sperm whale (*Physeter macrocephalus*)		X	X	X	X
Spotted bottlenose dolphin (*Tursiops aduncus*)		X	X	X	X
Dugong (*Dugong dugon*)		X			X
Australian snubfin dolphin (*Orcaella heinsohni*) (formally known as the Irrawaddy dolphin)		X			X
Indo-pacfic humpback dolphin (*Sousa chinensis*)		X			X
Marine Reptiles					
Loggerhead turtle (*Caretta caretta*)	Endangered	X	X	X	X
Green turtle (*Chelonia mydas*)	Vulnerable	X	X	X	X
Leatherback turtle (*Dermochelys coriacea*)	Endangered	X	X	X	X
Hawksbill turtle (*Eretmochelys imbricata*)	Vulnerable	X	X	X	X
Olive ridley turtle (*Lepidochelys olivacea*)	Endangered	X	X	X	X

Species	Threatened Status	Listed as Migratory	Search Area		
			In-field Development Area	Export Pipeline Corridor	Area of Influence
Flatback turtle (*Natator depressus*)	Vulnerable	X	X	X	X
Short-nosed sea snake (*Aipysurus apraefrontalis*)	Critically Endangered				X
Leaf-scaled sea snake (*Aipysurus foliosquama*)	Critically Endangered				X
Birds					
Australian lesser noddy (*Anous tenuirostris melanops*)	Vulnerable		X	X	X
Red knot (*Calidris canutus*)	Endangered	X	X	X	X
Curlew sandpiper (*Caladris ferruginea*)	Critically Endangered	X	X	X	X
Great knot (*Calidris tenuirostris*)	Critically Endangered	X			X
Greater sand plover (*Charadrius leschenaultii*)	Vulnerable	X			X
Lesser sand plover (*Charadrius mongolus*)	Endangered	X			X
Christmas Island frigatebird (*Fregata andrewsi*)	Endangered	X			X
Western Alaskan Bar-tailed Godwit (*Limosa lapponica baueri*)	Vulnerable				X
Northern siberian bar-tailed godwit (*Limosa lapponica menzbieri*)	Critically Endangered				X
Southern giant-petrel (*Macronectes giganteus*)	Endangered	X			X
Eastern curlew (*Numenius madagascariensis*)	Critically Endangered	X	X	X	X
Abbott's booby (*Papasula abbotti*)	Endangered		X	X	X
Christmas Island white-tailed tropicbird (*Phaethon lepturus fulvus*)	Endangered				X
Round Island petrel (*Pterodroma arminjoniana*)	Critically Endangered				X
Soft-plumaged petrel (*Pterodroma mollis*)	Vulnerable				X
Australian fairy tern (*Sternula nereis nereis*)	Vulnerable				X

Species	Threatened Status	Listed as Migratory	Search Area		
			In-field Development Area	Export Pipeline Corridor	Area of Influence
Tasmanian shy albatross (*Thalassarche cauta cauta*)	Vulnerable	X			X
White capped albatross (*Thalassarche cauta steadi*)	Vulnerable	X			X
Campbell albatross (*Thalassarche impavida*)	Vulnerable	X			X
Black-browed albatross (*Thalassarche melanophris*)	Vulnerable	X			X
Common noddy (*Anous stolidus*)		X	X	X	X
Fork-tailed swift (*Apus pacificus*)		X			X
Flesh-footed shearwater (*Ardenna carneipes*)		X			X
Wedge-tailed shearwater (*Ardenna pacifica*)		X			X
Streaked shearwater (*Calonectris leucomelas*)		X			X
Lesser frigatebird (*Fregata ariel*)		X	X	X	X
Greater frigatebrd (*Fregata minor*)		X	X	X	X
Caspian tern (*Hydroprogne caspia*)		X			X
Bridled tern (*Onychoprion anaethetus*)		X			X
White-tailed tropicbird (*Phaethon lepturus*)		X			X
Red-tailed tropicbird (*Phaethon rubricauda*)		X			X
Roseate tern (*Sterna dougallii*)		X			X
Little tern (*Sterna albifrons*)		X			X
Masked booby (*Sula dactylatra*)		X			X
Brown booby (*Sula leucogaster*)		X			X
Red-footed booby (*Sula sula*)		X			X
Oriental reed-warbler (*Acrocephalus orientalis*)		X			X

Species	Threatened Status	Listed as Migratory	Search Area		
			In-field Development Area	Export Pipeline Corridor	Area of Influence
Common sandpiper (*Actitis hypoleucos*)		X	X	X	X
Ruddy turnstone (*Arenaria interpres*)		X			X
Sharp-tailed sandpiper (*Calidris acuminata*)		X	X	X	
Sanderling (*Calidris alba*)		X			X
Pectoral sandpiper (*Calidris melanotos*)		X	X	X	
Red-necked stint (*Calidris ruficollis*)		X			X
Long-toed stint (*Calidris subminuta*)		X			X
Little ringed plover (*Charadrius dubius*)		X			X
Oriental plover (*Charadrius veredus*)		X			X
Swinhoe's snipe (*Gallinago megala*)		X			X
Pin-tailed snipe (*Gallinago stenura*)		X			X
Oriental Pratincole (*Glareola maldivarum*)		X			X
Broad-billed sandpiper (*Limocola falcinellus*)		X			X
Asian dowitcher (*Limnodromus semipalmatus*)		X			X
Bar-tailed godwit (*Limosa lapponica*)		X			X
Black-tailed godwit (*Limosa limosa*)		X			X
Little curlew (*Numenius minutus*)		X			X
Whimbrel (*Numenius phaeopus*)		X			x
Osprey (*Pandion haliaetus*)		X			X
Pacific Golden Plover (*Pluvialis fulva*)		X			X
Grey plover (*Pluvialis squatarola*)		X			X
Crested tern (*Thalasseus bergii*)		X			X

Species	Threatened Status	Listed as Migratory	Search Area		
			In-field Development Area	Export Pipeline Corridor	Area of Influence
Grey-tailed tattler (*Tringa brevipes*)		X			X
Wood sandpiper (*Tringa glareola*)		X			X
Wandering tattler (*Tringa incana*)		X			X
Common greenshank (*Tringa nebularia*)		X			X
Marsh sandpiper (*Tringa stagnatilis*)		X			X
Common redshank (*Tringa totanus*)		X			X
Terek sandpiper (*Xenus cinereus*)		X			X
Sharks and Rays					
Grey nurse shark (*Charcharius taurus*)	Vulnerable				X
Great white shark (*Carcharodon carcharias*)	Vulnerable	X	X	X	X
Northern river shark (*Glyphis garricki*)	Endangered		X	X	X
Speartooth shark (*Glyphis glyphis*)	Critically Endangered				X
Dwarf sawfish (*Pristis clavata*)	Vulnerable	X			X
Largetooth sawfish (*Pristis pristis*)	Vulnerable	X	X	X	X
Green sawfish (*Pristis zijsron*)	Vulnerable	X	X	X	X
Whale shark (*Rhincodon typus*)	Vulnerable	X	X	X	X
Shortfin mako (*Isurus oxyrinchus*)		X	X	X	X
Longfin mako (*Isurus paucus*)		X	X	X	X
Reef manta ray (*Manta alfredi*)		X	X	X	X
Giant manta ray (*Manta birostris*)		X	X	X	X
Narrow sawfish (*Anoxypristis cuspidata*)		X	X	X	X
Mackeral shark (*Lamna nasus*)		X			X

6.5.2 EPBC Listed Threatened Communities

The EPBC Protected Matters Database does not list any Threatened Ecological Communities (TECs) occurring in the marine environment within the project area (DoEE 2018b). However, one TEC occurs within the area of influence; Monsoon vine thickets on the coastal sand dunes of the Dampier Peninsula (DoEE 2018d). While identified as occurring within the area of influence, the risk of significant impacts to this TEC is not considered credible as, while predominantly restricted to coastlines, this community occurs on the coastal sand dunes (typically the leeward side) (DSEWPaC 2013a) that do not directly contact the marine environment.

6.5.3 Biologically Important Areas

BIAs are defined by DoEE as *"spatially defined areas where aggregations of individuals of a regionally significant species are known to display biologically important behaviours such as breeding, foraging, resting or migration"* (DoEE 2018e). BIAs provide a tool for defining areas of importance for marine fauna species.

A review of the DoEE National Conservation Values Atlas (an interactive web-based tool which supports the implementation of Marine Bioregional Plans) (DoEE 2018f) determined that the in-field development area is located within a biologically important area for whale sharks. The whale shark is listed as vulnerable under the EPBC Act and is discussed in detail in **Section 6.5.6**. No other BIAs are intersected or overlapped by the project area.

The area of influence includes a number of BIAs including migration corridors for pygmy blue whales and humpback whales; breeding, calving and foraging areas for the three nearshore dolphin species; nursing/foraging areas for dugongs; foraging and nesting/internesting areas for marine turtles; breeding/foraging/resting areas for a number of seabird species; a migration corridor for whale sharks; and foraging and nursing/pupping areas for three sawfish species. These BIAs are discussed under the relevant species-specific sections in **Section 6.5.6**.

6.5.4 Habitat Critical to the Survival of a Species

The EPBC Act Significant Impact Guidelines 1.1 – Matters of National Environmental Significance (DoE 2013a) define 'habitat critical to the survival of a species' as areas necessary:

- *"for activities such as foraging, breeding or dispersal*
- *for the long-term maintenance of the species (including the maintenance of species essential to the survival of the species)*
- *to maintain genetic diversity and long term evolutionary development, or*
- *for the reintroduction of populations or recovery of the species."*

Such habitat may be, but is not limited to, habitat identified in a recovery plan and/or habitat listed on the Register of Critical Habitat.

The Crux project does not overlap any habitat critical to the survival of a species. Within the area of influence Ashmore Reef, Cartier Island and Browse Island provide nesting habitat critical to the green turtle. Other mainland and island coastlines with the area of influence also provide habitat critical to the flatback turtle, green turtle, leatherback turtle, loggerhead turtle, and olive ridley turtle. Further discussion of habitat critical to the survival of marine turtles is provided in **Section 6.5.6.2**.

6.5.5 Key Biodiversity Areas

Key Biodiversity Areas (KBAs) are sites that contribute significantly to the global persistence of biodiversity (International Union for Conservation of Nature (IUCN) 2016). For a site to qualify as a global KBA it must meet one or more of 11 criteria, grouped into five categories that can be applied to species and ecosystems: threatened biodiversity; geographically restricted biodiversity; ecological integrity; biological processes; and, irreplaceability. Although KBA sites are unrelated to legal status, they are designed to assist Governments around the world to meet their obligations to international treaties.

A review of the World Database of KBAs (Birdlife International 2018) determined that the project area does not fall within any KBAs. The nearest relevant KBAs are Ashmore Reef (as the nearest offshore KBA), Adele Island and Prince Regent and Mitchell River (as the nearest mainland KBA) (Birdlife International 2018; **Figure 6-20**). There are several KBAs in the broader region, with most qualifying as KBAs based on the threatened bird species and populations occurring there. Relevant threatened bird species occurring within the area of influence are discussed in **Section 6.5.6.3**.

For the purpose of this OPP, with a key objective to consider alignment with DoEE published listings for threatened species/communities, BIAs and habitat critical to the survival of a species (as summarised in the previous **Sections 6.5.1 to 6.5.4** inclusive), this international KBA dataset is noted for completeness.

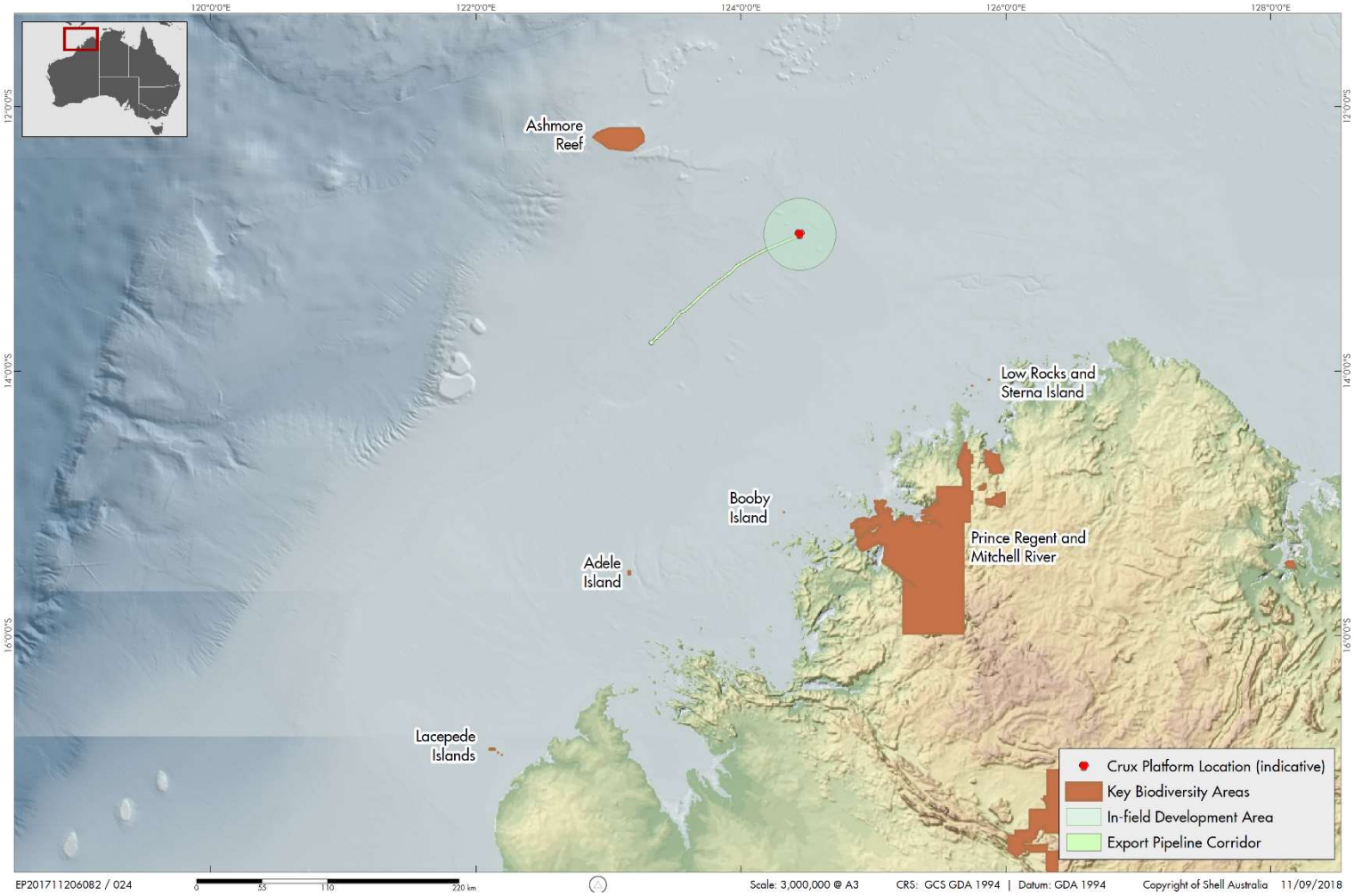


Figure 6-20: Key Biodiversity Areas in Nearest Proximity to the Project Area

6.5.6 Key Fauna Species of Relevance to the Crux Project

6.5.6.1 Marine Mammals

Marine mammals are generally widely distributed and highly mobile. In general, distribution patterns reflect seasonal feeding areas, characterised by high productivity, and migration routes associated with reproductive patterns.

Eight migratory species listed under the EPBC Act, including baleen whales, toothed whales and dolphins, were identified as potentially occurring or having habitat within the project area. This includes four threatened species; the blue whale (*Balaenoptera musculus*; endangered), humpback whale (*Megaptera novaeangliae*; vulnerable), sei whale (*Balaenoptera borealis*; vulnerable) and fin whale (*Balaenoptera physalus*; vulnerable).

An additional five listed migratory species (including one species also listed as threatened) were identified as potentially occurring or having habitat within the area of influence; the southern right whale (*Eubalaena australis*; also listed as endangered), Antarctic minke whale (*Balaenoptera bonaerensis*), dugong (*Dugong dugon*), Australian snubfin dolphin (*Orcaella heinsohni*) and Indo-Pacific humpback dolphin (*Sousa chinensis*).

Of those species identified in the EPBC Protected Matters search, the pygmy blue whale (endangered) and humpback whale (vulnerable) are most likely to occur in the project area based on historical distribution and habitat preference; albeit in low numbers. The species of primary relevance, and other threatened marine mammal species that may traverse through the area, are discussed in detail below.

Whales

Pygmy Blue Whale

The blue whale (*Balaenoptera musculus*; endangered) has four distinct sub-species, of which two are found in the southern hemisphere; the pygmy blue whale (*Balaenoptera musculus brevicauda*; Indo-Australian and Tasman-Pacific populations) and the Antarctic blue whale (*Balaenoptera musculus intermedia*; DoE 2015a).

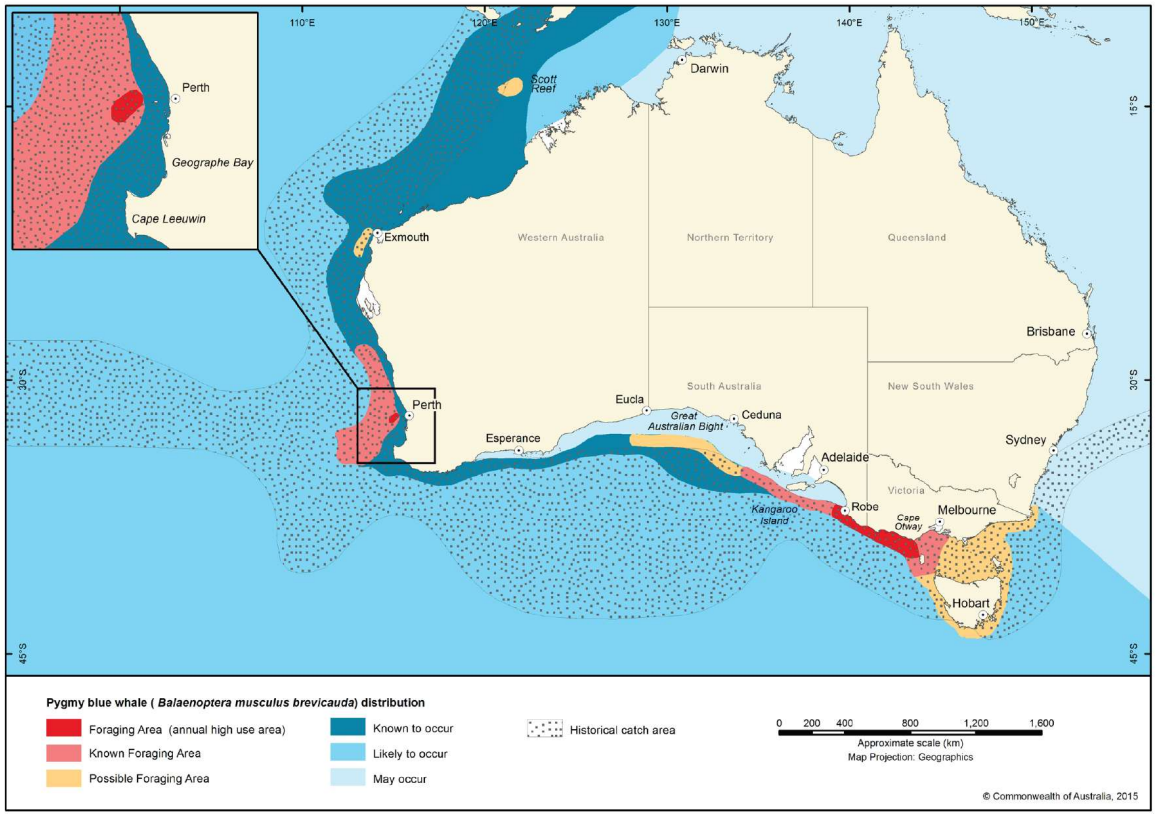
The pygmy blue whale is known to migrate along the WA shelf edge at depths between the 500 m and 1,000 m depth contours from the North West Cape south to Geographe Bay (**Figure 6-21**; DoE 2015a). The species has also been sighted in the NWMR region during offshore surveys and opportunistically (pers. comm. R. Clarke, Monash University, 2018).

A biologically important migration corridor is recognised in the deep offshore waters off WA (**Figure 6-22**; DoEE 2018f). The northerly migration toward the calving grounds near the equator occurs in March/April to June (DoE 2015a). Noise monitoring for the Barossa project, which is located in the Timor Sea approximately 713 km north-east of the Crux platform, detected the presence of blue whales in the months of May to August during their north-bound seasonal migration (McPherson et al. 2016). The southerly migration to the feeding grounds in the high-latitudes of the southern hemisphere occurs in September/October to December (DoE 2015a). Pygmy blue whales appear to travel as individuals or in small groups when making their migrations, based on acoustic data from noise loggers deployed around Scott Reef for the Woodside Browse project (Woodside 2014).

The Perth Canyon off WA and adjacent waters are known biologically important foraging grounds for the pygmy blue whale and are utilised from November to May (**Figure 6-21**; DoE 2015a). A biologically important foraging area also encompasses Seringapatam Reef, Scott Reef and the open waters to the west of these features, as shown in **Figure**

6-22. These steep gradient reef-features tend to stimulate upwelling and, in turn, increased productivity (seasonally variable) which provides a favourable foraging area (ConocoPhillips 2018).

Based on the known distribution, preferred feeding habitats and migration pathways of pygmy blue whales, it is considered possible that individuals may be encountered in low numbers in the project area. However, there are no BIAs for the pygmy blue whale within the project area. The migratory and foraging BIAs for pygmy whales are 121 km and 268 km from the Crux platform, respectively.



Foraging Area (Annual high use area)	Blue whales are regularly observed feeding on a seasonal basis
Known Foraging Area	Known foraging occurs in these areas but is highly variable both between and within seasons
Possible Foraging Area	Evidence for feeding is based on limited direct observations or through indirect evidence, such as occurrence of krill in close proximity of whales, or satellite tagged whales showing circling tracks. Blue whales travel through on a seasonal basis, possibly as part of their migratory route

Known to occur	Blue whales are known to occur based on direct observations, satellite tagged whales or based on acoustic detections
Likely to occur	Blue whales are likely to occur based on occasional observations in the area and nearby areas
May occur	Evidence for the presence of blue whales through strandings or rare observations
Historical catch area	Blue whales were caught during the whaling period based on whaling data

Figure 6-21: Pygmy Blue Whale Distribution around Australia (DoE 2015a)

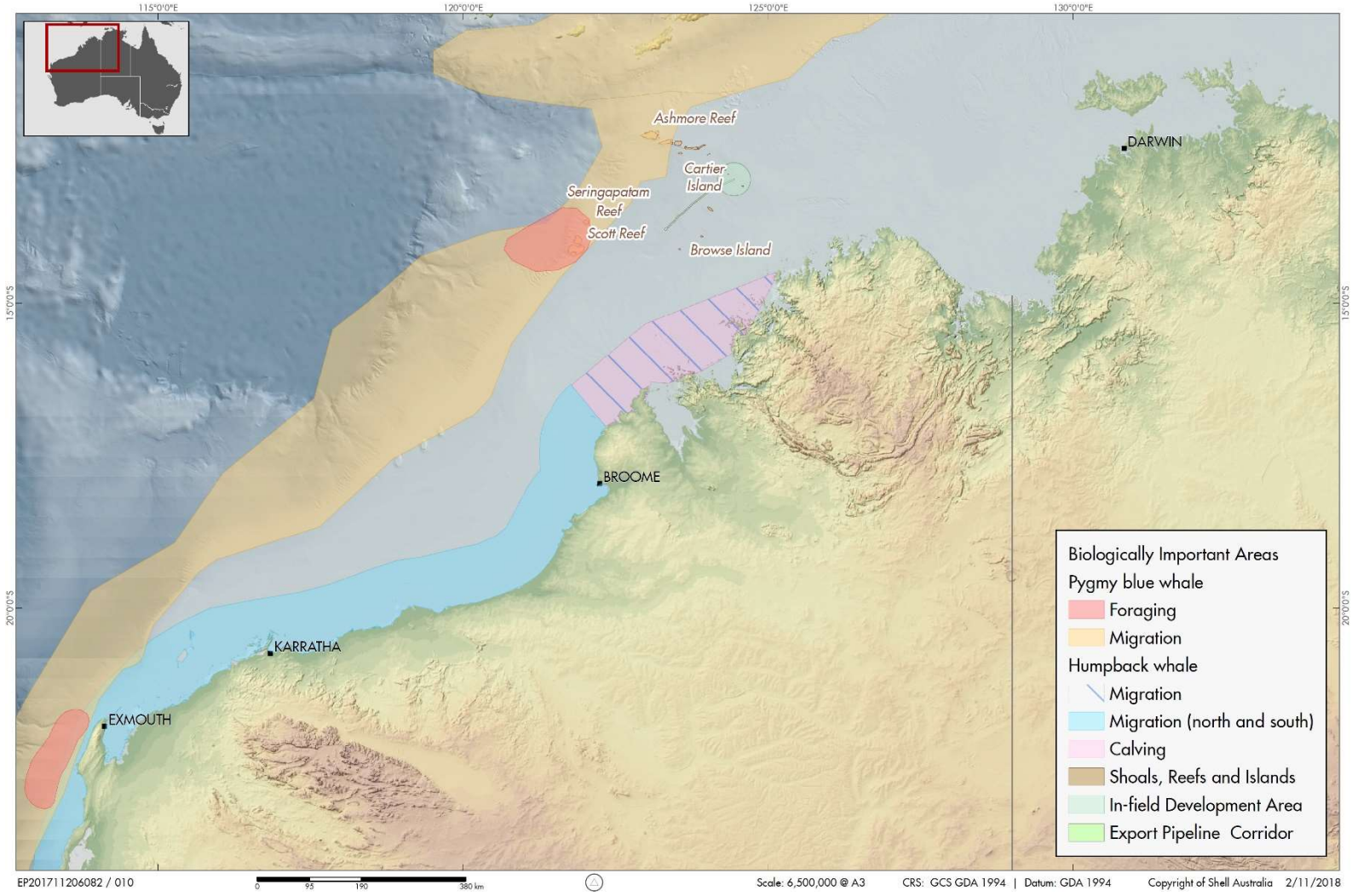


Figure 6-22: Biologically Important Areas for Whales

Humpback Whale

The humpback whale (*Megaptera novaeangliae*; vulnerable) has a wide distribution, shown in **Figure 6-23**, with recordings throughout Australian Antarctic waters and offshore from all Australian states (Bannister et al. 1996). The species migrates between summer feeding grounds in Antarctica and winter breeding and calving grounds in the sub-tropical and tropical inshore waters of north-west Australia (Jenner et al. 2001). A biologically important migration area for humpback whales is recognised in nearshore waters (< 100 km) along the WA coast from west of Esperance to 100 km north of Broome (DoEE 2018f; **Figure 6-22**). The northbound migration peaks between late July and early August, and the southbound migration peaks between late August and early September (Jenner et al. 2001).

Humpback whales breed and calve in the NWMR between Broome and the northern end of Camden Sound in the months of June to September each year (DoE 2015b; DoEE 2018g). A biologically important breeding and calving area for humpback whales is recognised in nearshore waters adjacent to the northern half of the Dampier Peninsula and encompasses Camden Sound (**Figure 6-22**; DoEE 2018g). Relatively few humpback whales have been known to travel north of Camden Sound (Jenner et al. 2001). Noise monitoring undertaken for the Barossa project, which is located within the NMR, did not detect any humpback whale calls in the Timor Sea (McPherson et al. 2016).

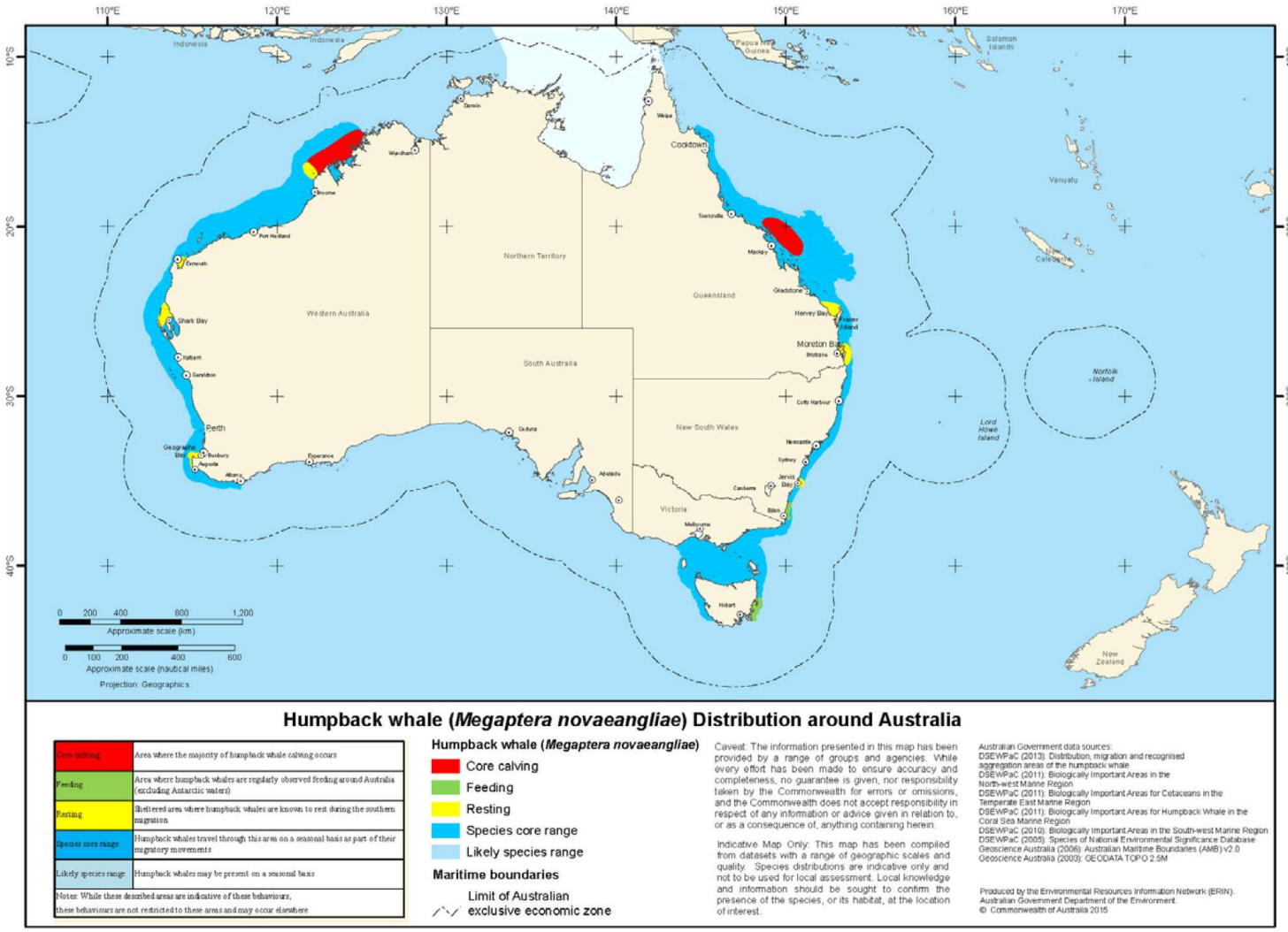


Figure 6-23: Distribution of Humpback Whales around Australia

Sei Whale

Sei whales (*Balaenoptera borealis*; vulnerable) have a wide distribution. Rare though sightings are, the species may be seen in coastal and offshore waters throughout Australia, as well as the waters surrounding Christmas and Cocos Keeling Islands (DoEE 2018h; Bannister et al. 1996). The species is able to utilise a diverse range of marine habitats, which has been attributed to a combination of dynamic physical and prey processes (DoEE 2018h).

Sei whale migratory movements are well defined (distinctly north-south) with the species moving between polar, temperate and tropical waters for foraging and breeding. The species feeds intensively between the Antarctic and sub-Antarctic boundary on planktonic crustacea (Bannister et al. 1996; DoEE 2018h). The species does not dive, rather it sinks, and tends to swim at shallower depths comparative to other species (DoEE 2018h). There are no mating or calving areas in Australian waters.

Based on their known distribution and movements, individual sei whales may be encountered in low numbers within the project area.

Fin Whale

Fin whales (*Balaenoptera physalus*; vulnerable) are widely distributed from polar to tropical waters and have been recorded in all Australian states, other than NSW and the NT (Bannister et al. 1996).

The species rarely occupies inshore waters and displays well defined migratory movements (essentially north-south) between polar, temperate and tropical waters (Bannister et al. 1996; DoEE 2018i). Migration within Australian waters does not appear to follow a clear route and is thought to occur in summer and autumn. Breeding in the Southern hemisphere occurs in tropical and sub-tropical latitudes between May and July (DoEE 2018i).

Fin whales feed on planktonic crustacea, such as Antarctic krill, and primarily forage in high latitudes (Bannister et al. 1996; DoEE 2018i). Within Australian waters, Antarctic waters and the Bonney Upwelling are thought to be important foraging grounds for this species.

Individual fin whales may be encountered in low numbers within the project area.

Bryde's Whale

Bryde's whales (*Balaenoptera edeni*; migratory) distribution encompasses tropical and warm temperate waters with individuals being recorded in all Australian states, except the NT. The species typically moves between 40 °N and 40 °S, with these movements seeming to be primarily linked to prey availability (DoEE 2018j). Bryde's whale are thought to be divided into offshore and onshore forms with the distinction between the two based on prey preference (DoEE 2018j). The offshore form is found in deeper waters (500 m to 1,000 m) and is thought to migrate seasonally in favour of warmer waters in winter months. The onshore form generally inhabits waters < 200 m and displays no distinct migratory movements (DoEE 2018j). The noise monitoring study undertaken for the Barossa project detected Bryde's whales almost year-round (January to October) (McPherson et al. 2016).

Individual Bryde's whales may transit through the project area, based on their known distribution and movements.

Sperm Whale

Sperm whales (*Physeter microcephalus*; migratory) occur in deep waters in all oceans, typically remaining at depths of 200 m or greater, and are known to occur throughout

Australian waters (Bannister et al. 1996). Key areas for sperm whales are known to occur in WA waters between Cape Leeuwin and Esperance (WA) and along the continental shelf approximately 20 nautical miles (nm)–30 nm offshore (Bannister et al. 1996). Sperm whales have a diverse diet, although they primarily feed on oceanic squid (Bannister et al. 1996).

Migration patterns vary between sex. Mature females and juveniles are thought to be resident in tropical and subtropical waters throughout the year, whereas mature males are thought to migrate between the tropics and Antarctic (Bannister et al. 1996; DoEE 2018k).

Considering the location of the project and the known distribution of the species, sperm whales may transit through the project area in low numbers.

Southern Right Whale

The southern right whale (*Eubalaena australis*; endangered) has been recorded in coastal waters of all Australian states, except the NT, with the northern extent being approximately 16°S (DoEE 2018l). The core coastal range for the species is along the southern coast of Australia from Perth to Sydney. The species is present in these coastal waters between late April and early November, thereafter heading to offshore calving grounds to the south (DoEE 2018l; Carroll et al. 2011). In WA, the species is predominantly found around the southern coastline off southern WA, with the northern extent being around Exmouth (DoEE 2018l; Carroll et al. 2011). Considering the distribution of this species, the southern right whale may occur only within a small portion of the area of influence (i.e. the very southern extent). They are not expected to transit through the project area given its location in offshore waters well north of their known distribution.

Antarctic Minke Whale

The Antarctic minke (*Balaenoptera bonaerensis*; migratory) occurs in the waters of all Australian states apart from the NT. Globally, the Antarctic minke whale primarily utilises cold temperate to Antarctic offshore and pelagic waters between 21 °S and 65 °S (Bannister et al. 1996). The majority of individuals seasonally migrate to tropical/sub-tropical breeding grounds, and then to higher latitudes in the summer where they forage primarily on Antarctic krill (DoEE 2018m). Mating occurs between August and September, with the calving season spanning June to July (Bannister et al. 1996). The calving grounds are situated in the warmer waters north of the Antarctic and sub-Antarctic boundary (DoEE 2018m).

The Antarctic minke is considered highly unlikely to occur in the area of influence, given the species preference for colder temperate waters. However, if they are present it is expected that only a few individuals may transit through the area.

Killer Whale

Killer whales (*Orcinus orca*; migratory) have a vast global distribution and utilise a wide range of habitats. However, they appear to be primarily concentrated in coastal waters and cooler regions of high productivity (Bannister et al. 1996; DoEE 2018n).

This species is distributed throughout Australian waters, in particular in Tasmanian waters and the waters surrounding Macquarie Island (1,500 km south-south-east of Tasmania) (Bannister et al. 1996; DoEE 2018n). Off Australia, the species is typically observed moving along the continental slope and shelf, and near seal colonies (Bannister et al. 1996). There are no key localities identified within continental Australian waters for this species. Killer whales are carnivores and their diet varies seasonally and regionally (Bannister et al. 1996; DoEE, 2018n).

Globally killer whales are known to migrate; however, specific routes and seasonal movement patterns are not known in detail and are thought to relate to prey availability (Bannister et al. 1996). Migration movements within Australian waters include a summer migration from subantarctic islands to Macquarie Island (DoEE 2018n). Mating occurs year-round and there are no known calving areas in Australian waters (Bannister et al. 1996).

Based on their known distribution and movements, killer whales may be encountered in within the project area; albeit in low numbers.

Dolphins

A search of the EPBC Protected Matters database identified three migratory dolphin species as potentially occurring within the area of influence; the spotted bottlenose dolphin (Arafura/Timor Sea populations) (*Tursiops aduncus*), Indo-pacific humpback dolphin (*Sousa chinensis*), and the Australian snubfin dolphin (*Orcaella heinsohni*). These species are described below. No breeding areas for these species are known to occur within the project area, however, BIAs for these species occur within inshore areas of the WA coastline, as shown in **Figure 6-24**.

Spotted Bottlenose Dolphin

The spotted bottlenose dolphin (Arafura/Timor Sea populations) (*Tursiops aduncus;* migratory) occurs primarily in continental shelf waters (< 200 m deep), nearshore and in areas with rocky or coral reefs, sandy or soft sediments, or seagrass beds (DSEWPaC 2012c). Small populations also occur in the inshore waters of some oceanic islands. The species also inhabits slightly the deeper and more open water estuarine habitats, when compared to those favoured by the Australian snubfin and humpback dolphins (Reeves and Brownell 2009, cited in DSEWPaC 2012c). Migration patterns for the species in Australia are variable, including of year-round residency in small areas, long-range movements and migration (DoEE 2018o). Due to their tendency to shallow water areas it is unlikely that the species will occur in the project area. No BIAs are known to occur within the project area. However, some BIAs for this species are intersected by the area of influence, as shown in **Figure 6-24**.

Indo-Pacific Humpback Dolphin

The Indo-pacific humpback dolphin (*Sousa chinensis;* migratory) is known to occur along the northern Australian coastline from Exmouth in WA to the Queensland/New South Wales (NSW) border region (DoEE 2018p). The species' preferred habitat is shallow (generally < 20 m in depth) coastal, estuarine and riverine (occasional) waters. However, individuals have been observed in shallow waters up to 55 km offshore. The species breeds throughout the year, with calving peaks reported to occur in the spring and summer months across most of their range (DoEE 2018p).

Given the species' preferred habitat, the Indo-pacific humpback dolphin is relevant to the project only in terms of the area of influence, with BIAs within this area shown in **Figure 6-24**.

Australian Snubfin Dolphin

The Australian snubfin dolphin (*Orcaella heinsohni;* migratory, also known as the Irrawaddy dolphin, *O. brevirostris*) shares similar habitat preferences with the Indo-Pacific humpback dolphin, occurring in shallow coastal and estuarine waters (typically less than 20 m deep) (DoEE 2018q). However, as with the Indo-pacific humpback dolphin, the species has also been recorded up to 23 km offshore. The Australian snubfin dolphin is likely to occur in higher densities in areas of complex habitat type which provide a variety of prey types (DSEWPaC 2012c). In Australia, the species distribution covers

the coastal waters of Queensland, NT and north-western Australia. The population in Australian waters is thought to be continuous with the Papua New Guinea species but separate from populations in Asia.

Within the NWMR the species is likely to migrate and forage off the eastern and western sides of the Cambridge Gulf; to the north and north-west of Cape Londonderry and Cape Talbot; west of Augustus Island; west and north-west of the Buccaneer Archipelago; and Cape Leveque to Broome (DSEWPaC 2012c). Breeding is thought to occur throughout the year for this species.

This species is not expected to occur within the project area due to its habitat preference. As with the other inshore dolphin species known to occur within the area of influence, this species has BIAs along the WA and NT coastlines, as shown in **Figure 6-24**.

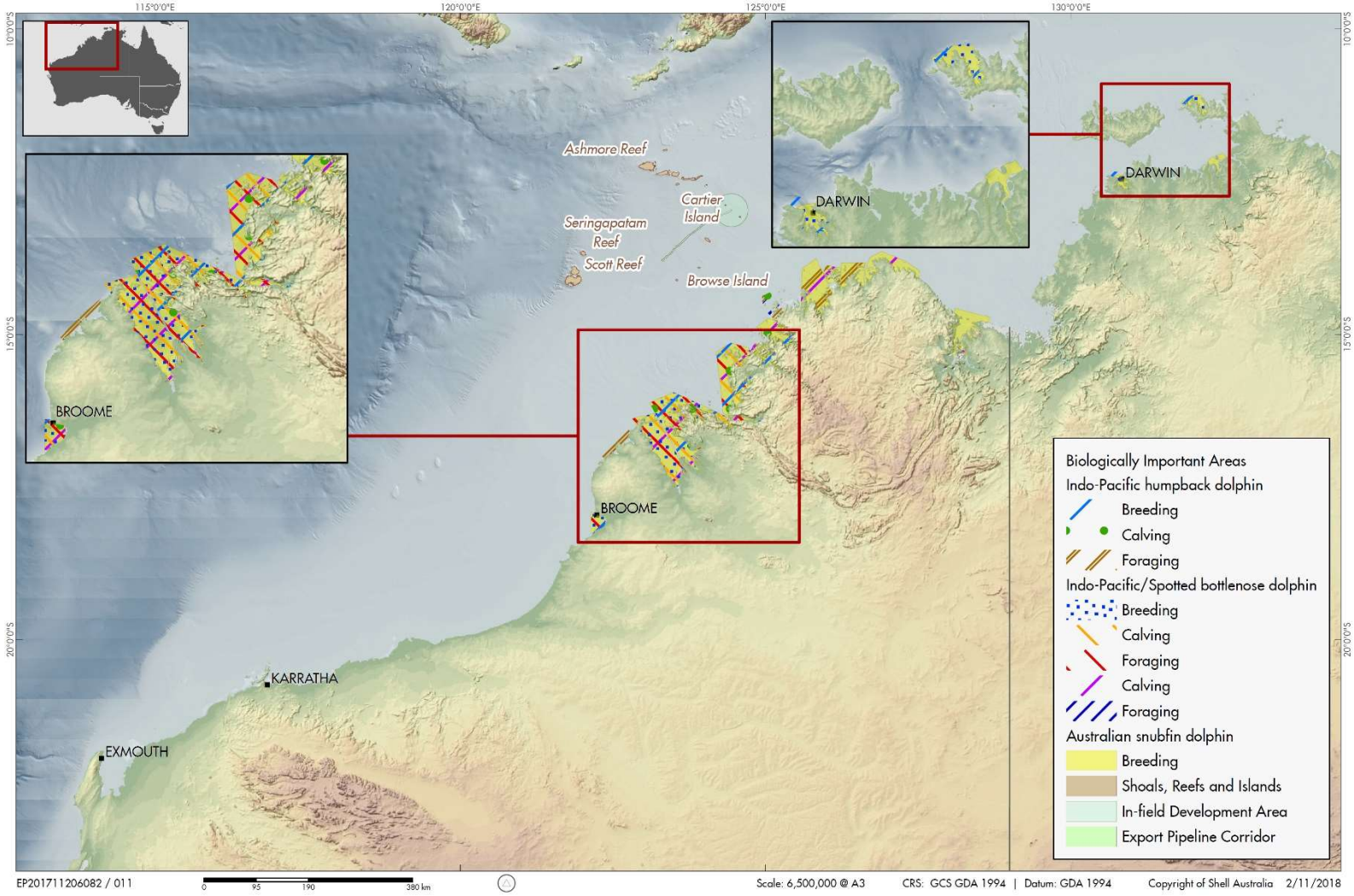


Figure 6-24: Biologically Important Areas for Dolphins

Dugong

Dugongs (*Dugong dugon*; migratory) occur in tropical and sub-tropical coastal and island waters broadly coincident with the distribution of seagrasses, which typically occur in shallow intertidal zone areas to water depths of around 25 m (DoEE 2018r). Dugong feeding aggregations tend to occur in large seagrass meadows within wide shallow protected bays, shallow mangrove channels and in the lee of large inshore islands. The movements of most individuals are limited to within tens of kilometres within the vicinity of seagrass beds (National Oceans Office 2004). However, some individuals have been observed to travel large distances of up to 600 km over a few days (National Oceans Office 2004).

Dugongs and areas of potential dugong habitat exist along the majority of WA coastline north from Shark Bay. Within the area of influence there are some small BIAs along the WA coastline, as shown in **Figure 6-25**. Specific areas supporting dugong populations along the WA coast include Shark Bay, Ningaloo and Exmouth Gulf, the Pilbara coast, Eighty Mile Beach and the Kimberley Coast Region (DoEE 2018r).

A small population of approximately 50 individuals exists at Ashmore Reef, which is considered to be genetically distinct from other nearby Australian or Indonesian populations (DoE 2014a). It is possible that the range of this population extends to Cartier Island where individuals maintain a presence (DoE 2014a). Dugongs may also frequent other shallow shoals on the Sahul Banks; however, there has only been a single sighting of this occurrence in 1996 (Whiting and Guinea 2003).

The north coast of the Tiwi Islands (located 624 km east of the in-field development area) is recognised as a key site for the conservation of dugongs (PWSNT 2003). A well-known major dugong aggregation of approximately 4,400 individuals occurs in waters seaward (within approximately 50 km) of the Tiwi Islands and ranks in the top eight of dugong populations in Australia (PWSNT 2003).

Considering the habitat preference of the species, it is unlikely that dugongs will transit the offshore waters of the project area.

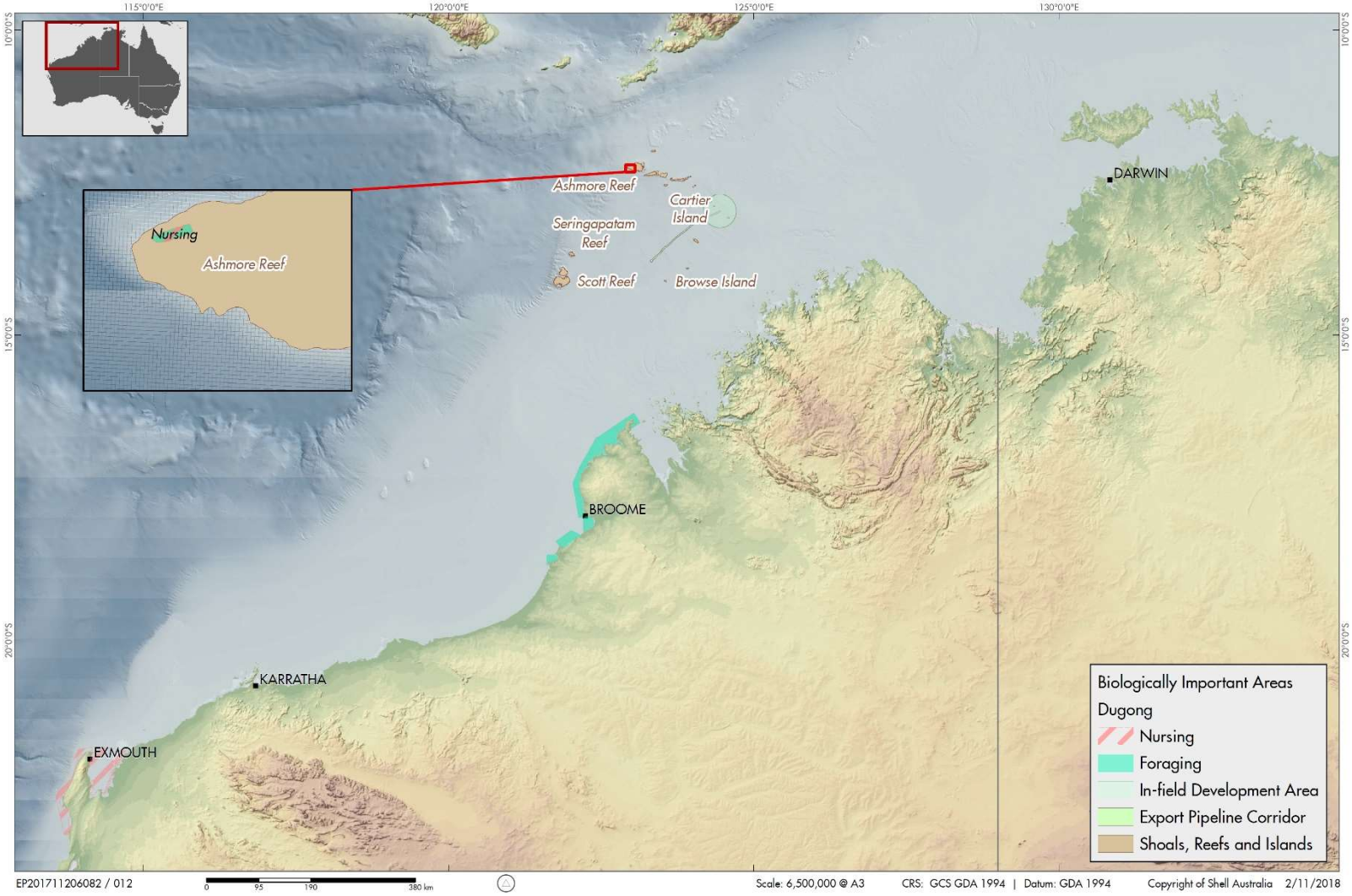


Figure 6-25: Biologically Important Areas for Dugongs

EPBC Management/Recovery Plans and Conservation Advices

The EPBC Management/Recovery Plans and conservation advices for the marine mammal species identified in the EPBC Protected Matters searches for the project area and area of influence are summarised in **Table 6-7**.

Table 6-7: Summary of EPBC Management/Recovery Plans and Conservation Advices Relevant to Marine Mammals

Species	EPBC Management Plan/Recovery Plan/ Conservation Advice	Key Threats Identified in relevant Management Plan/ Recovery Plan/Conservation Advice	Relevant ?	Cross-reference to OPP Impact and Risk Evaluation
Blue whale[P]	Conservation management plan for the blue whale; A recovery plan under the *Environment Protection and Biodiversity Conservation Act 1999* 2015–2025 (October 2015) (DoE 2015a)	Vessel disturbance	Y	Section 8.4.1
		Noise interference	Y	Section 8.4.3
		Habitat modification including presence of oil and gas platforms/rigs, marine debris infrastructure and acute/chronic chemical discharge	Y	Section 8.4.1, Section 8.4.6, Section 8.4.7, Section 8.4.8
		Whaling	N	The key threats are outside the scope of this OPP
		Climate variability and change		
Humpback whale[P]	Conservation advice on humpback whale (*Megaptera novaeangliae*) (October 2015) (DoE 2015b)	Vessel disturbance and strike	Y	Section 8.4.1
		Noise interference	Y	Section 8.4.3
		Entanglement – marine debris	Y	Section 8.4.6
		Whaling	N	The key threats are outside the scope of this OPP
		Climate and oceanographic variability and change		
		Overharvesting of prey		
		Habitat degradation including coastal development and port expansion		
		Entanglement – commercial fisheries or aquaculture equipment, and shark safety equipment		
Sei whale[P]	Conservation advice on sei whale (*Balaenoptera borealis*) (October 2015) (DoE 2015c)	Vessel strike	Y	Section 8.4.1
		Anthropogenic noise and acoustic disturbance	Y	Section 8.4.3
		Pollution (persistent toxic pollutants)	Y	Section 8.4.7, Section 8.4.8
		Climate and oceanographic variability and change	N	The key threats are outside the scope of this OPP
		Habitat degradation including pollution (increasing port expansion and coastal development)		
		Prey depletion due to fisheries (potential threat)		
		Resumption of commercial whaling (potential threat)		

Species	EPBC Management Plan/Recovery Plan/ Conservation Advice	Key Threats Identified in relevant Management Plan/ Recovery Plan/Conservation Advice	Relevant ?	Cross-reference to OPP Impact and Risk Evaluation
Fin whale[P]	Conservation advice on fin whale (*Balaenoptera physalus*) (October 2015) (DoE 2015d)	Vessel strike	Y	Section 8.4.1
		Anthropogenic noise and acoustic disturbance	Y	Section 8.4.3
		Pollution (persistent toxic pollutants)	Y	Section 8.4.7, Section 8.4.8
		Climate and oceanographic variability and change	N	The key threats are outside the scope of this OPP
		Habitat degradation including pollution (coastal development, increasing port expansion and aquaculture)		
		Fisheries catch, entanglement and bycatch		
		Resource depletion due to fisheries (potential threat)		
		Resumption of commercial whaling (potential threat)		
Southern right whale	Conservation management plan for the southern right whale: A recovery plan under the *Environment Protection and Biodiversity Conservation Act 1999* 2011–2021 (DSEWPaC 2012d)	Vessel disturbance and strike	N	The EPBC Protected Matters search has not recorded the species within the project area. Consideration is given to this species in the context of habitat degradation from pollution associated with emergency/ unplanned events (Section 8.4.8).
		Entanglement – marine debris	N	
		Noise interference	N	
		Habitat modification including infrastructure/coastal development and energy production facilities, and acute/chronic chemical discharge	Y	
		Whaling	N	The key threats are outside the scope of this OPP
		Climate variability and change		
		Overharvesting of prey		

[P] The species was identified as potentially occurring or having habitat in the project area.

6.5.6.2 Marine Reptiles

A range of marine reptiles (turtles and sea snakes) were identified as potentially occurring or having habitat in the project area and area of influence. These are discussed further below.

Marine Turtles

A search of the EPBC Act Protected Matters database identified six threatened species of marine turtle that may occur in the project area and area of influence; the flatback turtle (*Natator depressus*; vulnerable), green turtle (*Chelonia mydas*; vulnerable), olive-ridley turtle (*Lepidochelys olivacea*; endangered), hawksbill turtle (*Eretmochelys imbricata*; vulnerable), loggerhead turtle (*Caretta caretta*; endangered), and leatherback turtle (*Dermochelys coriacea*; endangered).

Turtles are oceanic species except during seasonal onshore nesting periods, which are species-dependent and vary along the north Australian coastline (Commonwealth of Australia 2017a). While the incubation time between turtle nesting and emergence of hatchlings varies between species, it is generally about 2 months (Commonwealth of Australia 2017a). Female turtles also exhibit an internesting phase in which they spend 2–3 months in shallow waters in the vicinity of the nesting beach or rookery while they produce the next clutch of eggs (Guinea 2013; Commonwealth of Australia 2017a). The female turtles will rest on the seabed during the internesting period but are not known to feed (ConocoPhillips 2018).

The project area does not contain any emergent land or shallow features that may be of importance to nesting or foraging turtles. Therefore, turtles are unlikely to be present in the area in significant numbers. However, low numbers are likely to transit the project area as they move from nesting beaches and offshore areas.

The broad distribution and habitats of each marine turtle species is summarised below, with further detail on BIAs and habitat critical to the survival of these species (based on geographically distinct genetic stocks) also provided in **Table 6-8** and **Table 6-9**, respectively:

- green turtle – within Australian waters green turtles are predominately found off the WA, NT, Queensland coastlines (Commonwealth of Australia 2017a). The green turtle is the most common marine turtle breeding in the NWMR and WA supports one of the largest remaining green turtle populations in the world (DSEWPaC 2012e). The species is primarily herbivorous and forages on algae, seagrass and mangroves, including where these habitats exist at offshore coral reef habitats (Commonwealth of Australia 2017a). Green turtles are also known to travel large distances of up to 2,600 km between nesting and feeding areas (DSEWPaC 2012e).
- loggerhead turtle – the species is known to range along most of the Australian coastline and throughout the NWMR (Commonwealth of Australia 2017a). Loggerhead turtles are carnivorous and mainly feed on benthic invertebrates in a wide range of habitats ranging from nearshore to 55 m in depth (Commonwealth of Australia 2017a).
- flatback turtle – the species is known to occur along the WA, NT, Queensland coastlines, and forages widely across the Australian continental shelf and into the continental waters off Indonesia and Papua New Guinea (Commonwealth of Australia 2017a). Flatback turtles are primarily carnivorous and feed predominantly on soft-bodied invertebrates (Commonwealth of Australia 2017a). Flatback turtles that nest within the Pilbara region typically migrate along the continental shelf to foraging grounds as far north as Darwin at the end of the nesting season (Commonwealth of Australia 2017a).
- hawksbill turtle – hawksbill turtles predominately occur along the northern WA, NT and northern Queensland coastlines. Hawksbill turtles are omnivorous and feed on algae, sponges, soft corals and soft bodied-invertebrates. This species is typically associated with rocky and coral reef habitats and is expected to be found foraging within these habitats along the WA coastline, from Shark Bay to the northern extent of the NWMR (Commonwealth of Australia 2017a).
- olive ridley turtle – olive ridley turtles are primarily carnivorous and feed predominantly on soft-bodied invertebrates (Commonwealth of Australia 2017a). The species is known to feed in water depths between 15 m and 200 m, and to migrate up to 1,130 km between their nesting and foraging grounds (Whiting et al. 2005). Nesting is known to occur in the NT and on western Cape York (Queensland). Low density nesting has also been described on the Kimberley coast (Commonwealth of

Australia 2017a). This species appears to remain on the Australian continental shelf into waters off Indonesia (Commonwealth of Australia 2017a).

- leatherback turtle – leatherback turtles are known to forage and migrate throughout the open offshore waters of Australia, with foraging more common in along the east coast and the Bass Strait. Records of leatherback turtle nesting in Australia are sparse and limited to the Cobourg Peninsula and Queensland coast (Commonwealth of Australia 2017a). There have been no confirmed accounts of nesting on beaches along the WA coastline. Leatherback turtles eat almost exclusively jellyfish and are pelagic throughout their life in oceanic waters around Australia (Commonwealth of Australia 2017a).

BIAs

BIAs for foraging, breeding, nesting and internesting activities identified for marine turtle species in the area of influence are listed in **Table 6-8** (Commonwealth of Australia 2017a) and shown in **Figure 6-26**.

Table 6-8: BIAs for Marine Turtles

BIA	General Location(s)
Green Turtle	
Internesting/nesting	Islands north-east of Cobourg Peninsula, north-west of Melville Island, Cassini Island, Lacepede Island, Islands in Dampier Archipelago, Barrow Island, Montebello Islands, North West Cape, North and South Muiron Island, Scott Reef, Ashmore Reef, Cartier Island.
Foraging	West Arnhem Land coastal and island areas, Kakadu National Park coastal areas, Joseph Bonaparte Gulf, Montgomery Reef, Ashmore Reef, James Price Point, De Grey River area out to Bedout Island, Dampier and Pilbara inshore coastal area and islands (including Barrow Island and reef habitats west of the Montebello Islands).
Loggerhead Turtle	
Internesting/nesting	Dampier Archipelago Islands, Karratha coastal area and nearby Islands, Montebello Islands, Muiron Island, Ningaloo and Jurabi coastline.
Foraging	Western Joseph Bonaparte Depression, James Price Point, De Grey River area out to Bedout Island.
Flatback Turtle	
Internesting/nesting	Coastal waters and islands adjacent to the Pilbara coastline from Exmouth to Broome, Lacepede Island, Cape Domett, Darwin coastal area and Cobourg Peninsula extending to include Melville Island.
Foraging	Western Joseph Bonaparte Depression, James Price Point, North Turtle Island, Dampier and Pilbara inshore islands.
Hawksbill Turtle	
Internesting/nesting	Islands north-east of Cobourg Peninsula, Greenhill Island, Ashmore Reef, Scott Reef, Islands adjacent to the Pilbara and Dampier coastline (including Barrow, Thevenard and Montebello Islands), Ningaloo coast and Jurabi coast.
Foraging	De Grey River area out to Bedout Island, Dampier and Pilbara inshore islands.
Olive-ridley Turtle	
Internesting	Islands north-east of Cobourg Peninsula, Greenhill Island, Bathurst and Melville Islands, Fog Bay to Cox Peninsula.
Foraging	Western Joseph Bonaparte Depression, northern Joseph Bonaparte Depression, Joseph Bonaparte Gulf.
Leatherback Turtle	
Internesting/nesting	Cobourg Peninsula

Habitat Critical to the Survival of Marine Turtles

Habitat identified as critical to the survival of marine turtles which occur within the area of influence are listed in **Table 6-9** (Commonwealth of Australia 2017a) and shown in **Figure 6-27**.

Table 6-9: Habitat Critical to the Survival of Marine Turtles

Genetic Stock	Habitat Critical Area within Area of Influence	Internesting Buffer	Nesting Season
Green Turtle			
Cobourg Peninsula	Black Point to Smith Point, Croker Island and McCluer Island Group	20 km radius	October to April
North West Shelf	Adele Island, Maret Island, Cassini Island, Lacepede Islands, Barrow Island, Montebello Islands (all with sandy beaches), Serrurier Island, Dampier Archipelago, Thevenard Island, Northwest Cape, Ningaloo Coast	20 km radius	November to March
Ashmore Reef	Ashmore Reef and Cartier Reef	20 km radius	All year (peak between December and January)
Scott-Browse	Scott Reef (Sandy Islet) and Browse Island	20 km radius	November to March
Cocos Keeling	Cocos (Keeling) Islands and within the Pulu Keeling National Park	20 km radius	October to April
Loggerhead Turtle			
WA	Dirk Hartog Island, Muiron Islands, Ningaloo Coast	20 km radius	November to May
Flatback Turtle			
Pilbara	Montebello Islands, Mundabullangana Beach, Barrow Island, Cemetery Beach, Dampier Archipelago (including Delambre Island and Huay Island), coastal islands from Cape Preston to Locker Island.	60 km radius	October to March
South-west Kimberley	Eighty Mile Beach, Eco Beach, Lacepede Islands	60 km radius	May to July
Unknown genetic stock Kimberley, WA	Maret Islands, Motilivet Islands, Cassini Island, Coronation Islands (includes Lamarck Island), Napier-Broome Bay Islands (West Governor Island, Sir Graham Moore Island – near Kalumbaru), Champagny, Darcy and Augustus Islands (Camden Sound)	60 km radius	
Cape Domett	Cape Domett, Lacrosse Island	60 km radius	All year (peak between July and September)
Arafura Sea	Field Island, Bare Sand Island, Tiwi Islands, Cobourg Peninsula, Wessel Islands, Crocodile Island Group	60 km radius	All year (peak between June and September)
Hawksbill Turtle			
WA	Dampier Archipelago (including Rosemary Island and Delambre Island), Montebello Islands (including Ah Chong	20 km radius	October to February

Genetic Stock	Habitat Critical Area within Area of Influence	Internesting Buffer	Nesting Season
	Island, South East Island and Trimouille Island), Lowendal Islands (including Varanus Island, Beacon Island and Bridled Island), Sholl Island		
Olive Ridley Turtle			
NT	Tiwi Islands, McCluer Island group, Cobourg Peninsula, Crocodile Island Group	20 km radius	All year (peak between April and August)
Unknown genetic stock Kimberley, WA	Prior Point, Vulcan Island, Darcy Island, Llangi, Cape Leveque	20 km radius	May to July
Leatherback Turtle			
Australia	Cobourg Peninsula and adjacent West Arnhem coastline to the east (including adjacent islands (e.g. Wessel Islands and Elcho Island))	20 km radius	December-January

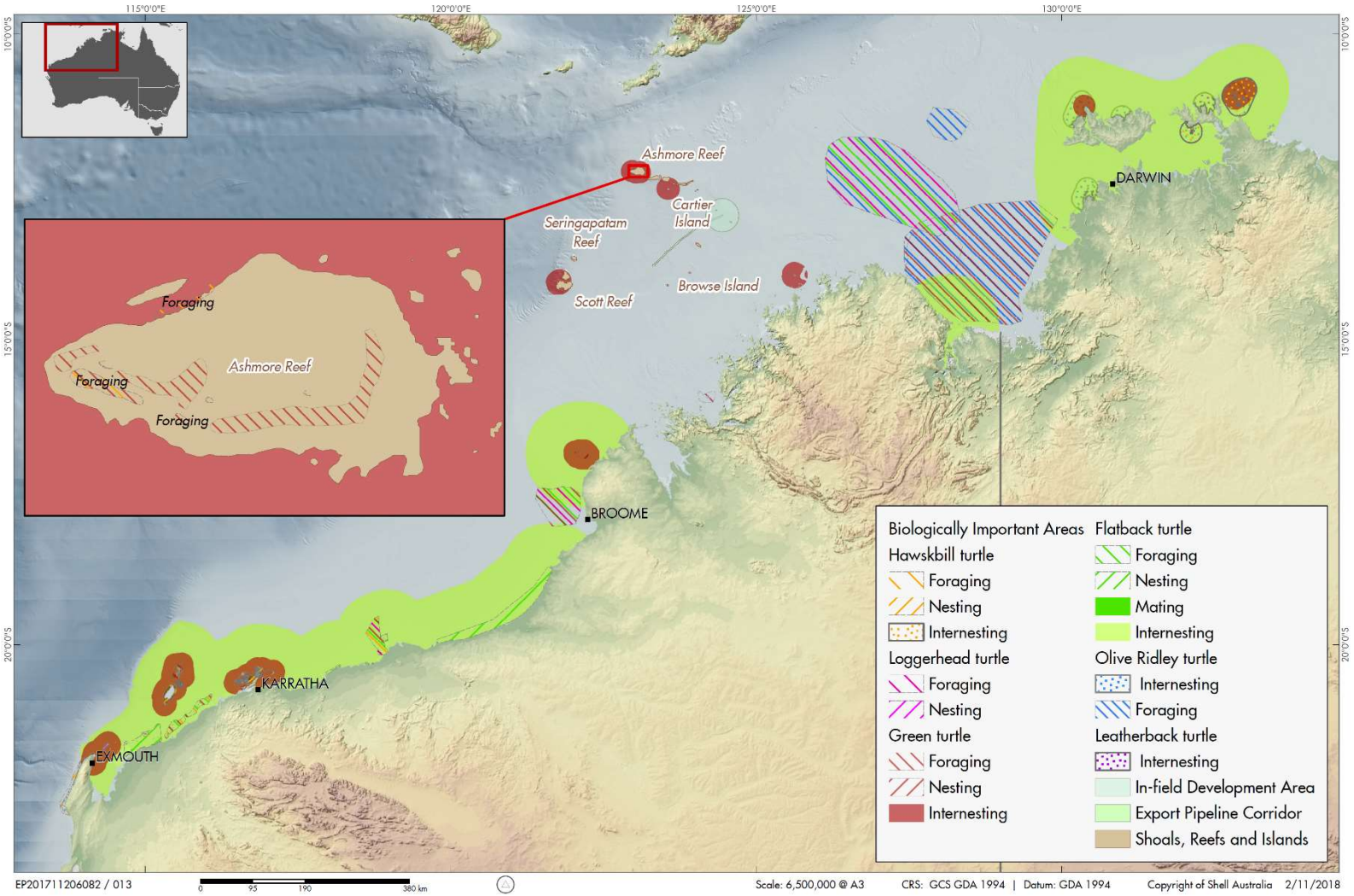


Figure 6-26: Biologically Important Areas for Marine Turtles

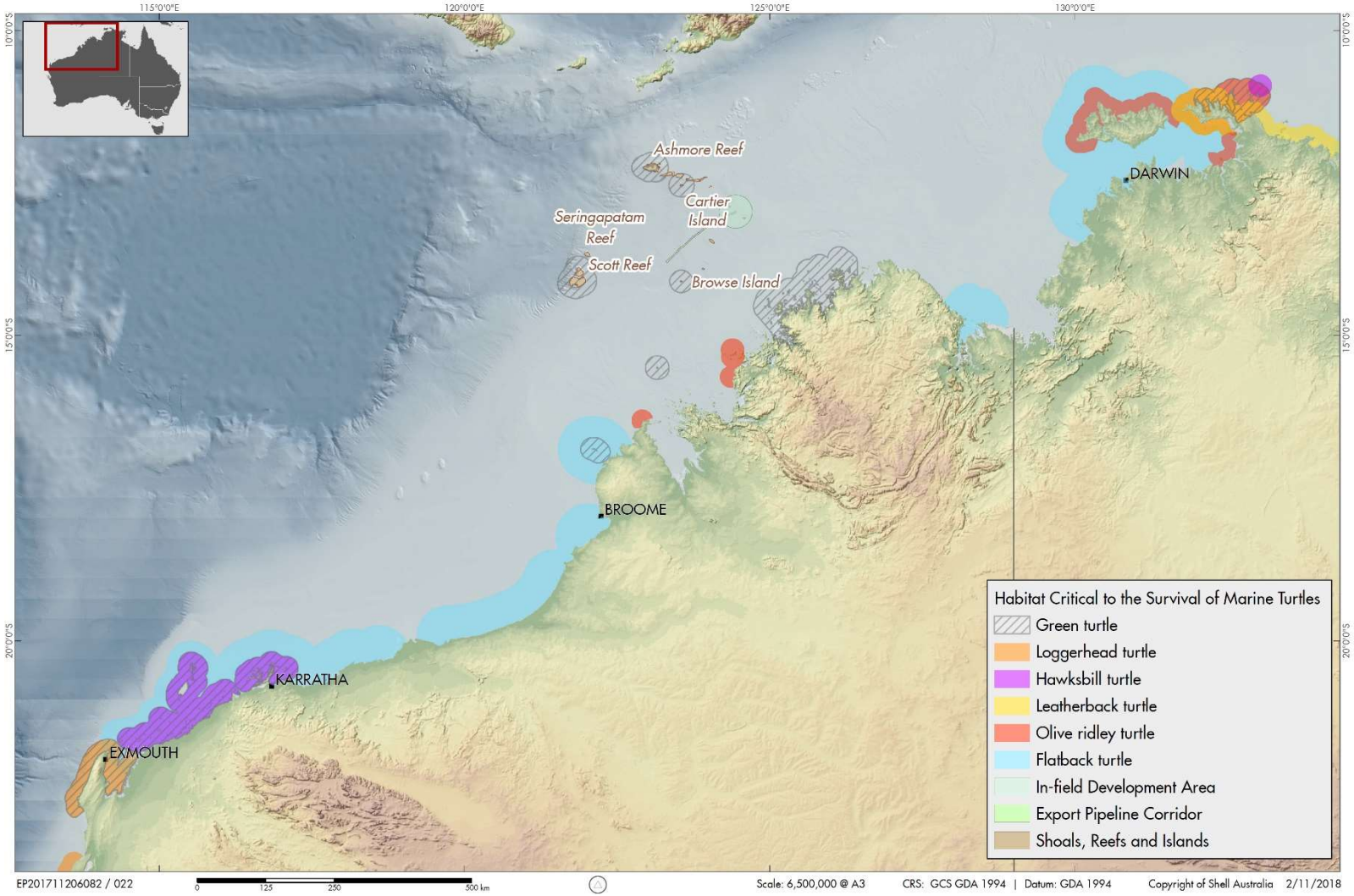


Figure 6-27: Habitat Critical to the Survival of Marine Turtles

Sea Snakes

A search of the EPBC Act Protected Matters database identified 13 sea snake species as potentially occurring in the project area, including two which are listed as threatened; the short-nosed sea snake (*Aipysurus apraefrontalis*; critically endangered) and Leaf-scaled sea snake (*Aipysurus foliosquama*; critically endangered). An additional 12 species may occur within the area of influence. All sea snakes in Australia are listed as protected species under the EPBC Act. Twenty-five species of sea snake are known to occur in the NWMR, including eight endemic species (Guinea 2006). Specific locations within the NWMR considered significant for specific species of sea snake are Shark Bay, the Pilbara coast, and the Kimberley coast (DSEWPaC 2012e).

Sea snakes generally inhabit shallow inshore regions and islands, both near the coastline and offshore, as they feed in shallow, benthic habitats. Sea snakes also inhabit waters surrounding offshore atolls and shoals/banks in the Timor Sea (Guinea 2013). Most sightings of sea snakes have been in water depths of 10 m to 50 m deep (RPS 2010), however, some species are known to dive to deeper depths. The non-pelagic sea snake species rarely, if ever, dive deeper than 100 m (Heatwole and Seymour 1975).

The distribution and movements of sea snakes vary between species. Some species, for example the pelagic yellow-bellied sea snake, traverse large distances in open offshore waters while others, such as the olive sea snake, are typically resident to a particular area. Sea snake species that reside on reefs do not actively disperse or migrate between reefs and are found to be present year-round at most reefs on the Sahul Shelf (Guinea and Whiting 2005). A survey undertaken by AIMS (Heyward et al. 2012) identified 117 sea snake individuals across nine submerged shoals, which are located within an approximately 150 km radius of the in-field development area. Of these individuals, 66 were identified as the olive sea snake, four as the spotted sea snake and the remaining individuals were unable to be identified. A study by Guinea et al. (2013) identified an additional eight common reef-dwelling species of sea snake historically reported to occur on Ashmore Reef, with some of these species also occurring on Cartier Island, Hibernia Reef, Scott Reef and Seringapatam Reef.

The short-nosed sea snake and the leaf-scaled sea snake were previously thought to be short-range endemic species restricted to Ashmore Reef and Hibernia Reef, which are located approximately 155 km and 105 km north-west of the Crux platform, respectively. However, two short-nosed sea snakes and two leaf-scaled sea snakes have recently been sighted at Ningaloo Reef, some 1,500 km south-south-west of the project area (D'Anastasi 2016). A leaf-scale sea snake was also observed in seagrass meadows in Shark Bay (D'Anastasi 2016). These species prefer the reef flats or shallow waters along the outer reef edge in water depths to 10 m (DSEWPaC 2010a, 2010b). Whilst once relatively common at Ashmore and Hibernia reefs, the species have not been recorded at these locations since the late 1990s/2001, despite an increase in survey effort (DSEWPaC 2010a, 2010b). The decline of sea snakes at Ashmore Reef is likely multi-faceted and has been linked to ecosystem degradation as a result of major coral bleaching events in the 1990s.

Based on known species distributions and habitat preferences of sea snakes, it is expected sea snakes may transit through the open waters of the project area, with any individuals expected to be in the vicinity of the shoals within the in-field development area.

Crocodiles

While not identified in the project area EPBC Protected Matter searches, two species of crocodile were noted as potentially occurring in the area of influence; the salt-water crocodile (*Crocodylus porosus*) and fresh-water crocodile (*Crocodylus johnstoni*). The salt-water crocodile was originally listed under the EPBC Act to regulate commercial hunting, which was causing significant population declines (DoEE 2018s).

The salt-water crocodile occurs within the nearshore marine and estuarine waters of the Kimberley coast (DoEE 2018s). Larger populations within the major river systems of the Kimberley occur in the rivers draining into the Cambridge Gulf, the Prince Regent and Roe River systems of the east and northwest Kimberley (DEC 2009b). There is limited availability of nesting habitat for this species within its distribution, with only the Ord, King and Roe River systems typically providing suitable nesting vegetation for the species (DEC 2009b).

The fresh-water crocodile is more widely distributed over the coastal and mainland areas of northern Australia than the salt-water crocodile (DoEE 2018t). The species occupies the same river systems as the salt-water crocodile in the Kimberley region and areas which exclude the larger saltwater crocodiles (DEC 2009b). Fresh-water crocodiles breed in all of the river systems in which it occurs (DEC 2009b).

There are no BIAs for the salt-water or fresh-water crocodile within the project area and, given the distance of the project area from the WA coastline (approximately 190 km), it is highly unlikely that individuals will transit through the project area.

EPBC Management/Recovery Plans and Conservation Advices

The EPBC Management/Recovery Plans and conservation advices for the marine reptile species identified in the EPBC Protected Matters searches for the project area and area of influence are summarised in **Table 6-10**.

Table 6-10: Summary of EPBC Management/Recovery Plans and Conservation Advices Relevant to Marine Reptiles

Species	EPBC Management Plan/Recovery Plan/ Conservation Advice	Key Threats Identified in relevant Management Plan/Recovery Plan/Conservation Advice	Relevant ?	Cross-reference to OPP Impact and Risk Evaluation
Loggerhead turtle[P] Green turtle [P] Leatherback turtle[P] Hawksbill turtle[P] Olive ridley turtle [P] Flatback turtle[P]	Recovery plan for marine turtles in Australia 2017-2027 (June 2017) (Commonwealth of Australia 2017a) Conservation advice on leatherback turtle (*Dermochelys coriacea*) (DEWHA 2009a)	Habitat modification	Y	Section 8.4.1
		Vessel disturbance	Y	Section 8.4.1
		Light pollution	Y	Section 8.4.2
		Noise interference	Y	Section 8.4.3
		Marine debris	Y	Section 8.4.6
		Chemical and terrestrial discharge	Y	Section 8.4.7, Section 8.4.8
		Climate change and variability	N	The key threats are outside the scope of this OPP
		International take		
		Terrestrial predation		
		Fisheries bycatch		
		Indigenous take		
		Recreational activities		
		Diseases and pathogens		

Species	EPBC Management Plan/Recovery Plan/ Conservation Advice	Key Threats Identified in relevant Management Plan/Recovery Plan/Conservation Advice	Relevant ?	Cross-reference to OPP Impact and Risk Evaluation
Short-nosed sea snake Leaf-scaled sea snake	Conservation advice on short-nosed sea snake (*Aipysurus apraefrontalis*) (DSEWPaC 2010a) Conservation advice on leaf-scaled sea snake (*Aipysurus foliosquama*) (DSEWPaC 2010b)	Degradation of reef habitat, primarily as a result of coral bleaching (principle threat)	N	The key threat is outside the scope of this OPP
		Oil and gas exploration	N	The EPBC Protected Matters search has not recorded the species within the project area. Consideration is given to this species in the context of habitat degradation from pollution associated with emergency/ unplanned events (Section 8.4.8).
		Incidental catch and death in commercial prawn trawling fisheries (relevant to the NWMR)	N	The key threats are outside the scope of this OPP
		Unsustainable and illegal fishing practices (Ashmore Reef region)		

[P] The species was identified as potentially occurring or having habitat in the project area.

6.5.6.3 Birds

A number of seabirds and migratory shorebirds are known to occur within the NWMR as they range over large distances to forage over the open ocean (DSEWPaC 2012f). The EPBC Protected Matters search identified 12 bird species as potentially occurring within the project area, five of which are threatened; the curlew sandpiper (*Calidris ferruginea*; critically endangered), eastern curlew (*Numenius madagascariensis*; critically endangered), Australian lesser noddy (*Anous tenuirostris melanops*; vulnerable), red knot (*Calidris canutus*; endangered) and Abbott's booby (*Papasula abbotti*; endangered). These species are discussed below.

An additional 48 listed migratory species (including nine threatened species) were identified to potentially occur within the area of influence. There are twelve bird species with BIAs within the area of influence, these are indicated in **Table 6-11** and **Figure 6-28**. Most migrant birds are expected to fly over the regional area as part of their large-scale transitory movements and are unlikely to land on the sea for significant periods of time (ConocoPhillips 2018). Considering this, and the general absence of landing areas at a regional offshore scale, the majority of seabird activity is likely to comprise foraging and migration pathways, as opposed to seabird stopover and roosting points during annual migrations. Whilst seabirds spend much of their lives at sea, migratory shorebirds overfly offshore areas during migratory periods and typically do not interact with the sea surface (DSEWPaC 2012f; ConocoPhillips 2018). Migratory wetland species also do not interact with open offshore waters. However, these species may land on offshore oil and gas infrastructure, especially during inclement weather, while flying between land masses (ConocoPhillips 2018).

No emergent land exists in the shoals or surrounding offshore areas in the immediate vicinity of the project area to support breeding populations of seabirds or migratory shorebirds. The nearest shorelines to the project area being Cartier Island and Ashmore Reef, which are located 105 km and 155 km north-west of the Crux platform, respectively. More broadly, Scott Reef and Browse Island may provide additional connectivity for shorebirds of the NWMR (DSEWPaC 2012f).

Curlew Sandpiper

The curlew sandpiper (*Calidris ferruginea*; critically endangered) has a vast distribution, being recorded along the coasts of all Australian states and territories (DoEE 2018u). The species preferred habitat is intertidal mudflats in sheltered coastal areas as they forage in nearshore waters or mud at the edge of wetlands (DoEE 2018u). However, they are also widespread inland; albeit in smaller numbers. The curlew sandpiper migrates along the East Asian-Australasian Flyway (Flyway) from their breeding grounds in Siberia to Australia, generally arriving in Australia around late August/early September and departing by mid-April (DoEE 2018u). Some non-breeding individuals may not undertake the migration northward but stay in Australia (DoEE 2018u).

Based on the known distribution, preferred feeding and roosting habitats, it is considered highly unlikely that individuals will interact with the project area due to the absence of any land.

Eastern Curlew

The eastern curlew (*Numenius madagascariensis*; critically endangered) is the world's largest species of shorebird (Menkhorst et al. 2017; DoEE 2018v). The species is restricted to the Flyway, undertaking an annual migration to breeding grounds in Russia and north-eastern China, before returning to Australia in August to forage, primarily in intertidal mudflats on larger prey items such as crab (Bamford et al. 2008; DoEE 2018v; Menkhorst et al. 2017). There are two internationally important non-breeding sites in northern WA; Roebuck Bay and Eighty Mile Beach (Bamford et al. 2008).

Considering the species preferred habitat and diet, the eastern curlew is very unlikely to land or interact with offshore waters during its migration through the Flyway.

Australian Lesser Noddy

The Australian lesser noddy (*Anous tenuirostris melanops*; vulnerable) is a tropical species of tern endemic to Australia (DoEE 2018w; DEWHA 2015a). Whilst the Australian lesser noddy has a large range, the species utilises primarily a small area in Houtman Abrolhos for breeding (DoEE 2018w; DEWHA 2015a). The species is also known to breed in small numbers at Ashmore Reef (Menkhorst et al. 2017). Individuals generally remain in close proximity to the breeding islands throughout the year. Therefore, while some individuals may occur within the project area, they are not expected to occur in significant numbers.

Red Knot

The red knot (*Calidris canutus*; endangered) is an omnivorous wading bird which utilises the intertidal mudflats, sandflats and sandy beaches of sheltered coastal areas, estuaries, bays and other similar marine habitats. The red knot may also utilise saline wetlands but rarely freshwater water sources (DoEE 2018x). The red knot is present throughout coastal and offshore Australia, including Christmas and Cocos Keeling Islands. Notably, large numbers of red knot are regularly recorded in the north-west of Australia (specifically at 80 Mile Beach and Roebuck Bay) and the species is present along the Ningaloo coast and at Lake Macleod (DoEE 2018x; Bamford et al. 2008).

While the species utilises the Flyway, the exact migration route of Australian populations of red knot to their Arctic breeding grounds is unknown (DoEE 2018x, Watkins 1993). It is, however, thought that individuals may begin the journey by moving south across the west Pacific Ocean and then north along the east Asian coast (DoEE 2018x). The species is thought to make minimal stop overs during this migration. At the end of the breeding season the species returns south, arriving in northern Australia in late August to early September to take up residence, as well as settling in other areas primarily in eastern Australia and New Zealand (DoEE 2018x; Watkins 1993).

Given the species' habitat preference, the red knot is unlikely to land or interact with offshore waters during its migration over the Timor Sea.

Abbott's Booby

The Abbott's booby (*Papasula abbotti*; endangered) spends the majority of its time at sea and generally only comes ashore to breed. Within Australia, the Abbott's booby breeds exclusively on Christmas Island, displaying a preference for nesting in the forests on the island and foraging in the surrounding waters (DEWHA 2015b). Recent population estimates on Christmas Island are of 2,500 breeding pairs (Menkhorst et al. 2017). The species' restricted geographical location is thought to be attributed to areas of upwelling in the waters surrounding Christmas Island, which may provide prey items that are seasonal and necessary for raising offspring. However, data suggests that individuals may travel up to hundreds of kilometres from Christmas Island in order to forage (DoEE 2018y). Considering the project area is significantly distant from Christmas Island (approximately 2,061 km), it is likely that only a few individuals may utilise the open waters of the project area.

Greater Frigatebird

The greater frigatebird (*Fregata minor*; migratory) is widespread and breeds on a number of small and remote tropical and sub-tropical islands (DSEWPaC 2012f; Birdlife International 2017a). Whilst the species typically nests in mangroves or bushes, it may also nest on the bare ground (Birdlife International 2017a). The greater frigatebird forages both inland and along coastlines, potentially straying up to 200 km from the colony to forage during the early breeding season (Birdlife International 2018; DSEWPaC 2012f). The species' diet consists largely of fish, squid and the chicks of other bird species (Birdlife International 2017a; DSEWPaC 2012f).

There are large breeding populations of this species in the tropical waters of the Pacific and Indian Oceans (Birdlife International 2017a). Within WA, the greater frigatebird has a small breeding colony at Ashmore Reef and is found throughout the north and eastern coastal and offshore areas of Australia (DoEE 2018z; DSEWPaC 2012f). The species also breeds on Christmas and North Keeling Islands (Menkhorst et al. 2017). There are BIAs for the greater frigatebird, both breeding and foraging, within the area of influence, as shown in **Figure 6-28**. Considering the species distribution and foraging habits, individuals are likely to utilise the open waters within the project area. Satellite tracking studies undertaken from Ashmore Reef have also shown the species traverses the project area (Mott 2016).

Lesser Frigatebird

The lesser frigatebird (*Fregata aerial*; migratory) occurs throughout the tropical and warmer waters of northern and eastern Australia (DSEWPaC 2012f), breeding on islands such as Ashmore Reef and North Keeling, as well as a number of other islands located off the north coast of WA (Menkhorst et al. 2017). There are BIAs for the lesser frigatebird within the area of influence, as shown in **Figure 6-28**. The lesser frigatebird feeds on prey items such as flying fish by catching their prey at or just above the ocean surface

(DSEWPaC, 2012f). This species also occasionally feeds on squid, octopus and other species chicks, and typically does not forage far from the breeding colony (DSEWPaC 2012f; Birdlife International 2017b).

As with the greater frigatebird, individuals are likely to utilise the open waters within the project area based on the species distribution and feeding preferences. Satellite tracking studies have also shown the species traverses the project area (Mott 2016).

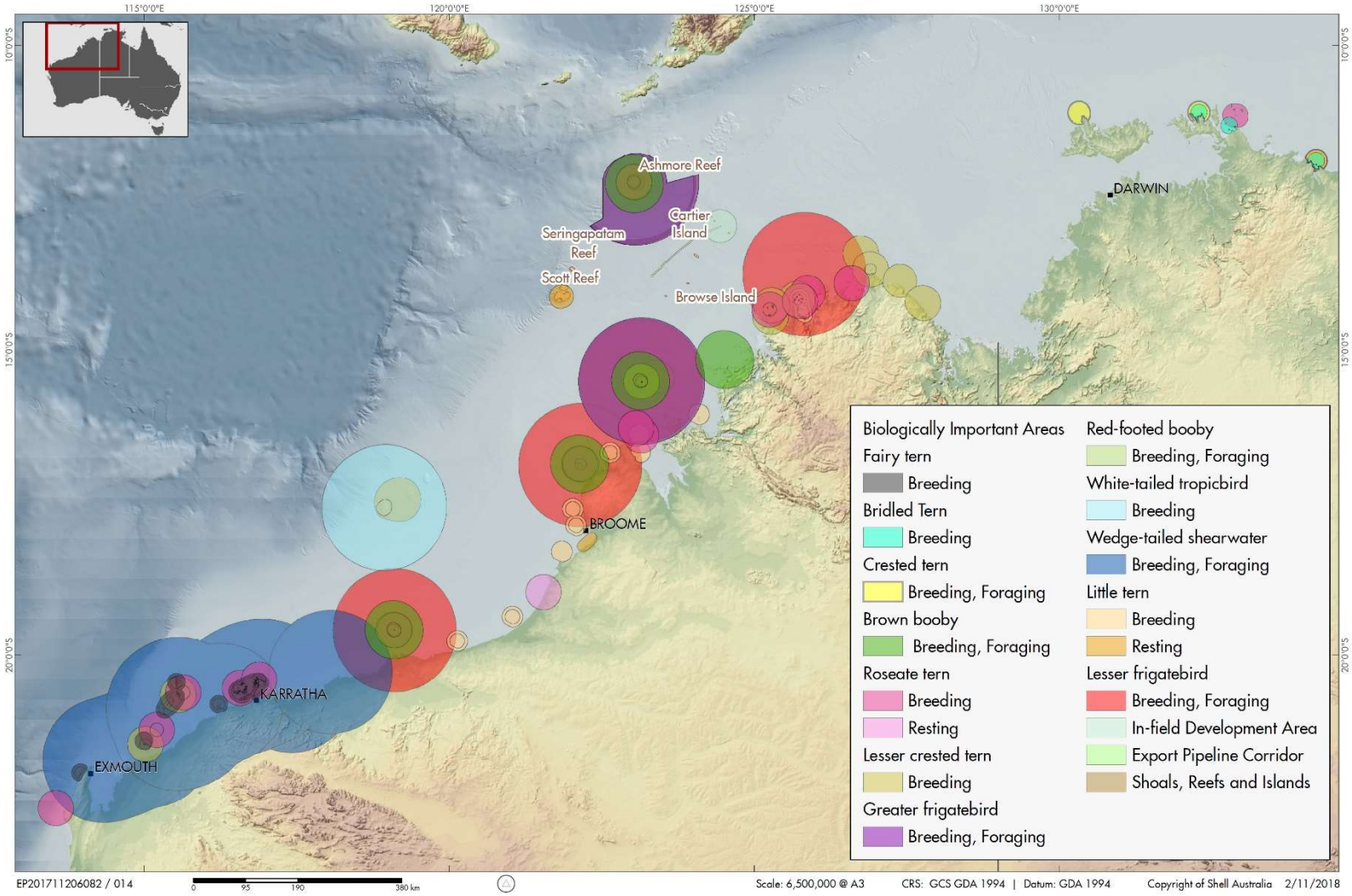


Figure 6-28: Biologically Important Areas for Birds

Table 6-11: Summary of BIAs relevant to Birds within the Area of Influence

Species	BIAs within the Area of Influence	General Location(s)
Fairy tern (*Sternula nereis nereis*)	Breeding	WA (Pilbara and Gascoyne) coastline and adjacent offshore islands
Roseate tern (*Sterna dougalii*)	Resting	Eighty Mile Beach (northern end)
	Breeding	Haul Round Island (Boucat Bay), Grant Island, WA (Kimberley, Pilbara and Gascoyne) coastline and offshore islands (including Ashmore Reef)
Lesser crested tern (*Thalasseus bengalensis*)	Breeding	WA (Kimberley, Pilbara and Gascoyne) coastline and offshore islands (including Ashmore Reef). It is noted that expert opinion provided for the Barossa Area Development Project indicated that this is predominantly an inshore species and does not occur at Ashmore Reef of Cartier Islands (ConocoPhillips 2018).
White-tailed tropicbird (*Phaethon lepturus*)		Ashmore Reef, Cartier Island, WA (Kimberley, Pilbara and Gascoyne) coastline and offshore islands (including Cunningham Island and Bedwell Island)
Lesser frigatebird (*Fregata ariel*)	Breeding/foraging	Ashmore Reef, Cartier Island, WA (north west Kimberley and Pilbara) coastline
Greater frigatebird (*Fregata minor*)		Ashmore Reef, Cartier Island, WA (north west Kimberley) coastline
Red-footed booby (*Sula sula*)		
Wedge-tailed shearwater (*Ardenna pacifica*)		Ashmore Reef, Cartier Island, WA (Kimberley, Pilbara and Gascoyne) coastline and offshore islands
Crested tern (*Thalasseus bergii*)		Crocodile Islands, north-east of Milingimbi (Large Island), Haul Round Island (Boucat Bay), Cobourg Peninsula (No. 2 Sandy Island), Seagull Island
Brown booby (*Sula leucogaster*)		Kimberley and northern Pilbara coastlines and adjacent islands, Ashmore Reef
Little tern (*Sternula albifrons*)	Breeding	WA (Kimberley and Pilbara) coastline
	Resting	Ashmore Reef, WA (kimberley, Pilbara and Gascoyne) coastline and offshore islands

EPBC Management/Recovery Plans and Conservation Advices

The EPBC Management/Recovery Plans and conservation advices for the birds identified in the EPBC Protected Matters searches for the project area and area of influence are summarised in **Table 6-12**.

Table 6-12: Summary of EPBC Management/Recovery Plans and Conservation Advices Relevant to Birds

Species	EPBC Management Plan/Recovery Plan/ Conservation Advice	Key Threats Identified in relevant Management Plan/ Recovery Plan/ Conservation Advice	Relevant?	Cross-reference to OPP Impact and Risk Evaluation
Sandpipers (includes snipes – excluding the Australian painted snipe, godwits, curlews, whimbrel, redshank, greenshank, sandpiper, tattler, turnstone, dowitcher, knots, sanderling, stints) and plovers listed in **Table 6-6**	Wildlife Conservation Plan for Migratory Shorebirds (DoE 2015e)	Habitat (wetland) loss due to infrastructure/ coastal development	N	The key threats are outside the scope of this OPP
		Anthropogenic disturbance (e.g. aircraft over-flights, industrial operations and construction, artificial lighting, recreational activities such as fishing, four-wheel driving, pets, water craft)	N	
		Climate change and variability	N	
		Harvesting of shorebird prey	N	
		Fisheries by-catch	N	
		Hunting	N	
		Modification habitat (e.g. chronic pollution from herbicides/ pesticides, acute pollution from oil/ chemical spills, invasive species (including introduced plant species, marine pests in intertidal habitats, pigs, cane toads and cats) and altered hydrological regimes)	N	The key threats are outside the scope of this OPP as they relate to disturbances to wetland habitats in coastal areas. Consideration is given to this species in the context of habitat degradation from pollution associated with unplanned waste management (Section8.4.6) and emergency/unplanned events (Section 8.4.8).
White-tailed tropicbird	Conservation advice on white-tailed tropicbird (*Phaethon letpurus fulvus*) (October 2014) (DoE 2014b)	Introduced predators and invasive species (e.g. feral cats, black rats, yellow crazy ant)	N	The key threat is outside the scope of this OPP as it relates to terrestrial pathways
Round Island petrel	Conservation advice on Round Island petrel (*Pterodroma arminjoniana*) (January 2015) (DoE 2015f)	Introduced predators (potential threat)	N	The key threat is outside the scope of this OPP as it relates to terrestrial pathways
		Disturbance and habitat loss (potential threat from cyclonic weather)	N	The key threat is outside the scope of this OPP
Soft-plumaged petrel	Conservation advice on soft-plumaged petrel (*Pterodroma mollis*) (January	Introduced predators (potential threat)	N	The key threat is outside the scope of this OPP as it relates to terrestrial pathways

Species	EPBC Management Plan/Recovery Plan/ Conservation Advice	Key Threats Identified in relevant Management Plan/ Recovery Plan/ Conservation Advice	Relevant?	Cross-reference to OPP Impact and Risk Evaluation
	2015) (DoE 2015g)			
Black-browed albatross Southern giant-petrel	National recovery plan for threatened albatrosses and giant petrels 2011–2016 (DSEWPaC 2011a)	Marine pollution	Y	Section 8.4.7, Section 8.4.8 These species are only relevant with regards to the area of influence
		Fishing (e.g. bycatch, resource competition, dependence on discards)	N	The key threats are outside the scope of this OPP
		Climate change	N	
		Disturbance (human, e.g. deliberate shooting/killing, nest disturbance)	N	
		Habitat loss (e.g. loss of nesting habitat)	N	
		Competition for nesting space	N	
		Introduced predators (e.g. cats, rabbits, rodents)	N	The key threat is outside the scope of this OPP as it relates to terrestrial pathways
		Parasites/disease	N	
Australian fairy tern	Conservation advice on fairy tern (*Sternula nereis nereis*) (February 2011) (DSEWPaC 2011b)	Oil spills (main potential threat; particularly in Victoria)	Y	Section 8.4.7, Section 8.4.8 Species is only relevant with regards to the area of influence
		Increased salinity in waters adjacent to colonies leading to a reduction in prey abundance	N	The key threats are outside the scope of this OPP
		Disturbance (e.g. humans, dogs, vehicles)	N	The key threats are outside the scope of this OPP as they relate to terrestrial pathways
		Irregular water management (causing flooding of nests or allowing predators access to breeding colonies)	N	
		Weed encroachment (on nest sites)	N	
		Introduced predators (e.g. foxes, dogs, cats, rats, native birds)	N	
Australian painted snipe	Conservation advice on Australian painted snipe	Habitat (wetland) loss and degradation (e.g. through agricultural development, livestock	N	The key threats are outside the scope of this OPP

Species	EPBC Management Plan/Recovery Plan/ Conservation Advice	Key Threats Identified in relevant Management Plan/ Recovery Plan/ Conservation Advice	Relevant?	Cross-reference to OPP Impact and Risk Evaluation
	(*Rostratula australis*) (May 2013) (DoE 2013b)	grazing/trampling of vegetation)		
		Human disturbance (e.g. coastal and port infrastructure developments)	N	
		Shale oil mining (potential threat on the Queensland coast)	N	
		Climate change	N	
		Predation (potential threat e.g. by introduced predators)	N	The key threats are outside the scope of this OPP as they relate to terrestrial pathways
		Invasive species (e.g. weed species)	N	
Curlew sandpiper[P] Eastern curlew[P]	Conservation advice on curlew sandpiper (*Calidris ferruginea*) (May 2015) (DoE 2015h) Conservation advice on eastern curlew (*Numenius madagascariens-is*) (May 2015) (DoE 2015i)	Ongoing human disturbance (in coastal areas and shoreline habitats)	N	The key threats are outside the scope of this OPP as they relate to disturbances in coastal areas and loss of intertidal mudflat habitat at key migration staging sites in the Yellow Sea. Consideration is given to these species in the context of habitat degradation from pollution associated with unplanned waste management (Section 8.4.6) and emergency/unplanned events (Section 8.4.8).
		Habitat (intertidal mudflats) loss and degradation from pollution		
		Changes to the water regime and invasive plants (in coastal areas and shoreline habitats)		
Australian lesser noddy[P]	Conservation advice on Australian lesser noddy (*Anous tenuirostris melanops*) (October 2015) (DoE 2015j)	Habitat loss from pollution	Y	Section 8.4.7, Section 8.4.8
		Habitat loss from catastrophic weather events	N	The key threats are outside the scope of this OPP
		Overfishing		
		Feral animals		
Red knot[P]	Conservation advice on red knot (*Calidris canutus*) (May 2016) (DoE 2016a)	Pollution/contamination	Y	Section 8.4.7, Section 8.4.8
		Habitat loss and habitat degradation (e.g. through land reclamation, industrial use and urban expansion, changes to the water/hydrological regime, loss of marine or estuarine vegetation, invasive plants and environmental pollution of foraging and roosting sites)	N	The key threats are outside the scope of this OPP as they relate to disturbances to foraging/roosting sites in coastal areas. Consideration is given to this species in the context of habitat degradation from pollution associated with unplanned waste management (Section 8.4.6)

Species	EPBC Management Plan/Recovery Plan/ Conservation Advice	Key Threats Identified in relevant Management Plan/ Recovery Plan/ Conservation Advice	Relevant?	Cross-reference to OPP Impact and Risk Evaluation
				and emergency/unplanned events (Section 8.4.8).
		Climate change	N	The key threats are outside the scope of this OPP
		Diseases		
		Disturbance (human-related, e.g. from recreational activities including fishing, boating, four-wheel driving, walking dogs, noise and night lighting)	N	These key threats are outside the scope of this OPP as they relate to disturbances from activities that are coastal related or are not directly relevant to the project. Consideration is given to this species in the context of disturbance from night lighting (Section 8.4.2).
		Direct mortality (e.g. wind farms, bird strike with vehicles and aircraft, hunting, chemical spills and oil spills)	N	These key threats are outside the scope of this OPP as they relate to disturbances from activities that are not directly relevant to the project. Consideration is given to this species in the context of disturbance from chemical/ oil spills (Section 8.4.8).
Great knot	Conservation advice on great knot (*Calidris tenuirostris*) (May 2016) (DoE 2016b)	Pollution/contaminants	Y	Section 8.4.7, Section 8.4.8
		Habitat loss and degradation (e.g. through land reclamation, industrial use and urban expansion, changes to the water regime, invasive plants, water quality deterioration and environmental pollution)	N	The EPBC Protected Matters search has not recorded the species within the project area. Some of the key threats are also outside the scope of this OPP. Consideration is given to this species in the context of habitat degradation from pollution associated with unplanned waste management (Section 8.4.6) and emergency/unplanned events (Section 8.4.8).
		Climate change	N	The key threats are outside the scope of this OPP
		Diseases		
		Direct mortality – hunting		
		Disturbance (human-related, e.g. from recreational activities including fishing, boating, four-wheel driving, walking dogs, noise and night lighting)	N	These key threats are outside the scope of this OPP as they relate to disturbances from activities that are coastal related or are not directly relevant to the project.

Species	EPBC Management Plan/Recovery Plan/ Conservation Advice	Key Threats Identified in relevant Management Plan/ Recovery Plan/ Conservation Advice	Relevant?	Cross-reference to OPP Impact and Risk Evaluation
Abbott's booby[P]	Conservation advice on Abbott's booby (October 2015) (DoE 2015k)	Loss of rainforest habitat	N	Not applicable – the key threats are outside the scope of this OPP
		Introduced terrestrial species (e.g. yellow crazy ant)		
Greater sand plover Lesser sand plover	Conservation advice on greater sand plover (*Charadrius leschenaultii*) (May 2016) (DoE 2016c) Conservation advice on Lesser sand plover (*Charadrius mongolus*) (May 2016) (DoE 2016d)	Pollution/contamination	Y	Section 8.4.7, Section 8.4.8
		Habitat loss and degradation (e.g. loss of marine or estuarine vegetation, land clearing, intertidal reclamation, changes to the water/ hydrological regime, changes in water quality, hydrology or structural changes near roosting sites, water pollution, and residential, farming, industrial and aquaculture/fishing activities)	N	The EPBC Protected Matters search has not recorded the species within the project area. Some of the key threats are also outside the scope of this OPP. Consideration is given to this species in the context of habitat degradation from pollution associated with unplanned waste management (Section 8.4.6) and emergency/unplanned events (Section 8.4.8).
		Climate change	N	The key threats are outside the scope of this OPP
		Diseases		
		Disturbance (human-related, e.g. from recreational activities including fishing, boating, four-wheel driving, walking dogs, noise and night lighting)	N	These key threats are outside the scope of this OPP as they relate to disturbances from activities that are coastal related or are not directly relevant to the project.
		Introduced species (invasion of intertidal mudflats by terrestrial weeds)	N	The key threat is outside the scope of this OPP as it relates to terrestrial pathways
		Direct mortality (e.g. from collision with large structures (e.g. wind farms) or vehicles/aircraft, commercial hunting and predation)	N	The EPBC Protected Matters search has not recorded the species within the project area. The key threats are also outside the scope of this OPP.
Northern Siberian bar-tailed godwit	Conservation advice on bar-tailed godwit (northern Siberian) (*Limosa lapponica menzbieri*) (May 2016) (DoE 2016e)	Pollution/contamination	Y	Section 8.4.7, Section 8.4.8
		Habitat loss and degradation (e.g. loss of marine or estuarine vegetation, changes to the water/hydrological regime, reduced river flows, intertidal reclamation, environmental pollution,	N	The EPBC Protected Matters search has not recorded the species within the project area. Some of the key threats are also outside the scope of this OPP. Consideration is given to this species in the context of

Species	EPBC Management Plan/Recovery Plan/ Conservation Advice	Key Threats Identified in relevant Management Plan/ Recovery Plan/ Conservation Advice	Relevant?	Cross-reference to OPP Impact and Risk Evaluation
		industrial use and urban expansion)		habitat degradation from pollution associated with unplanned waste management (Section 8.4.6) and emergency/unplanned events (Section 8.4.8).
		Climate change	N	The key threats are outside the scope of this OPP
		Diseases		
		Disturbance (human-related, e.g. from recreational activities including fishing, boating, four-wheel driving, walking dogs, noise and night lighting)	N	These key threats are outside the scope of this OPP as they relate to disturbances from activities that are coastal related or are not directly relevant to the project.
		Introduced species (invasion of intertidal mudflats by terrestrial weeds)	N	The key threat is outside the scope of this OPP as it relates to terrestrial pathways
		Direct mortality (e.g. from collision with large structures (e.g. wind farms) or vehicles/aircraft, commercial hunting and predation)	N	The EPBC Protected Matters search has not recorded the species within the project area. The key threats are also outside the scope of this OPP.
Christmas Island frigatebird	Conservation advice on Christmas Island frigatebird *(Fregata andrewsi)* (DoE 2016f) National recovery plan for the Christmas Island Frigatebird (*Fregata andrewsi*) (Hill and Dunn 2004)	Habitat loss, disturbance and modifications (e.g. deforestation (past threat) and phosphate dust)	N	The key threats are outside the scope of this OPP
		Fishing (e.g. mortality from bycatch, poisoning and shooting and starvation due to overfishing of large predatory fish)		
		Invasive species (e.g. weeds and potential threats due to yellow crazy ants, cats and rats)		
		Climate change (e.g. increased frequency of severe storms and increased sea surface temperatures) (future threats)		

[P] The species was identified as potentially occurring or having habitat in the project area.

6.5.6.4 Fish

The Timor Sea supports a variety of fish species of high conservation value as well as fisheries of commercial and recreational importance. The current state of knowledge of fishing activities within the project area in a socio-economic and indigenous use context is discussed further in **Section 6.6.9** and **Section 6.6.10**.

A search of the EPBC Act Protected Matters database identified 30 fish species that may occur or have habitat in the project area, and 52 species which may occur in the area of influence. These are ray-finned fishes and are either pipefish or seahorses (family Syngnathidae). All species of Syngnathidae are listed marine species under the EPBC Act. These species may pass through the offshore waters of the project area but are more likely to be associated with the shallow waters around the nearby shoals/banks (**Section 6.4.4**) and close to the WA coastline where benthic communities provide suitable shelter and foraging habitats (DSEWPaC 2012g). Knowledge about the distribution, abundance and ecology of Syngnathidae within the NWMR is limited, however, almost all species live in nearshore and inner shelf habitats, usually in shallow coastal waters (DSEWPaC 2012g).

Fish Communities at Shoals

Fish communities found at the submerged shoals within the area of influence are described in **Section 6.4.4**. In summary, the pelagic biota of the shoals were found to be similar to those on coral reefs and biologically rich. Of the species recorded, 97% were teleost fish with the remainder consisting predominantly of sharks and rays.

6.5.6.5 Sharks and Rays

The NWMR has a rich fauna of sharks and rays due to the diverse marine habitats within the region's waters (DSEWPaC 2012h). A search of the EPBC Act Protected Matters database identified twelve listed threatened and/or migratory shark and ray species that may occur in or have habitat in the area of influence. Listed threatened shark and ray species (five of which are also listed as migratory) were the great white shark (*Carcharodon carcharias;* vulnerable), speartooth shark (*Glyphis glyphis*; critically endangered), northern river shark (*Glyphis garricki*; endangered), green sawfish (*Pristis zijsron*; vulnerable), largetooth sawfish (*Pristis*; vulnerable) and dwarf sawfish (*Pristis clavata*; vulnerable).

The listed migratory species of shark and rays that may occur within the area of influence include the narrow sawfish (*Anoxypristis cuspidata*), longfin mako (*Isurus paucus*), shortfin mako (*Isurus oxyrinchus*), reef manta ray (*Manta alfredi*) and giant manta ray (*Manta birostris*).

Whale Shark

The whale shark (*Rhincodon typus*; vulnerable) is globally distributed in tropical and warm temperate waters, and it is thought individuals form one single genetic population (DoE 2015l). Key areas of concentration within Australian waters include the Ningaloo coast (March – July), Christmas Island (December – January) and the Coral Sea (November – December), with the timing of the aggregations thought to be linked to seasonal fluctuations in prey abundance (DoE 2015l). The species is an epipelagic filter feeder; therefore, their diet typically consists of planktonic and nektonic species, including small crustaceans and smaller schooling fish species (DoEE 2018aa; DoE 2015l).

Whale sharks are known to be highly migratory with migrations of 13,000 km being recorded (Eckert and Stewart 2001). Migration along the northern WA coastline broadly follows the 200 m isobath and typically occurs between July and November (DoE 2015l).

A biologically important area for whale sharks is located in northern WA, offshore of the Pilbara and Kimberley coastline, and broadly follows the 200 m isobath (**Figure 6-29**; DoEE 2018aa). The BIA is listed as a foraging habitat, however the Conservation Advice (DoE 2015l) for this species indicates this BIA up the north west coast is a migration corridor than significant foraging habitat. This is consistent with tagging studies; Meekan and Radford (2010) showed that whale sharks migrated up the coast from Ningaloo Reef and dispersed individually over a broad migratory area either north-west into the open Indian Ocean, northward towards Sumatra and Java, or north-east towards the Timor Sea. The project area and area of influence intersect a portion of this BIA. Therefore, whale sharks are expected to transit through the project area as part of their broad migratory movement.

Great White Shark

The great white shark (*Carcharodon carcharias*; vulnerable) was identified by the EPBC Protected Matters database search as potentially occurring within the project area. The species is primarily temperate, however, there are no known aggregation sites within the NWMR and the species is most likely to be found south of North West Cape (some 1,400 km south-southwest of the project area) (DSEWPaC 2012h). Ongoing research into the seasonal movements of this species along the WA coast suggests great white sharks travel northward during spring, returning to more southern waters in summer (DoEE 2018ab). Little information is available on reproductive activities of great white sharks in Australian waters, with no pupping grounds having been identified (DSEWPaC 2012h).

Due to their relatively wide ranging and migratory behaviour along the WA coast, it is likely that great white sharks may transit the project area.

Mako

The shortfin mako (*Isurus oxyrinchus*; migratory) and longfin mako (*Isurus paucus*; migratory) were identified by the EPBC Protected Matters database search as potentially occurring in the project area and area of influence. The shortfin mako is a highly migratory epipelagic species widely distributed in tropical and temperate waters of temperatures above 16 °C (Groeneveld et al. 2014). The distribution and biology of the longfin mako is less well documented, however, it is also an epipelagic shark inhabiting tropical and warm-temperature waters (Reardon et al. 2006). Makos exhibit sexual and developmental segregation; juveniles spend 90% of their time near the surface whereas adults dive much deeper (Groeneveld et al. 2014).

There are no known BIAs for the shortfin or longfin mako within the area if influence. Due to their migratory nature and known species distribution it is possible that these species may transit the project area.

Sawfish

The listed threatened (vulnerable) dwarf sawfish (*Pristis clavata*), green sawfish (*Pristis zijsron*) and largetooth sawfish (*Pristis pristis*) occur mainly in inshore coastal waters and riverine environments in northern Australia. Considering declining global populations of these sawfishes, northern and north-west Australia may contain the last significant populations of these species (DSEWPaC 2012h).

The dwarf sawfish is primarily a coastal and estuarine species and juveniles appear to remain in estuarine waters only. Individuals have been shown to show site fidelity and maintain a coastal fringe of just a few square kilometres (DSEWPaC 2012h). The largetooth sawfish has been recorded in river, estuarine and marine environments within north-west Australia. Newborns and juveniles occur primarily in the freshwater areas of rivers and in estuaries, while adults mostly occupy marine and estuarine environments

(DSEWPaC 2012h). The green sawfish does not occupy freshwater habitats and has been recorded in depths of up to 70 m. However, it is predominately recorded as occurring in inshore coastal areas, including estuaries and river mouths (DSEWPaC, 2012h). It is therefore unlikely that these species of sawfish will transit the project area. There are BIAs for all three sawfish species along the WA coastline within the area of influence, as shown in **Figure 6-29**.

Rays

The giant manta ray (*Manta birostris;* migratory) and reef manta ray (*Manta alfredi*; migratory) are globally distributed in both tropical and temperate waters. Whilst considered the more solitary of the two species, the giant manta ray is often sighted in high numbers to engage in foraging, mating or cleaning activities (Marshall et al. 2011a). The giant manta ray also exhibits seasonality in habitat preference and is known to frequent offshore seamounts and islands, including the Cocos Islands (Marshall et al. 2011a). The giant manta ray is less frequently sighted than the reef manta ray (Marshall et al. 2011a).

The reef manta ray typically utilises productive nearshore habitats, including island groups, atolls and continental coastlines (Marshall et al. 2011b). However, the species has been known to undertake coastal migrations of significant distances and traverse international waters. As with the giant manta ray, this species is often sighted in high numbers, predominately when undertaking foraging activities as a group or migrating.

There are no known foraging or breeding aggregation areas for these species within the project area. Based on the nearshore habitat preference of both the giant manta ray and reef manta ray, and the offshore location of the project area, it is considered highly unlikely that they will occur in significant numbers in this area. If present, they would most likely be restricted to individuals transiting through the area.

Speartooth Shark and Northern River Shark

Sharks of the genus *Glyphis* are considered among the most threatened elasmobranchs worldwide and appear to have limited habitat preferences (Stevens et al. 2005). The speartooth shark (*Glyphis glyphis;* critically endangered) has been recorded as occurring in riverine and marine environments, and juveniles and sub-adults reportedly utilise large tropical river systems as their primary habitat (Stevens et al. 2005; DSEWPaC 2010c). It is thought that their marine distribution may be limited to the coastal marine environment outside of rivers, much like that of the bull shark (DSEWPaC 2010c). Northern river sharks (*Glyphis garricki;* endangered) also exhibit segregation during developmental stages and similarly occupy rivers, tidal sections, large tropical estuarine systems, macrotidal embayments, inshore and offshore marine habitats (DSEWPaC, 2010d). The northern river shark has been recorded in offshore waters, however, the frequency of this occurrence is unknown.

Within WA speartooth sharks are known to occur historically in the Cambridge Gulf, however, remaining populations (throughout Australia) are considered isolated and their viability is therefore questionable. The northern river shark has a wider known distribution including locations in the west and east Kimberley (DSEWPaC 2010c, 2010d). Both species were listed threatened in 2001 due to their limited geographical distribution and low population estimates of mature individuals which was considered likely to continue to decline (DSEWPaC 2010c, 2010d). Given their typically limited distribution in proximity to estuarine environments, neither species are expected to transit the project area.

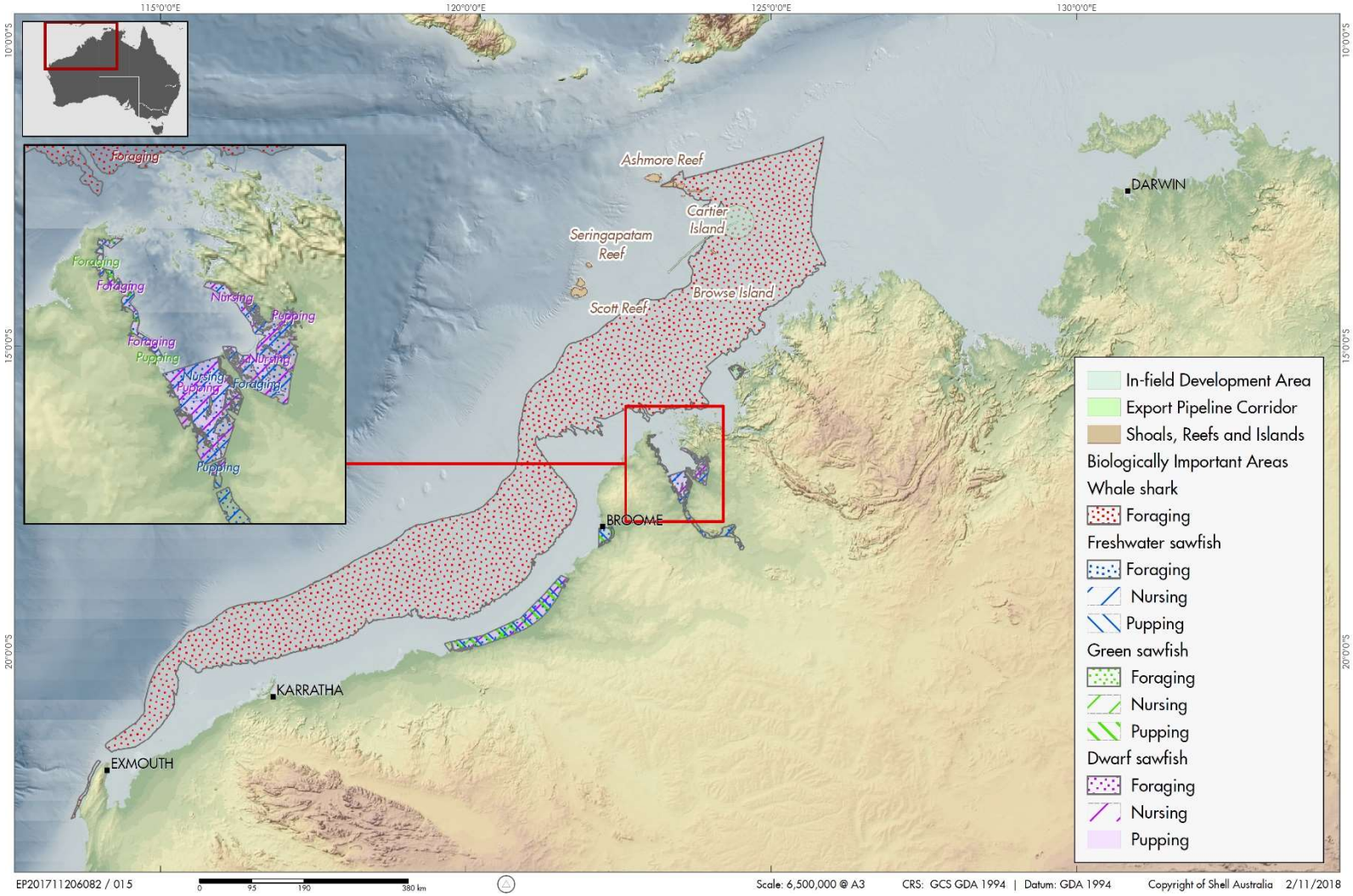


Figure 6-29: Biologically Important Areas for Sharks and Rays

EPBC Management/Recovery Plans and Conservation Advices

The EPBC Management/Recovery Plans and conservation advices for the shark and ray species identified in the EPBC Protected Matters searches for the project area and area of influence are summarised in **Table 6-13**.

Table 6-13: Summary of EPBC Management/Recovery Plans and Conservation Advices Relevant to Sharks and Rays

Species	EPBC Management Plan/Recovery Plan/ Conservation Advice	Key Threats Identified in relevant Management Plan/ Recovery Plan/ Conservation Advice	Relevant?	Cross-reference to OPP Impact and Risk Evaluation
Whale shark[P]	Whale shark (*Rhincodon typus*) Recovery Plan (2005) (May 2005) (DEH 2005a) Conservation advice on whale shark (*Rhincodon typus*) (October 2015) (DoE 2015l)	Habitat disruption from mineral exploration, production and transportation	Y	Section 8.4.1
		Vessel strike	Y	Section 8.4.1
		Pollution and marine debris	Y	Section 8.4.6, Section 8.4.7
		Intentional/ unintentional mortality from fishing outside of Australian waters (principle threat)	N	The key threats are outside the scope of this OPP
		Climate change		
		Disturbance from tourism operations		
Great white shark[P]	Recovery Plan for the White Shark (*Carcharodon carcharias*) (August 2013) (DSEWPaC 2013b)	Habitat modification/ degradation (e.g. development, pollution) (note, coastal habitat degradation and anthropogenic activities in near-coast areas are of primary relevance as they are often a preferred habitat)	Y	Section 8.4.1, Section 8.4.6, Section 8.4.7, Section 8.4.8
		Accidental (bycatch) or illegal (targeted) capture by commercial and recreational fisheries (including issues of post release mortality)	N	The key threats are outside the scope of this OPP
		Shark control activities (e.g. beach meshing or drum lining)		
		Illegal trade		
		Climate change		
		Ecotourism		

Species	EPBC Management Plan/Recovery Plan/ Conservation Advice	Key Threats Identified in relevant Management Plan/ Recovery Plan/ Conservation Advice	Relevant?	Cross-reference to OPP Impact and Risk Evaluation
Speartooth shark Northern river shark[P] Green sawfish[P] Largetooth sawfish[P] Dwarf sawfish	Sawfish and River Sharks Multispecies Recovery Plan (November 2015) (DoE 2015m) Conservation advice on speartooth shark (*Glyphis glyphis*) (April 2014) (DoE 2014c), northern river shark (*Glyphis garricki*) (April 2014) (DoE 2014d), dwarf sawfish (*Pristis clavata*) (October 2009) (DEWHA 2009b) and green sawfish (*Pristis zijsron*) (2008) (DEWHA 2008b)	Habitat degradation and modification (note, the recovery plan focusses on river and estuarine barriers that affect the migration of river sharks/sawfish)	Y	Section 8.4.1, Section 8.4.6, Section 8.4.7, Section 8.4.8
		Marine debris (potential threat)	Y	Section 8.4.6
		Fishing activities including being caught as by-catch and illegal, unreported and unregulated fishing (principle threat)	N	The key threats are outside the scope of this OPP
		Collection for display in public aquaria (potential threat)		

[P] The species was identified as potentially occurring or having habitat in the project area.

6.6 Socio-economic and Cultural Environment

The primary focus for the socio-economic and cultural setting of the Crux project is the existing marine users and interests relevant to the offshore context of the NNM platform and supporting infrastructure in Commonwealth marine waters, reflecting the scope of this OPP. Given the remote distance of the proposed Crux platform (approximately 190 km offshore north-west Australia and 620 km north-north-east of Broome), there are limited socio-economic interactions, expected to be primarily related to other marine users (specifically other marine traffic, oil and gas facilities and commercial fishing).

In the future operations phase, it is expected that the Crux project will utilise the onshore facilities (Broome and Darwin) used to service the Prelude FLNG facility, and leveraging the established supply chain, logistics and community partnerships that have been embraced by Shell and its supply chain partners to date. Specifically, Crux will use the same logistics arrangements as the Prelude FLNG facility, to take advantage of existing infrastructure, such as infield support vessels and helicopters. As for the Prelude FLNG facility, it is expected people movements will occur through fixed wing commercial flights to Broome and then rotary wing transport to field, with helicopter re-fuelling stops as required at the Djarindjin Airport. For marine movements, it is envisaged the supply chain will mainly operate through the existing Shell supply base in Darwin, utilising the platform support vessel or other vessels as required. While the onshore support facilities are not specifically within the scope of this OPP, an overview of the existing socio-economic environment of the communities of Broome and Darwin are provided for context and consistent with Shell's internal impact assessment requirements.

Local content is a core element of Shell's operations, and is prioritised alongside safety, environment, performance and cost.

6.6.1 Kimberley Region

The Kimberley region is remote from metropolitan areas, with the major towns of Broome being 2,213 km and Kununurra being 3,205 km from Perth by road. Other major towns include Derby, Halls Creek, Wyndham and Fitzroy Crossing. Throughout the region there are over 100 Aboriginal communities of varying population sizes.

The most populous local government area in the Kimberley region is the Shire of Broome, with approximately 43% of the regional population (Department of Regional Development 2014).

Broome is also the regional employment hub and a significant centre for servicing and growing the region's industries.

The Kimberley is renowned to be rich in both natural and cultural assets and enjoys a broad-based and diverse economy (Kimberley Development Commission 2015). With a geographic area in excess of 420,000 square kilometres, equivalent to one-sixth of WA, the Kimberley has a population of 34,364 (Australian Bureau of Statistics (ABS) 2016a), with the principal towns of Broome and Kununurra having populations of 16,222 and 5,308, respectively (ABS 2016b, 2016c). As noted above, the main interaction with regional onshore communities will be limited to Broome and community of Djarindjin-Lombadina.

The Broome international airport is the largest airport in the region and will be the primary flight centre to be used for workforce to/from the Crux project when transiting through Broome. In line with our social performance policies and our commitments to acting as a good neighbour, Shell continually engages with stakeholders in Broome and Djarindjin-Lombadina and has in place existing grievance and community feedback mechanisms to facilitate community engagement.

6.6.2 Darwin

Darwin is the capital city of the NT and is located approximately 700 km to the east of the Crux platform and approximately 1,100 km north east of Broome.

Darwin has an established industrial and commercial centre and is serviced by the Darwin Port. Darwin Port's facilities predominantly serve shipping and cargo markets for livestock exports, dry bulk imports and exports, container and general cargo, cruise and naval vessels, petroleum and other bulk liquids and offshore oil and gas rig services (Darwin Port 2015). The Onshore Darwin Supply Base for the Prelude FLNG facility is located at East Arm Port in Darwin and is proposed to be used in support of the Crux project. Commercial and recreational fishing industries are both represented in Darwin, operating in Darwin Harbour (recreational only) and offshore.

6.6.3 Commonwealth Marine Area and Land

6.6.3.1 Commonwealth Marine Area

The Crux project is located within the Commonwealth marine area, which includes *"any part of the sea, including the waters, seabed and airspace, within Australia's exclusive economic zone and/or over the continental shelf of Australia, that is not state or NT waters. The Commonwealth marine area stretches from three to 200 nm from the coast"* (DoEE 2018aj).

6.6.3.2 Commonwealth Land

Commonwealth land includes land owned or leased by the Commonwealth or a Commonwealth agency, land in the external territories, and any other area of land that is included in a Commonwealth reserve (DSEWPaC 2013c).

Given the remote offshore location context of this proposal within Commonwealth waters, the consideration of Commonwealth land is only of relevance to this OPP in the context of Australia's external territories; Ashmore Reef, Christmas Island and Cocos (Keeling) Islands. These features are only relevant in the context of the area of influence and are discussed in detail in **Section 6.4.5**.

6.6.4 World Heritage Properties

There are no World Heritage properties in, or in the immediate surrounds of, the project area. Kakadu National Park, which is approximately 800 km to the east of the Crux platform, is a World Heritage Property relevant only in the context of the area of influence (**Figure 6-30**).

Kakadu National Park encompasses an area 19,804 km^2 and was made a World Heritage Property due to its outstanding natural and cultural values (DoEE 2018ac). The National Park has been cared for by generations of Aboriginal people known as Bininj/Mungguy and boasts rock art documenting one of the longest historical records of any group of people in the world. The National Park is also known as a biodiversity hotspot with a number of rare species of birds, mammals, reptiles and plants (DoEE 2018ac). While the majority of the National Park encompasses the NT mainland, the site also includes the mangrove-fringed coast from Wildman River to East Alligator River and offshore islands of Barron Island and Field Island in the Van Diemen Gulf (DoEE 2018ac).

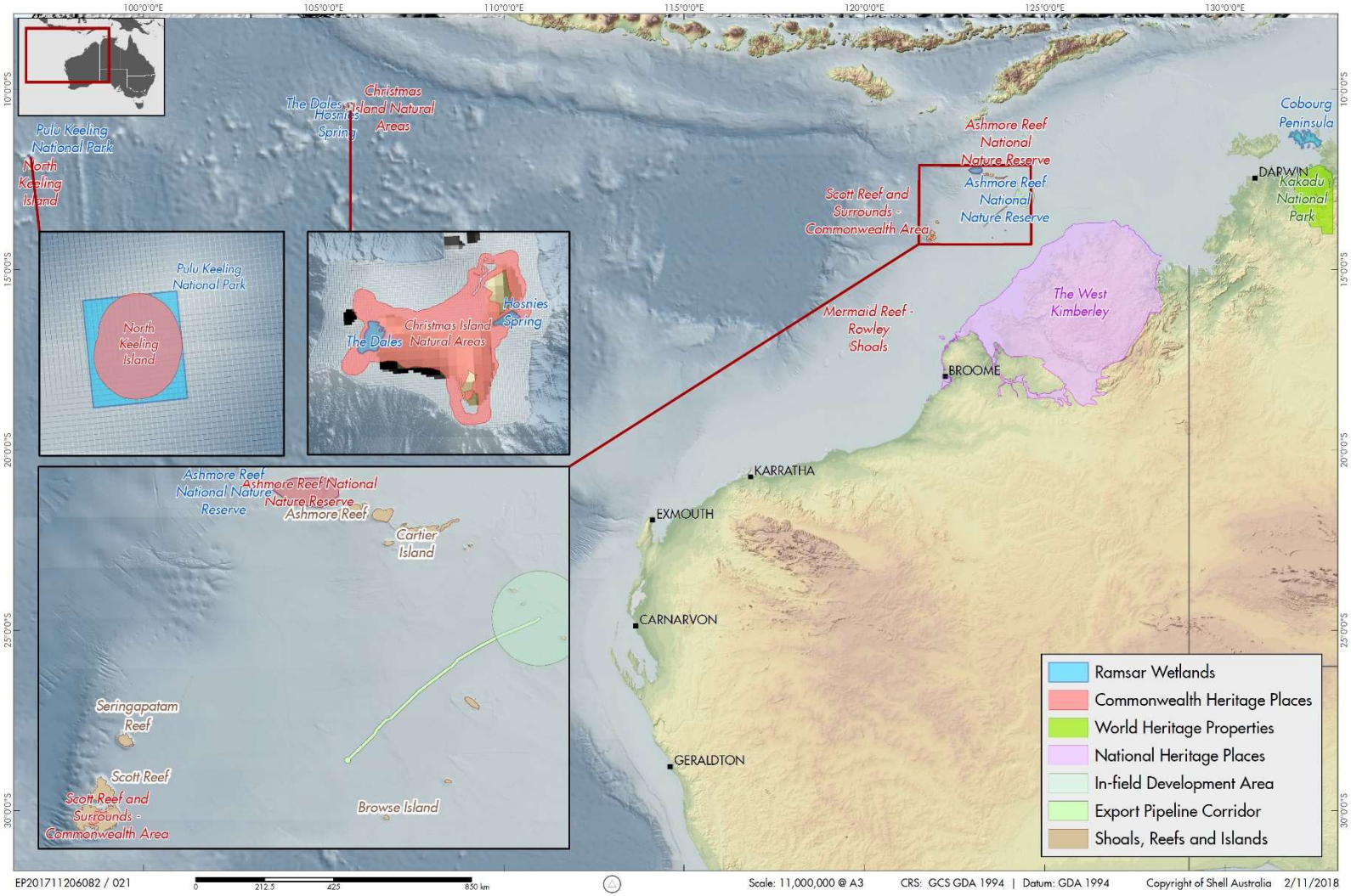


Figure 6-30: Heritage Properties, Places and Ramsar Wetlands

6.6.5 National Heritage Places

The National Heritage List is Australia's list of natural, historic and Indigenous places of outstanding significance to the nation. There are no National Heritage properties in, or in the immediate surrounds of, the project area. Within the area of influence, the West Kimberley National Heritage Place is listed as a National Heritage Place and is located approximately 170 km from the Crux platform.

The West Kimberley is known for its ancient geology, Aboriginal culture, stunning landscapes, and biological richness (DoEE 2018ad). The West Kimberley coastline includes a range of landforms, including cliffs, rocky headlands, sandy beaches, rivers, waterfalls and numerous islands located off the coast. The West Kimberley holds extensive history of Aboriginal people who have lived in the area for at least 40,000 years. The West Kimberley also provides remnant habitats for many native animals and plants which are now absent elsewhere in Australia (DoEE 2018ad).

6.6.6 Commonwealth Heritage Places

The Commonwealth Heritage List is a list of Indigenous, historic and natural heritage places owned or controlled by the Australian Government. The project is not located in, or in the immediate surrounds of, any Commonwealth Heritage places. There are a number of Commonwealth Heritage Places within the area of influence. These are listed in **Table 6-14**, with a supporting summary of their key values as Commonwealth Heritage Places.

Table 6-14: Commonwealth Heritage Places within the Project Area of Influence

Commonwealth Heritage Place	Approximate Distance from the Crux Platform (km)	Description
Ashmore Reef National Nature Reserve	149	The Ashmore Reef National Nature Reserve protects Ashmore Reef, a large platform reef with coral reefs, sand flats and three vegetated islands (DoEE 2018ae; see also **Section 6.4.5**). Specific values of this site include: • breeding and foraging habitat for marine turtles • considered to have the world's greatest abundance and diversity of sea snakes • habitat for 569 species of fish, 255 species of corals and 433 species of mollusc, as well as species not previously recorded or rarely recorded in Australia • an important seabird rookery and provides an important staging/feeding area for many seabirds and migratory shorebirds (Environment Australia 2002), and • breeding and feeding habitat for a small dugong population (< 50 individuals) (DoEE 2018ae)
Scott Reef and surrounds	291	Scott Reef (see also **Section 6.4.5**) is considered regionally important for the following features: • high diversity of marine fauna, including corals, fish and marine invertebrates • physical characteristics of the reefs create environmental conditions which are rare for shelf atolls, including clear deep oceanic water and large tidal ranges that provide a high physical energy input to the marine ecosystem • high representation of species not found in coastal waters off WA and for the unusual nature of their fauna which has affinities with the oceanic reef habitats of the Indo-West Pacific, as well as the reefs of the Indonesian region, and • important for scientific research and benchmark studies into long term geomorphological and reef formation

Commonwealth Heritage Place	Approximate Distance from the Crux Platform (km)	Description
		processes due to the age of the reef and the documentation of its geophysical and physical environmental characteristics (DoEE 2018af)
Mermaid Reef – Rowley Shoals	688	Mermaid Reef (see also **Section 6.4.5**) is one of three reef systems, located 30 – 40 km apart, which make up the Rowley Shoals. The shoal consists of a reef flat roughly 500 to 800 m wide, shallow back reefs and a large lagoon. The Rowley Shoals have been described as the most perfectly formed shelf atolls in Australian waters, and the clear, deep water and large tidal range of the atolls are considered rare environmental conditions for shoals (DoEE 2018ag). The specific values of Mermaid Reef include: • high diversity of marine reef fauna, including corals, fish and marine invertebrates (DoEE 2018ah) • important area for sharks, marine turtles and toothed whales, dolphins, tuna and billfish • important resting and feeding site for migratory seabirds (DoEE 2018ah) • regionally significant due to the presence of many species not found in inshore tropical waters of Northern Australia, and species that are close to their geographical ranges (DoEE 2018ah; DoEE 2018ag). Includes 216 species of fish, 39 species of mollusc and seven species of echinoderms (DoEE 2018ag), and • considered a genetic stepping stone between the Indonesian archipelago and reefs to the south (DoEE 2018ag).
North Keeling Island	3,000	The North Keeling Island forms the northern atoll of the Cocos (Keeling) Islands (see also **Section 6.4.5**). The island is significant as it is: • one of the remaining pristine islands in the Indian Ocean • the only seabird rookery within 900 km • home to rare species including robber crabs and the buff banded rail, and • important habitat for crabs, and provides nesting area for marine turtles and the red footed booby (DoEE 2018ae).
Christmas Island Natural Areas	2,060	This 1,220 km^2 listing includes the entirety of Christmas Island (see also **Section 6.4.5**). The site has the following values: • a unique ecosystem which makes the study of species evolution in relative isolation possible, as well as the study of adaptions of migrant species to new habitats • a diverse range of land crabs • globally significant seabird island with regards to both diversity and abundance, and • unique relict populations of black-mangrove species and cycads, including a globally significant wetland (DoEE 2018ae)

6.6.7 Declared Ramsar Wetlands

There are no “Wetlands of International Importance” under the Convention on Wetlands of International Importance (Ramsar 1975) in, or in the immediate surrounds of, the project area. The area of influence, however, encompasses a number of Ramsar Wetlands. A summary of the values relevant to each Ramsar site is provided in **Table 6-15**.

Table 6-15: Ramsar Wetlands within the Project Area of Influence

Ramsar Wetland	Approximate Distance from the Crux Platform (km)	Description
Ashmore Reef National Nature Reserve (now part of Ashmore Reef Marine Park)	149	The Ashmore Reef Marine Park, also a KEF (see **Section 6.4.7**), was designated a Ramsar site primarily due to its importance in supporting large seabird breeding colonies and as a resting place for migratory shorebirds. The boundary of the Ramsar site coincides with the Marine Park (Hale and Butcher 2013). Notably, Ashmore Reef has been managed for conservation purposes for more than 30 years. The five wetland types that have been identified within this Ramsar site are permanent shallow marine waters, sand, shingle or pebble shores, marine subtidal aquatic beds, coral reefs, and intertidal mud, sand or salt flats. Each of these wetland types are in near natural condition and have been recorded as having low densities of coral predators and disease (Hale and Butcher 2013). The three islands of the Ramsar site are the only vegetated islands in the Timor Province bioregion. At the time of listing, this Ramsar site boasted 62 threatened species, including 42 coral, five sea cucumber, eight fish, six reptile and one mammal species. Historically, the site was also significant with regards to sea snake abundance and diversity. The site supports breeding and/or foraging areas for green, loggerhead and hawksbill turtles, and breeding areas for dugongs (Hale and Butcher 2013). The site has been identified as hotspot of biological diversity within the Timor province bioregion, and broader NWMR.
Cobourg Peninsula	817	The Cobourg Peninsula Ramsar site is located in the NT, approximately 163 km north-east of Darwin. The site was the first Ramsar Wetland in the world, designated for its diversity of coastal and inland wetland habitats, support for populations of endangered species and life-cycle functions (BMT WBM 2011). Wetland types include coral reefs, rocky marine shores, intertidal mud, sand or salt flats, karst, and intertidal marshes. Notably, the majority of the site is terrestrial land, with large areas of Eucalypt-dominated woodlands, and does not support wetland habitat (BMT WBM 2011). Whilst the site contains no towns or settlements the area has been inhabited continuously for at least 50,000 years, and therefore has significant cultural characteristics.
"The Dales" Christmas Island	2,074	The Dales Ramsar site refers to a system of seven watercourses within the Christmas Island National Park (Butcher and Hale 2010). Three of The Dales support permanent streams and four support intermittent streams. These are predominately surrounded by semi-deciduous forest and a range of karst features typical of Christmas Island (Butcher and Hale 2010). The Ramsar site boasts nine wetland types, including coral reefs, karst and other subterranean hydrological systems, and freshwater, tree-dominated wetlands (Butcher and Hale 2010). The site features many endemic and rare species of plants and animals. The Dales features habitats which support roosting and breeding habitat for seabirds and migratory birds, including populations of the endangered Abbott's Booby and vulnerable Christmas Island frigatebird (Butcher and Hale 2010).

Ramsar Wetland	Approximate Distance from the Crux Platform (km)	Description
Hosnies Spring Christmas Island	2,060	The Hosnies Spring Ramsar site refers to a freshwater spring which surrounds terrestrial vegetation and a small portion of coast within the Christmas Island National Park (Hale and Butcher 2010). The Ramsar site was expanded from approximately 0.3 ha to 202 ha in 2010 in order to provide greater protection for unique freshwater mangrove stand estimated to be 120,000 years old. These mangroves occur at an elevation which has not been recorded elsewhere in the world (Hale and Butcher 2010). The site features a permanent, shallow freshwater wetland fed by a natural spring system, surrounded predominately by rainforest. This is one of the few permanent freshwater features on Christmas Island. Three wetland types have been identified in the Hosnies Spring Ramsar site; permanent rivers/streams/creeks, freshwater, tree dominated wetlands, and freshwater springs; oases (Hale and Butcher 2010). The site also encompasses shallow coral reefs and supports a number of crab, wetland and terrestrial bird species (Hale and Butcher 2010).
Pulu Keeling National Park	3,002	Pulu Keeling National Park Ramsar site is comprised of the uninhabited North Keeling Island, the northernmost island in the Cocos Islands atoll. The Ramsar site boundary coincides with the Pulu Keeling National Park (Hale 2010). The site comprises approximately 122 ha of land above the high water mark and 2,480 ha of surrounding coral reef and sea (Hale 2010). The four main wetland types identified within the site are marine subtidal aquatic beds, coral reefs, rocky marine shores, and sand, shingle or pebble shores. The site supports a number of seabirds including large breeding colonies of the EPBC listed red-footed booby and lesser frigatebirds, and resident populations of the endangered buff-banded rail (Hale 2010; DoEE 2018ai). Fish fauna within the Ramsar site are considered unique due to the mixing and hybridisation of species from the Cocos (Keeling) Islands and Christmas Island, many of which are at their geographical limits at this location (Hale 2010).

6.6.8 Marine Parks

A search of the EPBC Protected Matters Database confirmed that the project area does not overlap with any Australian Marine Parks (AMPs). However, there are a number of AMPs within the area of influence (refer **Figure 6-31**). In addition, there are a number of State/Territory Marine Parks/Management Areas that are within the area of influence (refer **Figure 6-32**). These Marine Parks/Management Areas are described in **Table 6-16**.

Table 6-16: Marine Parks and Management Areas within the Project Area of Influence

Marine Park	Approximate Distance from the Crux Platform (km)	Description
AMPs – NWMR		
Argo-Rowley Terrace	460	The 146,099 km^2 Argo Rowley Terrace Marine Park comprises 83,379 km^2 of Multiple Use Zone (IUCN Category VI) and 62,720 km^2 of

Marine Park	Approximate Distance from the Crux Platform (km)	Description
		Marine National Park Zone (IUCN Category II). The depth ranges between 220 m and 6,000 m. It is important for foraging areas for migratory seabirds and the endangered loggerhead turtle as well as sharks. It provides connectivity between the Mermaid Reef Marine Park. The area includes canyons linking the Argo Abyssal Plain with the Scott Plateau, which is a unique seafloor feature with enhanced productivity and feeding aggregations of species (DoEE 2018ak).
Ashmore Reef	150	The 583 km^2 Ashmore Reef Marine Park comprises a Sanctuary Zone (IUCN category Ia) and a Recreational Use Zone (IUCN category II). It provides an important area for a number of EPBC listed species, including sea snakes, marine turtles, dugongs and migratory seabirds. Ashmore Reef also supports important cultural and heritage sites, such as Indonesian artefacts and grave sites. In 2003, the Ashmore Reef Marine Park was declared a Ramsar Wetland of International Importance due to its conservation values (refer to **Section 6.6.7** for further information) (DoEE 2018al).
Cartier Island	100	The Cartier Island Marine Park covers a reasonably small area (172 km^2) and is comprised of a Sanctuary Zone (IUCN category Ia). The Marine Park provides an important area for a number of EPBC listed species, including sea snakes, turtles and migratory seabirds. Additionally, it supports some of the most important seabird rookeries on the NWS (DoEE 2018am).
Dampier	1,100	The Dampier Marine Park comprises an area of 1,252 km^2, with a Marine National Park Zone (IUCN Category II) and a Habitat Protection Zone (IUCN Category IV). Conservation values for the Marine Park include important staging areas for migratory seabirds, and nesting and foraging areas for marine turtles. It also contains an important migratory pathway for the humpback whale. It also provides a high level of protection for offshore shelf habitats adjacent to the Dampier Archipelago and for the shallow shelf with a depth range of 15 m–70 m (DoEE 2018an).
Eighty Mile Beach	707	Eighty Mile Beach Marine Park comprises a 10,785 km^2 Multiple Use Zone. It contains major foraging areas for migratory seabirds, marine turtles, and part of the migratory pathway for humpback whales. It also contains important foraging, nursing and pupping areas for freshwater, green and dwarf sawfish. The Marine Park provides protection for the shelf with depths ranging from 15 m to 70 m (DoEE 2018ao).
Gascoyne	1,424	The Gascoyne Marine Park encompasses an area of 81,766 km^2 and is comprised of a Multiple Use Zone (IUCN Category VI), Habitat Protection Zone (IUCN Category IV) and Marine National Park Zone (IUCN Category II). The reserve provides protection to many seafloor features and to sponge gardens, as well as providing important foraging areas for seabirds, marine turtles and the whale shark. The reserve also provides a corridor of connectivity from shallow depths of approximately 15 m to deep offshore waters on the abyssal plain at more than 5,000 m depth (DoEE 2018ap).
Kimberley	95	The 74,469 km^2 Kimberley Marine Park is comprised of a National Park Zone (IUCN category II), Habitat Protection Zone (IUCN category IV, specifically intended to protect humpback whale calving) and Multiple Use Zone (IUCN category VI). The marine parks numerous conservation values include the provision of important foraging areas for migratory seabirds, dugongs, dolphins, marine turtles and a migration pathway and nursery areas for humpback whales. The Marine Park also lies adjacent to important foraging and pupping areas for sawfish and important nesting sites for green turtles.

Marine Park	Approximate Distance from the Crux Platform (km)	Description
		The Marine Park ranges in depth from less than 15 m to 800 m and provides protection for the communities and habitats of waters offshore of the Kimberley coastline. Ancient coastline and continental slope demersal fish communities are two KEFs are represented in the reserve (refer to **Section 6.4.7**) (DoEE 2018aq). The Kimberley Marine Park supports or is adjacent to recreational and commercial fishing, tourism activities and areas of Native Title claims and determinations (DoEE 2018aq).
Mermaid Reef	675	The 540 km^2 Mermaid Reef Marine Park is a key area for over 200 species of hard corals and 12 classes of soft corals with coral formations in pristine condition. It is also an important area for sharks, marine turtles, toothed whales, dolphins, tuna and billfish. The Marine Park also has important nesting and feeding sites for migratory seabirds. Mermaid Reef Marine Park is listed on Australia's Commonwealth Heritage List due to its conservation values (DoEE 2018ah).
Montebello	1,197	The Montebello Marine Park comprises a 3,413 km^2 Multiple Use Zone. The area is important for foraging for migratory shorebirds, and breeding and foraging for migratory seabirds and marine turtles. It contains an important migratory pathway for humpback whales and whale sharks, and foraging areas for whale sharks. The Marine Park has a KEF; the ancient coastline at 125 m depth contour (refer to **Section 6.4.7**) (DoEE 2018ar).
Ningaloo	1,181	The Ningaloo Marine Park ranges in depth from approximately 15 to 150 m and encompasses a total area of 2,435 km^2. The entire Marine Park is an IUCN Category II Recreational Use Zone. The Marine Park provides foraging areas to whale sharks and marine turtles, as well as forming part of the migratory pathway for the humpback whale. This relatively shallow Marine Park provides protection for shelf and slope habitats, pinnacles and terrace seafloor features (DoEE 2018as).
Roebuck	610	The Roebuck Marine Park comprises a 304 km^2 Multiple Use Zone (IUCN Category VI). It includes part of the migratory pathway for humpback whales, as well as foraging areas for flatback turtles and migratory seabirds. It is adjacent to important foraging, nursing and pupping areas for freshwater, green and dwarf sawfish, and foraging and calving areas for Australian snubfin, Indo-pacific humpback and Indo-pacific bottlenose dolphins. The Marine Park provides protection for shallow shelf habitats with a depth range of 15 m to 70 m (DoEE 2018at).
AMPs – NMR		
Arafura	917	The Arafura Marine Park is a 22,924 km^2 IUCN Category VI Multiple Use Zone. The Marine Park includes important resting (or internesting) areas for marine turtles, as well as important foraging habitat for breeding aggregations of the migratory roseate tern. The tributary canyons of the Arafura Depression, a unique seafloor feature, occur within this Marine Park (DoEE 2018au).
Arnhem	990	The Arnhem Marine Park ranges in depth from 5 m to 30 m. It is a 7,125 km^2 IUCN Category VI Special Purpose Zone. The marine park has important internesting habitat for the flatback turtle, as well as important foraging habitat for three species of tern (DoEE 2018av).
Joseph Bonaparte Gulf	407	The Joseph Bonaparte Marine Park ranges in depth from approximately 5 m to 75 m and comprises a Multiple Use Zone (IUCN Category VI) and Special Purpose Zone (IUCN Category VI) to total an area of 8,597 km^2. The Marine Park provides important foraging area for marine turtles and the Australian snubfin dolphin. The carbonate banks of the Joseph Bonaparte Gulf, a unique seafloor feature typified

Marine Park	Approximate Distance from the Crux Platform (km)	Description
		by enhanced productivity and high biodiversity, falls within this Marine Park (DoEE 2018aw).
Oceanic Shoals	182	The Oceanic Shoals Commonwealth Marine Park comprises a 71,743 km^2 area, with a large proportion (39,964 km^2) designated as Multiple Use Zone (IUCN Category VI). There are smaller areas designated for National Park Zone (Category II, 406 km^2), Habitat Protection Zone (Category IV, 6,929 km^2), and Special Purpose Zone for Trawling (Category VI, 10,461 km^2). The depth ranges between approximately 5 m and 500 m. The Marine Park provides important foraging areas for loggerhead and olive ridley turtles, as well as important internesting areas for flatback and olive ridley turtles. KEFs represented in the reserve are carbonate banks, pinnacles and the shelf break and slope of the Arafura Shelf (further detail in **Section 6.4.7**) (DoEE 2018ax).
WA Marine Parks		
Barrow Island Marine Park and Barrow Island Marine Management Area	> 1,263	The Barrow Island Marine Park and Barrow Island Marine Management Area are located approximately 180 km north-east of Exmouth and encompass 42 km^2 and 115 km^2 of marine habitat respectively (DEC 2007a). The managed area is characterised by coral reefs, macroalgal and seagrass communities, subtidal soft-bottom communities, rocky shores, intertidal reef platforms and mangrove communities (DEC 2007a). These habitats in turn support nesting turtles, breeding seabird populations, humpback whales and dugongs (DEC 2007a).
Montebello Islands Marine Park	1,246	The Montebello Islands Marine Park covers approximately 583 km^2 and encompasses over 250 islands and islets (DBCA 2017). The habitats provided by the various reef systems, lagoons, channels and island coastline support a highly diverse array of marine flora and fauna including dugongs, cetaceans and nesting turtles (DBCA 2017).
Eighty Mile Beach Marine Park	742	The Eighty Mile Beach Marine Park covers approximately 2,000 km^2. Intertidal sand and mud flats within the Marine Park, support nesting flatback turtles and are recognised as a site of international importance for foraging migratory shorebirds (DPaW 2014). The Marine Park is known to have a high level of endemism and high diversity of benthic infauna (DPaW 2014).
Ningaloo Marine Park and Muiron Islands Marine Management Area	1,430	The Ningaloo Marine Park and Muiron Islands Marine Management Area encompass a 2,900 km^2 area within the Ningaloo Coast World Heritage Area (DBCA 2018). Both the Marine Park and Management Area include a diversity of mangrove systems, lagoons, reef, continental slope and the continental shelf habitats (DBCA 2018). The Marine Park is an important feeding and breeding area for whale sharks, manta rays, marine turtles, dugongs, seabirds and cetaceans, and supports a large number of fish species.
Rowley Shoals Marine Park	720	The Rowley Shoals Marine Park (approximately 877 km^2) is characterised by complex intertidal and subtidal reefs which support diverse marine fauna, including more than 233 species of coral and 688 species of fish (DEC 2007b). The reefs are thought to be a source of recruitment for invertebrates and fish on reefs further south due to conveyance by the Leeuwin Current (DEC 2007b).
Lalang-garram/ Horizontal Falls Marine Park and North Lalang-	330	The Lalang-garram/Horizontal Falls and North Lalang-garram Marine Parks encompass approximately 3,530 km^2 and 1,100 km^2, respectively, and include coastal gorges, estuaries, bays, offshore islands, and a vast intertidal area (DPaW 2016a). The marine parks provide important foraging and nursery areas for dugongs, turtles, estuarine crocodile, humpback whales, dolphins, sawfish, manta rays,

Marine Park	Approximate Distance from the Crux Platform (km)	Description
garram Marine Park		sea snakes and migratory seabirds and shorebirds (DPaW 2016a). The subtidal habitat also supports a diverse filter feeding community.
Lalang-garram/ Camden Sound Marine Park	245	The Lalang-garram/Camden Sound Marine Park encompasses approximately 7,050 km^2 of marine habitat including numerous islands and reefs (DPaW 2013). The Marine Park supports turtles, snubfin and Indo-pacific humpback dolphins, dugongs, saltwater crocodiles, and several species of sawfish (DPaW 2013). Camden Sound is also the biggest calving area for humpback whales in the southern hemisphere (Jenner et al. 2001).
North Kimberley Marine Park	160	The 18,450 km^2 North Kimberley Marine Park features geomorphologically complex and varied seascapes and marine habitats, including bays and estuaries with mangroves, sandy beaches, coral reefs, rocky reefs, seagrass meadows and sponge gardens. There are in excess of 1,000 islands within the Marine Park which provide valuable intertidal and subtidal habitats utilised by manta rays, dugongs, dolphins, turtles, sawfish and seabirds/shorebirds (DPaW 2016b).
Yawuru Nagulagun/ Roebuck Bay Marine Park	610	The 780 km^2 Yawuru Nagulagun/Roebuck Bay Marine Park is recognised as being regionally, nationally and internationally significant (DPaW 2016c). Roebuck Bay in particular (a Ramsar wetland, see **Section 6.6.7**) provides habitat for internationally significant numbers of migratory birds, as well as supporting dugongs, dolphins, humpback whales and turtles (DPaW 2016c).
NT Marine Parks		
Garig Gunak Barlu National Park	814	The marine component of the Garig Gunak Barlu National Park (previously known as the Cobourg Marine Park) encompasses the waters surrounding the Cobourg Peninsula (NT Government 2012). The National Park supports a variety of marine habitats such as rocky reefs, mangroves and mudflats, which in turn support diverse and abundant marine life, including reef and pelagic fish species, coral reefs, and seagrass. Seabirds, crocodiles, turtles and dugong are also supported by these waters (NRETAS 2011).

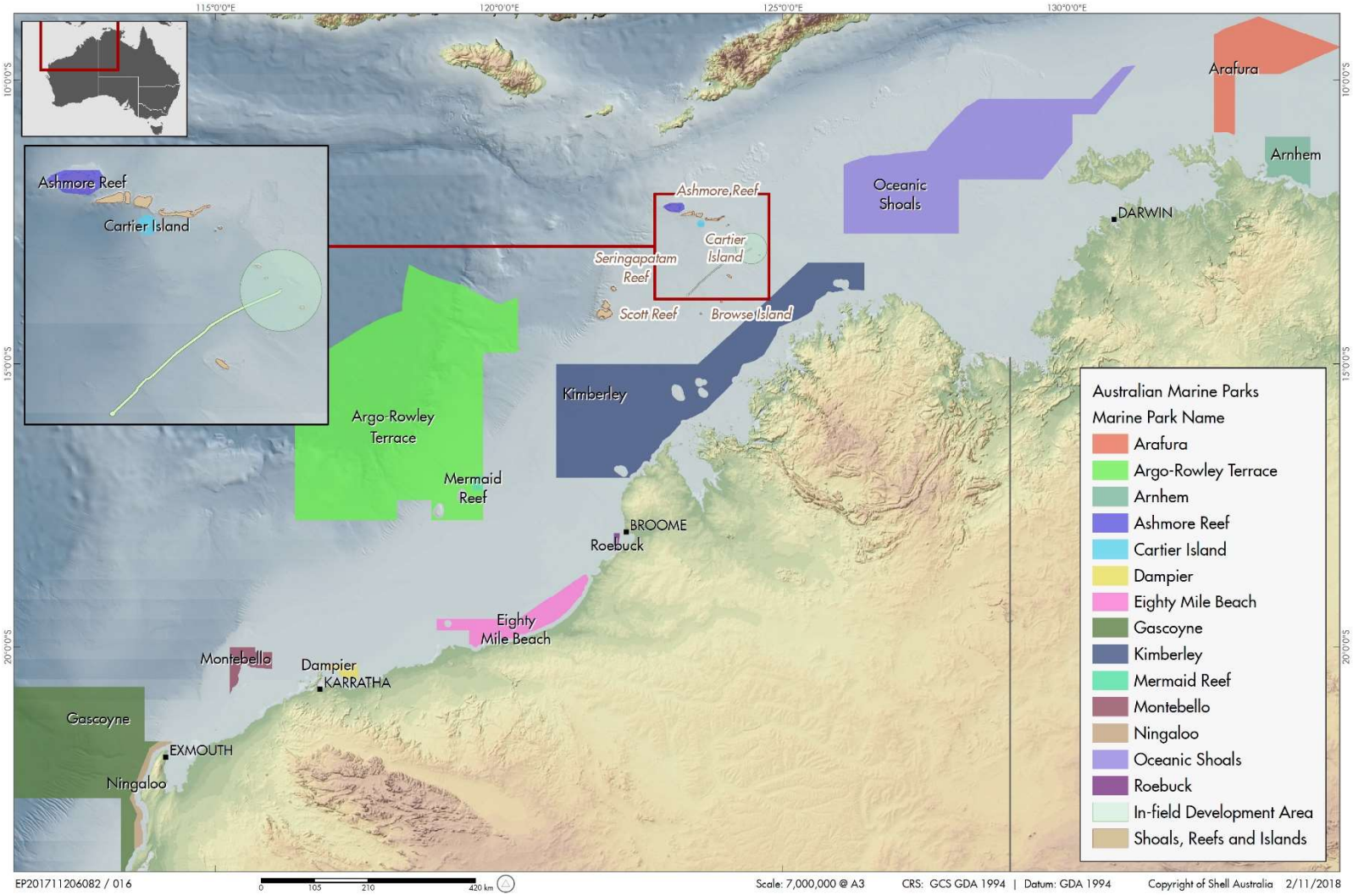


Figure 6-31: Australian Marine Parks

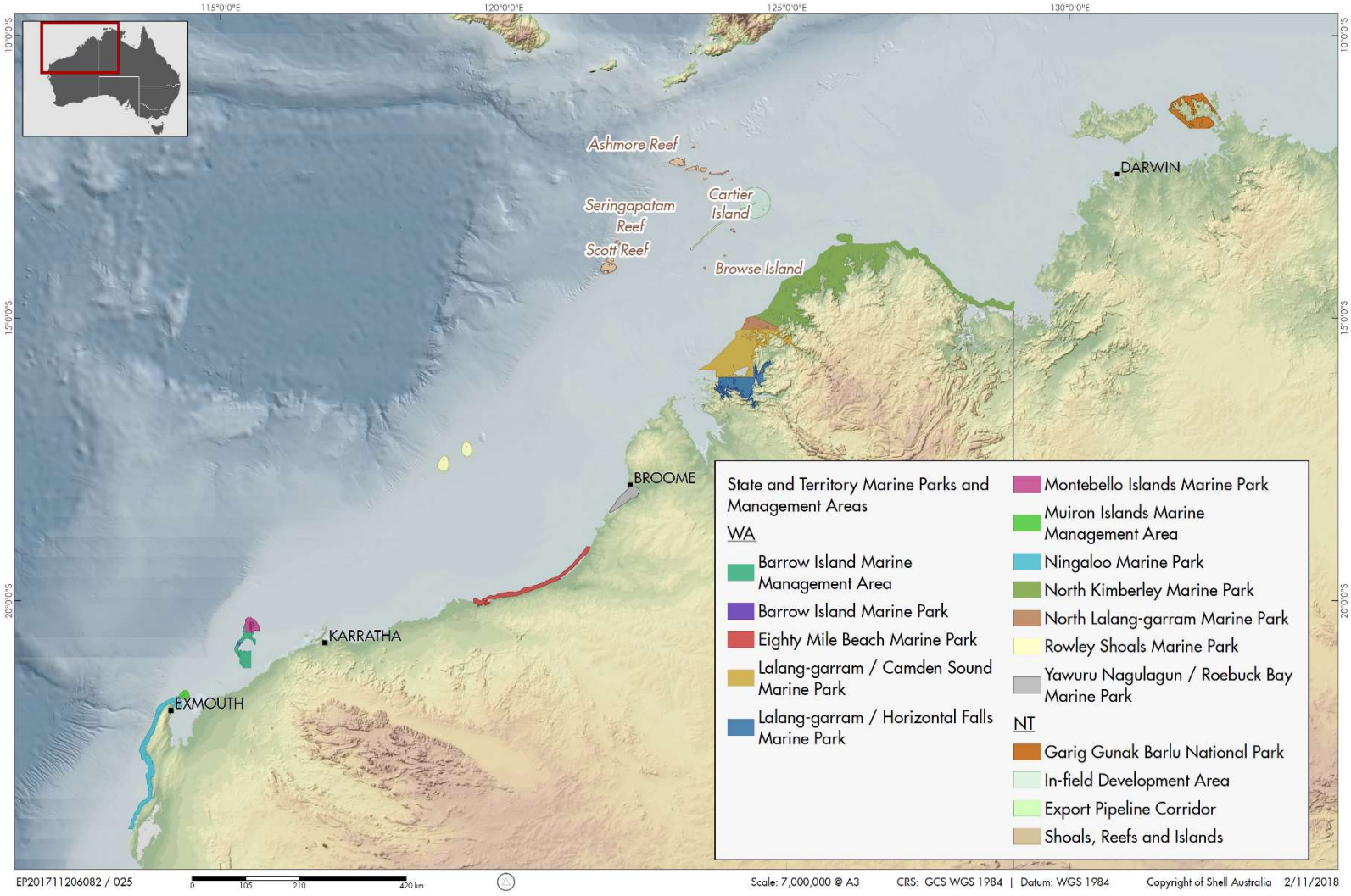


Figure 6-32: State/Territory Marine Parks/Management Areas

6.6.9 Commercial Fisheries

The project area overlaps with a variety of Commonwealth and WA State commercial fishing management areas, and this section identifies fisheries interests within the broader area of influence. Commercial fishing is typically concentrated mostly in coastal waters and minimum fishing effort is known to occur within the vicinity of the project area, given its remoteness offshore. This assessment will be validated through direct communication with fishers who have interests in the area (see **Section 4**).

6.6.9.1 Commonwealth Fisheries

There are six Commonwealth managed commercial fisheries occurring with the area of influence (as shown in **Figure 6-33**). Of these, four fisheries management areas are indicated to overlap the project area – the North West Slope Trawl Fishery (NWSTF), Western Tuna and Billfish Fishery, Western Skipjack Fishery, and the Southern Bluefin Tuna Fishery.

A description of each of the Commonwealth managed commercial fisheries relevant to the Crux project context, with a summary of current status, is provided in **Table 6-17**.

Only one of these fisheries, the NWSTF demonstrated active fishing effort within proximity of the project area (approximately 50 km south of the export pipeline) in the 2015–16 season (Patterson et al. 2017). In addition, the Western Deepwater Trawl Fishery historically focuses fishing effort in relative proximity to the project area, however, no effort was recorded for the entire fishery during the 2015–16 season. This follows a period of reduced fishing effort over a number of years (Patterson et al. 2017).

6.6.9.2 WA Managed Fisheries

There are ten WA managed commercial fisheries occurring within the area of influence (**Figure 6-34**). Of these, seven WA fisheries management areas are indicated to occur in the project area – the Northern Demersal Scalefish Fishery, Mackerel Fishery, Northern Shark Fishery, Pearl Oyster Fishery, Specimen Shell Managed Fishery, Marine Aquarium Fish Managed Fishery, and the West Coast Deep Sea Crustacean Fishery.

A description of each of the WA managed commercial fisheries relevant to the Crux project context, with a summary of current status, is provided in **Table 6-18**.

6.6.9.3 NT Managed Fisheries

The project area does not directly overlap with any fisheries in NT waters. However, NT fisheries are relevant in the context of the broader area of influence and are described below for completeness.

The NT commercial fisheries occurring within the area of influence are shown in **Figure 6-35**, and further described in **Table 6-19**. These fisheries primarily operate in the NT "Top End" in nearshore island and mainland waters, including intertidal zones. Exceptions to this include the Demersal Fishery, Timor Reef Fishery, situated offshore north-west of Darwin, and the Spanish Mackerel Fishery and those fisheries targeting snapper species which are known to operate in areas further offshore.

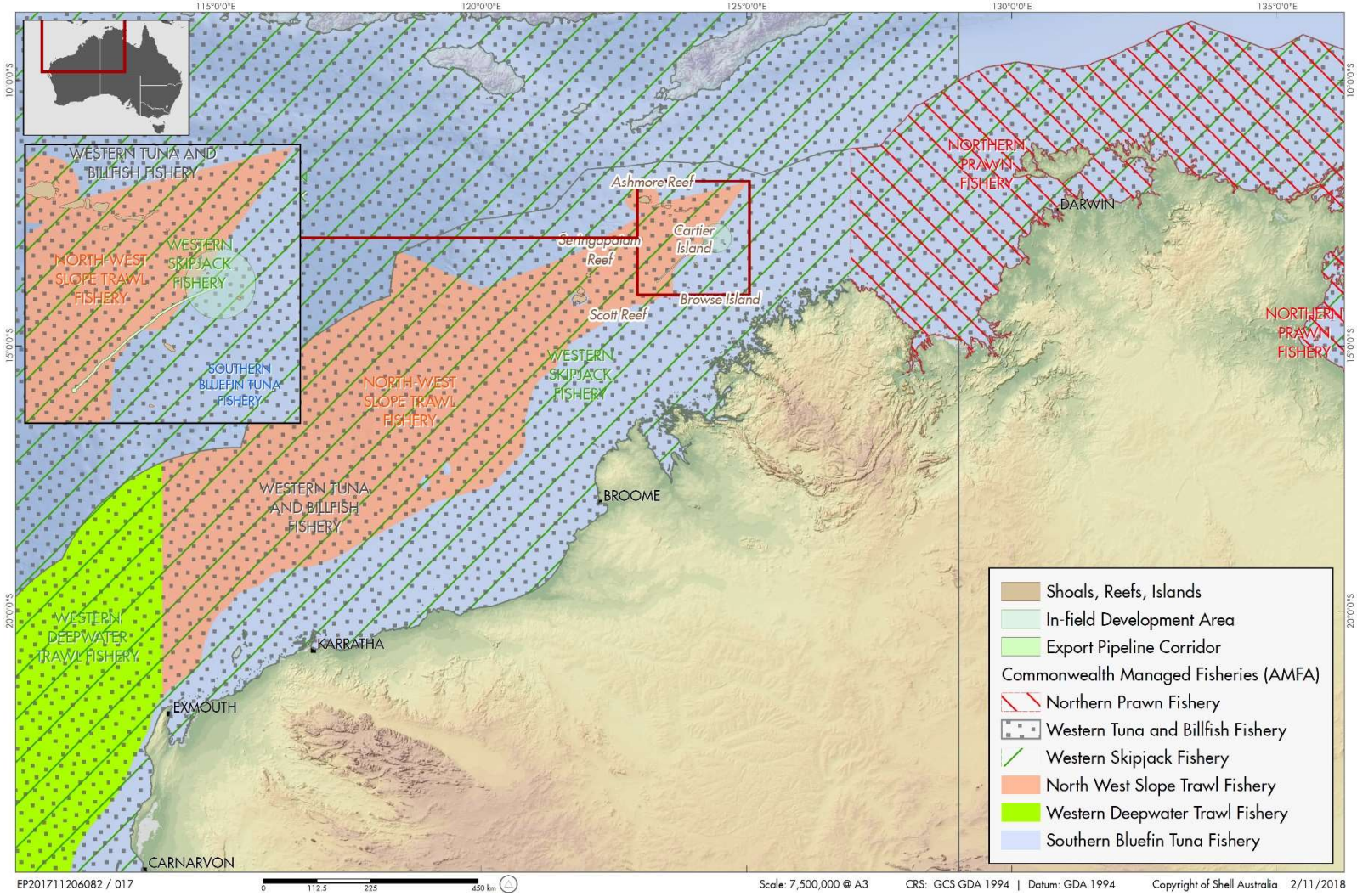


Figure 6-33: Commonwealth Managed Commercial Fisheries in the Area of Influence

Table 6-17: Commonwealth Managed Fisheries Occurring within the Area of Influence

Commercial Fishery	Description	Method	Number of Licences/Vessels and Effort
North West Slope Trawl Fishery (NWSTF)	The NWSTF operates within the 200 m isobath and the AFZ, between 114 E and 125 E. The Memorandum of Understanding (MoU) box; refer to **Section 6.6.10** for detail) falls within this fishery. Target species is scampi, including Australian scampi, velvet scampi and Boschma's scampi.	The NWSTF primarily uses demersal trawl methods.	Since 2008–09 the number of active fishing vessels per season has been one to two. Total catch for the 2015–16 season was 54.8 tonnes from two fishing vessels, 33 tonnes of which was scampi. There were five fishing permits in the 2015–16 season.
Western Tuna and Billfish Fishery	Fishery operates within the Australian Exclusive Economic Zone and the high seas of the Indian Ocean. Key species in the fishery are swordfish, striped marlin, yellowfin tuna and bigeye tuna.	Main method is pelagic longline with some minor-line fishing.	After peaking in 2000 at 50 active vessels, fishing effort has declined and since 2005 there has been less than five vessels active each season. Catch effort for the fishery was 320 tonnes in the 2016 season with 95 boat statutory fishing rights (SFRs), and three active fishing vessels. Notably, whilst the fishery extends throughout the project area, fishing effort in the 2016 season did not extend north of Exmouth. Effort was concentrated off the south-west of WA and South Australia.
Western Skipjack Fishery	Fishery comprises the same area as the Western Tuna and Billfish Fishery. Part of the Skipjack Tuna Fishery which collectively describes the Western and Eastern Skipjack Tuna Fishery.	14 fishing permits for the 2015–16 season, no active vessels. No effort since the 2008–09 fishing season, coinciding with the closure of the main cannery in Port Lincoln in 2010.	Majority of fishing effort uses purse-seine gear, small amount of pole-and-line effort.
Southern Bluefin Tuna Fishery	The Southern Bluefin Tuna Fishery extends throughout the AFZ. There is a single spawning location for southern bluefin tuna located in the north-east Indian Ocean. Juveniles move southwards from this location along the WA coast.	2015–16 season: 89 SFR owners; 6 active Purse-seine and 19 active long-line vessels The majority of fishing effort is focused in the Great Australian Bight and waters off South Australia, targeting juveniles for transfer to aquaculture farming operations off Port Lincoln, South Australia. In the 2015–16 season a total effort of 5,636 tonnes was recorded for the fishery.	The majority of catch is taken by purse-seine netting methods. Pelagic long-line (of which southern bluefin tuna is bycatch) and minor line (troll and poling) catch methods are also used.
Northern Prawn Fishery	The fishery extends from the NT high tide mark to the extent of the AFZ. Target species include a number of tropical prawn species including white banana prawn, brown tiger	Otter trawl gear is used.	The total catch for the Northern Prawn Fishery was 5,807 tonnes in 2016, 375 tonnes of which was by-product species. Fifty-two permits were all utilised with 52 licensed vessels active in this season.

Commercial Fishery	Description	Method	Number of Licences/Vessels and Effort
	prawn, and grooved tiger prawn, which comprise 80% of catch.		Notably, seasonal fishing effort fluctuates naturally with variability in banana prawn availability. The highest fishing effort for the Northern Prawn Fishery is concentrated within inshore coastal areas of the Gulf of Carpentaria.
Western Deepwater Trawl Fishery	Fishery extends seaward of approximately the 200 m depth contour Target species number greater than 50, though catch is historically dominated by six commercial finfish species. In recent years, deep-water bugs (*Ibacus* spp.) have become an important target species group.	Demersal trawl fishing methods used.	There were 11 fishing permits in the 2015–16 season but no active vessels and no catch reported. This follows relatively low catch levels in recent years.

Source: Patterson et al. 2017

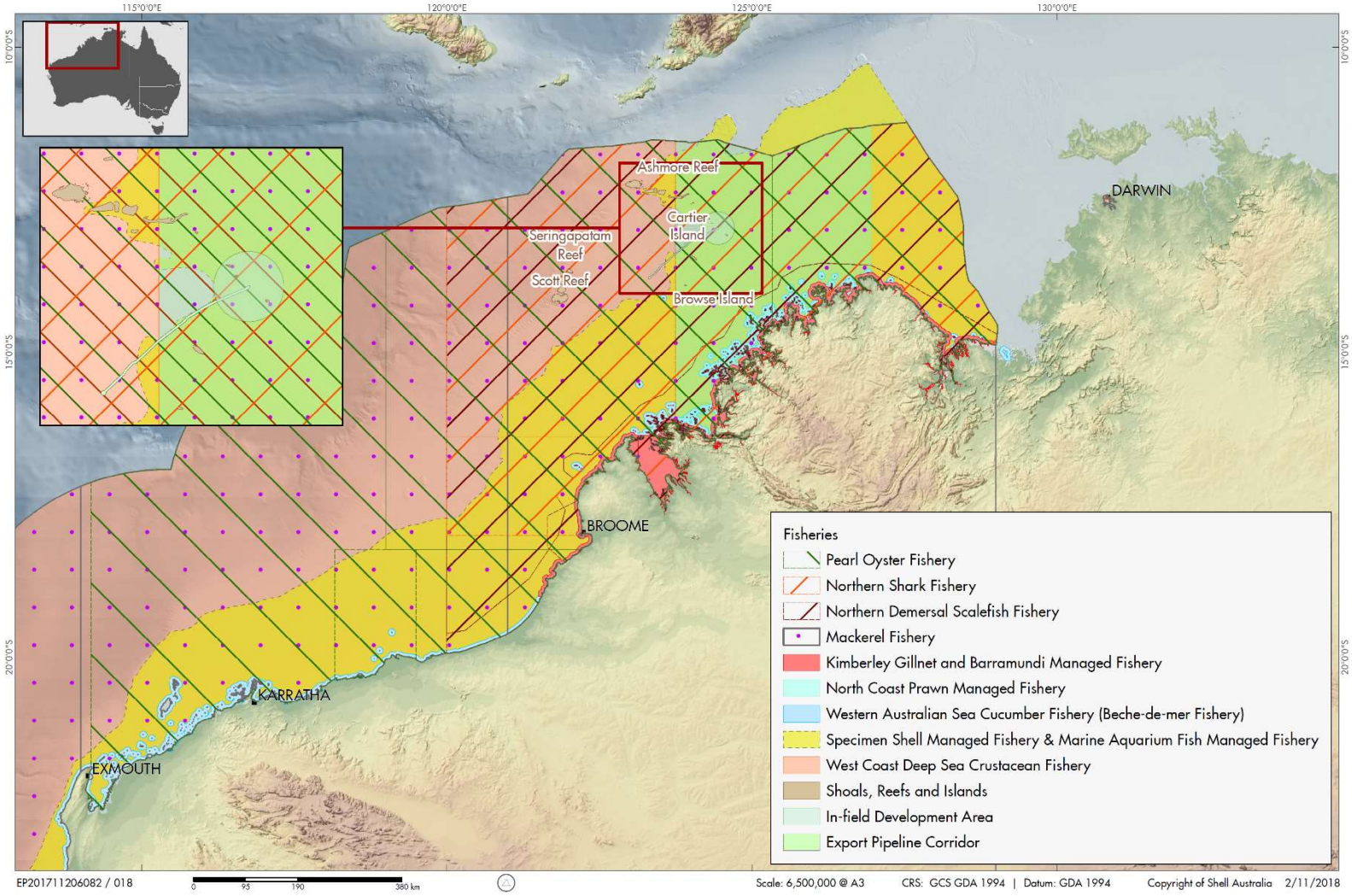


Figure 6-34: WA Managed Commercial Fisheries in the Area of Influence

Table 6-18: WA Managed Commercial Fisheries Occurring within the Area of Influence

Commercial Fishery	Description	Method	Number of Licences/Vessels and Effort
Mackerel Fishery	The Mackerel Fishery extends north from the West Coast Bioregion to the NT border (DPIRD 2018a).	Dominant fishing method is trolling, also use jigging methods to catch grey mackerel in some areas (Mackie et al. 2010).	Catch effort in the 2016 season was 276 tonnes (DPIRD 2018b). The primary fishing effort is typically concentrated in the North Coast Bioregion, which encompasses the Pilbara and Kimberley coastline (DPIRD 2018a).
Northern Demersal Scalefish Fishery	The fishery includes all waters of the Indian Ocean and Timor Sea off the north coast of WA that are east of 120° 00.079' and north of 19°59.917'. There are some restricted areas within the fishery. The fishery is divided into two fishing areas; Area 1 – inshore and Area 2 – offshore. Area 2 is further divided into Zone A, B and C (Department of Fisheries 2016).	The fishing method is restricted to either hand-line, drop-line or fish traps (Department of Fisheries 2016).	Fishing effort for the 2016 season was 1,173 tonnes (Department of Fisheries 2017).
Northern Shark Fishery	The Northern Shark Fishery comprises the WA North Coast Shark Fishery (Pilbara and Kimberley regions) and the Joint Authority Northern Shark Fishery (JANSF) (Eastern Kimberley) (DPIRD 2018b).	Pelagic net and longline fishery (DEH 2003).	No catch effort has been recorded since the 2008/09 season (DPIRD 2018b).
Pearl Oyster Fisheries	This fishery targets only the silver lipped pearl oyster (*Pinctada maxima*) and operates from Exmouth to the NT border, effort is predominately focused along the shallow coastal waters of the NWS (Fletcher et al. 2006).	This is a dive based fishery. Divers collect oysters individually as they are towed along behind the fishing vessel, using hookah or surface compressor supplied air (Fletcher et al. 2006).	Catch effort for the 2016 season was 541,260 oysters (Department of Fisheries 2017). Historically as many as 16 vessels would operate each season, however, since 2009 numbers have been much lower and only 5 were active in 2013 (WAFIC 2018a).
North Coast Prawn Fishery	This fishery is comprised of the Onslow, Nickol Bay, Broome, and Kimberley Prawn Managed Fisheries. The fishery extends south from Cape Londonderry (and the Northern Prawn Managed Fishery boundary) to the north-eastern extent of the Exmouth Gulf Prawn Fishery (WAFIC 2018b).	Trawl fishery (WAFIC 2018b). Most of the fishing occurs at night, except for targeted fishing for banana prawns which occurs mostly during the day (DPIRD 2018c).	Catch effort from the 2016 (Department of Fisheries 2017) season was: - Kimberley: 155 tonnes - Nickol Bay: 17 tonnes - Onslow: Negligible - Broome: Negligible
West Coast Deep Sea Crustacean Fishery	The fishery operates off the WA coast from 34° 24' S to the NT border, from the 150 m isobath out	Fishery uses fish traps with an average of 120 per line (Department of Fisheries 2015).	Catch effort for the 2016 season occurred primarily south of Exmouth and totalled 153.3 tonnes of crystal crab

Commercial Fishery	Description	Method	Number of Licences/Vessels and Effort
	to the Australian Exclusive Economic Zone (Department of Fisheries 2015).		(99.6% of catch) and 30 kg of champagne crab (DPIRD 2018d).
Specimen Shell Managed Fishery	Fishery encompasses the entire WA coastline between the high water mark and the 200 m isobath (DEH 2005b).	Dive based fishery (some new methods include controlled underwater vehicles at depths of 60 – 300 m, and baited habitat structures at depths) (DPIRD 2018d)	Primary areas of effort include Broome, Karratha, Shark Bay, metropolitan Perth, Mandurah, the Capes area and Albany. Total catch in 2016 was 8,531 shells (DPIRD 2018d).
Marine Aquarium Fish Managed Fishery	The fishery encompasses all WA State waters. The fishery has the capacity to target 950 marine aquarium fish species (DPIRD 2018d).	Primarily dive based using hand-held nets (DPIRD 2018d).	In recent years effort has been in waters from Esperance to Broome, with a focus around the Capes region, Perth, Geraldton, Exmouth and Dampier (DPIRD 2018b). The total catch in the Marine Aquarium Fish Managed Fishery and Hermit Crab Fishery in 2016 was 128,610 fishes, 16.4 tonnes of coral, live rock and living sand, and 75 L of marine plants (DPIRD 2018d).
Kimberley Gillnet and Barramundi Managed Fishery	This fishery operates in nearshore and estuarine zones from the NT border to the top end of Eighty Mile Beach (DPIRD 2018d).	Gillnet fishery.	There are three principal fishing areas: Cambridge Gulf (including the Ord River), Kimberley coast (six small river systems) and King Sound (DPIRD 2018b). Fishing effort for the 2016 season was 74.6 tonnes (DPIRD 2018d).
WA Sea Cucumber Fishery (formerly Beche-de-mer Fishery)	The fishery comprises all WA State waters (with some minor exceptions) (WAFIC 2018c).	Hand harvest (DPIRD 2018d)	There is only one active operator. Catch effort for 2016 was 21 tonnes sandfish, 70 tonnes sandfish, and 2 tonnes redfish (DPIRD 2018d).

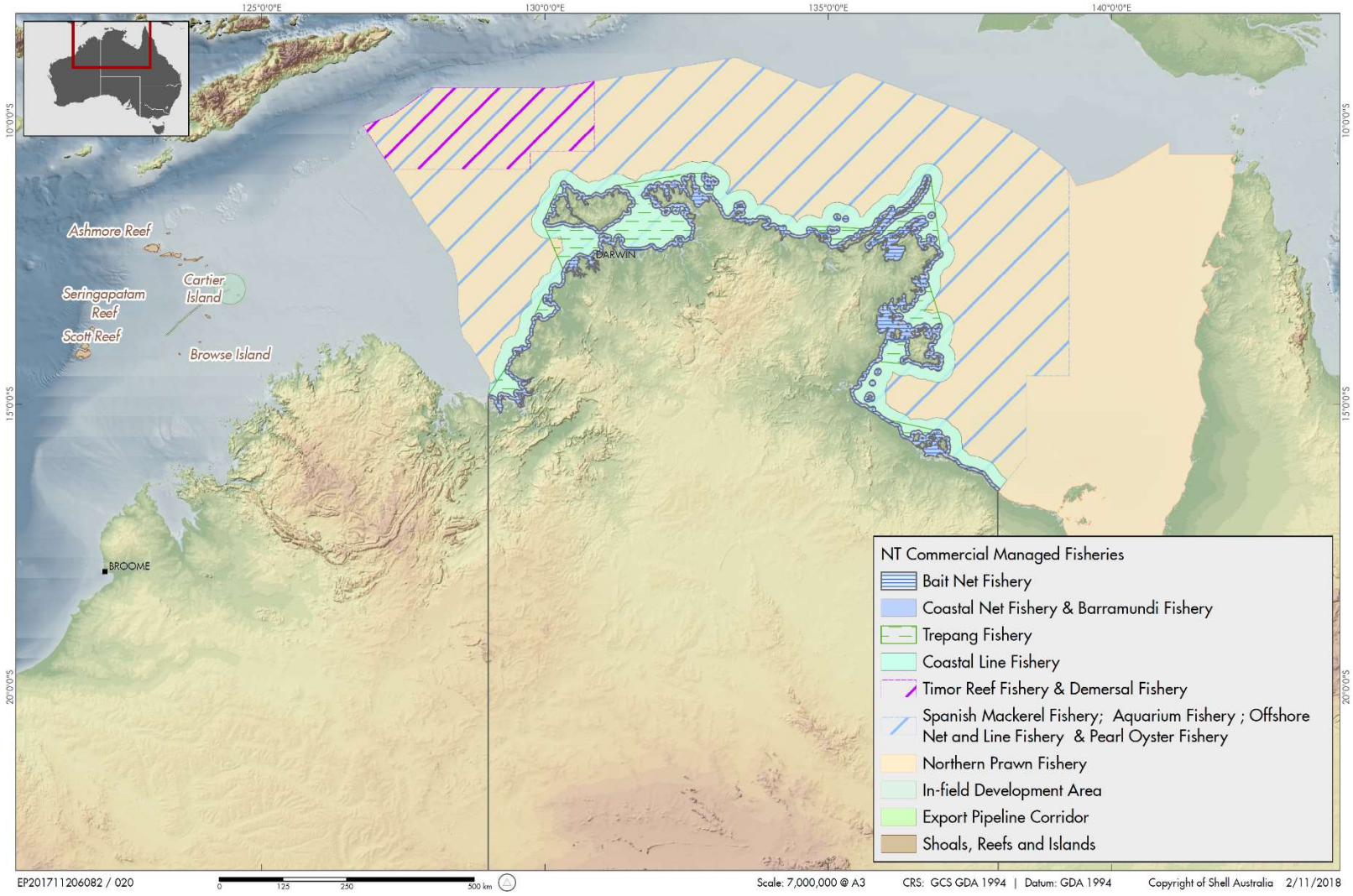


Figure 6-35: NT Managed Commercial Fisheries in the Area of Influence

Table 6-19: NT Managed Commercial Fisheries Occurring within the Area of Influence

Commercial Fishery	Description	Method	Number of Licences/Vessels and Effort
Barramundi Fishery	Fishery extends from the NT coast high water mark to three nm seaward of the low water mark. Some area exclusions apply. Fishing typically takes place over tidal mud flats and inside a restricted number of rivers. Primary species include barramundi and king threadfin.	Use of gill nets.	Catch effort in 2015 was 661 tonnes, 58% of which was Barramundi and 38% of which was king threadfin. Fishing effort is primarily focused in Anson Bay, Van Diemen Gulf, East Arnhem Land, Central Arnhem Land and Limmen Bight. Fishery is restricted to 14 licences.
Coastal Line Fishery	Fishery extends seaward from the high water mark to 12 nm from the low water mark, within the Territory water boundaries. Primary target species is Black Jewfish	Hook and line gear primarily. Also permitted to use rod and line, hand lines, cast nets (bait only), scoop nets or gaffs throughout the fishery. Restrictions apply to the use of droplines and fish traps within the fishery.	Majority of fishing effort is concentrated around rocky reeds within 150 km of Darwin. 2015 catch effort was 139 tonnes. The fishery is limited to 52 licences. All 52 are currently allocated.
Coastal Net Fishery	Fishery extends seaward 3 nm from the high water mark along the NT coast. Target species include mullets, blue threadfin, sharks and queenfish.	The fishery uses gill nets and cast nets which adhere to fishery specific specifications.	The fishery is limited to five licences. 2015 catch effort was recorded at 11.7 tonnes.
Spanish Mackerel Fishery	Fishery extends to the outer limit the AFZ from the high water mark, along the NT coastline. Target species is Spanish Mackerel.	Trolled lines, floating hand lines or rods.	Primary fishing effort is concentrated in waters near Bathurst Island, New Year Island, the Wessel Islands and the sir Edward Pellew Group of Islands. Catch effort for 2015 was 346 tonnes, 95% of which was Spanish mackerel, 5% grey mackerel. The fishery is limited to 15 licences. All licences are currently allocated.
Demersal Fishery	Fishery extends to the outer limit of the AFZ (with exclusion of the Timor Reef Fishery area) to 15 nm from the low water mark off the NT coastline.	Demersal trawl nets are restricted to two defined zones, whereas fish traps, hand lines and droplines are permitted throughout the fishery.	Catch effort in 2015 was 3,107 tonnes, primarily comprising of rad snappers and goldband snappers. There are currently 18 licences that have been issued within the fishery. Unlike other fisheries, these may not be bought or sold.
Offshore Net and Line Fishery	Fishery extends seaward to the outer limit of the AFZ from the high water mark of the NT coastline.	Pelagic gillnet (primary method) and pelagic longline methods are restricted within the fishery, whereas demersal longline gear may be used throughout.	Catch effort in 2015 was 522 tonnes (78% grey mackerel). The Fishery is limited to 17 licences, all of which are currently allocated.

Commercial Fishery	Description	Method	Number of Licences/Vessels and Effort
	Target species include Australian blacktip sharks, common blacktip sharks, spottail sharks and grey mackerel.		
Mud Crab Fishery	The Mud Crab Fishery is restricted to tidal waters of the Top End. Some areas of exclusion apply including Darwin Harbour. Primary target species is mud crabs, *Scylla* spp.	Baited pots, and restricted bait nets (gillnets) up to 100 m in length as crab bait within specific areas of the fishery.	There are 49 licences within this fishery and each licence holder is allowed 60 pots. Catch effort is focused primarily in the Gulf of Carpentaria. Catch effort in 2015 was 186 tonnes.
Aquarium Fish/Display Fishery	Fishery operates within tidal and non-tidal waters of the Top End out to the AFZ boundary. Target species include a range of fish and invertebrates, coral rubble and live rock (substrates covered in encrusting organisms).	Various methods permitted including several types of nets, hand pumps, freshwater pots and hand-held instruments.	No record of catch effort. Catch limits in place.
Trepang Fishery	This fishery is also known as the Sea Cucumber Fishery. The Fishery extends from the high water mark of the NT coastline to 3 nm offshore. Target species is sandfish and is the only species taken between 2005-15.	Hookah diving. Sea cucumbers may only be taken by hand.	Fishing effort is typically concentrated along the Arnhem land coast, from Cobourg Peninsula and Groote Eylandt. There are six licences which are owned by a single entity. Each licence is restricted to four collectors. Only four of the licences were active in 2015.
Timor Reef Fishery	Fishery operates in an 8,400 nm^2 zone, known as the Timor Box, offshore north-west of Darwin bordering the NT/WA border and the AFZ. Target species is tropical snapper species.	Fishing methods include baited traps, hand lines, droplines and demersal longlines. Trawl gear is currently being trialled in the fishery.	Catch effort in 2015 was 806 tonnes. There are currently 15 licences issued within the Fishery, licences cannot be bought or sold but new licences can be purchased.
Fishing Tour Operator Fishery	Typically comprised of a recreational and sport fishing client target group. Target species of this fishery include sport fish, with barramundi and golden snapper forming the highest portion of catch.	Primary fishing method is hook and line.	Number of licences: Not applicable. Must also hold an approved operator card as of 01/01/17. Fishing effort is typically located near coastal population centres. Approximately three quarters of catch is released with survivorship high for barramundi but not so for reed fish.
Pearl Oyster Fishery	This fishery operates from the high water mark along the NT coastline out to the AFZ.	Dive based fishery. Oysters must only be taken by hand.	There are currently five licences within this fishery. Annual catch limit is 138,000 oysters for the fishery.

Commercial Fishery	Description	Method	Number of Licences/Vessels and Effort
Bait Net Fishery	The fishery is limited three nm offshore of the high water mark. This excludes Darwin Harbour and Shoal Bay.	Bait net, cast net or scoop nets are permitted.	The fishery is limited to two licences which have been allocated. These licences cannot be bought, leased or sold.

Source: NT Government 2016; NT Government 2018b

6.6.10 Traditional Indigenous Fishing

In 1974, Australia recognised access rights for traditional Indonesian fishers in shared waters to the north of Australia, granting long-term fishing rights in recognition of the long history of traditional Indonesian fishing in the area (DAWR 2018). The resulting MoU between the Governments of Australia and Indonesia enables Indonesian traditional fishers to continue their customary practices. This includes the harvest of species such as trepang, trochus, clams, finfish, abalone, shark (for dried fins) and sponges in Australian waters, using traditional fishing methods only (Environment Australia 2002; DAWR 2018). This area is known as the 'MoU Box'.

Whilst the in-field development area is located 40 km outside of the edge of the MoU Box, the export pipeline will lie within this area. Given the shallow water target species, however, traditional Indonesian fishermen are only likely to be found in deep water areas during transit to and from the reef locations; therefore, they are unlikely to be affected by project activities.

6.6.11 Marine Archaeology

Information on historic shipwrecks is maintained in the Australian National Shipwrecks Database (ANSD), a searchable database of Australian shipwrecks containing records provided by the Australian State and Territory Governments. A search of the ANSD did not locate any shipwrecks, aircraft wrecks or other maritime cultural heritage sites in the project area (DoEE 2018ay).

The closest shipwreck to the project is the Anne Millicent, which is approximately 108 km from the proposed Crux platform, and 78 km from the proposed export pipeline corridor at its nearest point. A number of other shipwrecks occur within the area of influence; however, these are highly unlikely to be affected given they are located on the seabed and they are distant from the project area. They include a number of unnamed Indonesian Fishing Vessels and the Sinar Bonerate in the vicinity of Ashmore Reef and Cartier Island, and the Browse Island Unident and Selina in the vicinity of Browse Island (DoEE 2018ay).

6.6.12 Cultural Heritage

There are no known sites of Aboriginal cultural significance within the in-field development area and there are not believed to be any along the export pipeline corridor, given that the location is more than 200 km from the mainland. Due to the distance from the mainland it is highly unlikely that the project area is used for hunting or fishing by Australian Aboriginal people. There are no islands or land within the project area and therefore there are no land based Aboriginal heritage sites. A review of the Aboriginal Heritage Inquiry System (DPLH 2018) indicates that the nearest registered sites are on the coastal islands of the Bonaparte Archipelago off the Kimberley coast, a minimum 165 km away from the proposed Crux platform.

6.6.13 Tourism and Recreation

Currently, there are no known recreational fishing activities in the project area as the site is too far from shore to be accessed by recreational fishermen in small boats. Even at relatively high speed (30 km/hour), it would take at least 15 hours for a recreational boat to reach the project area from the nearest port of Broome.

There are no known tourist attractions or destinations within the project area or surrounding marine waters.

Whilst charter fishing companies frequent the broader region, there are no known tourist attractions or destinations within the project area. Tourism, however, has a much larger

presence along the coast from Exmouth to Darwin, largely confined to coastal waters and inshore islands, with Cape Leveque, Beagle Bay, Cockatoo Island and the Buccaneer Archipelago all being popular destinations for coastal cruises.

Fishing and diving charters operate out of Broome and Derby and the occasional charter vessel may visit Scott Reef, Ashmore Reef, Browse and Adele Island. A search of recreational fishing charters in the north-west region of WA did not reveal any recreational fishing to the marine waters representing the project area.

Birdwatching tours operate occasionally out of Broome, with annual expeditions visiting Ashmore Reef and associated offshore islands such as the Lacepede Islands, Adele Island, Browse Island, and Scott Reef.

6.6.14 Military/Defence

The Australian Border Force undertake civil and maritime surveillance (and enforcement) in and around the project area (Department of Home Affairs (DHA) 2018a, 2018b). The primary purpose of the activity is to monitor the passage of suspect illegal entry vessels and illegal foreign fishing activity within and beyond Australia's Exclusive Economic Zone, which extends to approximately 200 nm from the mainland (DHA 2018a).

There are no designated military/defence exercise areas in the project area and surrounds. However, regionally relevant activities include the North Australian Exercise Area (NAXA) offshore training area and the Browse Basin and Northern Carnarvon Basin offshore air-to-air weapons ranges, which are maritime military zones administered by the Department of Defence. The NAXA extends approximately 300 km north and west from just east of Darwin into the Arafura Sea and is used for offshore naval exercises and onshore weapon-firing training (Department of Defence 2015). The Browse Basin (Curtin) and Northern Carnarvon (Learmonth) situated air-to-air weapons ranges are 513 km and 1,500 km from the proposed Crux platform, respectively.

6.6.15 Ports and Commercial Shipping

There are no major shipping routes traversing the in-field development area or export pipeline corridor. The nearest major shipping channel is approximately 560 km to the west of the proposed Crux platform. Given the distances between the project area and shipping channels, the Crux project and related activities pose a minimal navigational risk to commercial shipping.

There may potentially be coastal ships traversing the project area supporting other petroleum activities in the vicinity, as well as the major State and Territory ports of Broome, Derby, Wyndham and Darwin. Additionally, Civil and maritime surveillance in and around the project area may occur by the Australian Border Force Maritime Border Command to monitor the passage of illegal entry vessels and illegal foreign fishing activity (DHA 2018b).

A summary of the regional shipping movements and port areas relevant to the project area is presented in **Figure 6-36**.

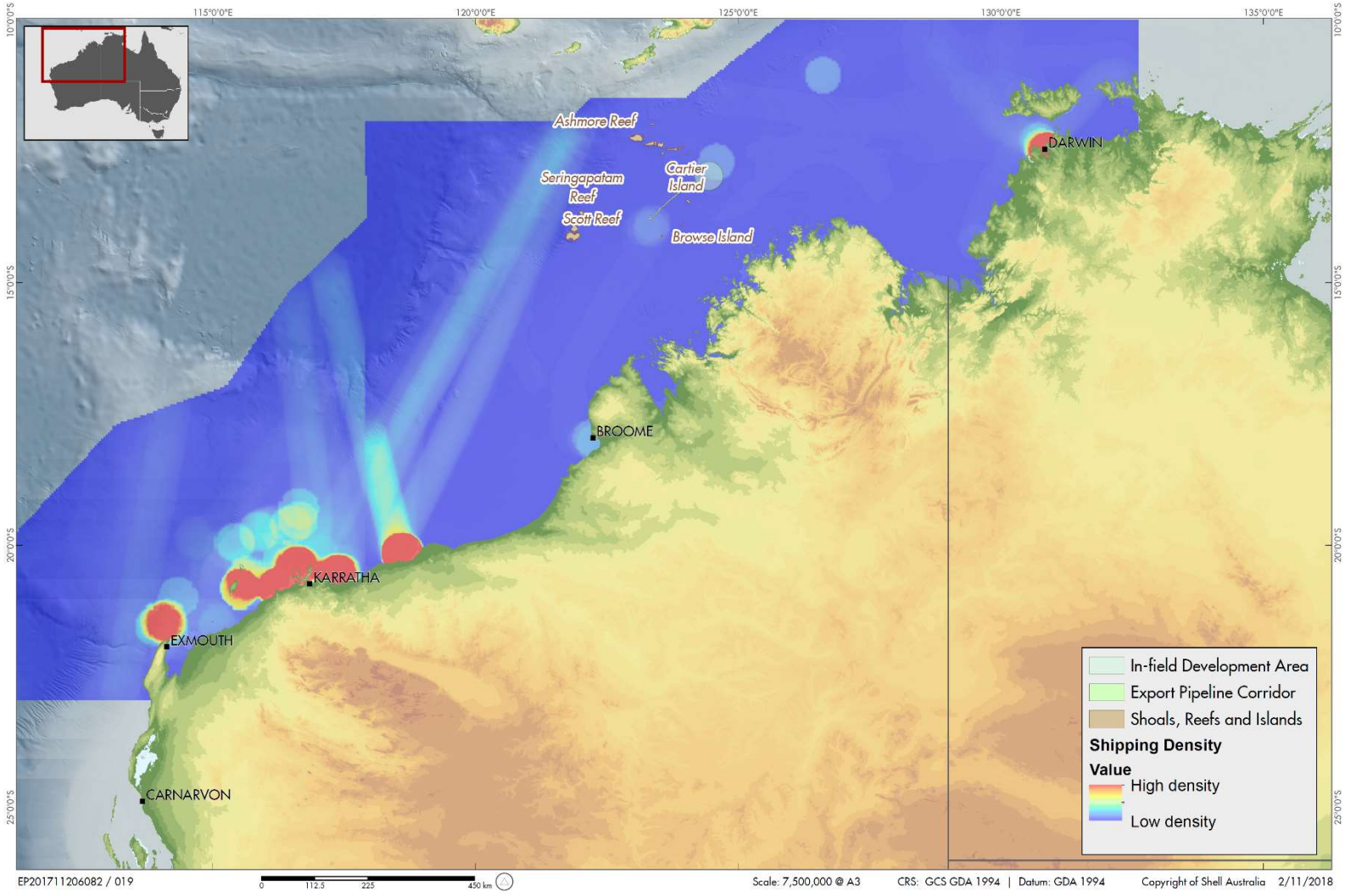


Figure 6-36: Overview of Regional Shipping Movements

6.6.16 Offshore Petroleum Exploration and Operations

Since the 1960s there has been significant growth in exploration, production and the oil and gas market. Energy companies have undertaken petroleum activities such as seismic and exploration in WA State and Commonwealth waters for a number of years. Specifically, petroleum exploration commenced in the Browse Basin in 1967, with several commercial discoveries since that time. The fourth well drilled in the basin, Scott Reef 1 (completed in 1971), was significant in discovering the large Torosa gas field. Since then, more than 105 wells have been drilled and there have been over 20 hydrocarbon discoveries.

The petroleum exploration and production industry is a significant user of offshore waters in northern WA, particularly within and adjacent to the Browse and Northern Bonaparte basins (DMP 2014). The closest facility to the proposed Crux platform is the Montara production FPSO facility, which is located approximately 36 km north. The Ichthys project offshore facilities are located approximately 164 km to the south-west of the proposed Crux platform, and the Prelude FLNG facility is approximately 165 km to the south-west of the Crux platform, representing the location where the export pipeline will feed into.

6.6.17 Indonesian and Timor-Leste Coastlines

The Indonesian and Timor-Leste Coastlines are located 280 km and 400 km north of the Crux platform and are relevant to the project in the context of the area of influence only.

Indonesia is the world's largest archipelagic state and Indonesian waters play an important role in the global water mass transport system (ADB 2014a). Indonesia boasts some of the most biologically rich coral reefs in the world with over 590 coral species having been identified. These coastal reefs are a primary source of food and income for coastal communities, as well as forming an integral part of the countries tourism industry (ADB 2014a).

In addition to coral reefs, coastal habitats include extensive seagrass meadows, which provide habitat and foraging grounds for marine animals including dugongs and marine turtles, and mangroves, of which Indonesia has the highest plant, animal and microorganism mangrove ecosystem diversity in the world (ADB 2014a). There are also numerous cetacean species in Indonesian coastal waters.

The island of Timor is shared with Timor-Leste, which has similar coastal environmental values. Timor-Leste has a coastline of more than 700 km and a marine Exclusive Economic Zone which extends 200 nm offshore (Coral Triangle Center 2018). Notably, Timor-Leste is located in a biodiversity hotspot with a number of endemic species (Asian Development Bank (ADB) 2014b). The island has 30 declared protected areas, including Nino Konis Santana National Park which encompasses nearly 350 km^2 of coral reef (ADB 2014b; Coral Triangle Center 2018). The environmental values of Timor-Leste's coastline are under pressure from illegal fishing, over-exploitation of natural resources and lack of waste management (ADB 2014b).

6.7 Summary of Key Values and Sensitivities of Relevance to the Project

Taking into account the existing environmental setting described in the preceding sections, the key values and sensitivities identified to be of relevance to the Crux project are summarised in **Table 6-20**.

As outlined in **Section 2.3.1**, the EPBC Act is a key piece of legislation that is applicable to the environmental management of the Crux project. MNES that may credibly interact with aspects of the Crux project include:

- World heritage properties,
- National heritage places,
- Wetlands of international importance,
- Listed threatened species and ecological communities,
- Migratory species, and
- Commonwealth marine areas.

The potential interactions are summarised in **Table 6-21**. The assessments of potential impacts and risks to MNES, including whether the impact constitutes a significant impact[2], are provided in the evaluation of environmental impacts and risks (**Section 8**).

[2] As defined by the EPBC Act Significant Impact Guidelines 1.1 – Matters of National Environmental Significance (DoE 2013a).

Table 6-20: Summary of Key Values and Sensitivities of Relevance to the Crux Project context

Value/Sensitivity	Present in the Crux Project Area	Particular Values/Sensitivities of Relevance	Present in the Area of Influence	Particular Values/Sensitivities of Relevance	Factor Category in the Evaluation of Environmental Impacts and Risks (Section 8)
Physical Environment					
Climate	Not relevant – the Crux project is not expected to influence physical climate				Not applicable
Oceanography	Not relevant – the Crux project is not expected to influence physical oceanographic processes				Not applicable
Bathymetry and seabed features	Y	Seabed features	Y	Seabed features	Physical environment (including seabed features, water quality, sediment quality, air quality, underwater noise)
Water quality	Y	Water quality	Y	Water quality	
Sediment quality	Y	Sediment quality	Y	Sediment quality	
Air quality	Y	Air quality		Not relevant in a regional context	
Underwater noise	Y	Marine mammals Marine reptiles Sharks and rays		Not relevant in a regional context	
Ecosystems, Communities and Habitats					
Marine regions and Bioregions	Not relevant - the Crux project is not expected to influence bioregional scale environment				Not applicable
Benthic communities	Y	Benthic communities associated with predominantly silty sand or muddy sand, with some hard substrate in the shallower areas of the in-field development area.	Y	Benthic communities have potential to be affected by the potential scenario of an unplanned (emergency) discharge.	Physical environment (seabed features)
Plankton	Y	Plankton present across the open ocean environment characteristic of the project area.	Y	Planktonic communities have potential to be affected by the potential scenario of an unplanned (emergency) discharge.	Plankton

Value/Sensitivity	Present in the Crux Project Area	Particular Values/Sensitivities of Relevance	Present in the Area of Influence	Particular Values/Sensitivities of Relevance	Factor Category in the Evaluation of Environmental Impacts and Risks (Section 8)
Shoals and banks	Y	The following shoals/banks are of relevance to the project area: Goeree Shoal – located within the in-field development area with a 1 km exclusion buffer around the shoal, 13 km north-west of the Crux platform Eugene McDermott Shoals - located within the in-field development area with a 1 km buffer, 18 km south-east of the Crux platform Vulcan Shoal - located within the in-field development area with a 1 km buffer, approximately 22 km north-west of the Crux platform	Y	The shoals/banks nearest to the project area include Goeree Shoal, Eugene McDermott Shoals, Vulcan Shoal, Barracouta Shoals, Heywood Shoals, Echuca Shoals, with other shoals and banks in the broader region. These have potential to be affected by the potential scenario of an unplanned (emergency) discharge.	Shoals and banks
Offshore reefs and islands		None in the project area	Y	The offshore reefs and islands in the wider area of influence include: • Ashmore Reef • Cartier Island • Hibernia Reef • Browse Island • Seringapatam Reef • Scott Reef • Adele Island, and • other offshore reefs and islands in the broader region. These have potential to be affected by the potential scenario of an unplanned (emergency) discharge.	Offshore reefs and islands

Value/Sensitivity	Present in the Crux Project Area	Particular Values/Sensitivities of Relevance	Present in the Area of Influence	Particular Values/Sensitivities of Relevance	Factor Category in the Evaluation of Environmental Impacts and Risks (Section 8)
WA and NT mainland coastline		None in the project area	Y	These have potential to be affected by the potential scenario of an unplanned (emergency) discharge.	WA and NT mainland coastline
Key Ecological Features	Y	Only one KEF is of relevance to the project area – the continental slope demersal fisheries KEF (intersected by the export pipeline corridor).	Y	The KEFs in the wider area of influence include: • Continental slope demersal fish communities • Ancient coastline at 125 m depth contour • Ashmore Reef and Cartier Islands and surrounding Commonwealth waters • Canyons linking the Argo Abyssal Plain with Scott Plateau • Carbonate bank and terrace system of the Sahul Shelf • Glomar Shoals • Mermaid Reef and Commonwealth waters surrounding Rowley Shoals • Pinnacles of the Bonaparte Basin • Seringapatam Reef and Commonwealth waters in the Scott Reef complex • Exmouth Plateau • Shelf break and slope of the Arafura Shelf • Carbonate bank and terrace system of the Van Diemen Rise, and • Canyons Linking the Cuvier Abyssal Plain and the Cape Range Peninsula	KEFs

Value/Sensitivity	Present in the Crux Project Area	Particular Values/Sensitivities of Relevance	Present in the Area of Influence	Particular Values/Sensitivities of Relevance	Factor Category in the Evaluation of Environmental Impacts and Risks (Section 8)
				• Commonwealth waters adjacent to Ningaloo Reef. These have potential to be affected by the potential scenario of an unplanned (emergency) discharge.	
Threatened Species and Ecological Communities					
Listed threatened and migratory species of conservation significance	Y	Potential for 20 listed threatened fauna species and 33 listed migratory species that may occur or pass through the project area. Only one BIA is of relevance to the project area – the BIA for whale shark, which represents a broad migratory corridor for this oceanic species. The project area does not overlap any habitat critical to the survival of a species.	Y	Potential for 43 listed threatened fauna species and 89 listed migratory species that may occur or pass through the area of influence. The area of influence includes a number of BIAs including foraging areas for marine turtles, a migration corridor for pygmy blue whales, migration area for humpback whales, foraging areas for whale sharks, breeding/foraging/resting areas for a number of seabird and shorebird species, and a breeding, calving and foraging area for the Indo-pacific humpback dolphin. Within the area of influence Ashmore Reef, Cartier Island and Browse Island provide critical nesting habitat for the green turtle as well as the dugong. These have potential to be affected by the potential scenario of an unplanned (emergency) discharge.	Marine mammals Marine reptiles Birds Fish Sharks and rays

Value/Sensitivity	Present in the Crux Project Area	Particular Values/Sensitivities of Relevance	Present in the Area of Influence	Particular Values/Sensitivities of Relevance	Factor Category in the Evaluation of Environmental Impacts and Risks (Section 8)
Socio-economic and Cultural Environment					
Commonwealth Marine Area	Not relevant – there are no distinct values or sensitivities associated with this feature which are not otherwise addressed in other values and sensitivities elsewhere				Not applicable
Commonwealth land	-	Not relevant to the project area	Y	Ashmore Reef Cartier Island (as addressed above)	AMPs
World Heritage Properties	-	None in the project area	Y	Kakadu National Park, which is approximately 830 km to the east of the Crux platform, is relevant only in the context of the area of influence.	World Heritage Properties
National Heritage Places	-	None in the project area	Y	The West Kimberley, located 169 km from the Crux platform, is a National Heritage Place relevant only in the context of the area of influence.	WA and NT Mainland Coastline
Commonwealth Heritage Places	-	None in the project area	Y	The following are relevant only in the context of the area of influence: • Ashmore Reef National Nature Reserve • Scott Reef and surrounds • Mermaid Reef – Rowley Shoals • North Keeling Island, and • Christmas Island Natural Areas.	Other offshore reefs, islands and WA and NT mainland coastline
Declared Ramsar wetlands	-	None in the project area	Y	The following are relevant only in the context of the area of influence: • Ashmore Reef National Nature Reserve • Cobourg Peninsula • “The Dales” Christmas Island • Hosnies Spring Christmas Island, and • Pulu Keeling National Park.	Other offshore reefs, islands and WA and NT mainland coastline

Value/Sensitivity	Present in the Crux Project Area	Particular Values/Sensitivities of Relevance	Present in the Area of Influence	Particular Values/Sensitivities of Relevance	Factor Category in the Evaluation of Environmental Impacts and Risks (Section 8)
Australian Marine Parks	-	None in the project area	Y	The following are relevant only in the context of the area of influence: • Ashmore Reef Marine Park • Cartier Island Marine Park • Argo-Rowley Terrace Marine Park • Eighty Mile Beach Marine Park • Kimberley Marine Park • Dampier Marine Park • Gascoyne Marine Park • Mermaid Reef Marine Park • Montebello Marine Park • Ningaloo Marine Park • Roebuck Marine Park • Oceanic Shoals Marine Park • Joseph Bonaparte Gulf Marine Park • Arafura Marine Park, and • Arnhem Marine Park.	Marine parks
WA Marine Parks	-	None in the project area	Y	The following are relevant only in the context of the area of influence: • Barrow Island Marine Park • Barrow Island Marine Management Area • Montebello Islands Marine Park • Eighty Mile Beach Marine Park • Ningaloo Marine Park • Muiron Islands Marine Management Area • Rowley Shoals Marine Park	Marine parks

Value/Sensitivity	Present in the Crux Project Area	Particular Values/Sensitivities of Relevance	Present in the Area of Influence	Particular Values/Sensitivities of Relevance	Factor Category in the Evaluation of Environmental Impacts and Risks (Section 8)
				• Lalang-garram/Horizontal Falls Marine Park • North Lalang-garram Marine Park • Lalang-garram/Camden Sound Marine Park • North Kimberley Marine Park, and • Yawuru Nagulagun/Roebuck Bay Marine Park.	
NT Marine Parks	-	None in the project area	Y	The following is relevant only in the context of the area of influence: • Garig Gunack Barlu National Park.	Marine parks
Commercial fisheries	Y	Commonwealth – 4 fisheries of relevance: North West Slope Trawl Fishery, Western Tuna and Billfish Fishery, Western Skipjack Fishery, Southern Bluefin Tuna Fishery WA – 7 fisheries of interest: Northern Demersal Scalefish Fishery, Mackerel Fishery, Northern Shark Fishery, Pearl Oyster Fishery, Specimen Shell Managed Fishery, Marine Aquarium Fish Managed Fishery, West Coast Deep Sea Crustacean Fishery	Y	Commonwealth – 6 fisheries of relevance: North West Slope Trawl Fishery, Western Tuna and Billfish Fishery, Western Skipjack Fishery, Southern Bluefin Tuna Fishery, Northern Prawn Fishery, Western Deepwater Trawl Fishery. WA – 10 fisheries of interest: Northern Demersal Scalefish Fishery, Mackerel Fishery, Northern Shark Fishery, Pearl Oyster Fishery, Specimen Shell Managed Fishery, Marine Aquarium Fish Managed Fishery, West Coast Deep Sea Crustacean Fishery, Kimberley Gillnet and Barramundi Managed Fishery, North Coast Prawn Managed Fishery, Western Australian Sea Cucumber Fishery (Beche-de-mer Fishery). Up to 13 NT managed commercial fisheries overlap the area of influence.	Commercial fisheries

Value/Sensitivity	Present in the Crux Project Area	Particular Values/Sensitivities of Relevance	Present in the Area of Influence	Particular Values/Sensitivities of Relevance	Factor Category in the Evaluation of Environmental Impacts and Risks (Section 8)
Traditional Indigenous fishing	Y	MoU Box – while 70 km away from the Crux platform location, the export pipeline will transect this area. Potential for low level traditional Indonesian fishing activity in the area.	Y	MoU Box, traditional/customary fishing by Indonesian fishermen and Indigenous fishing around the WA and NT coastline and surrounding nearshore islands in the area of influence.	Indigenous fishing
Marine archaeology	-	None in the project area	Y	The nearest shipwreck to the project area is the Ann Millicent (approx. 108 km NW of the Crux platform, near Cartier Island). Additionally, there are five unnamed wrecked Indonesian fishing vessels and the Sinar Bonerate shipwreck in the vicinity of Ashmore Reef and Cartier Island. These shipwrecks are Federally protected. There are a number of additional shipwrecks within the area of influence (including at Browse Island).	Marine archaeology
Cultural heritage	-	Not relevant to the project area	Y	The northern Kimberley coastline, and surrounding offshore islands, is of high intrinsic indigenous heritage value. Similarly, the NT coastline and offshore islands (e.g. Tiwi Islands) is of high indigenous heritage value. These are relevant only in the context of the area of influence.	Other offshore reefs, islands and WA and NT mainland coastline
Tourism and recreation		Not relevant to the project area	Y	There is potential for low intensity tourism and recreational marine users in the offshore marine environment, including around the offshore islands and reefs in the region.	Tourism and recreation
Military/defence		Not relevant to the project area	Y	Defence activities are expected to occur in the offshore marine environment in the region.	Defence activities

Value/Sensitivity	Present in the Crux Project Area	Particular Values/Sensitivities of Relevance	Present in the Area of Influence	Particular Values/Sensitivities of Relevance	Factor Category in the Evaluation of Environmental Impacts and Risks (Section 8)
Ports and commercial chipping		Not relevant to the project area	Y	While no major shipping routes traverse the project area, commercial shipping transits through the offshore marine environment in the region.	Ports and commercial shipping
Offshore petroleum exploration and operations		Not relevant to the project area	Y	The closest facility to the proposed Crux platform is the Montara production FPSO facility, which is located approximately 36 km north.	Offshore petroleum exploration and operations
Indonesian and Timor-Leste coastlines		Not relevant to the project area	Y	The Indonesian and Timor-Leste Coastlines are relevant only in the context of the area of influence.	Indonesian and Timor-Leste coastlines

Table 6-21: Potential Interactions between MNES and Aspects of the Crux Project

MNES Category	MNES Sub-category	Aspects							
		Physical Presence and Vessel Movements (Sections 5.7.1 and 5.7.2)	Light Emissions (Section 5.7.3)	Underwater Noise (Section 5.7.4)	Atmospheric Emissions (Section 5.7.5)	Invasive Marine Species (Section 5.7.6)	Waste Management (Section 5.7.8)	Liquid Discharges (Section 5.7.7)	Unplanned Spills (Section 5.7.9)
World Heritage Properties (Section 6.6.4)	**N/A**	No	No	No	No	No	No	No	Yes (Section 8.4.8)
National Heritage Places (Section 6.6.5)	**N/A**	No	No	No	No	No	No	No	Yes (Section 8.4.8)
Wetlands of International Importance (Section 6.6.7)	**N/A**	No	No	No	No	No	No	No	Yes (Section 8.4.8)
Listed Threatened Species and Ecological Communities **Listed Migratory Species (Section 6.5.1)**	**Marine mammals**	Yes (Section 8.4.1)	Yes (Section 8.4.2)	Yes (Section 8.4.3)	No	No	Yes (Section 8.4.6)	Yes (Section 8.4.7)	Yes (Section 8.4.8)
	Marine reptiles	Yes (Section 8.4.1)	Yes (Section 8.4.2)	Yes (Section 8.4.3)	No	No	Yes (Section 8.4.6)	Yes (Section 8.4.7)	Yes (Section 8.4.8)
	Birds	No	Yes (Section 8.4.2)	No	No	No	Yes (Section 8.4.6)	No	Yes (Section 8.4.8)
	Sharks and rays	Yes (Section 8.4.1)	Yes (Section 8.4.2)	Yes (Section 8.4.3)	No	No	Yes (Section 8.4.6)	Yes (Section 8.4.7)	Yes (Section 8.4.8)
Commonwealth Marine Area (Section 6.6.3)	**N/A**	Yes (Section 8.4.1)	Yes (Section 8.4.2)	Yes (Section 8.4.3)	Yes (Section 8.4.4)	Yes (Section 8.4.5)	Yes (Section 8.4.6)	Yes (Section 8.4.7)	Yes (Section 8.4.8)

7 Acceptable Levels of Impact and Risk for the Crux Project

The OPGGS (E) Regulations require the proponent include an evaluation of all the impacts and risks that reaches a conclusion on whether the impacts and risks will be of an 'acceptable' or 'unacceptable' level. To this end, Shell has determined acceptable levels of impact to the environmental receptors that may credibly be impacted by the Crux project. The process by which Shell has determined the acceptability of risks and impacts is detailed below.

7.1 Considerations in Developing Defined Acceptable Levels of Impact and Risk

Shell has established defined acceptable levels of impacts and risks for the Crux project relating to all the environmental receptors that were identified as being credibly impacted by, or at risk of impacts from aspects. The outcomes of the evaluation of environmental impacts and risks were assessed against these defined acceptable levels to demonstrate if the impacts or risks meet the acceptable levels of impact or not.

The following were considered when establishing the acceptable levels of impacts and risks outlined in **Section 8**:

- The principles of ecologically sustainable development (ESD)
- Other requirements applicable to the Crux project (e.g. laws, policies, standards, conventions etc.), including significant impacts[3] to MNES
- Internal context, and
- External context.

Each of these considerations are elaborated on below.

7.1.1 Principles of ESD

Shell has considered the principles of ESD in defining acceptable levels of impacts and risks, as defined in Section 3A of the EPBC Act. The principles of ESD are summarised as:

- Decision-making processes should effectively integrate both long-term and short-term economic, environmental, social and equitable considerations.
- If there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation.
- The principles of inter-generational equity – that the present generation should ensure that the health, diversity and productivity of the environment is maintained or enhanced for the benefit of future generations.
- The conservation of biological diversity and ecological integrity should be a fundamental consideration in decision-making.

[3] Significant impacts refer specifically to the levels of impacts defined in the Matters of National Environmental Significance - Significant impact guidelines 1.1 (DoE 2013a). Any subsequent reference in this OPP to significant impacts refers to these levels unless stated otherwise.

- Improved valuation, pricing and incentive mechanisms should be promoted.

7.1.2 Other Requirements

Shell considered other requirements that apply to the environmental management of the Crux project, including legislation, policies, standards and guidelines in establishing acceptable levels of impacts and risks (refer to **Section 2.3**). Given the Crux OPP forms the basis for NOPSEMA's assessment of matters protected under Part 3 of the EPBC Act in Commonwealth waters, Shell has given attention to the acceptability of impacts and risks to MNES. The potential interactions between MNES and aspects of the Crux project are provided in **Table 6-21**.

Where a potential interaction between MNES and an aspect of the Crux project was identified, the criteria provided in **Table 7-1** were considered. Potential impacts and risks to MNES from aspects of the Crux project were inherently acceptable if:

- The significant impact criteria in relation to the MNES were not exceeded, and
- The management of the aspect is aligned with published guidance material from the DoEE, including threat abatement plans, recovery plans and conservation advice.

Table 7-1: MNES Significant Impact Criteria of Relevance to the Crux Project

Category	Significant Impact Criteria
Critically Endangered and Endangered species	An action is likely to have a significant impact on critically endangered or endangered species if there is a real chance or possibility that it will: • Lead to a long-term decrease in the size of a population, • Reduce the area of occupancy of the species, • Fragment an existing population, • Adversely affect habitat critical to the survival of a species, • Disrupt the breeding cycle of a population, • Modify, destroy, remove, isolate or decrease the availability or quality of habitat to the extent that the species is likely to decline, • Result in invasive species that are harmful to a critically endangered or endangered species becoming established in the endangered or critically endangered species' habitat, • Introduce disease that may cause the species to decline, or Interfere with the recovery of the species.
Vulnerable species	An action is likely to have a significant impact on vulnerable species if there is a real chance or possibility that it will: • Lead to a long-term decrease in the size of an important population, • Reduce the area of occupancy of and important population, • Fragment an existing important population into two or more populations, • Adversely affect habitat critical to the survival of a species, • Disrupt the breeding cycle of a population, • Modify, destroy, remove, isolate or decrease the availability or quality of habitat to the extent that the species is likely to decline, • Result in invasive species that are harmful to a vulnerable species becoming established in the vulnerable species' habitat, • Introduce disease that may cause the species to decline, or • Interfere substantially with the recovery of the species.
Migratory Species	An action is likely to have a significant impact on migratory species if there is a real chance or possibility that it will: • Substantially modify, destroy or isolate an area of important habitat for a migratory species, • Result in an invasive species that is harmful to the migratory species becoming established in an area of important habitat for the migratory species, or • Seriously disrupt the lifecycle of an ecologically significant proportion of the population of a migratory species.

Category	Significant Impact Criteria
Wetlands of International Importance	An action is likely to have a significant impact on a wetland of international importance if there is a real chance or possibility that it will result in: • Areas of wetland being destroyed or substantially modified, • A substantial and measurable change in the hydrological regime of the wetland, • The habitat or lifecycle of native species dependent upon the wetland being seriously affected, • A substantial and measurable change in the water quality of the wetland which may adversely impact on the biodiversity, ecological integrity, social amenity or human health, or • An invasive species that is harmful to the ecological character of the wetland being established in the wetland.
Commonwealth Marine Environment	An action is likely to have a significant impact on the environment in a Commonwealth marine area if there is a real chance or possibility that it will: • Result in a known or potential pest species becoming established in the Commonwealth marine area, • Modify, destroy, remove, isolate or disturb an important or substantial area of habitat such that an adverse impact on marine ecosystem functioning or integrity on a Commonwealth marine area results, • Have a substantial adverse effect on a population of a marine species or cetacean including its life cycle and spatial distribution, • Result in a substantial change in air quality or water quality which may adversely impact on biodiversity, ecological integrity, social amenity or human health, • Result in persistent organic chemicals, heavy metals, or other potentially harmful chemicals accumulating in the marine environment such that biodiversity, ecological integrity, social amenity or human health may be adversely affected, or • Have a substantial adverse impact on heritage values of the Commonwealth marine area, including damage or destruction of an historic shipwreck.

Significant Impacts and Impacts – What's the difference?

When determining the acceptability of an environmental impact, Shell references significant impacts and impacts. These are two related, but distinct, concepts used when determining if an impact or risk is acceptable.

Significant impacts refer to the Matters of National Environmental Significance - Significant impact guidelines 1.1 published by the DoEE (DoE 2013a). These guidelines assist proponents and regulators in determining if an activity has the potential to significantly impact upon MNES, which are protected under Part 3 of the EPBC Act. There are several potential interactions between aspects of the Crux project and MNES. Shell has used the significant impact criteria defined in the MNES - Significant impact guidelines 1.1 to assist in determining the acceptable levels of impact, along with other material published by the DoEE.

Significant impacts can also include indirect, or offsite, impacts. These include:

- 'downstream impacts', such as a reduction in water quality from the discharge of drill cuttings and fluids down current from a MODU,
- 'upstream impacts', such as the extraction of materials and energy used to undertake an activity, and
- 'facilitated impacts', which result from future actions that are enabled as a result of the Crux project.

In comparison, Shell considers an impact to be any effect on an environmental receptor. This includes any changes to the environmental receptors that may be considered harmful, or even beneficial (e.g. an increase in the diversity of benthic communities from the creation of artificial reefs by subsea infrastructure).

Based on these definitions, all significant impacts are impacts, but not all impacts are necessarily significant impacts. A significant impact will generally have greater potential for environmental harm than an impact that is not significant.

Additional Considerations for Significant Impacts to MNES

Where an impact or risk was evaluated as having the potential to exceed any significant impact criteria, additional consideration was given to the establishment of acceptability of the impact or risk. This additional consideration is reflected in the EPOs for aspects that may exceed the significant impact criteria.

A conceptual diagram showing the relationship between the significant impact criteria, aspects and potential for impacts and risks is provided in Figure 7-1. In this diagram, aspects 1, 2 and 4 do not exceed the significant impact criteria and hence are acceptable in relation to MNES (assuming the aspect is aligned to the requirements of MNES-specific advice published by the DoEE). Aspects 3 and 5 exceed the significant impact criteria for MNES. These aspects pose a greater risk to MNES and require additional consideration of acceptable levels of impacts and risks beyond the significant impact criteria.

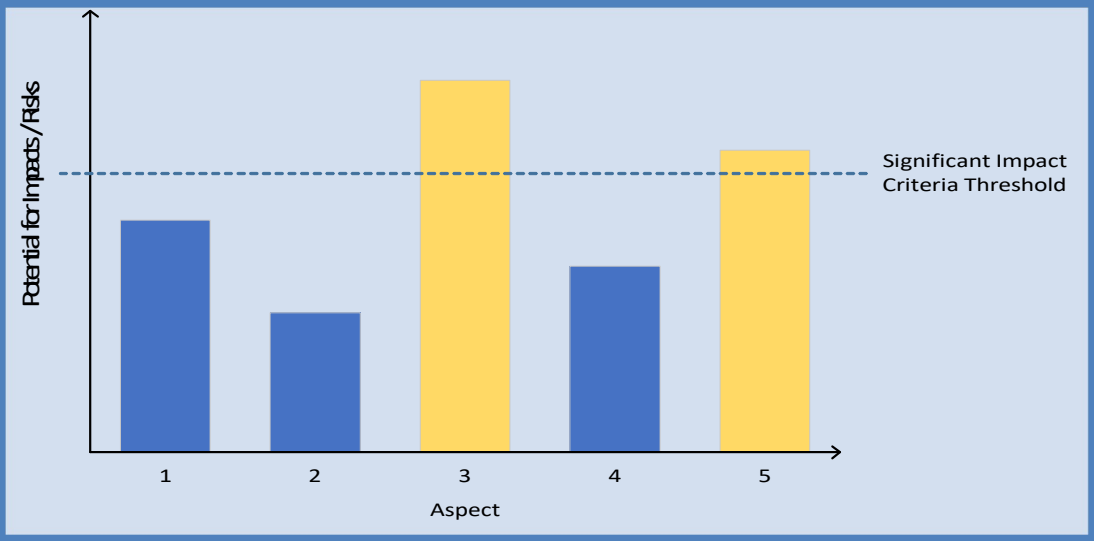


Figure 7-1: Conceptual Diagram Showing the Relationship between the MNES Significant Impact Criteria Threshold, Aspects and Potential for Impacts or Risks

7.1.3 Internal Context

Shell considered its internal context when establishing acceptable levels of impacts and risks. This context included Shells environment policy, environmental risk management framework, technical guidance material and opinions of internal stakeholders.

Details of Shell's impact assessment methodology referred to below can be found within Section 8.3. The following outlines Shell's internal impact and risk assessment defined acceptable levels:

- residual planned impacts that are ranked as minor or less (i.e. minor, slight, no effect or positive effect) and residual risks for unplanned events ranked negligible and minor, are inherently 'acceptable', if they meet legislative and Shell requirements and the established acceptable levels of impacts and risks.
- moderate residual impacts, and moderate and major residual risks, are 'acceptable' if good industry practice can be demonstrated. In this acceptability evaluation, in addition to the considerations above, the following points are also considered:
    - internal context – the proposed controls are consistent with Shell policies, procedures and standards
    - external context – consideration of stakeholder expectations, objections and claims, and
    - other requirements – the proposed controls are consistent with national and international standards, laws and policies.
- major and massive magnitude effects from planned impact, and massive residual risks from unplanned risks, are 'unacceptable'. The activity (or element of) should not be undertaken as the impact or risk is serious and does not meet the principles of ESD, legal requirements, Shell requirements or regulator and stakeholder expectations. The activity requires further assessment to reduce the risk to an acceptable level.

Table 7-2 provides a summary of the acceptability statements, as correlated to the risk rankings presented in **Table 8-4** (for planned impacts/risks) and **Table 8-6** (for unplanned impacts/risks).

Table 7-2: Acceptability Categories

Acceptability Statement	Residual Impact (Planned)	Residual Risk (Unplanned)
Inherently acceptable	• Positive effect • No effect • Slight • Minor	• No effect • Negligible • Minor
Acceptable with controls	• Moderate	• Moderate • Major
Unacceptable	• Major • Massive	• Massive

7.1.4 External Context

Shell also considered the external context when establishing acceptable levels of impacts and risks. This includes any available information provided by stakeholders during the preparation of the Crux OPP. Shell acknowledges the public comment period on the Crux OPP will provide additional external context and will consider the views of stakeholders providing comment on the Crux OPP. This will be incorporated into the revision of the Crux OPP submitted to NOPSEMA for assessment following the public comment period.

7.2 Defined Acceptable Levels of Impact and Risk for the Crux Project

The acceptable levels of impacts and risks to environmental receptors from the Crux project are summarised in **Table 7-3**.

Table 7-3: Summary of Acceptable Levels of Impact for Environmental Receptors that may be Impacted by Aspects of the Crux Project

Receptor Category	Receptor Sub-category	Acceptable Level of Impact	Justification
Physical Environment	**Water quality**	No significant impacts to water quality during the Crux project.	The routine discharge of PFW at the Crux platform may result in substantial impacts in the immediate area of the Crux platform. Modelling studies indicate these impacts will be localised around the Crux platform and will persist during the operational phase of the Crux project. Liquid discharges from the Crux project cannot be avoided; but by limiting substantial impacts to within 1 km of the liquid discharge locations the potential impacts to marine ecosystems is very low. Shell's environmental performance outcome in relation to water quality is to limit substantial impacts to within 1 km of the discharge location (refer to **Section 8.4.7.6**). Given the offshore location and absence of particularly sensitive marine ecosystems at the Crux platform location, potential substantial impacts within 1 km of the Crux platform are acceptable. Bakke et al. (2013) states that typically no impacts are detected beyond 2 km from offshore facilities around the world. The nearest sensitive habitat to the Crux platform is Goeree Shoal, approximately 13 km away. Other discharges, such as hydrotest water and utility discharges from vessels, are of typically short duration and will not have the potential for significant impacts over an extended period.
	Sediment quality	No significant impacts to sediment quality during the Crux project.	The discharge of drill cuttings and fluids may result in elevated levels of potential contaminants near wells, such as the foundation wells at the Crux platform. Additionally, the discharges from the Crux platform (e.g. drainage water) may also increase the concentration of potential contaminants around the Crux platform. Sediment quality in the vicinity of the Crux in-field development area is characteristic of the sediment quality conditions of the offshore region. Bakke et al. (2013) states that typically no impacts are detected beyond 2 km from offshore facilities around the world. Impacts to sediment quality from the Crux project cannot be avoided; but by limiting substantial impacts to within 1 km of sources of potential sediment contamination (e.g. drilling locations and the Crux platform) the potential impacts to marine ecosystems is very low. Shell's environmental performance outcome in relation to sediment quality is to limit substantial impacts to within 1 km of the discharge location (refer to **Section 8.4.7.6**). By limiting potentially substantial impacts to sediment to within 1 km of the discharge point, the potential for environmental impacts as a result of contaminated sediments is localised. These impacts are considered to be acceptable.
	Air quality	No significant impacts to air quality during the Crux project.	Defined as substantial change in air quality which may adversely impact on biodiversity, ecological integrity; social amenity or human health. Planned atmospheric emissions from the Crux project consist primarily of combustion engine exhaust emissions (e.g. gas turbine

Receptor Category	Receptor Sub-category	Acceptable Level of Impact	Justification
			generators on the Crux platform, vessel engines etc.). Small quantities of fugitive emission from hydrocarbon processing infrastructure will also occur. These emissions will be in accordance with relevant requirements, such as Australian greenhouse gas reporting and MARPOL air pollution requirements. The Crux project is located in the open ocean, and is well-removed from nearest residential or sensitive populations of the WA coast, with limited interaction with regional airsheds.
Ecosystems, Communities and Habitats	**Benthic communities**	No significant impacts to benthic habitats and communities. Impacts to non-sensitive benthic communities limited to a maximum of 5% of the project area.	With the exception of banks and shoals, the benthic habitats and communities within the Crux project area are widely represented in the Timor Sea, with millions of hectares of broad soft benthic habitats occurring in the region and they are not of high environmental value. With the exception of banks and shoals, impacts to benthic habitats within the Crux project area are acceptable if the area impacted is <5% of the total project area.
	Shoals and banks	No direct impacts to named banks and shoals. No loss of benthic habitats and communities at named banks or shoals as a result of indirect/offsite[4] impacts.	The shoals and banks of the Timor Sea, including the three shoals within the boundary of the Crux in-field development area, are of high environmental value. Shell considers direct impacts to these features unacceptable. Indirect impacts are considered acceptable (e.g. minor pulsed turbidity events) if they do not result in any loss of benthic habitats or communities.
	Offshore reefs and islands	No impacts to offshore reefs and islands.	Offshore reefs and islands would only be impacted by a large-scale hydrocarbon spill, such as a well blowout. Shell considers any large-scale hydrocarbon spill to be unacceptable.
	WA and NT mainland coastline	No impacts to WA and NT mainland coastline.	The WA and NT mainland coastline would only be impacted by a large-scale hydrocarbon spill, such as a well blowout. Shell considers any large-scale hydrocarbon spill to be unacceptable.
	Key Ecological Features	No significant impacts to environmental values of KEFs.	KEFs in the Timor Sea are largely geomorphic features that provide important ecosystem services primarily as a result of their unique physical features (e.g. provision of hard substrates, facilitation of upwelling etc.). These are geographically diverse features that cover a large extent. Only one KEF is intersected by the Crux project, with the export pipeline intersecting a small portion of the continental slope demersal fish communities. Given the nature and scale of the planned impacts to KEFs from the Crux development, impacts to KEFs will be below the significant impact threshold. Shell considers impacts to KEFs below this threshold to be acceptable.

[4] As defined in the Matters of National Environmental Significance - Significant impact guidelines 1.1 (DoE 2013a).

Receptor Category	Receptor Sub-category	Acceptable Level of Impact	Justification
Threatened Species and Ecological Communities	**Marine mammals**	No mortality of threatened or migratory MNES fauna from the Crux project. Management of aspects of the Crux project must be aligned to conservation advice, recovery plans and threat abatement plans published by the DoEE. No significant impacts to threatened or migratory MNES fauna.	Shell considers any mortality of, or significant impact to, threatened species that are MNES to be unacceptable for the Crux project. Impacts that are below the significant impact threshold are acceptable.
	Marine reptiles		
	Birds		
	Fish		
	Sharks and rays		
Socio-economic and Cultural Environment	**Commonwealth Marine Area**	No significant impacts to the Commonwealth marine area beyond 1 km from the Crux platform or drilling locations.	Discharges at the Crux platform may result in significant impacts to water and sediment quality, both of which are components of the Commonwealth marine environment, within 1 km of the Crux platform or drilling locations. As outlined above in the Water Quality and Sediment Quality sub-categories, significant impacts to water and sediment quality within 1 km are considered acceptable. Significant impacts beyond this range are unacceptable.
	World Heritage Properties	No impacts to world heritage values.	World heritage values would only be impacted by a large-scale hydrocarbon spill, such as a well blowout. In a regional environmental context, the nearest world heritage property is 800 km away. Shell considers any large-scale hydrocarbon spill to be unacceptable.
	National Heritage Places	No impacts to national heritage values.	National heritage values would only be impacted by a large-scale hydrocarbon spill, such as a well blowout. In a regional environmental context, the nearest national heritage place is 170 km away. Shell considers any large-scale hydrocarbon spill to be unacceptable.
	Commonwealth Heritage Places	No impacts to Commonwealth heritage values	Commonwealth heritage values would only be impacted by a large-scale hydrocarbon spill, such as a well blowout. In a regional environmental context, the nearest Commonwealth heritage place is 149 km away. Shell considers any large-scale hydrocarbon spill to be unacceptable.
	Declared Ramsar Wetlands	No impacts to ecological values of Ramsar wetlands	Ramsar wetlands would only be impacted by a large-scale hydrocarbon spill, such as a well blowout. In a regional environmental context, the nearest Ramsar wetland is 149 km away. Shell considers any large-scale hydrocarbon spill to be unacceptable.
	Marine Parks	No impacts to the values of marine parks	The environmental values within Australian marine parks would only be impacted by a large-scale hydrocarbon spill, such as a well blowout. In a regional environmental context, the nearest Marine Park is 95 km away. Shell considers any large-scale hydrocarbon spill to be unacceptable.

Receptor Category	Receptor Sub-category	Acceptable Level of Impact	Justification
	Commercial fisheries	No negative impacts to exploited fisheries resource stocks which result in a demonstrated direct loss of income. Temporary displacement of commercial fishing activities within the Crux project area (excluding petroleum safety zones) is acceptable. Permanent exclusion of commercial fishing activities from gazetted petroleum exclusion zones is acceptable.	Impacts to commercially exploited fish stocks may measurably reduce the potential revenue for commercial fishers. Shell considers this to be unacceptable. In a regional context, commercial fishing is typically concentrated mostly in coastal waters and minimum fishing effort is known to occur within the vicinity of the project area, given its remoteness offshore. Shell considers the displacement of other users (e.g. commercial fishers) from relatively small areas of the open ocean environment in the Crux project area to be acceptable.
	Traditional Indigenous fishing	No negative impacts to exploited fisheries resource stocks. Temporary displacement of traditional fishing activities within the Crux project area (excluding petroleum safety zones) is acceptable. Permanent exclusion of traditional fishing activities from gazetted petroleum exclusion zones is acceptable.	Impacts to traditionally exploited fish stocks may deprive traditional fishers of the benefits provided by the environment. Shell considers this to be unacceptable. In a regional context, the in-field development area is located 40 km outside of the edge of the MoU Box for traditional indigenous fishing, while the export pipeline will lie within this area. Shell considers the displacement of other users (e.g. traditional indigenous fishers) from relatively small areas of the open ocean environment in the Crux project area to be acceptable.
	Marine archaeology	No disturbance to historical shipwrecks is acceptable.	Shell considers any disturbance of historical shipwrecks to be unacceptable. In a regional context, the nearest known historical shipwreck is 108 km away from the Crux platform, and 78 km from the export pipeline corridor at its nearest point.
	Tourism and recreation	No negative impacts to nature-based tourism resources resulting in demonstrated loss of income. Temporary displacement of tourism activities within the Crux project area (excluding petroleum safety zones) is acceptable. Permanent exclusion of tourism activities from gazetted petroleum exclusion zones is acceptable.	Impacts to nature-based tourism resources may deprive the tourism industry of revenue. Shell considers this to be unacceptable. In a regional context, there are no known tourist attractions or destinations within the project area or surrounding marine waters, however charter vessels may transit the broader regional waters. Shell considers the displacement of other users (e.g. tourism operators) from the Crux project area, which is a relatively small area of the open ocean environment where existing tourism and recreation use is very low, to be acceptable.

Receptor Category	Receptor Sub-category	Acceptable Level of Impact	Justification
	Military/defence	Temporary displacement of defence activities within the Crux project area (excluding petroleum safety zones) is acceptable. Permanent exclusion of defence activities from gazetted petroleum exclusion zones is acceptable.	Shell considers the displacement of other users (e.g. defence vessels and aircraft) from relatively small areas of the open ocean environment in the Crux project area to be acceptable. In a regional context, there are no designated military/defence exercise areas in the Crux project area and surrounds, however there are regional defence exercise areas with large geographic extents.
	Ports and commercial shipping	Temporary displacement of commercial shipping within the Crux project area (excluding petroleum safety zones) is acceptable. Permanent exclusion of commercial shipping from gazetted petroleum exclusion zones is acceptable.	Shell considers the displacement of other users (e.g. commercial shipping) from relatively small areas of the open ocean environment in the Crux project area to be acceptable. In a regional context, there are no major shipping routes traversing the in-field development area or export pipeline corridor. The nearest major shipping channel is approximately 560 km to the west of the proposed Crux platform.
	Offshore petroleum exploration and operations	Temporary displacement of petroleum exploration activities and operations within the Crux project area (excluding petroleum safety zones) is acceptable. Permanent exclusion of petroleum exploration activities and operations from gazetted petroleum exclusion zones is acceptable.	Shell considers the displacement of other users (e.g. petroleum exploration and operations) from relatively small areas of the open ocean environment in the Crux project area to be acceptable. In a regional context, the nearest operational facility to the Crux platform is the Montara production FPSO facility, approximately 36 km away.
	Indonesian and Timor-Leste coastlines	No impacts to Indonesian or Timor-Leste coastlines are acceptable.	The Indonesian and Timor-Leste coastlines could only be impacted by a large-scale hydrocarbon spill, such as a well blowout. In a regional context, these coastlines are located a minimum 280 km away. Shell considers any large-scale hydrocarbon spill to be unacceptable.

8 Evaluation of Environmental Impacts and Risks

8.1 Introduction

This section documents the process that identifies and evaluates potential environmental impacts and risks and develops means of mitigating the impacts of the proposed Crux project on the environment, including socio-economic, cultural and human-health impacts.

It describes the approach undertaken to evaluate the magnitude of impact to environmental and social receptors from activities associated with the Crux project. This description includes the identification of potential impacts and benefits, and the evaluation of their significance.

The proposed management controls form the basis of the Environmental Performance Framework (refer **Section 9**) which will be implemented during the Crux project.

8.2 Shell Company Approach to Risk Management

At a corporate level, Shell has a standardised Hazards and Effects Management Process (HEMP), as the process by which Shell identifies and assesses hazards, implements measures to manage them. This process is consistent with the principles outlined in the Australian Standard AS/NZS ISO 31000:2009 Risk Management and Handbook 203:2006 Environmental Risk Management (**Figure 8-1**). HEMP is a fundamental element of the Shell Group HSSE and SP Control Framework and is a process that is applied at every phase of projects and operations.

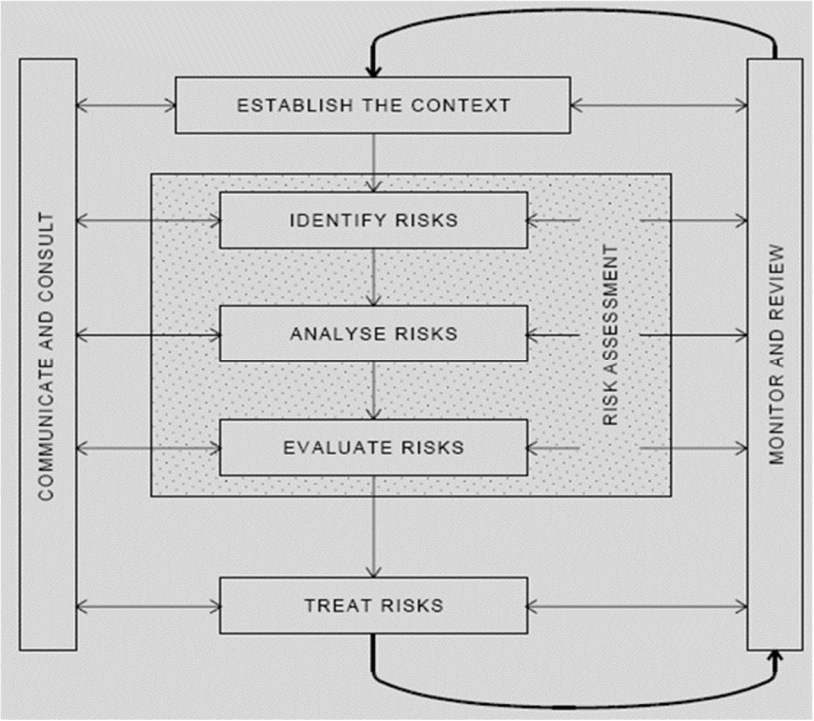


Figure 8-1: Risk Management Framework (AS/NZS 4360:2004 Risk Management)

Shell's HSSE and SP Management System is a system that is continually improving due to incorporation of legislative requirements, changing community expectations, improved available technology, learning from incidents industry wide and within Shell, and regular

management review. Assurance that the HSSE and SP Management System is working, continually improving and that each Shell company is correctly applying new Shell standards occurs via local self-assurance and the Shell Global auditing process, which is ongoing and serves to identify gaps and drive gap closure. Company standards are at least equal to, but in many cases more stringent than legislation, and aligned with global good industry practice benchmarks such as those published by the IFC and World Bank. Both legislation and company standards are continually being updated and requiring a higher level of performance over time. Concurrently new technologies are becoming available and making improved performance possible and more affordable. This continual improvement is reflected in more challenging ALARP and tolerable benchmarks, leading to better environmental outcomes over time.

In accordance with the NOPSEMA OPP Guidance Note (NOPSEMA 2018a), the OPP *"must include an evaluation of all the impacts and risks that reaches a conclusion on whether the impacts and risks will be 'acceptable' or 'unacceptable'"*. The demonstration of ALARP is an evaluation criterion relevant to subsequent activity-specific EPs, but is not considered further when evaluating impacts and risks for the purposes of this OPP. At the time of preparing the OPP, project design and execution detail is high level and preliminary, and not sufficiently detailed to perform an ALARP assessment. A much greater level of detail regarding project design and execution will be known during development of activity-specific EPs, at which time an ALARP assessment will be performed.

For the Crux project, the process of identifying and evaluating environmental impacts and risks was derived, at an appropriate level of definition, for a whole-of-project assessment of acceptability at an OPP level. The specific methodology adopted is summarised in the following **Section 8.3**.

8.3 Impact Assessment Methodology

This section describes the approach adopted for identifying and assessing impacts and risks on the physical, biological and human environment as relevant to the Crux project. Planned activities give rise to environmental impacts, while unplanned and accidental events pose a risk of environmental impact, if they occur. The risk of environmental impacts resulting from unplanned or accidental events is evaluated by taking the likelihood of the event occurring into consideration.

The approach aligns with Shell's methodology that enables a balanced assessment of planned impacts and unplanned risks, noting that there are some difficulties in relying solely on the Shell Risk Assessment Matrix (RAM) for assessment of significance of potential environmental impacts. Therefore, an adapted methodology has been developed by Shell United Kingdom, for use across Shell Group companies, that ties together both potential 'Magnitude' of a predicted impact and the 'Receptor Sensitivity' as shown in a summary impact significance matrix (see **Section 8.3.2**). The matrix is used for the assessment of impacts for both planned and unplanned events. However, in accordance with the Shell RAM, for assessment of unplanned events, the additional likelihood of occurrence of an event is taken into account.

For the purpose of this assessment, key terminology is defined in **Table 8-1**.

Table 8-1: Definition of Key Terminology for Impact Assessment.

Term	Definition
Activity	Components or elements of work associated with the project. All activities associated with the project have been considered at a broad level (as outlined in **Section 5**).
Aspect	Elements of the proponent's activities or products or services that can interact with the environment. These include planned and unplanned (including those associated with emergency conditions) activities.
Consequence	The outcome of an event, which can lead to a range of consequences. A consequence can be certain or uncertain and can have positive or negative effects. Consequences can be expressed qualitatively or quantitatively.
Control	A measure which mitigates risk through the reduction of the likelihood for a consequence to occur. Controls include existing controls (i.e. Company management controls or industry standards) or additional controls (i.e. additional measures identified during the risk assessment processes).
Event	An occurrence of a particular set of circumstances. An event can be one or more occurrences and can have several causes.
Factor	Relevant physical, biological, socio-economic and cultural features of the environment. These are also referred to within the OPP as values/sensitivities.
Hazard	A substance, situation, process or activity that has the ability to cause harm to the environment.
Impact	Any change to the environment, whether adverse or beneficial, wholly or partially resulting from a proponent's environmental aspects.
Likelihood	Description of probability or frequency of a consequence occurring with safeguards in place.
Inherent risk	The level of risk when existing controls are in place, but before the application of additional risk controls arising from risk assessment processes.
Residual risk	The level of risk remaining after risk treatment, i.e. application of additional controls (inclusive of unidentified risk).
Acceptable	The level of impact and risk to the environment that may be considered broadly acceptable with regard to all relevant considerations.

8.3.1 Impact Identification and Aspects

The identification of potential impacts is carried out prior to any detailed assessment of the relative importance of each issue, the sensitivity of the existing environmental and/or socio-economic values, or the magnitude of the potential impact, and does not take into account potential mitigation measures.

As summarised in **Section 5.7**, the key project aspects arising from the Crux project have been identified as:

- physical impacts (including vessel movements)
- lighting
- underwater noise
- atmospheric emissions
- IMS
- waste management
- liquid discharges, and
- unplanned spills.

8.3.2 Evaluation of Impacts

Impact Assessment Significance

The significance of environmental impacts is assessed in terms of:

- magnitude based on the size, extent and duration/frequency of the impact
- the sensitivity of the receiving receptors, and
- the likelihood of an unplanned event occurring.

These are described further below.

Magnitude

Levels of magnitude of environmental impacts are outlined in **Table 8-2**. The magnitude of an impact or predicted change takes into account the following (shown descriptively in **Figure 8-2**):

- nature of the impact and its reversibility
- duration and frequency of an impact
- extent of the change, and
- potential for cumulative impacts.

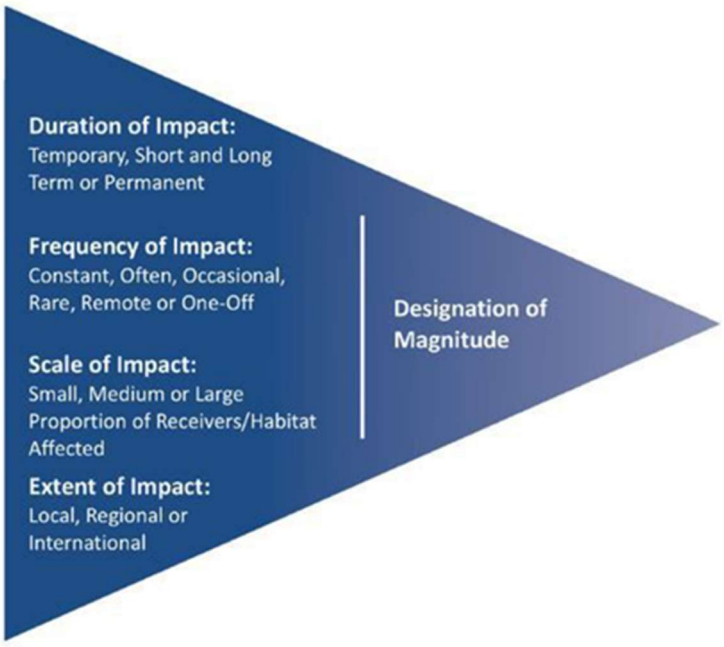


Figure 8-2: Definition of Magnitude in the Context of Impact Identification

The impact magnitude is defined differently according to the type of impact. For readily quantifiable impacts, such as noise or liquid discharge plume extent, numerical values can be used whereas for other topics (e.g. communities and habitats) a more qualitative definition is applicable. These criteria capture high level definitions, adapted as appropriate to the offshore context of the Crux project.

Table 8-2: Magnitude Criteria.

Definition	Environmental Impact
Positive effect	Net positive effect arising from a proposed aspect of the Crux project
No effect	No environmental damage or effects
Slight effect	Slight environmental damage contained within the project area Effects unlikely to be discernible or measurable No contribution to trans-boundary or cumulative effects Short-term or localised decrease in the availability or quality of a resource, not effecting usage
Minor effect	Minor environmental damage, no lasting effects or persistent effects are highly localised Minor change in habitats or species Unlikely to contribute to trans-boundary or cumulative effects Short-term or localised decrease in the availability or quality of a resource, likely to be noticed by users
Moderate effect	Moderate environmental damage that will persist or require cleaning up Widespread change in habitats or species beyond natural variability Observed off-site effects or damage, e.g. fish kill or damaged habitats Decrease in the short-term (1–2 years) availability or quality of a resource affecting usage Local or regional stakeholders' concerns leading to complaints Minor trans-boundary and cumulative effects
Major effect	Severe environmental damage that will require extensive measures to restore beneficial uses of the environment Widespread degradation to the quality or availability of habitats and/or wildlife requiring significant long-term restoration effort Major oil spill over a wide area leading to campaigns and major stakeholders' concerns Trans-boundary effects or major contribution to cumulative effects Mid-term (2–5 year) decrease in the availability or quality of a resource affecting usage National stakeholders' concern leading to campaigns affecting Company's reputation
Massive effect (to be used only for unplanned events)	Persistent severe environmental damage that will lead to loss of use or loss of natural resources over a wide area Widespread long-term degradation to the quality or availability of habitats that cannot be readily rectified Major impact on the conservation objectives of internationally/nationally protected sites Major trans-boundary or cumulative effects Long-term (> 5 year) decrease in the availability or quality of a resource affecting usage International public concern

Receptor Sensitivity

For this OPP, receptors are categorised into different groups (as described in **Section 6**):

- physical environment – including water quality, sediment quality and oceanography
- threatened species and ecological communities – including marine fauna (marine mammals, marine reptiles, fish, sharks, rays and birds) and associated BIAs, benthic infauna and plankton
- ecosystems, communities and habitats – including shoals/banks, offshore reefs/islands and KEFs, and

- socio-economic and cultural environment – including heritage areas, marine parks, shipwrecks, fishing (commercial, traditional and recreational), tourism and recreation, commercial shipping, and offshore petroleum exploration and operations.

Receptor sensitivity criteria are based on the following key factors:

- importance of the receptor at local, national or international level – for instance, a receptor will be of high importance at international level if it is categorised as a designated protected area (such as a Ramsar site). Areas that may potentially contain high value habitats are of medium importance if their presence/extent have not yet been confirmed
- sensitivity/vulnerability of a receptor and its ability to recovery – for instance, certain species could adapt to changes easily or recover from an impact within a short period of time. Thus, as part of the receptor sensitivity criteria (**Table 8-3**), professional judgement considers immediate or long-term recovery of a receptor from identified impacts. This also considers if the receptor is under stress already, and
- sensitivity of the receptor to certain impacts – for instance, flaring emissions will potentially cause air quality impacts and do not affect other receptors such as seabed.

Table 8-3: Receptor Sensitivity Criteria

Sensitivity	Definition
Low	Receptor with low value or importance attached to them, e.g. habitat or species which is abundant and not of conservation significance, or Immediate recovery and easily adaptable to changes
Medium	Receptor of importance, e.g. recognised as an area/species of potential conservation significance for example, KEF or listed threatened species, or Recovery likely within 1–2 years following cessation of activities, or localised medium-term degradation with recovery in 2–5 years.
High	Receptor of key importance, e.g. recognised as an area/species of potential conservation significance with development restrictions for example marine parks or conservation reserves, or habitat critical to the survival of a species, or Recovery not expected for an extended period (> 5 years following cessation of activity) or that cannot be readily rectified

Significance Criteria for Planned Events

The magnitude of the impact and sensitivity of receptor is then combined to determine the impact significance as shown in **Table 8-4**. Key management controls are subsequently identified to reduce the potential for such an event occurring in order to determine residual impact and inform an assessment of acceptability.

Table 8-4: Impact Significance Matrix (Planned)

		Sensitivity		
		Low	Medium	High
Magnitude	+1 - Positive	Positive effect	Positive effect	Positive effect
	0 – No effect	No effect	No effect	No effect
	1 - Slight effect	Slight	Slight	Minor
	2 – Minor effect	Minor	Minor	Moderate
	3 – Moderate effect	Minor	Moderate	Major
	4 – Major effect	Moderate	Major	Major

Unplanned Events (Likelihood Criteria)

For unplanned events the likelihood of such an event occurring also requires consideration. For example, based on magnitude and sensitivity alone a hydrocarbon spill associated with a long-term well blowout would be classed as having major impact significance, however, the likelihood of such an event occurring is very low. In addition, the mitigation measures for such impacts focus on reducing the likelihood of the impact occurring as opposed to reducing the effects of the impact itself. Thus, unplanned events also require assessment in terms of environmental risk.

As with planned activities, the potential impacts of unplanned events are identified, and the impact significance is determined, which inherently takes into account the sensitivity of the relevant receptor(s). The significance of the impact will then be combined with the likelihood of the event occurring (**Table 8-5**) in order to determine its overall environmental risk as summarised in **Table 8-6**. Key management controls are then identified to reduce the risk of such an event occurring in order to determine residual risk and inform assessment of acceptability.

Table 8-5: Likelihood Criteria

Likelihood	Definition
A	• Never heard of in the industry – extremely remote • < 10^{-5} per year • Has never occurred within the industry or similar industry but theoretically possible
B	• Heard of in the industry – remote • 10^{-5} – 10^{-3} per year • Similar event has occurred somewhere in the industry or similar industry but not likely to occur with current practices and procedures
C	• Has happened in the Company or more than once per year in the industry – unlikely • 10^{-3} – 10^{-2} per year • Event could occur within lifetime of similar facilities. Has occurred at similar facilities
D	• Has happened at the location or more than once per year in the Company – possible • 10^{-2} – 10^{-1} per year • Could occur within the lifetime of the development
E	• Has happened more than once per year at the location – likely • 10^{-1} – > 1 per year • Event likely to occur more than once at the facility

Table 8-6: Environmental Risk Matrix (Unplanned Events)

		Likelihood				
		A	B	C	D	E
Impact Significance	No effect	No effect				
	Slight	Negligible	Negligible	Minor	Minor	Minor
	Minor	Negligible	Minor	Minor	Moderate	Moderate
	Moderate	Minor	Minor	Moderate	Moderate	Major
	Major	Moderate	Moderate	Moderate	Major	Major
	Massive	Major	Major	Massive	Massive	Massive

For the purpose of the Crux risk review, the following key risks were assessed in accordance with the risk-based approach summarised in this section:

- vessel movements, in the context of unplanned interactions with marine fauna
- IMS
- unplanned (spill) events, and
- unplanned release of off-specification PFW.

8.3.3 Assessment of Residual Impacts and Risks

The iterative impact assessment process takes into account the mitigation measures that have been adopted as part of the project design and project plan. As such each impact will be re-assessed taking mitigation measures, controls and safeguards into account in order to determine the residual impact (or risk for unplanned events). In the evaluation of residual impacts and risks, all controls are assumed to be implemented effectively and functioning as intended.

The residual impact detailed in **Section 8.4** represents a summary of the various individual environmental value/sensitivity rankings defined from a detailed environmental risk workshop attended by specialist environmental scientists together with key members of the Shell project team who are directly responsible for the design and development the Crux project. The residual impact rankings provided represent the highest residual impact for that receptor group (i.e. physical environment, threatened species and ecological communities, ecosystems, communities and habitats, and socio-economic and cultural environment), and therefore may be a conservative assessment for some individual environmental values/sensitivities.

8.3.4 Environmental Performance Outcomes

Environmental Performance Outcomes (EPOs) have been developed for all aspects of the Crux project. The purpose of the EPOs is to provide specific, measurable levels of environmental performance that are:

- consistent with the principles of ESD, and
- demonstrate that the environmental impacts and risks of the Crux project are of an acceptable level.

Note that the consideration of acceptability for each aspect is provided in the relevant **Acceptability** sections in the evaluation of environmental impacts and risks. Consequently, these acceptability considerations are a component of the EPO.

The EPOs in this OPP will be inherited by the subsequent EPs for petroleum activities conducted within the scope of the OPP. Given the relatively early stage of technical definition (i.e. pre-FEED) phase of the Crux project, the EPOs in the OPP may not be inherited verbatim on subsequent EPs, however any EP EPOs will maintain the equivalent, or better, level of environmental performance.

EPOs provided in this OPP will be demonstrated through the implementation of subsequent EPs. EPOs associated with planned impacts will generally be demonstrated through successful implementation of controls, environmental performance standards and associated measurement criteria. Note that control may include environmental monitoring programs, however these are not required where there is high confidence in the effectiveness of controls and the potential for environmental impact is low. Where an unplanned event (e.g. accidental discharge) results in the potential for environmental harm, the incident reporting and investigation process will identify if there is the potential for environmental impacts. This process will provide sufficient information to determine if the EPO has not been achieved.

Considering the ongoing concept refinement and remaining front end engineering work required to be completed, key controls outlined in this **Section 8** are all considered to be initial judgements on likely available key controls, however where a control relates to elements of operations or design yet to be established, it should be recognised that adjustments in what these key controls end up being established may change, subject to final design and operational processes established. It should also be recognised that all environmental impacts and risks will be managed to acceptable levels on an ongoing basis.

8.4 Evaluation of Project Environmental Impacts and Risks

8.4.1 Physical Presence and Vessel Movements

8.4.1.1 Project Context

Aspects of the Crux project will result in a physical presence in the marine environment, which may interact with environmental receptors. These aspects are described in **Section 5.7.1** and include:

- drilling the foundation wells with a moored semi-submersible rig,
- installation, operation and decommissioning of the Crux platform (jacket structure),
- installation, operation and decommissioning of the export pipeline and subsea integration system (e.g. Crux PLET and Prelude PLEM),
- completion, operation and abandonment of wells,
- potential future subsea facilities associated with well and tie-back infrastructure, and
- vessel operations associated with the above points.

A petroleum safety zone of 500 m will be established around the Crux platform, as per the OPGGS Act, from which unauthorised marine users will be excluded. The petroleum safety zone is a key safety measure to reduce potential interactions with the Crux platform and associated subsea infrastructure. Temporary exclusion zones will be maintained around any drilling rigs and the pipelay vessel.

Refer to **Section 5.7.1** for additional information on these aspects.

The proposed direct seabed disturbance for the Crux project are summarised in **Table 5-4**.

8.4.1.2 Description and Evaluation of Impacts and Risks

A range of environmental sensitivities within the following groups may be impacted by the physical presence of the Crux project, including:

- physical environment
- ecosystems, communities and habitats
- threatened species and ecological communities, and
- socio-economic and cultural environment.

Potential impacts and risks associated with aspects of the Crux project with these are discussed below. As outlined in **Section 8.3.3**, the assessment considers only the residual impacts and risks following the application of controls.

Physical Environment

Bathymetry and Seabed Features

Extensive seabed surveys of the Crux project footprint have been carried out in 2017 (e.g. Fugro 2017a, 2017b), which indicate the seabed is relatively flat with a gentle gradient, with one area of outcropping reef identified in the north-eastern portion of the in-field development area (**Figure 6-4**). Sediments within the project area are typically smooth and bare, with sediment particle size distribution characterised by sand particles (muddy sands at the western end of the pipeline corridor, transitioning to gravelly sands at the proposed location of the Crux platform).

Activities associated with the drilling and installation of wells will result in physical disturbance of the seabed via the deployment and retrieval of drilling rig anchors and mooring lines. Seabed disturbance from anchoring is localised to the footprint of the mooring spread, which is estimated to cover an area of approximately 10,000 m^2 for the foundation development drilling program. A small footprint of disturbed seabed will remain (e.g. pull-out scar or mound) following anchor recovery. This footprint is expected to be subject to natural sedimentary processes and will result in slight seabed disturbance contained entirely within the project area.

Drilling will also result in the discharge of cuttings to the marine environment. The environmental impacts and risks associated with the discharge of drill cuttings are provided in **Section 8.4.7**.

Installation of the Crux platform will result in modification of the seabed in the immediate area surrounding the jacket piles. The jacket piles will provide hard substrate, which is likely to lead to the development of associated biological communities and increase the potential for localised scouring. This disturbance will persist while the platform jacket is in place. Seabed disturbance from the construction and operation of the Crux platform will result in a slight effect to bathymetry and seabed features, which will be highly localised to the seabed immediately around the platform.

Installation of the export pipeline will modify the habitat directly below the pipeline, with the existing unconsolidated sediments replaced by hard substrate (i.e. the pipeline). Given the nature of the sediments within the pipeline corridor, it is expected that sections of the pipeline may become buried over time because of natural sediment movement,

resulting in the return of soft sediment habitat. No pipeline stabilisation or trenching is planned during installation of the export pipeline.

Localised scour and/or pipeline movement may also occur and potentially result in free spans that require rectification or stabilisation (e.g. installation of grout bags, concrete mattresses etc.). The disturbance from rectification and stabilisation activities is expected to be highly localised to discrete areas of the export pipeline. The footprint on the seabed of grout bags on the seabed is typically confined to a small area directly below the pipeline. The footprint of a grout bag is a consequence of the size of the bag. Bag size selection typically depends on the size of the span that requires rectification; larger spans typically require larger bags; most have a footprint < 100 m^2. The footprint of a mattress depends on the size of the mattress being used; typical mattresses cover approximately 100 m^2. Mattress size selection is dependent on the scale of the span or stabilisation required. While the need for grout bags or mattresses (if any) is currently unknown, operational experience indicates they are not typically required in large numbers given the export pipeline will have a concrete weight coating.

Installation of the subsea integration system and associated subsea facilities (including for any future tiebacks) in the in-field development area will consist of infrastructure such as a PLET, PLEM, manifold, flowlines, spools and potentially subsea compression, where this a preferred concept in future. The footprint associated with these subsea components will be highly localised.

The preferred decommissioning option of the Crux platform and export pipeline have not yet been selected and will depend on a range of factors. If decommissioning in situ is undertaken, the modification of the seabed by the decommissioned infrastructure will effectively be long term (i.e. many decades to potentially hundreds of years) before reverting to a condition consistent with the natural seabed. The infrastructure remaining in situ will provide the basis for artificial reefs.

Water Quality

Impacts to water quality from the physical presence of the Crux project are expected to be restricted to localised sediment plumes during deployment and recovery of drilling rig anchors and installation of the export pipeline, platform and subsea integration system. Sediment plumes from these activities may result in a slight and temporary decrease in water quality due to increase in suspended sediments. These slight, temporary impacts to water quality will not impact biodiversity or ecological integrity within the Crux project area.

Sediment Quality

Impacts to sediment quality from physical presence during all phases of the Crux project are expected to be minor. Changes to physical properties, such as particle size distribution and geological origin, are not expected to occur beyond the immediate footprint of the subsea infrastructure. These changes will not impact biodiversity or ecological integrity within the Crux project area.

The discharge of drill cuttings may result in changes to sediment quality; the environmental impacts and risks from the discharge of drill cuttings are considered in **Section 8.4.7**.

Other liquid discharge streams (e.g. liquid discharges such as produced water, sewage and putrescible waste) and unplanned releases of solid waste may also impact sediment quality. Waste management and liquid discharges, and the associated environmental impacts and risks, are discussed in **Sections 8.4.6** and **8.4.7** respectively.

Ecosystems, Communities and Habitats

Benthic Communities

Surveys of the project area identified several benthic communities, which were closely associated with seabed characteristics (Fugro 2017).

Much of the project area comprises unconsolidated sediments, with the characteristics of the sediment influencing benthic communities (**Section 6.4.2**). Coarser sediments (e.g. higher gravel or sand fractions) appeared to support sparse assemblages of filter (e.g. sea pens and sponges) and deposit feeders (e.g. urchins). Sediments with a relatively high portion of muds tended to host burrowing (e.g. polychaete worms, bivalve molluscs, crustaceans) and deposit feeding organisms (e.g. urchins, sea cucumbers). These benthic communities were observed at low densities. The habitats associated with these communities are broadly distributed in the wider region and are not considered to be unique or highly sensitive. The installation infrastructure associated with the Crux project (including stabilisation or span rectification using grout bags or mattresses) will result in the disruption of a relatively small area of soft sediment habitats, which will become hard substrate habitats due to the presence of subsea infrastructure. The potential impacts and risks to these communities from the physical presence of the Crux project are considered to be minor and do not exceed the significant impact criteria for the Commonwealth marine environment listed in **Table 7-1**.

Relatively small areas of hard substrate were observed in the in-field development area, and a small portion of the export pipeline corridor. The hard substrate in the in-field development area consists of an outcropping of reef with benthic habitats comprising filter feeders, some hard corals and burrowing macrofauna (**Figure 6-5**). The area of hard substrate observed within the export pipeline corridor comprised a relatively small portion of benthic habitats in the area, and was characterised by hydroids, sponges and branching corals (Fugro 2017). This area overlaps the Continental Slope Demersal Fish Communities KEF (refer to **Key Ecological Features** below).

Shoals and Banks

There are three shoals within the in-field development area; Goeree Shoal, Eugene McDermott Shoals and Vulcan Shoal. These will not be directly impacted by the physical presence of the Crux project as Shell will apply a 1 km buffer around such features (refer to the blue box titled **Will a One Kilometre Buffer Protect the Shoals?** below for further information). This buffer is expected to be sufficient to avoid direct and indirect impacts and risks from the physical presence of the Crux project. The potential impacts and risks to shoals and banks from the physical presence and vessel movements aspect of the Crux project are expected to result in no direct impacts on the shoals within (i.e. Goeree Shoal, Eugene McDermott Shoal and Vulcan Shoal) or beyond the Crux in-field development area.

Will a One Kilometre Buffer Protect the Shoals?

The shoals and banks in the Timor Sea are features that are "islands" of notable biodiversity, hosting benthic habitats and communities that are of high environmental value (refer to **Section 6.4.4**). Three shoals are situated within the Crux in-field development area: Goeree Shoal, Eugene McDermott Shoal and Vulcan Shoal. The nearest of these shoals (Goeree Shoal) is approximately 13 km from the Crux platform. Shell will implement a 1 km buffer around the outer boundary of these shoals within which no project activities will take place.

Shell recognises the high environmental value of these shoals, and has situated the Crux platform and export pipeline corridor away from these features to reduce the potential for environmental impacts. As a result, Shell is confident the foundation development drilling, Crux platform construction, export pipeline installation, operations and decommissioning will have no direct impacts on the banks and shoals in the Crux project area.

The scope of this OPP also includes future tieback wells in the Crux in-field development area. The locations of future tieback wells has not yet been determined, and they may occur in proximity to Goeree Shoal, Eugene McDermott Shoal and Vulcan Shoal. Shell recognises that the drilling of these wells may result in environmental impacts and risks to the habitats and communities of these shoals from:

- Physical presence and vessel movements:
  - installation, use and removal of the anchoring spread for the MODU
  - presence of support vessels
- Liquid discharges:
  - discharge of drilling fluids and cuttings
  - utility discharges from the drilling rig and support vessels (e.g. sewage, putrescible wastes etc.)
- Underwater noise:
  - underwater noise emissions from VSP
  - underwater noise from support vessels
- Unplanned spills:
  - Loss of well control
  - Loss of vessel fuel.

Shell has evaluated the environmental impacts and risks from these activities. Based on the outcomes of this evaluation, Shell has committed to implementing a 1 km buffer around the outer boundaries of each of these shoals within which no activities associated with the Crux project will take place. The reasoning for the 1 km buffer for each of the aspects listed above is provided below.

Physical Presence and Vessel Movements

The risks and impacts from physical presence and vessel movements to the benthic habitats and communities of the shoals occur within the direct footprint of these activities. The 1 km buffer ensures the footprint of any future tieback drilling is well beyond the shoals, resulting in no impacts.

Liquid Discharges

Shell has undertaken numerical modelling studies of the discharge of drilling fluids and cuttings to inform the assessment of potential impacts and risks (refer to **Section 8.4.7**). This assessment concluded the low impact threshold (1 mm) for sediment deposition would be reached within < 326 m, and be consistent with natural levels within < 2 km. Given the MODU will be moored in place using anchors (which must be outside the 1 km buffer), and the horizontal distance between anchors and the MODU is approximately > 1,000 m for the waters depths in the Crux in-field development area, the discharge point for drilling fluids and cuttings will be well beyond the 1 km buffer. This ensures that sediment deposition is well below impact thresholds beyond the shoals.

The discharge of drilling fluids and cuttings will result in a plume of increased suspended sediments, which may move towards a shoal, depending on prevailing currents. Given the distance between the discharge location and the shoals, this plume has little potential to impact upon the benthic habitats and communities (refer to **Section 8.4.7** for further discussion).

Utility discharges from the MODU and support vessels will mix rapidly and will not result in impacts beyond the discharge point.

Underwater Noise

Modelling of underwater noise levels for VSP indicated that noise levels would not exceed the permanent injury, temporary threshold shift and behavioural impact thresholds at any range. Noise from support vessels was also estimated not to exceed these thresholds at any range. The provision of the 1 km buffer ensures that received noise levels from tieback drilling at the shoals will be well below the levels that may impact the benthic habitats and communities of the shoals.

Unplanned Spills
Unplanned spills such as loss of well control, have the potential to impact large areas, and a worst-case loss of well control from any location within the Crux in-field development area is likely to have potential imapcts on shoals. A 1 km buffer is not effective in preventing impacts from a loss of well containment. Shell applies its considerable resources and experience in ensuring that such large-scale hydrocarbon releases during during drilling do not occur.

Key Ecological Features

The Continental Slope Demersal Fish Communities KEF is partially overlapped by the export pipeline corridor, with the corridor covering approximately 14 km^2 (less than 0.05%) of the KEF. No other components of the project area overlap this KEF. Environmental surveys of the export pipeline corridor did not observe particularly high or diverse fish assemblages within the overlap, although isolated areas of hard substrates and associated communities were observed (Fugro 2017). The installation of the export pipeline may result in disturbance to benthic communities within the KEF. The presence of pipelines has been positively correlated with the diversity and abundance of fish (McLean et al. 2017); over time, the export pipeline is expected to host an artificial reef community with relatively high fish diversity and abundance compared to the surrounding seabed.

Given the ecological value of the Continental Slope Demersal Fish Communities KEF is the relatively high diversity of demersal fish species, physical presence of the export pipeline is not expected to have any impact on the environmental value of the KEF. Subsea infrastructure construction has not been identified as an actual or potential concern in relation to the KEF (DSEWPaC 2012b). No other KEFs overlap the project area.

Threatened Species and Ecological Communities

Key Fauna Species

Project vessels moving in the project area may present a hazard to protected marine fauna, such as whales, turtles and whale sharks. Vessel movements can result in collisions between the vessel and marine fauna, potentially resulting in injury or death. Factors affecting the likelihood and severity of impacts from collisions include vessel type, vessel speed, water depth and the behaviours of animals present (Commonwealth of Australia 2017b). The risks of vessel collisions with marine fauna, particularly threatened and migratory species (i.e. MNES), described below are consistent with the acceptable levels of impacts defined in **Section 7**. Shell's environmental management of the physical presence and vessel movements aspect of the Crux project is aligned with conservation advice, recovery plans and threat abatement plans published by the DoEE; refer to discussion of MNES in the discussion of Acceptability below (**Section 8.4.1.4**).

Whales are vulnerable to collisions with vessels due to their large size and the relatively high proportion of time spent at or near the sea surface. The likelihood and consequence of vessel collisions with whales are influenced by vessel speed; the greater the speed at impact, the greater the risk of mortality (Jensen and Silber 2004; Laist et al. 2001). Vanderlaan and Taggart (2007) found that the chance of lethal injury to a large whale as a result of a vessel strike increases from about 20% at 8.6 knots to 80% at 15 knots. According to the data of Vanderlaan and Taggart (2007), it is estimated that the risk is less than 10% at a speed of 4 knots. Vessel-whale collisions at this speed are uncommon and, based on reported data contained in the United States National Ocean and Atmospheric Administration (NOAA) database (Jensen and Silber 2004), there only two

known instances of collisions when the vessel was travelling at less than 6 knots. Both of these were from whale watching vessels that were deliberately placed amongst whales.

Project vessels within the project area, carrying out petroleum activities, are likely to be travelling less than 8 knots; much of the time vessels are holding station or moving very slowly (e.g. pipelay vessels typically move < 1–2 knots, laying up to 2 km of pipe per day). Therefore, the risk of a vessel collision with whales is inherently low. No known key aggregation areas for whales (resting, breeding, migration or feeding) are located within or immediately adjacent to the project area. The nearest recognised BIAs for cetaceans is the pygmy blue whale migration area, which lies approximately 69 km west of the project area. Shell acknowledges that the BIA is indicative only, and that blue whales may be present beyond the boundary of the BIA.

Whale sharks are at risk from vessel strikes when feeding at the surface or in shallow waters (where there is limited option to dive). Whale sharks occur within the project area (e.g. traversing the open waters within or surrounding the project area during migration to and from aggregation off Ningaloo Reef) and a BIA for whale sharks overlaps with the project area. However, it is expected that whale shark presence within the project area would not comprise of significant numbers given there is no main aggregation area within the vicinity of the project area, and their presence would be transitory and of a short duration. This is consistent with tagging studies of whale shark movements which show continual movement of whale sharks in deeper, open offshore waters (Meekan and Radford 2010). There are no constraints preventing whale sharks from moving away from vessels (e.g. shallow water or shorelines).

The project area is unlikely to represent important habitat for marine turtles given the absence of potential nesting. Much of the project area is in water depths > 90 m, which is deeper than typical foraging dives by marine turtles (e.g. Hays et al. 2001; Polovina et al. 2003), although there are three named shoals that rise to approximately 30 m water depth. Shell has established a 1 km exclusion zone around these shoals (**Figure 5-3**). As such, the presence of marine turtles within the project area is likely to be restricted to individual turtles transiting the area, with potential foraging at the relatively shallow shoals in the in-field development area. No BIAs or habitat critical for the survival of marine turtles, as identified in the Recovery Plan for Marine Turtles in Australia (Commonwealth of Australia 2017a), overlap the project area. As with cetaceans, the risk of collisions between turtles and vessels increases with vessel speed (Hazel et al. 2007). The typical response from turtles on the surface to the presence of vessels is to dive (a potential “startle” response), which decreases the risk of collisions (Hazel et al. 2007). Given the low speeds of project vessels, along with the expected low numbers of turtles within the project area, interactions between vessels and turtles are highly unlikely.

Given the offshore location and distance to the closest shorelines (approximately > 100 km from the Crux platform), the number of birds within the project area is expected to be low. No BIAs for birds overlap the project area. The Crux platform may eventually provide roosting habitat for seabirds, which may be attracted to the platform. The presence of birds can lead to damage of the platform (e.g. guano fouling of equipment). Shell may install non-lethal bird deterrents (e.g. acoustic deterrents) to reduce the attractiveness of the platform for birds. Such deterrents are routinely used throughout the world to prevent damage to offshore platforms. Birds may also be attracted to vessels, resulting in a temporary behavioural disturbance. The potential behavioural disturbance resulting from the physical presence of the Crux project is slight.

Fish species, particularly site attached species, will be attracted to the Crux platform and subsea infrastructure, which will function as an artificial reef. As outlined above in the discussion of benthic communities, the physical presence of the Crux project infrastructure is expected to have a slight positive effect on fish species diversity and abundance resulting from the creation of an artificial reef in an area which consists primarily of soft, unconsolidated sediments.

Socio-economic and Cultural Environment

Marine Archaeology

A review of the ANSD did not identify any known shipwrecks within the project area. Bathymetric surveys of the project area did not identify any seabed features consistent with wrecks or archaeological features. As such, no impacts to marine archaeological values will occur as a result of the project.

Commercial Fishing

Several State- and Commonwealth-managed commercial fisheries overlap the project area (**Section 6.6.9**). However, only the Commonwealth managed North-West Slope Trawl Fishery and the State managed Northern Demersal Scalefish Managed Fishery are active near the project area. Potential impacts and risks from physical presence of the Crux project include temporary displacement of commercial fishers (primarily during the installation phase) and the permanent exclusion of commercial fishers from the 500 m petroleum safety zone surrounding the Crux platform. There have been no concerns from commercial fishers regarding the presence of the Shell Prelude FLNG facility and associated exclusion area, which is 165 km south-west of the Crux platform.

Most historical fishing effort in the Commonwealth-managed NWSTF lies beyond the project area, with the majority of fishing occurring south-east of Scott Reef. The fishery primarily targets scampi using demersal trawls. The export pipeline corridor is the only element of the project area that overlaps the NWSTF managed area, with the overlapping area (approximately 233 km^2) representing less than 0.06% of the managed fishery area. Historical effort in the NWSTF lies primarily to the south-west of the project area (**Section 6.6.9**), with little recorded effort in the immediate vicinity of the project area. Effort in the fishery is relatively low, with one to two vessels active in the fishery in the 2014–15 and 2015–16 fishing seasons (Woodhams and Bath 2017). Given the fishing method (demersal trawls) may interact with infrastructure on the seabed, there is the potential for interactions such as gear entanglement. Participants in the fishery may also be temporarily displaced by vessels during installation of the export pipeline. This potential is considered very low given:

- the location of all subsea infrastructure will be provided to the Australian Hydrographic Office for inclusion on nautical charts
- prior to formal consultation and release of this document, Shell's targeted and ongoing consultation program has not as this stage identified any concerns from participants in the NWSTF, and
- the relatively small project footprint and the lack of fishing effort near the project area.

The project area partially overlaps Zones B and C of Area 2 (offshore area) of the State-managed Northern Demersal Scalefish Managed Fishery. Zone B contains most activity in the fishery, with Zone C representing a developing deep-water fishery area (Department of Fisheries 2017). The fishery in Zones B and C is primarily a trap-based fishery, with some line fishing. The in-field development area overlaps approximately

146 km^2 of Zone B (approximately 0.2%); the export pipeline corridor overlaps approximately 62 km^2 and 252 km^2 of Zones B (approximately 0.08%) and C (approximately 0.34%) respectively. The petroleum safety zone exclusion represents less than 0.01% of Zone B of the Northern Demersal Scalefish Fishery. The fishery is active, with seven vessels participating in the Northern Demersal Scalefish Fishery in 2015 (Department of Fisheries 2017). Given the fishery does not use trawls, the chance of gear entanglement with subsea infrastructure is very unlikely. Entanglement of set fishing gear (e.g. traps) with project vessels and equipment is also considered unlikely. Participants in the Northern Demersal Scalefish Fishery may temporarily be displaced by project vessels and the drilling rig, and permanently excluded from the 500 m petroleum safety zone around the Crux platform. Once installed, the subsea infrastructure (predominantly the export pipeline) may enhance targeted fish stocks by functioning as an artificial reef. The impacts and risks of exclusion/displacement from areas of the managed fishery from the Crux project are slight.

Traditional Indigenous Fishing

The export pipeline corridor partially overlaps the MoU box, within which traditional Indonesian fishing is permitted. These fishing activities are restricted to relatively shallow waters, such as waters surrounding Ashmore Reef, Cartier Island, Seringapatam Reef, Scott Reef and Browse Island. The export pipeline corridor does not include any shallow seabed features that may be targeted by traditional Indonesian fishers. The potential impacts and risks from the physical presence of the Crux project are considered to result in no effect on traditional fishing.

Ports and Commercial Shipping

Vessel tracking data from the AMSA indicates that commercial shipping in the project area is negligible, with the exception of support vessels at the existing Prelude FLNG facility and the Montara development. Potential impacts and risks to commercial shipping include temporary displacement from around project vessels and the drilling rig (primarily during the installation phase) and exclusion from the petroleum safety zone surrounding the Crux platform. The potential impacts and risks from the physical presence of the Crux project are considered to result in no effect on ports and commercial shipping.

8.4.1.3 Risk and Impact Summary and Key Management Controls

Table 8-7: Physical Presence and Vessel Movements Evaluation of Impacts and Risks

Project Component/ Activity	Environmental Value/Sensitivity				Evaluation – Planned		
	Physical Environment	Threatened Species and Ecological Communities	Ecosystems, Communities and Habitats	Socio-economic and Cultural Environment	Magnitude	Sensitivity	Residual Impact
Evaluation – Planned Impacts							
Planned impacts resulting from the physical presence of the Crux project, including: • drilling of the foundation wells with a		X	X	X	Minor effect	Low	Minor

moored semi-submersible drilling rig • physical presence of the Crux platform, export pipeline and subsea integration system, • presence of project vessels and vessel movements, and • seabed disturbance from project footprint.							
Evaluation – Unplanned							
Project Component/ Activity	**Physical Environment**	**Threatened Species and Ecological Communities**	**Ecosystems, Communities and Habitats**	**Socio-economic and Cultural Environment**	**Significance**	**Likelihood**	**Residual Risk**
Unplanned risks resulting from the physical presence of the Crux project, including: • presence of project vessels and vessel movements – collision with marine fauna.		X			Minor	Unlikely	Minor
Key Management Controls							

All project vessels operating within the project area will adhere to the navigation safety requirements contained within the International Regulations for Preventing Collisions at Sea 1972 (COLREGS), Chapter 5 of The International Convention for the Safety of Life at Sea 1974 (SOLAS Convention), International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW Convention), the *Navigation Act 2012* and any subsequent Marine Orders, which specify standards for crew training and competency, navigation, communication, and safety measures.

Maintenance of a minimum 1 km buffer from shoals within the in-field development area (**Figure 5-3**).

Vessels will adhere to the requirements of the EPBC Regulations Part 8.1 – Interacting with cetaceans, (except in emergency conditions or when manoeuvring is not possible, such as in the case of pipelay activities), which include:

- implement a caution zone of 150 m for dolphins and 300 m for whales
- vessels will not knowingly approach closer than 100 m to a whale and 50 m for a dolphin (i.e. no approach zone)
- make sure a vessel does not drift or approach within 50 m of a dolphin or 100 m of a whale
- vessels will not knowingly travel > 6 knots within the caution zone of a whale or dolphin, and
- there will not knowingly be no more than three vessels within 300 m of a whale (i.e. caution zone).

All areas of the seabed disturbed by installation activities will be surveyed prior to installation (the Crux NNM platform location and export pipeline corridor have been surveyed as part of the baseline environmental studies for the Crux project).

Validate that the Crux platform, export pipeline and subsea integration system facilities are laid according to planned locations within allowable tolerances.

An anchoring plan will identify suitable areas for anchors to be placed within the in-field development area and will confirm no anchoring on shoals.

Australian Hydrographic Service will be advised of project activities and installed infrastructure to facilitate issuing Notices to Mariners.

Decommissioning

Development and implementation of a project decommissioning plan which considers environmental impacts and risks.

Prior to the end of operating life, a comparative assessment of potential decommissioning options will be undertaken to inform the development of a Decommissioning EP that will be submitted to NOPSEMA. The comparative assessment will consider the merits of each option in the context of health, safety and environmental protection, technological feasibility, local capacity, regulatory compliance, public participation and economic stewardship within a broader ALARP framework to inform selection of the preferred decommissioning strategy.

The Decommissioning EP will present the outcomes of the comparative assessment and include an ALARP and acceptability assessment of the preferred option. The acceptability assessment will consider ESD, industry standard at the time and stakeholder expectations. The Decommissioning EP will be implemented for the duration of the decommissioning activities.

8.4.1.4 Acceptability of Impacts and Risks

The acceptable levels of impact for the receptors that may credibly be impacted or at risk from the physical presence and vessel movements aspect of the Crux project are summarised in **Table 8-8**. The method by which these acceptable levels were determined, along with a justification as to why these are acceptable, are discussed in **Section 7**.

Based on the outcomes of the evaluation of impacts and risks, Shell considers that the environmental risks and impacts that may result from the physical presence and vessel movements aspect of the Crux project are acceptable.

Further discussion of the acceptability considerations outlined in **Section 7** in relation to the physical presence and vessel movements aspect of the Crux project is provided below.

Table 8-8: Acceptable Levels of Impacts and Risks from Physical Presence and Vessel Movements

Receptor Category	Receptor Sub-category	Acceptable Level of Impact	Are the Crux Project's Impacts and Risks of an Acceptable Level?
Physical Environment	Water quality	No significant impacts to water quality beyond 1 km of the Crux platform or drilling locations.	Yes, no significant impacts are likely beyond 1 km of the Crux platform as a result of physical presence and vessel movements, given the localised disturbance from these activities. These slight, temporary impacts to water quality will not impact biodiversity or ecological integrity within the Crux project area.
	Sediment quality	No significant impacts to sediment quality beyond 1 km of the Crux platform or drilling locations.	Yes, no significant impacts are likely beyond 1 km of the Crux platform as a result of physical presence and vessel movements, given the localised disturbance from these activities. These slight, temporary impacts to sediment quality will not impact biodiversity or ecological integrity within the Crux project area.

Receptor Category	Receptor Sub-category	Acceptable Level of Impact	Are the Crux Project's Impacts and Risks of an Acceptable Level?
Ecosystems, Communities and Habitats	Benthic communities	No significant impacts to benthic habitats and communities. Impacts to non-sensitive benthic communities limited to a maximum of 5% of the project area.	Yes, no significant impacts are expected, given the development footprint represents a small portion of a large regional benthic environment. Habitats associated with these communities are broadly distributed in the wider region and are not considered to be unique or highly sensitive. Impacts to non-sensitive communities is estimated to be <5% of the total project area.
	Shoals and banks	No direct impacts to named banks and shoals. No loss of benthic habitats and communities at named banks or shoals as a result of indirect/offsite[5] impacts.	Yes, the application of a 1 km buffer around the shoals will ensure that there are no direct impacts as a result of physical presence or vessel movements. This buffer will also achieve the acceptable environmental level of no loss of benthic habitats and communities from indirect impacts.
	Key Ecological Features	No significant impacts to environmental values of KEFs.	Yes, no significant impacts are expected as a result of physical presence or vessel movements, given the project footprint only overlaps less than 0.05% of the Continental Slope Demersal Fish Communities KEF. No other KEFs overlap the project area.
Threatened Species and Ecological Communities	Key fauna species	No mortality of threatened or migratory MNES fauna from the Crux project. Management of aspects of the Crux project must be aligned to conservation advice, recovery plans and threat abatement plans published by the DoEE. No significant impacts to threatened or migratory MNES fauna.	Yes, project impacts and risks are of an acceptable level, given the Crux project is not located in any BIAs or habitat critical to the survival of a species, with the single exception of the BIA for the whale shark, which represents a broad migratory corridor. Given the low speeds of project vessels, along with the expected low numbers of marine fauna within the project area, interactions between vessels and MNES fauna are unlikely. Shell's environmental management of the physical presence and vessel movements aspect of the Crux project is aligned with conservation advice, recovery plans and threat abatement plans.

[5] As defined in the Matters of National Environmental Significance - Significant impact guidelines 1.1 (DoEE 2013).

Receptor Category	Receptor Sub-category	Acceptable Level of Impact	Are the Crux Project's Impacts and Risks of an Acceptable Level?
Socio-economic and Cultural Environment	Commercial fisheries	No negative impacts to exploited fisheries resource stocks which result in a demonstrated direct loss of income. Temporary displacement of commercial fishing activities within the Crux project area (excluding petroleum safety zones) is acceptable. Permanent exclusion of commercial fishing activities from gazetted petroleum exclusion zones is acceptable.	Yes, project impacts and risks are of an acceptable level, given commercial fishing is typically concentrated mostly in coastal waters and little fishing effort is known to occur within the vicinity of the Crux project area. Temporary displacement within the Crux project area. Permanent displacement with the gazetted petroleum exclusion zone will be managed through consultation with fishing representatives and designation on Australian Hydrographic Office nautical charts.
	Shipping	Temporary displacement of commercial shipping within the Crux project area (excluding petroleum safety zones) is acceptable. Permanent exclusion of commercial shipping from gazetted petroleum exclusion zones is acceptable.	Yes, project impacts and risks are of an acceptable level, given commercial shipping in the project area is negligible. The nearest major shipping channel is approximately 560 km to the west of the proposed Crux platform. Temporary displacement within the Crux project area, and permanent displacement with the gazetted petroleum exclusion zone, will be managed through consultation with commercial shipping representatives and designation on Australian Hydrographic Office nautical charts.

Principles of ESD

The risks and impacts from the physical presence of the Crux project are consistent with the principles of ESD based on the following points:

- The physical presence and vessel movements aspect of the Crux project does not degrade the biological diversity or ecological integrity of the Commonwealth marine area in the Timor Sea. Significant impacts to MNES will not occur.
- The health, diversity and productivity of the marine environment will be maintained for future generations.
- The project does not significantly impinge upon the rights of other parties to access environmental resources (e.g. commercial and traditional fishers).
- The precautionary principle has been applied, and studies undertaken where knowledge gaps were identified. This knowledge has been applied during the evaluation of environmental impacts and risks.

Relevant Requirements

Management of the impacts and risks from the physical presence of the Crux project are consistent with relevant legislative requirements, including:

- compliance with international maritime conventions, including:
  - STCW Convention
  - SOLAS Convention, and
  - COLREGS.
- compliance with Australian legislation and requirements, including:
  - *Navigation Act 2012*:
    - Marine Order 21 (Safety of Navigation and Emergency Procedures)
    - Marine Order 30 (Prevention of Collisions), and
    - Marine Order 71 (Masters and Deck Officers).
  - EPBC Regulations:
    - adherence to the requirements of Part 8 (Interacting with cetaceans and whale watching).
- management of impacts and risks are consistent with policies, strategies, guidelines, conservation advice, and recovery plans for threatened species (**Table 8-9**).

Matters of National Environmental Significance

Threatened and Migratory Species

The evaluation of impacts and risks indicates significant impacts[6] to threatened and migratory species will not credibly result from the planned direct impacts from the physical presence and vessel movements aspects of the Crux project.

An unplanned collision between project vessels and threatened or migratory fauna (particularly cetaceans) is unlikely to occur and may result in injury to or death of individual animals. This unplanned event is not considered to have the potential for significant impacts to threatened or migratory species.

Alignment of the Crux project with management plans, recovery plans and conservation advice for threatened and migratory fauna is provided in **Table 8-9**.

Commonwealth Marine Environment

The impacts and risks from the physical presence of the Crux project on the Commonwealth marine environment do not breach any of the significant impact criteria provided in **Table 7-1** (note that the risk of IMS is considered in **Section 8.4.5**).

The impacts and risks from the physical presence and vessel movements aspect of the Crux project on the Continental Slope Demersal Fish Communities do not significantly affect the environmental values of the KEF. The overlap between the Crux pipeline corridor and the KEF constitutes a small portion of the total KEF area. The impacts and risks that may credibly arise from the physical presence of the Crux project will not impact upon the environmental values of the KEF. Hence, Shell considers the impacts and risks to the KEF to be acceptable.

[6] as described in Matters of National Environmental Significance - Significant impact guidelines (DoE 2013a)

Table 8-9: Summary of Alignment of the Impacts and Risks from Physical Presence and Vessel Movements Aspect of the Crux Project with Relevant Requirements for EPBC Threatened Fauna

Matters of National Environmental Significance	MNES Acceptability Considerations (Significant Impact Guidelines, EPBC Management Plans/Recovery Plans/Conservation Advices)	Threats Relevant to the Project	Demonstration of Alignment as Relevant to the Project
Threatened and Migratory species - marine mammals	Significant impact guidelines for Critically Endangered, Endangered, Vulnerable and Migratory species (**Table 7-1**)	Vessel collisions with marine fauna	The impact assessment indicates that vessel collisions with threatened or migratory marine mammals are very unlikely, and the consequence of any such collision would be restricted to an individual animal (refer to **Section 8.4.1.2**). As such, the Crux project does not exceed any of the significant impact criteria for Threatened and Migratory marine species provided in **Table 7-1**.
	National Strategy for Reducing Vessel Strikes on Cetaceans and other Marine Megafauna (Commonwealth of Australia 2017b)	Vessel collisions with marine fauna	The Crux project is aligned to 'Objective 3: Mitigation' of Strategy by: • maintaining separation of vessels and whales • maintaining slow vessel speeds, and • avoidance manoeuvres. This will be met by project vessels adhering to Part 8 (Interacting with cetaceans and whale watching) of the EPBC Regulations. Note the other objectives of the Strategy relate to actions for Government agencies.
	Conservation advice on sei whale (*Balaenoptera borealis*) (DoE 2015c)	Vessel collisions with marine fauna	The risk of vessel strikes will be managed by project vessels adhering to Part 8 (Interacting with cetaceans and whale watching) of the EPBC Regulations.
	Conservation advice on fin whale (*Balaenoptera physalus*) (DoE 2015d)	Vessel collisions with marine fauna	
	Conservation management plan for the blue whale: A recovery plan under the *Environment Protection and Biodiversity Conservation Act 1999* 2015-2025 (Commonwealth of Australia 2015a)	Vessel collisions with marine fauna	
	Conservation advice on humpback whale (*Megaptera novaeangliae*) (DoE 2015b)	Vessel collisions with marine fauna	
Threatened and Migratory species - marine reptiles	Significant impact guidelines for Critically Endangered, Endangered, Vulnerable and Migratory species (**Table 7-1**)	Vessel collisions with marine fauna	The impact assessment indicates that vessel collisions with threatened or migratory marine reptiles are very unlikely, and the consequence of any such collision would be restricted to an individual animal (refer to **Section 8.4.1.2**). As such, the Crux project does not exceed any of the significant impact criteria for Threatened and Migratory marine species provided in **Table 7-1**.

Matters of National Environmental Significance	MNES Acceptability Considerations (Significant Impact Guidelines, EPBC Management Plans/Recovery Plans/Conservation Advices)	Threats Relevant to the Project	Demonstration of Alignment as Relevant to the Project
	Recovery Plan for Marine Turtles in Australia 2017-2027 (Commonwealth of Australia 2017a)	Vessel collisions with marine fauna	Project vessel interactions with turtles are inherently unlikely due to the offshore location (and resultant low densities of turtles), slow speeds of project vessels and diving startle response of turtles.
	Conservation advice on leatherback turtle (*Dermochelys coriacea*) (DEWHA 2009a)	Vessel collisions with marine fauna	
Threatened and Migratory species - sharks and rays	Significant impact guidelines for Critically Endangered, Endangered, Vulnerable and Migratory species (**Table 7-1**)	Vessel collisions with marine fauna	The impact assessment indicates that vessel collisions with threatened or migratory sharks and rays are very unlikely, particularly given these taxa spend relatively little time at the sea surface. The consequence of any such collision would be restricted to an individual animal (refer to **Section 8.4.1.2**). As such, the Crux project does not exceed any of the significant impact criteria for Threatened and Migratory marine species provided in **Table 7-1**.
	Conservation advice on whale shark (*Rhincodon typus*) (DoE 2015l)	Habitat disruption from mineral exploration, production and transportation	The project area is not recognised as a critical habitat for whale sharks, although the project overlaps a broad BIA that represents a migration corridor. The conservation advice recommends minimising offshore developments close to marine features that may aggregate whale sharks and cites Ningaloo Reef and Christmas Island as examples. Studies of whale sharks tagged while aggregating at Ningaloo Reef have shown individuals transiting through the Timor Sea (Meekan and Radford 2010) but showed no evidence of aggregation around particular marine features in the open offshore waters within or in the vicinity of the project area.
Commonwealth marine area	Significant Impact Guidelines for the Commonwealth marine environment (**Table 7-1**)	Physical disturbance of the seabed. Vessel collisions with marine fauna.	The impact assessment indicates that the physical presence and vessel movements aspect of the Crux project will not exceed the Commonwealth marine environment significant impact criteria provided in **Table 7-1**.

Internal and External Context

Shell's ongoing consultation program will consider statements and claims made by stakeholders when undertaking the assessment of impacts and risks. Shell has also considered the internal context, including Shell's environmental policy and ESHIA requirements. The environmental performance outcomes, and the controls which will be implemented, are consistent with the outcomes from stakeholder consultation for the Prelude FLNG facility and Shell's internal requirements.

Acceptability Summary

The assessment of impacts and risks from the physical presence determined the residual impact and risk rankings were all minor or lower (**Table 8-7**). As outlined above, the acceptability of the impacts and risks from the physical presence of the Crux project has been considered in the context of:

- the established acceptability criteria for the physical presence and vessel movements aspect of the Crux project,
- ESD,
- relevant legislative requirements,
- external context (i.e. likely stakeholder claims), and
- internal context (i.e. Shell requirements).

The residual impacts and risks are minor. Shell considers residual impacts of minor or lower to be acceptable if they meet legislative and Shell requirements. The discussion above demonstrates that these requirements have been met in relation to physical presence and vessel movement aspects of the Crux project.

Based on the points discussed above, Shell considered the impacts and risks from the physical presence of the Crux project to be acceptable.

8.4.1.5 Environmental Performance Outcomes

Physical and Biological Environment

Direct impacts to benthic habitats from the Crux project will be limited to < 5% of the total project area.

Impacts to the Continental slope demersal fish communities KEF will not exceed the Commonwealth marine environment significant impact criteria listed in **Table 7-1**.

No direct impacts to the biological communities at Goeree Shoal, Eugene McDermott Shoal and Vulcan Shoal will occur as a result of the Crux project.

Threatened Species and Ecological Communities

No collisions between project vessels and marine fauna listed as threatened or migratory under the EPBC Act will occur within the Crux project area.

Socio-economic Environment

No adverse interactions[7] between Shell's activities within the Crux project area and other marine users.

Displacement of other marine users within the Crux project area restricted to:

- temporary displacement from project activities (e.g. from pipelaying vessels and drilling activities), and
- exclusion from gazetted Petroleum Safety Zones (e.g. 500 m exclusion around the Crux platform).

Other marine users will be provided with information on the timing, nature and scale of aspects of the Crux project through Shell's consultation program.

[7] Whether an interaction constitutes an adverse interaction will be determined on a case by case basis. Examples of adverse interactions may include substantiated complaints by other marine users to Shell or NOPSEMA, vessel collisions, or damage to unsupervised fishing equipment (e.g. traps). Interactions where other users have not taken reasonable measures to avoid the interaction (e.g. third-party vessel not adhering to standard maritime requirements or ignoring advice provided during consultation) are not considered to be adverse.

8.4.2 Light Emissions

8.4.2.1 Project Context

Artificial light emissions will be generated from two primary sources:

- navigational and operational lighting required for functional operation, and
- flaring activities.

Refer to **Section 5.7.3** for additional information on these sources. Functional lighting is required on vessels, drill rigs, and the offshore Crux platform at levels that provide a safe working environment for personnel for safety and navigational purposes, typical of offshore vessels and facilities. Light emissions are also associated with intermittent flaring and will vary in duration and intensity.

Given the current concept for the Crux project is a NNM platform containing minimal processing facilities, utility systems and accommodation, to be operated remotely from the Prelude FLNG facility and only require periodic maintenance visits, this significantly reduces light exposure to the surrounding marine environment.

8.4.2.2 Overview of Light Modelling

A modelling study was commissioned by Shell to inform the assessment of impacts and risks from light arising from the Crux project (Imbricata 2018). The objective of the light study was to characterise the primary sources of light emissions from the Crux project and assess the predicted impact of light in the context of the nearest sensitive receptors.

The report documenting the assessment is provided in **Appendix H**, with a summary of the approach provided below.

The study was undertaken in two primary stages:

- line of sight (LOS) modelling – LOS modelling was undertaken to determine the extent of direct light to the horizon from the Crux project light sources and identify which receptors fall within this area, and
- light intensity modelling – light intensity modelling was undertaken to calculate the intensity of luminance from the light sources to ambient light conditions.

In the context of the in-field development area, the nearest receptors are the submergent shoals (Goeree, Eugene McDermott and Vulcan Shoals), and the nearest emergent coastline (Cartier Island, representing the nearest turtle nesting beach) is approximately 105 km from the Crux platform.

This section evaluates the environmental impacts and risks associated with the light emissions aspects of the Crux project. Key light sources subject of evaluation include the Crux platform, a drill rig, and a supply vessel. At the current stage of early engineering definition, the lighting design has not commenced and not likely to be definitively completed until significantly later in detailed design. Therefore, for this early stage assessment, the assumed inputs draw on comparable analogue data to present a current conservative project estimation of what could be reasonably expected in typical light scenarios from the Crux project.

8.4.2.3 Description and Evaluation of Impacts and Risks

The presence of artificial lighting associated with activities during all phases of the Crux project has the potential to impact marine fauna and birds, particularly those that use visual cues for orientation, navigation, or other purposes. Impacts from artificial lighting associated with the Crux project may include:

- disorientation, attraction or repulsion
- disruption to natural behavioural patterns and cycles, and
- secondary impacts such as increased predation and reduced fitness.

To inform the evaluation of potential impacts and risks, the potential area of influence from light, as informed by the LOS modelling and light intensity modelling is required to place the potential effect on receptors into context.

The results of the LOS modelling are shown in **Figure 8-3**. The LOS modelling shows that light from the Crux project is not expected to reach any of the emergent receptors (e.g. Cartier Island, Ashmore Reef, or Browse Island) under any scenario.

The assessment shows that the theoretical limit of visibility from the Crux platform may extend up to 38.3 km during a safety flaring event, 34.1 km during maintenance flaring, 33.7 km during operation and 22.6 km during start-up activities. The direct light from all flaring scenarios has potential to be visible at Goeree Shoal, Eugene McDermott Shoals and Vulcan Shoal (**Figure 8-3**; Imbricata 2018), however these represent submergent receptors with limited influence from atmospheric light.

Lights of the Crux platform and the drill rig and mast (assumed to be 25 m above sea level) may be visible at distances of 30.9 km, encompassing Goeree Shoal and Eugene McDermott Shoals. The Crux platform and drill rig decks (assumed to be 25 m above sea level) may be visible on the horizon at a distance of 17.9 km, which would be seen from Goeree Shoal. The lights of a supply vessel in the in-field development area may be visible on the horizon at a distance of 19.6 km (Imbricata 2018; **Appendix H**).

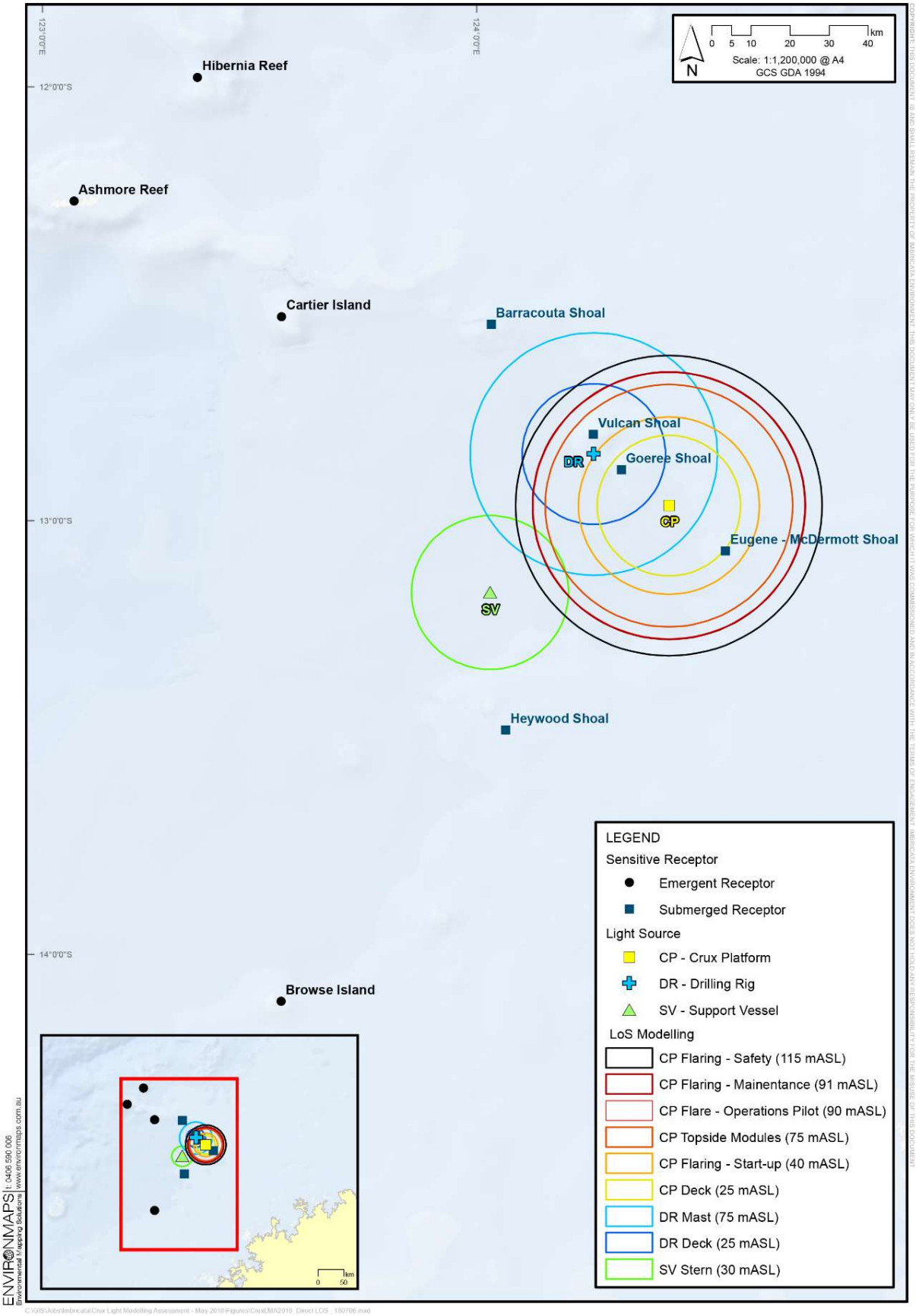


Figure 8-3: Line-of-sight Assessment of Limit of Visibility from the Crux Project

Building on the results of the LOS analysis, light intensity modelling was subsequently undertaken to provide an indication of the outputs for:

- periodic flaring scenarios from the Crux platform – safety flaring, start-up flaring, and maintenance flaring events, and
- operational scenarios – reflecting unmanned and manned operational situations respectively.

The results of the light intensity modelling are summarised in **Table 8-10** (Imbricata 2018).

To contextualise these results, light intensity represents the intensity of light that arrives at or leaves a surface, as perceived by the human eye, and is typically measured in Lux. The total amount of light as it arrives at a surface is referred to as illuminance and is the parameter that has been modelled in this assessment. Light intensity decreases as distance increases from the source of light.

Comparison of the results can be made with typical ambient light conditions, as summarised below:

- > 1 Lux (day light)
- 0.1–1.0 Lux (full moon to twilight)
- 0.01–0.1 Lux (quarter moon to full moon), and
- 0.001–0.01 Lux (moonless clear night to quarter moon).

Table 8-10: Extent of Horizontal and Vertical Light Propagation at Ambient Light Conditions (Luminance = 0.001 Lux) for Various Scenarios

Location of Light Source	Modelling Analogues (max. luminance at 100 m) (Lux)	Horizontal Light Propagation (km)	Key Habitats Reached
Periodic Flaring Scenarios			
Crux platform flare – start up	1.1	3.2	None
Crux platform flare – safety event	103	32	Goeree Shoal, Eugene McDermott Shoals, Vulcan Shoal
Crux platform flare – maintenance	0.5	2.2	None
Continuous Operations			
Crux platform flare – pilot (unmanned)	0.5	2.2	None
Crux platform deck and topside modules (manned)	8.9	9	None
Drilling rig deck and mast	8.9	9	Goeree Shoal, Vulcan Shoal
Support vessel stern	8.9	9	None

The model outputs of the horizontal propagation of light for these scenarios are presented in luminance/distance graphs to show the exponential attenuation of light with distance (as summarised in **Figure 8-4**; Imbricata 2018).

These plots show that the extent of light propagation at ambient conditions from a flaring event at the Crux platform was 32 km, which would reach Goeree Shoal (Ev = 0.0061 Lux), Eugene McDermott Shoals (Ev = 0.0031 Lux) and Vulcan Shoal (Ev = 0.0021 Lux),

all of which represent low light levels comparable to a moonless clear night. The extent of light propagation was significantly less for the start-up flaring scenario (3.2 km) and maintenance flaring (2.2 km) from the Crux platform (Imbricata 2018). Taking into account the results of the light modelling, none of the sensitive receptors would be affected by light intensity greater than 0.001 Lux (i.e. comparable to a moonless clear night).

The results of light intensity modelling for the operational scenarios similarly show low levels of light influence. The extent of continuous pilot flaring (assuming a period when the platform is unmanned, consistent with the NNM operational philosophy) is predicted to be 2.2 km. The functional lighting to ambient conditions is predicted to be 9 km from the Crux platform (when manned), drill rig and supply vessel (Imbricata 2018). Therefore, light from a drill rig may reach the nearest submergent receptors of Goeree Shoal (Ev = 0.0055 Lux) and Eugene McDermott Shoals (Ev = 0.0014 Lux), while the other light sources would not reach any of the key habitats at intensities greater than 0.001 Lux.

Ecosystems, Communities and Habitats

Shoals and Banks

Given the low levels of light reaching the shoal habitats nearest to the Crux project (comparable to a moonless clear night, as shown by the light assessment presented in the preceding section) and that they are submergent features, with no emergent features such as nesting beach or tidal flats, the flaring and functional lighting scenarios pose a low risk to sensitive receptors within the outer area of influence. The shoals surrounding the in-field development area are not known to support large areas of coral communities, with the closest large reef system at Cartier Island (105 km from the Crux platform). Therefore, it is unlikely that the project lighting will impede or disturb natural lighting cycles that may affect coral spawning.

Offshore Reefs and Islands

As summarised previously, light from the Crux project is not expected to reach any of the emergent receptors (e.g. Cartier Island, Ashmore Reef, or Browse Island) under any scenario. Therefore, it is concluded that there are no significant impacts from light emissions anticipated to be experienced at these distances.

Threatened Species and Ecological Communities

Marine Reptiles

The project area does not contain any emergent land or shallow features that may be of importance to nesting or foraging turtles, as the primary marine reptile group that may be influenced by light emissions. Therefore, turtles are unlikely to be present in the area in significant numbers. However, it is reasonably assumed that turtles may transit the project area as they move from nesting beaches and offshore areas.

Light pollution on nesting beaches can alter nocturnal behaviours in adult and hatchling turtles. Artificial lighting can disrupt or affect the choice of nesting location by female turtles, particularly light visible on the landward side of nesting beaches (Salmon et al. 1992). Turtle hatchlings leaving nesting beaches are particularly sensitive to artificial lighting as they use celestial cues to orientate (Limpus 2008; Salmon et al. 1992, cited in Lorne et al. 1997). Once in the water, marine turtle hatchlings may still use celestial lights as navigational markers during oceanic migrations and are known to be attracted towards bright lights. Hatchlings can become disorientated and trapped within light spill around platforms and vessels, resulting in increased energy expenditure, increased predation and decreased survival rates.

Extensive light attraction studies have been conducted on turtle hatchlings, including at Barrow Island (Pendoley 2005). These studies demonstrated that hatchlings crawl away from tall, dark horizons (sand dunes and vegetation) towards lower and lighter horizons (the sea and stars), and that artificial lighting can alter this response. Studies have demonstrated that when on land, hatchlings are not significantly affected by artificial light at a distance of 800 m (Pendoley 2005). Once in the water, hatchling navigation is understood to be influenced predominantly by wave motion, currents and the earth's magnetic field.

The results of the Crux light assessment show that light from the Crux platform is not expected to reach any of the emergent receptors which represent nearest turtle nesting beaches (nearest being Cartier Island, approximately 105 km from the Crux platform). Therefore, there is no potential for adverse disturbance to hatchling turtles arising from the project. Adult turtles passing through the offshore in-field development area may temporarily alter their normal behaviour whilst attracted to the light spill from infrastructure. Given the wide migratory distribution (i.e. several hundred kilometres) of adult turtles outside of nesting season and their low density presence within the offshore in-field development area, the area of influence and subsequent attraction from direct lighting is expected to be minor and a temporary disruption to a small portion of the adult turtle population.

Birds

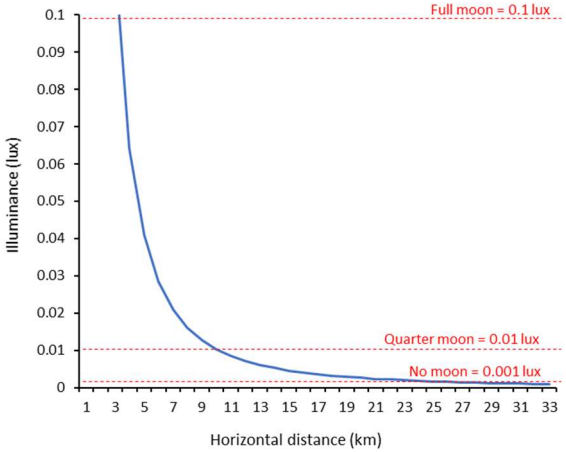
Studies conducted in the North Sea confirmed that artificial light was the reason that seabirds were attracted to and accumulated around lit offshore infrastructure (Marquenie et al. 2008) and that lights can attract birds from large catchment areas (Wiese et al. 2001). Either seabirds may be attracted by the light source itself or indirectly as structures in deep water environments tend to attract marine life at all trophic levels, creating food sources and shelter for seabirds (Surman 2002, cited in Apache Energy 2008). The light from operating production facilities may also provide enhanced capability for seabirds to forage at night. Negative potential impacts to seabirds attracted by artificial lighting are limited but include collisions with infrastructure and alteration of normal behaviours.

Migratory birds are thought to use the Earth's magnetic field as a reference when undertaking migrations (Archer 2017; Chernetsov 2016; Chernetsov et al. 2017; Heyers et al. 2017), although may rely on other cues such as visual cues for shorter-range movements. Light from offshore platforms in the North Sea have been shown to attract migrating birds and birds that migrate during the night are especially affected (Verheijen 1985). Light from the Crux project may potentially attract migratory birds, however given the Earth's magnetic field is the primary navigation cue, the Crux project is not expected to have any influence on large-scale bird migrations.

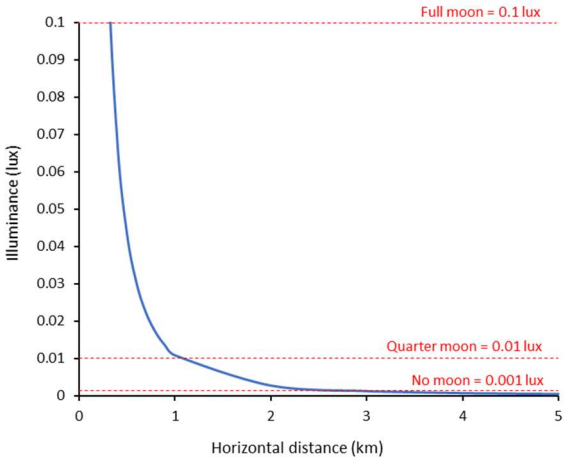
It is reasonably expected that light will project vertically from the Crux project activities, although the actual vertical propagation is highly influenced by the degree of variability in atmospheric conditions (e.g. cloud density, cover and ceiling height, aerosols and suspended participles). The natural behaviour of migratory birds may be affected when entering the area of influence as they will see the light source from a flying altitude. Given that only a small number of individuals are expected to pass within the area of influence whilst in transit, any behavioural disturbances such as disorientation, attraction and/or exhaustion are considered to potentially affect a small proportion of individual birds, and not expected to result in any population level effects on even a local scale.

Given the location of the Crux project in a remote offshore location, distant from known migratory aggregation areas for birds, and with the low lighting requirements for a NNM

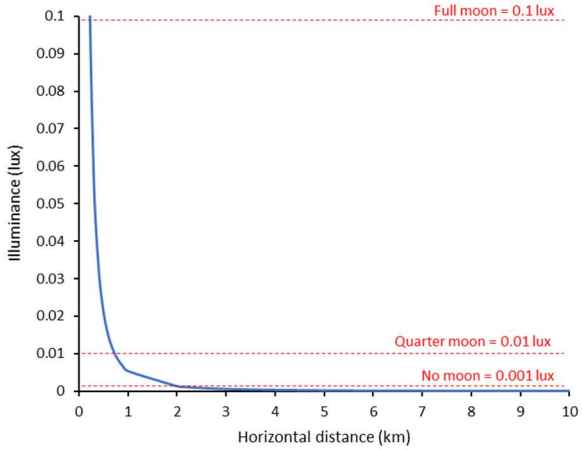
operational platform philosophy, significant impacts arising from light emissions are not expected.



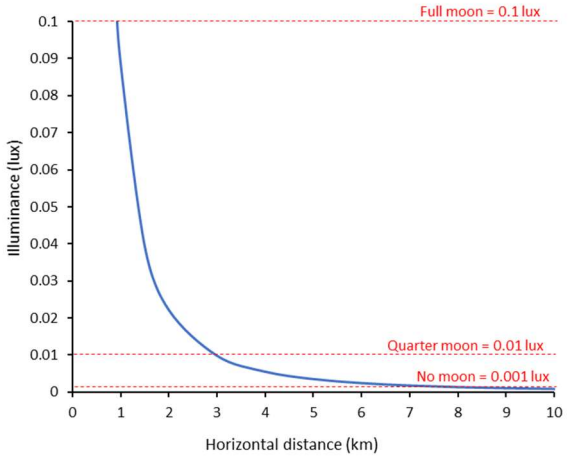
a) Predicted light propagation during a safety flaring event from the Crux platform



b) Predicted light propagation during a start-up flaring scenario from the Crux platform



c) Predicted light propagation during pilot (unmanned) scenario from the Crux platform



d) Predicted light propagation from the Crux platform (manned), drill rig and supply vessel

Figure 8-4: Light Intensity Modelling Outputs for Different Scenarios

8.4.2.4 Risk and Impact Summary and Key Management Controls

Table 8-11: Light Emissions Evaluation of Impacts and Risks

Project Component/ Activity	Environmental Value/Sensitivity				Evaluation – Planned		
	Physical Environment	Threatened Species and Ecological Communities	Ecosystems, Communities and Habitats	Socio-economic and Cultural Environment	Magnitude	Sensitivity	Residual Impact
Evaluation – Planned Impacts							
Planned impacts resulting from light emissions arising from the Crux project		X	X		Minor effect	Medium	Minor
Key Management Controls							
External lighting on offshore facilities/infrastructure will be minimised through design to that required for navigation, and safety of deck operations, except in the case of an emergency. Flaring during operations is optimised to enable the safe and economically efficient operation of the facility.							

8.4.2.5 Acceptability of Impacts and Risks

The acceptable levels of impact for the receptors that may credibly be impacted or at risk from the light emissions aspect of the Crux project are summarised in **Table 8-12**. The method by which these acceptable levels were determined, along with a justification as to why these are acceptable, are discussed in **Section 7**.

Based on the outcomes of the evaluation of impacts and risks, Shell considers that the environmental risks and impacts that may result from the light emissions aspect of the Crux project are acceptable.

Further discussion of the acceptability considerations outlined in **Section 7** in relation to the light emissions aspect of the Crux project is provided below.

Table 8-12: Acceptable Levels of Impacts and Risks from Light Emissions

Receptor Category	Receptor Sub-category	Acceptable Level of Impact	Are the Crux Project's Impacts and Risks of an Acceptable Level?
Ecosystems, Communities and Habitats	Shoals and banks	No direct impacts to named banks and shoals. No loss of benthic habitats and communities at named banks or shoals as a result of indirect/offsite[8] impacts.	Yes. Given the distance to the nearest shoal (approximately 13 km to Goeree Shoal), fauna at the shoals and banks are unlikely to perceive light from the Crux platform. Hence, they are unlikely to be impacted. Future tieback wells may be drilled closer to the shoals within the Crux in-field development area (although no activities will occur within the 1 km buffer surrounding the shoals). Given the depths of the

[8] As defined in the Matters of National Environmental Significance - Significant impact guidelines 1.1 (DoEE 2013).

Receptor Category	Receptor Sub-category	Acceptable Level of Impact	Are the Crux Project's Impacts and Risks of an Acceptable Level?
			shoals and the buffer applied, lighting from drilling activities perceived by fauna at the shoals is expected to be similar to a moonlit night. This is not considered to be a direct impact.
Threatened Species and Ecological Communities	Key fauna species	No mortality of threatened MNES fauna from the Crux project. Management of aspects of the Crux project must be aligned to conservation advice, recovery plans and threat abatement plans published by the DoEE. No significant impacts to threatened or migratory fauna.	Yes. Light from vessels may result in temporary attraction of threatened and migratory birds. This attraction will be of short duration and will not result in significant impacts or mortality. Lighting on the Crux platform may also attract threatened and migratory birds, which may roost on the platform. This will not result in significant impacts or mortality.

Principles of ESD

The risks and impacts from light emissions from the Crux project are consistent with the principles of ESD based on the following points:

- the light emissions aspect of the Crux project does not degrade the biological diversity or ecological integrity of the Commonwealth marine area in the Timor Sea. Significant impacts to MNES will not occur.
- the precautionary principle has been applied, and studies undertaken where knowledge gaps were identified. This knowledge has been applied during the evaluation of environmental impacts and risks.

Relevant Requirements

Management of the impacts and risks from light emissions associated with the Crux project are consistent with relevant legislative requirements, including:

- management of impacts and risks are consistent with policies, strategies, guidelines, conservation advice, and recovery plans for threatened species
- implementation of recognised industry standard practice, such as:
    - external lighting on offshore facilities/infrastructure will be minimised to that required for navigation, safety and safety of deck operations, except in the case of an emergency.

Matters of National Environmental Significance

Threatened and Migratory Species

The evaluation of impacts and risks indicates significant impacts[9] to threatened and migratory species will not credibly result from the light emissions aspect of the Crux project.

Alignment of the Crux project with management plans, recovery plans and conservation advice for threatened and migratory fauna is provided in **Table 8-13**.

[9] as described in Matters of National Environmental Significance - Significant impact guidelines (Department of the Environment 2013)

Commonwealth Marine Environment

The impacts and risks from the light emissions aspect of the Crux project on the Commonwealth marine environment do not exceed any of the significant impact criteria provided in **Table 7-1**.

Table 8-13: Summary of Alignment of the Impacts and Risks from Light Emissions Aspect of the Crux Project with Relevant Requirements for EPBC Threatened Fauna

Matters of National Environmental Significance	MNES Acceptability Considerations (Significant Impact Guidelines, EPBC Management Plans/Recovery Plans/Conservation Advices)	Threats Relevant to the Project	Demonstration of Alignment as Relevant to the Project
Threatened and Migratory species - birds	Significant impact guidelines for Critically Endangered, Endangered, Vulnerable and Migratory species (**Table 7-1**)	Artificial light emissions	The evaluation of environmental impacts and risks indicates that impacts from artificial light emissions on threatened or migratory marine mammals are very unlikely and would not constitute a significant impact. As such, the Crux project does not exceed any of the significant impact criteria for Threatened and Migratory marine species provided in **Table 7-1**.
	Wildlife Conservation Plan for Migratory Shorebirds (DoE 2015)	Artificial light emissions	The Crux project is aligned to 'Objective 4' of the plan by ensuring that anthropogenic disturbance is considered in development assessment processes. Migratory birds have been considered as an environmental receptor in the evaluation of impacts and risks.
Threatened and Migratory species - marine reptiles	Significant impact guidelines for Critically Endangered, Endangered, Vulnerable and Migratory species (**Table 7-1**)	Artificial light emissions	The evaluation of environmental impacts and risks indicates that impacts from artificial light emissions on threatened or migratory marine reptiles are very unlikely and would not constitute a significant impact. As such, the Crux project does not exceed any of the significant impact criteria for Threatened and Migratory marine species provided in **Table 7-1**.
	Recovery Plan for Marine Turtles (DoEE 2017)	Artificial light emissions	Light pollution has been identified as a threat in the Recovery Plan for Marine Turtles (DoEE 2017). Nesting females and hatchling turtles are at greatest risk of light impacts; however, the nearest potential nesting habitat is Cartier Island (approximately 105 km from the Crux platform). Potential light-related impacts to turtles on nesting beaches is not considered credible. Actions in the Recovery Plan for Marine Turtles (DoEE 2017) relating to the threat of artificial light include: • Artificial light within or adjacent to habitat critical to the survival of marine turtles will be managed such that marine turtles are not displaced from these habitats • Develop and implement best practice light management guidelines for existing and future developments adjacent to marine turtle nesting beaches • Identify the cumulative impacts on turtles from multiple sources of onshore and offshore light pollution Given the Crux project area is beyond any BIAs or habitat critical for the survival of marine turtles (e.g. nesting, inter-nesting or foraging areas) and the light modelling studies (Imbricata 2018) indicate that potential impacts to marine turtles will not extend beyond the Crux project area, the actions listed above are not applicable to the Crux project.

Matters of National Environmental Significance	MNES Acceptability Considerations (Significant Impact Guidelines, EPBC Management Plans/Recovery Plans/Conservation Advices)	Threats Relevant to the Project	Demonstration of Alignment as Relevant to the Project
Commonwealth marine area	Significant Impact Guidelines for the Commonwealth marine environment (**Table 7-1**)	Artificial light emissions	The evaluation of environmental impacts and risks indicates that the light emissions aspect of the Crux project will not exceed the Commonwealth marine environment significant impact criteria provided in **Table 7-1**.

Internal and External Context

Shell's ongoing consultation program will consider statements and claims made by stakeholders when undertaking the assessment of impacts and risks. Shell has also considered the internal context, including Shell's environmental policy and ESHIA requirements. The environmental performance outcomes, and the controls which will be implemented, are consistent with the outcomes from stakeholder consultation for the Prelude FLNG facility and Shell's internal requirements.

Acceptability Summary

The assessment of impacts and risks from light emissions determined the residual impact and risk ratings were Minor or lower (**Table 8-11**). As outlined above, the acceptability of the impacts and risks from light emissions associated with the Crux project has been considered in the context of:

- the established acceptability criteria for the light emissions aspect of the Crux project,
- ESD
- relevant legislative requirements
- external context (i.e. stakeholder claims), and
- internal context (i.e. Shell requirements).

The residual impacts and risks are minor. Shell considers residual impacts of minor or lower to be acceptable if they meet legislative and Shell requirements. The discussion above demonstrates that these requirements have been met in relation to the light emission aspect of the Crux project.

Based on the points discussed above, Shell considered the impacts and risks from light emissions associated with the Crux project to be acceptable.

8.4.2.6 Environmental Performance Outcomes

Biological Environment

No mortality of, or significant impacts to, threatened and migratory MNES species as a result of artificial light emissions from the Crux project.

8.4.3 Underwater Noise

8.4.3.1 Project Context

Aspects of the Crux project will generate underwater noise above ambient levels. This noise may result in impacts and risks to environmental receptors. These aspects are described in **Section 5.7.4** and include:

- pile driving activities for the installation of the platform foundations
- development drilling
- vertical seismic profiling (VSP) during drilling activities, and
- vessels-related noise, particularly while using dynamic positioning (DP).

An underwater water noise assessment, including numerical sound transmission loss modelling, was undertaken for each of these noise sources. A description of the assessment and key results is provided in **Section 8.4.3.2**; the modelling report is provided as **Appendix I**.

Underwater noise may be generated by other sources associated with the Crux project, such as the operation of subsea infrastructure (e.g. noise generation from fluid flow through choke valves, discharge of PFW to the sea surface, subsea compression etc.). Many of these low intensity noise sources will be continuous during the operational phase of the development. Monitoring of operational offshore oil and gas facilities indicates these sources have little potential for environmental impacts (Erbe et al. 2013, McCauley 2002).

The propagation of noise in the marine environment is influenced by many factors, such as:

- the characteristics of the noise (e.g. frequency, intensity, location)
- the characteristics of the water column (e.g. density interfaces, water depth, sea surface state), and
- the characteristics of the sediment (e.g. capacity to reflect and absorb noise).

The aspects that may generate noise, and the characteristics of the noise, are discussed further below. The characteristics of the water column (e.g. density) and seabed will affect the transmission of underwater noise in the marine environment. As the majority of underwater noise associated with the Crux project will be generated within the in-field development area, the water column and seabed characteristics at this location have been used for the basis of the impact assessment (including the modelling studies described in **Section 8.4.3.2** and presented in **Appendix I**).

Underwater Noise Units Explained

Underwater (and atmospheric) noise is typically measured in units of decibels (dB), which are base 10 logarithmic units of sound pressure. Human perception of the intensity of sound is approximately logarithmic, making decibels a commonly used unit. Decibel measurements require use of a reference pressure; all underwater noise measurements presented in this OPP use a reference pressure of 1 micropascal (1 µPa). This reference pressure is commonly used in studies assessing the potential environmental impacts of underwater noise, which facilitates comparisons between measurements.

Underwater noise frequency is a measure of the pitch of noise. It is measured in units of hertz (Hz), which is a measure of the number of sound wave amplitude peaks (i.e. cycles) per second. Underwater noises may cover a relatively narrow frequency band or a broad frequency band. For example, noise from seismic energy sources is highly concentrated in relatively low frequencies and is hence relatively narrow band. In contrast, noise energy from vessel thruster cavitation is spread over a large range of frequencies and hence is relatively broadband in nature.

Underwater noise can generally be considered as two types:

- impulsive noise – typically discrete, short duration noises punctuated by periods of low/no noise, characterised by high peak sound pressure levels with relatively rapid rise and decay times, and
- non-impulsive – noises that do not have rapid rise and decay times, typically of longer duration.

The difference in the nature of these noise types may result in different mechanisms for environmental impacts. Two different underwater noise units have been applied to quantifying each type. Impulsive noises, such as piling and VSP, have been quantified as Sound Exposure Level (SEL, or $L_{E,p}$) using units of dB re 1 μPa^2.s. Non-impulsive noises have been quantified as Sound Pressure Level (SPL, or L_p) using units of dB re 1 µPa. The maximum peak pressure level (L_{pk}) is the absolute peak pressure (i.e. peak amplitude) of a sound pressure wave (either impulsive or continuous) in dB re 1 µPa.

Refer to the *Principles of Underwater Noise* attached to Appendix I for additional information.

Piling

The installation of Crux platform jacket legs may require piling. While the piling method has yet to be finalised, it is expected that installation will require the use of a hydraulic hammer to drive the piles into the seabed. Piling activity will only occur at the Crux platform location. The number of piles required is yet to be finalised, however an indicative number of 12–16 piles are expected to be installed. Hammering of individual piles is expected to require less than 24 hours of continuous hammering. Hammering of consecutive piles will not occur continuously; there will be a break between the hammering stage for the installation of each pile.

Piling noise is not continuous, with each strike of the hammer on the pile generating a short, discrete sound impulse. This type of noise contrasts with continuous sources of noise, such as continuous use of vessel thrusters. Piling will not be undertaken concurrently with drilling or VSP.

Piling has the potential to generate high-intensity noise when the hammer strikes the pile. Each hammer strike induces the pile to vibrate briefly, converting some of the energy applied to the pile into a pressure wave in the water column. This pressure wave is perceived as noise and is radiated from the pile into the water column. The vibration of the pile may also result in a pressure wave propagating along the density interface between the sediment and water column. An indicative SEL for piling using a relatively large (2,027 kilojoules (kJ)) hammer is approximately 220 dB re 1 μPa^2.s. The frequency spectrum of piling is expected to be broad, with most energy concentrated between 10 hertz (Hz) and 2,000 Hz.

Drilling

Drilling of the foundation wells, and any tieback wells, will be carried out using a semi-submersible rig. The semi-submersible rigs suitable for use in the in-field development area are typically moored, although other methods to hold station may be used (e.g. dynamically positioned). Drilling activities will result in the generation of underwater noise, with most noise being generated through vibration of the drill string and the transmission of machinery noise through the rig hull (SVT Engineering Consultants 2018). Foundation drilling will occur at the proposed Crux platform location. The drilling locations for future tieback wells are not yet determined, although these locations will be within the in-field development area. A typical offshore well of the depths required for the Crux project is expected to take 60–120 days to drill, excluding any operational or weather-related delays and associated well completion activities which does not involve actual drilling.

The noise generated by drilling operations, excluding the use of thrusters for DP (refer to **Vessels** below for information on thruster noise) is relatively low intensity continuous noise. Extrapolation from measurements of underwater noise from a semi-submersible drilling rig by McCauley (1998) indicates noise source levels for non-drilling and drilling noise from a rig range from 160 to 164 dB re 1 µPa at 1 m (SVT Engineering Consultants 2018).

Vertical Seismic Profiling

VSP is a standard well logging technique that is routinely used to collect geophysical measurements within well bores. VSP is not expected to be used in relation to the foundation wells but may be used on future tieback wells. VSP typically involves the use of a seismic energy source (e.g. a single air gun or a small air gun array) suspended in the water column and a receiver (e.g. hydrophone or geophone) suspended within the well bore. The seismic source may be suspended directly below the drilling rig or may be offset (e.g. suspended behind a vessel). Vertical seismic profiling typically required noise emissions between 8 hours and 24 hours per well. VSP will not be undertaken concurrently with piling.

VSP noise is not continuous. Each discharge of the seismic source generates a short, discrete, low frequency sound impulse. Seismic impulses during VSP are typically much lower than those generated during typical marine seismic surveys. Source levels for typical VSP seismic energy sources is estimated at 193.5 dB re 1 μPa^2.s, with the majority of the noise energy occurring at low frequencies (< 100 Hz) (SVT Engineering Consultants 2018).

Vessels

Vessels will be required during all phases of the Crux project, with relatively high levels of use during installation and hook-up of facilities and decommissioning. The types of vessels used will range from relatively small supply vessels to large pipelay and heavy lift vessels (**Table 5-5**). Vessel activity will be concentrated around the proposed Crux platform location and within the export pipeline corridor but will occur throughout the in-field development area.

Vessels may generate underwater noise from propellers and thrusters, which tend to generate considerable noise due to cavitation. Thruster nose is typically the highest intensity noise source generated by the vessels that may be used during the Crux project. Other noise sources include the transmission of machinery noise (e.g. main engines) through the hull and signal noise from acoustic survey equipment (e.g. multibeam echo sounders).

Vessels will often be required to hold station throughout the project area. This is a critical safety requirement that cannot be avoided. Vessels holding station typically do so using DP, during which the vessel's navigation system will automatically control the vessel's thrusters to hold a given position. Holding position by DP typically requires considerable use of thrusters; hence vessels using DP may generate considerable underwater noise.

Thruster noise is typically broad-band in nature, with a noise frequency spectrum ranging from < 10 Hz to > 8,000 Hz (McCauley 1998; SVT Engineering Consultants 2018). Extrapolation from measurements of underwater noise from a support vessel holding station by McCauley (1998) indicates the noise source level for a support vessel holding station using DP up to 183 dB re 1 µPa at 1 m (SVT Engineering Consultants 2018).

8.4.3.2 Overview of Underwater Noise Modelling

Numerical modelling of underwater noise propagation was carried out by SVT for the following sources (**Appendix I**):

- piling
- development drilling
- VSP, and
- vessel noise.

The scenarios modelled for each of these noise sources are summarised in **Table 8-14**. The modelling report is provided as **Appendix I**.

Table 8-14: Summary of Modelled Underwater Noise Sources

Source	Location	Duration	Source Level
Impulsive Noise			
Piling (632 kJ hammer)	Proposed Crux platform location	16 days (assuming 16 piles installed at a rate of 1 per day)	214 dB re 1 µPa^2.s @ 1 m
Piling (2,027 kJ hammer)	Proposed Crux platform location	16 days (assuming 16 piles installed at a rate of 1 per day)	220 dB re 1 µPa^2.s @ 1 m
VSP	Proposed Crux platform location	10 shots per event, one event per day	193.5 dB re 1 µPa^2.s
Continuous Noise			
Drill rig	In proximity to Eugene McDermott Shoal (outside 1 km buffer)	Continuous	167 dB re 1 µPa @ 1 m
	In proximity to Vulcan Shoal (outside 1 km buffer)	Continuous	
	Proposed Crux platform location	Continuous	
Vessel using DP	Proposed Crux platform location	Continuous	171 dB re 1 µPa @ 1 m

The sound speed profile of the water column used for the modelling was derived from in-field water column measurements in the in-field development area. Conditions resulting in the greatest sound propagation were observed during the month of July. These conditions were the "worst-case" and were applied to the modelling studies to provide an inherently conservative assessment. The modelling studies included the nature of the seabed, as measured during geophysical investigations of the in-field development area. Sea surface scattering was not considered in the model. This makes the results of the model more conservative (i.e. the model is likely to over-estimate received noise levels).

Underwater Noise Impact Thresholds

Results from the underwater noise modelling studies were compared against a range of impact thresholds for the following key fauna groups:

- marine mammals
- marine turtles
- sea snakes
- fish (including larvae)
- sharks and rays, and
- invertebrates.

Impacts to marine fauna can be grouped as follows in decreasing order of effect:

- mortality or potential mortal injury – physical injury that may result in the death of an animal
- impairment:
    - recoverable injury – physical injury from which an animal is expected to recover,
    - permanent threshold shift (PTS) – a permanent reduction in the ability of an animal to perceive sound. Recovery is not expected to occur.
    - temporary threshold shift (TTS) – a temporary reduction in the ability of an animal to perceive sound. Recovery to a pre-exposure levels is expected to occur, and
    - masking – no change in the ability for an animal to perceive sound, but biologically meaningful sounds may be "drowned out" by anthropogenic noise.
- behavioural impacts – typically short-term behavioural responses such as avoidance, surfacing etc. Behaviour will return to normal following cessation of the anthropogenic noise.

Impact thresholds for fauna groups were derived from scientific literature and published guidelines, including:

- Sound exposure guidelines for fishes and sea turtles: a technical report prepared by American National Standards Institute (ANSI)-Accredited Standards Committee S3/SC1 and registered with ANSI (Popper et al. 2014)
- Technical guidance for assessing the effects of anthropogenic sound on marine mammal hearing (NOAA 2018), and
- Underwater noise piling guidelines (Department of Planning, Transport and Infrastructure 2012).

Fish, Larvae and Sea Turtles

The impact thresholds applied during the noise modelling assessment for fish, fish larvae and turtles for impulsive and non-impulsive underwater noise are summarised in **Table 8-15** and **Table 8-16** respectively. These are derived primarily from the extensive review and recommendations of Popper et al. (2014). Refer to **Appendix I** for further discussion on threshold selection.

Table 8-15: Fish, Larvae and Marine Turtle Noise Criteria for Impulsive Noise Sources (Piling and VSP) (SVT Engineering Consultants 2018)

Type of Animal	Mortality and Potential Mortal Injury	Impairment			Behaviour
		Recoverable Injury	TTS	Masking	
Piling					
Fish: No swim bladder (particle motion detection)	> 219 dB $L_{E,p}$ or > 213 dB L_{pk}	> 216 dB $L_{E,p}$ or > 213 dB L_{pk}	> 186 dB $L_{E,p}$	(N) Moderate (I) Low (F) Low	(N) High (I) Moderate (F) Low
Fish: Swim bladder is not involved in hearing (particle motion detection)	210 dB $L_{E,p}$ or > 207 dB L_{pk}	203 dB $L_{E,p}$ or > 207 dB L_{pk}	> 186 dB $L_{E,p}$	(N) Moderate (I) Low (F) Low	(N) High (I) Moderate (F) Low
Fish: Swim bladder involved in hearing (primarily pressure detection)	207 dB $L_{E,p}$ or > 207 dB L_{pk}	203 dB $L_{E,p}$ or > 207 dB L_{pk}	186 dB $L_{E,p}$	(N) High (I) High (F) Moderate	(N) High (I) High (F) Moderate
Eggs and larvae	210 dB $L_{E,p}$ or > 207 dB L_{pk}	(N) Moderate (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) Moderate (I) Low (F) Low
Marine turtles	> 210 dB $L_{E,p}$ or > 207 dB L_{pk}	(N) High (I) Low (F) Low	(N) High (I) Low (F) Low	(N) High (I) Moderate (F) Low	(N) High (I) Moderate (F) Low
VSP					
Fish: No swim bladder (particle motion detection)	> 219 dB $L_{E,p}$ or > 213 dB L_{pk}	> 216 dB $L_{E,p}$ or > 213 dB L_{pk}	> 186 dB $L_{E,p}$	(N) Low (I) Low (F) Low	(N) High (I) Moderate (F) Low
Fish: Swim bladder is not involved in hearing (particle motion detection)	210 dB $L_{E,p}$ or > 207 dB L_{pk}	203 dB $L_{E,p}$ or > 207 dB L_{pk}	> 186 dB $L_{E,p}$	(N) Low (I) Low (F) Low	(N) High (I) Moderate (F) Low
Fish: Swim bladder involved in hearing (primarily pressure detection)	207 dB $L_{E,p}$ or > 207 dB L_{pk}	203 dB $L_{E,p}$ or > 207 dB L_{pk}	186 dB $L_{E,p}$	(N) Low (I) Low (F) Moderate	(N) High (I) High (F) Moderate
Eggs and larvae	210 dB $L_{E,p}$ or > 207 dB L_{pk}	(N) High (I) Low (F) Low	(N) High (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) High (I) Moderate (F) Low

Marine turtles	> 210 dB $L_{E,p}$ or > 207 dB L_{pk}	(N) Moderate (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) Low (I) Low (F) Low	175 dB L_p 164 dB $L_{E,p}$
Note: Where insufficient data existed to recommend objective guidelines, a subjective approach is adopted in which the relative risk (High, Moderate, Low) of an effect is placed in order of rank at three distances from the source – Near (N), Intermediate (I), and Far (F) (top to bottom within each cell of the table, respectively). "Near" might be considered to be in the tens of metres from the source, "intermediate" in the hundreds of metres, and "far" in the thousands of meters.					

Notes: $L_{E,p}$ – sound exposure level; L_p – sound pressure level; L_{pk} – peak pressure level

Table 8-16: Fish, Larvae and Marine Turtle Noise Criteria for Continuous Noise Sources (Operations and Vessels) (SVT Engineering Consultants 2018)

Type of Animal	Mortality and Potential Mortal Injury	Impairment			Behaviour
		Recoverable Injury	TTS	Masking	
Fish: No swim bladder (particle motion detection)	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) High (I) High (F) Moderate	(N) Moderate (I) Moderate (F) Low
Fish: Swim bladder is not involved in hearing (particle motion detection)	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) High (I) High (F) Moderate	(N) Moderate (I) Moderate (F) Low
Fish: Swim bladder involved in hearing (primarily pressure detection)	(N) Low (I) Low (F) Low	170 dB L_p for 48 hour	158 dB L_p for 12 hour	(N) High (I) High (F) High	(N) High (I) Moderate (F) Low
Eggs and larvae	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) High (I) High (F) Moderate	(N) High (I) Moderate (F) Low
Marine turtles	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) High (I) Moderate (F) Low	(N) Moderate (I) Moderate (F) Low
Note: Where insufficient data existed to recommend objective guidelines, a subjective approach is adopted in which the relative risk (High, Moderate, Low) of an effect is placed in order of rank at three distances from the source – Near (N), Intermediate (I), and Far (F) (top to bottom within each cell of the table, respectively). "Near" might be considered to be in the tens of metres from the source, "intermediate" in the hundreds of metres, and "far" in the thousands of meters.					

Marine Mammals

The vulnerability of marine mammals to underwater noise is linked to their ability to perceive sound. Cetaceans can be grouped based on similarities in their hearing. Underwater noise exposure thresholds can then be weighted for each cetacean group to emphasise noise frequencies that a group may be particularly vulnerable to. This approach is described in Southall et al. (2007) and has been applied to a range of underwater noise guidelines and impact assessments on cetaceans. The South

Australian Government Underwater noise piling guidelines (Department of Planning, Transport and Infrastructure 2012) applied in this assessment use this approach.

The impact thresholds applied during the noise modelling assessment for marine mammals for impulsive and non-impulsive underwater noise are summarised in **Table 8-17**. These are derived primarily from technical guidelines published by NOAA (2018). Refer to **Appendix I** for further discussion on threshold selection.

Table 8-17: Mammal Sound Exposure Criteria

Type of Animal	PTS – Permanent Injury		TTS – Impairment		Behaviour	
	Impulsive	Non-impulsive	Impulsive	Non-Impulsive	Impulsive	Non-impulsive
Low-frequency cetaceans	219 dB L_{pk} 183 dB $L_{E,p}$	199 dB $L_{E,p}$	213 dB L_{pk} 168 dB $L_{E,p}$	179 dB $L_{E,p}$	160 dB L_p	120 dB L_p
Mid-frequency cetaceans	230 dB L_{pk} 185 dB $L_{E,p}$	198 dB $L_{E,p}$	224 dB L_{pk} 170 dB $L_{E,p}$	178 dB $L_{E,p}$	160 dB L_p	120 dB L_p
High-frequency cetaceans	202 dB L_{pk} 155 dB $L_{E,p}$	173 dB $L_{E,p}$	196 dB L_{pk} 140 dB $L_{E,p}$	153 dB $L_{E,p}$	160 dB L_p	120 dB L_p

Table 8-18: Summary of Cetacean Safety Zones for Impact Piling

Species	Noise Exposure Threshold SEL in dB(M) re 1 $\mu Pa^2.s$	Observation Zone	Shot Down Zone	Zone of Behavioural Response
Low/mid/high-frequency cetaceans	≤ 150 dB at 100 m	1 km	100 m	≤ 150 m
	≤ 150 dB at 300 m	1.5 km	300 m	≤ 500 m
	> 150 dB at 300 m	2 km	1 km	≤ 3 km

Other Fauna

Sharks and rays do not typically have gas-filled cavities such as swim bladders and are considered less vulnerable to underwater noise related injuries. As such, sharks and rays were grouped with fish without a swim bladder (**Table 8-15** and **Table 8-16**) for this assessment of impacts and risks.

No suitable published guidelines were identified for sea snakes. Sea snakes were grouped with fish without a swim bladder (**Table 8-15** and **Table 8-16**) for this assessment of impacts and risks.

While there are reputable published studies indicating the potential for underwater noise to impact upon invertebrates, no suitable published guidelines were identified. Invertebrates have been considered in the assessment of risks and impacts from underwater noise, although no threshold values have been applied.

Key Modelling Results

This section summarises the key results and conclusions from the noise assessment study undertaken to inform the assessment of impacts and risks. A detailed presentation of the noise assessment conclusions, including numerical modelling results, is provided in **Appendix I**.

Activities conducted during the Crux project have the potential for localised and temporary impacts on marine fauna, including fish, marine turtles and cetaceans. Based on the thresholds outlined above, underwater noise levels would:

- fall below the relevant permanent injury and fatality criteria where applicable to the marine fauna type, and the relevant instantaneous permanent hearing damage criteria, at all locations.
- fall below the relevant permanent hearing damage criteria based on daily exposures beyond ranges of 389 m for fish and marine turtles, 14 km for mid-frequency cetaceans and 17.3 km for low-frequency cetaceans. The daily exposure criteria are considered extremely conservative, as these require an animal to remain within the exposure zone for 24 hours. This is considered very unlikely as animals, particularly cetaceans, are expected to move away from the noise source as they are inherently highly mobile.
- exceed the relevant temporary hearing threshold shift criteria (pile strike number and exposure time dependent) at ranges of up to 13.3 km for fish and 57.8 km for cetaceans.
- fall below the relevant behavioural disturbance criteria for low-frequency cetaceans at ranges beyond 2.7 km.

8.4.3.3 Description and Evaluation of Impacts and Risks

Ecosystems, Communities and Habitats

Benthic Communities

There is some evidence to suggest components of benthic communities may be vulnerable to underwater noise-related impacts, while other components are not. Studies have indicated scallops exposed to seismic survey noise show increased potential for mortality (Day et al. 2016; Harrington et al. 2010), however no studies have shown evidence of significant or short-term mortality (Przeslawski et al. 2018). The noise intensity from these studies was much higher than the levels that will occur during the Crux project. Preliminary studies on the effects of underwater noise on sponges did not observe any effects attributable to noise exposure (Wilmut et al. 2006).

Underwater noise generated by operational platforms does not appear to have any detrimental effect on benthic communities. Inspection of fixed platforms worldwide shows these structures serve as artificial reefs and develop relatively diverse benthic communities.

Benthic habitat surveys of the project area did not indicate the presence of particularly diverse or sensitive benthic communities. Potentially vulnerable taxa, such as bivalve molluscs, were not observed. Given the duration, frequency spectrum and intensity of potential noise generated during the Crux project, no impacts to benthic communities as a consequence of underwater noise are expected to occur.

Shoals and Banks

The shoals and banks near the Crux project may potentially be exposed to increased underwater noise levels as a result of piling, VSP and vessels using DP. These shoals and banks host relatively diverse fauna communities, such as demersal fish and marine turtles (see **Threatened Species and Ecological Communities** below for further discussion). However, given the distance of these shoals and banks from the noise source and the consequential reduction in noise intensity, the received noise levels will be significantly lower than the source levels. The nearest shoal to the Crux platform location is Goeree Shoal, which lies approximately 13 km to the north-west.

The noise assessment (**Appendix I**) indicated that, based on the 24-hour exposure criterion, TTS for fish may occur out to 13.4 km based on the use of the heavy piling hammer. This may result in TTS impacts to fish on a part of Goeree Shoal; received underwater noise levels at Eugene McDermott and Vulcan shoals will not exceed any impact thresholds for fish. Given the short duration of the piling activity and the temporary nature of the TTS impact, any fish at Goeree Shoal that experience TTS are expected to recover their ability to perceive sound fully.

VSP during drilling of tieback wells will not result in underwater noise levels above impact thresholds for fish at any of the shoals within the Crux in-field development area.

Key Ecological Features

The nearest KEF to the Crux platform location is the Ancient coastline at 125 m depth contour. Environmental values associated with the geomorphology of this KEF (e.g. enhanced vertical mixing) will not be affected by underwater noise. Benthic communities such as fish assemblages associated with the Continental Slope Demersal Fish Communities KEF may be affected by noise generated by the pipelaying activities (e.g. pipelay vessel DP noise) but will not be significantly impacted by noise from piling, VSP at the Crux platform location, or operational noise. Refer to **Threatened Species and Ecological Communities** below for further discussion of noise impacts on fish. Other KEFs are too distant from the project area to be credibly impacted by underwater noise.

Threatened Species and Ecological Communities

Marine Mammals

Most cetacean species use sound to communicate (e.g. humpback whale calls) or perceive their environment (e.g. echolocation of prey). This reliance on underwater noise, and their high conservation value, makes cetaceans of concern when assessing potential impacts from underwater noise.

Low frequency cetaceans are expected to be most vulnerable to underwater noise from piling and VSP due to the frequency spectra of these noise sources overlapping the functional hearing range of these species (approximately 7 Hz to 30 kilohertz (kHz)), and the relatively high intensity of the noise sources. Several low frequency cetaceans (blue, humpback, sei, fin and Bryde's whales) were identified as potentially occurring within the project area (**Section 6.5.6.1**). Noise monitoring in the Timor Sea for the Barossa development indicated pygmy blue and Bryde's[10] whales are the most likely to occur (McPherson et al. 2016). Detection of calling low-frequency cetaceans calls were not constant, but occurred sporadically, often in groups or sets of calls. Humpback, southern right and Antarctic minke whales are considered to be low frequency cetaceans. These three species were identified by the Protected Matters search tool report but are not likely to occur within the Timor Sea based on known distribution data.

The noise assessment (**Appendix I**) indicated that the low frequency cetacean instantaneous peak thresholds (i.e. the L_p from a single hammer strike) for PTS and TTS will not be exceeded at any range. The instantaneous behavioural disturbance threshold for a single hammer strike is exceeded out to a radius of 2.7 km.

The cumulative (i.e. 24-hour) PTS and TTS thresholds for low frequency cetaceans are exceeded at 17.3 km and 57.8 km respectively. These thresholds are highly

[10] McPherson et al. (2016) distinguish Omura's whale (*Balaenoptera omurai*) as a distinct species from Bryde's whale (*B. edeni*), however the taxonomy of Omura's whale is unclear. *B. omurai* is a recent description. Many authorities (including the DoEE) do not make any distinction between *B. omurai* and *B. edeni* and retain *B. edeni* as this species name has priority. As such, this OPP refers only to *B. edeni*, with this classification including *B. omurai*.

conservative as they are based on a worst-case hammer size. Shell considers it unlikely that such a hammer will be used during piling. These thresholds are also highly conservative, as they rely on the cetacean remaining within the threshold radius for the duration of the entire 24-hour period. This is considered very unlikely, as low frequency cetaceans in the area are typically migrating and would be expected to move away from uncomfortable stimuli (i.e. high noise levels). Behavioural responses of cetaceans exposed to acoustic disturbance shows typical behavioural response is to move away from unpleasant stimuli. Several species of cetacean, including humpback and minke whales, have been shown to avoid high intensity low frequency sound (Dunlop et al. 2013, Kvadsheim et al. 2017, Sivle et al. 2015). The oceanic low frequency cetaceans that may occur within the Crux project area are expected to be able to move away from the piling noise rapidly. For example, speeds of sei whales and blue whales have been estimated at > 6 km/hr, and individual animals can easily exceed 100 km in a 24-hr period (Double et al. 2014, Prieto et al. 2014) and hence move away from the piling before the time-based PTS and TTS are exceeded. Considering the expected low utilisation of the Crux project area by low frequency cetaceans, avoidance behavioural responses and nature of the piling activity, no low frequency cetaceans are expected to be exposed to noise levels exceeding the 24-hr PTS or TTS thresholds. The nearest known aggregation of whales is the seasonal presence of blue whales in their migratory corridor, which lies approximately 268 km north-west of the Crux platform. Given this distance is well beyond the range at which PTS or TTS may occur, blue whales will not be significantly impacted by piling noise or VSP.

Mid frequency cetaceans are also vulnerable to underwater noise, although their hearing range means they are more vulnerable to noise frequencies overlapping their functional hearing range (approximately 150 Hz to 160 kHz). Mid frequency cetaceans include most toothed whales, dolphins and porpoises; a number of species of mid frequency cetaceans were identified as potentially occurring within the vicinity of the project area (**Section 6.5.6.1**). Noise monitoring in the Timor Sea indicates mid-frequency cetaceans are present year-round (R. Clarke, pers. comm.; McPherson et al. 2016).

The noise assessment (**Appendix I**) indicated that mid frequency cetaceans' instantaneous peak thresholds (i.e. the L_p from a single hammer strike) for PTS and TTS will not be exceeded at any range. The cumulative (i.e. 24-hour) PTS and TTS thresholds for low frequency cetaceans are exceeded at 14 km and 56.9 km respectively. As with the low frequency cumulative thresholds, these PTS and TTS thresholds are highly conservative, as they rely on the cetacean remaining within the threshold radius for the duration of the entire 24-hour period. This is considered very unlikely, as mid frequency cetaceans in the area are highly mobile and would be expected to move away from uncomfortable stimuli (i.e. high noise levels). The instantaneous behavioural disturbance threshold for a single hammer strike is exceeded out to a radius of 2.7 km.

The noise assessment (**Appendix I**) did not indicate that VSP or drilling would exceed any of the low or mid frequency cetacean impact thresholds defined for continuous noise at any range. Vessel DP noise was predicted to exceed the low frequency cetacean cumulative (24-hour) TTS threshold at a range of 350 m and the low frequency behavioural impact threshold at a range of 1.6 km. Low-frequency cetaceans are highly unlikely to remain within these ranges for a 24-hour period, and these impacts are not considered credible.

Based on the results of the noise assessment, the cetacean species that may occur within the project area and the controls Shell will implement, potential impacts are expected to consist of behavioural disturbance only. This behavioural disturbance is likely to consist of avoidance of areas of high noise intensity, which may inhibit other behaviours such as feeding. Behavioural will be restricted in time to relatively short periods when high noise intensity activities are occurring (e.g. piling and VSP). Following

cessation of noise generation, animal behaviour is expected to return to normal. Following implementation of controls (e.g. piling "soft start-up"), potential impacts such as mortality, injury, PTS and TTS are considered very unlikely to occur.

Marine Reptiles

Marine reptiles such as turtles and sea snakes are not known to be particularly sensitive to underwater noise. Research on marine turtles suggests that functional hearing is concentrated at frequencies between 100 and 600 Hz (which is a subset of the low frequency cetacean range). Several turtle species were identified as likely to occur within the project area (**Section 6.5.6.2**), although no critical habitat or BIAs overlap of occur near the project area. The water depth and benthic habitat within the project area is typically too deep for turtle foraging for several species (e.g. Hays et al. 2001; Polovina et al. 2003), although species that eat primarily pelagic prey (e.g. leatherback and juvenile green turtles) may forage for pelagic prey. As such, turtles are expected to occur only at low densities within the project area and are likely to be transiting the area rather than foraging, breeding or nesting (although foraging at the relatively shallow shoals within the in-field development area may occur).

The noise assessment (**Appendix I**) indicated that none of the noise sources that may arise from the Crux project would not exceed the instantaneous threshold for permanent injury of fatality, nor the behavioural impact threshold, for marine turtles or sea snakes at any range. The 48-hour cumulative PTS threshold for turtles is exceed out to a range of 390 m for piling noise, however continuous piling activities will not occur for 48 consecutive hours. PTS for marine turtles is not considered credible.

Based on the results of the noise assessment, potential impacts to marine reptiles will be restricted to short term behavioural disturbance to animals in close proximity to high intensity noise sources. Given the expected low density of turtles within the project area this potential impact would only affect a relatively small portion of turtle populations in the region. Recovery from behavioural disturbance is expected to occur immediately once the noise emission is ceased.

Fish, Sharks and Rays

The project area is not expected to host highly abundant or diverse assemblages of fishes or sharks and rays. Whale sharks occur within the project area (e.g. traversing the open waters within or surrounding the project area during migration to/from aggregation off Ningaloo Reef) and a BIA for whale sharks overlaps with the project area. However, it is expected that whale shark presence within the project area would not be in significant numbers as there is no main aggregation area within the vicinity of the project area, and their presence would be transitory and of a short duration. This is consistent with tagging studies of whale shark movements which show continual movement of whale sharks in deeper, open offshore waters (Meekan and Radford 2010). Given the contrast to the feeding behaviour off aggregation areas such as Ningaloo Reef, the BIA is unlikely to be a dedicated foraging area; rather, it is likely to be a broad area within which migratory movements can be expected. This is consistent with the Conservation Advice (DoE 2015l) for this species which indicates this BIA up the north west coast is a migration corridor than significant foraging habitat. There are no constraints preventing whale sharks from moving away from the project area (e.g. shallow water or shorelines).

Whale sharks forage on plankton (as well as small fish), and high intensity underwater noise has been shown to result in some taxa within zooplankton communities. Recent observations by McCauley et al. (2017) provides evidence of considerable mortality of crustacean zooplankton (e.g. copepods and nauplii larval stage of crustaceans) over short timeframes. However, longer term impacts may be much less discernible due to the high turnover of planktonic communities and the movement of water masses. Modelling studies by the CSIRO indicate that planktonic communities are highly dynamic

and have the potential to recover rapidly following disturbance (Richardson et al. 2017). As a result, impacts to zooplankton, which are of short duration, will not negatively affect whale sharks moving through the area. Note that small crustacean zooplankton comprise only part of whale shark diets, with larger plankton and nekton (e.g. krill and baitfish) forming a part of the species' diet (Colman 1997). Whale sharks are not considered to be particularly vulnerable to noise related impacts (refer to **Underwater Noise Impact Thresholds**; see **Other Fauna**).

The noise assessment (**Appendix I**) predicted that no exceedance of the permanent injury threshold for any category of fish (**Table 8-15** and **Table 8-16**) would occur under any of the noise scenarios considered. The noise modelling study results indicated piling noise may exceed the 48 hour cumulative recoverable injury threshold for fish with a swim bladder at a range of 1 km. Given the benthic habitats within 1 km of the piling location are relatively flat unconsolidated soft sediments, which are widely distributed in the region, fish are expected to be within the 1 km radius in low densities only. Fish within this 1 km radius are expected to move away from the source of noise if it was harmful. Once piling is completed, any displaced fish may return.

The cumulative TTS for piling noise may occur out to a range of 13.4 km, which overlaps the range to the nearest shoal (Goeree Shoal). Noting that the study results are conservative (i.e. likely to over-estimate received sound levels) due to the assumption regarding the heaviest hammer weight, TSS of fish may occur within 13.4 km of the pile. Fish, including fish associated with Goeree Shoal, would be expected to recover fully following the cessation of piling noise.

Modelling study results indicated VSP noise did not exceed any of the mortality or impairment thresholds for fish, sharks and rays at any range. Impacts to VSP on fish will be restricted to short-term behavioural disturbances during VSP operations. Resumption of normal behaviour is expected to occur once VSP operations cease.

Many species of pelagic and demersal fish have a planktonic larval stage. Experiments have shown mixed results of larval stages to undertaker noise. For example, experiments on several species of fish larvae and lobster larvae did not detect significant effects as a result of high intensity impulsive noise (Bolle et al. 2012; Day et al. 2016; Payne et al. 2009).

Based on the results of the noise assessment, the potential impacts to fish and sharks and rays are expected to be a minor, short-term behavioural disturbance. Given the habitat within the project area does not host particularly abundant or diverse fish assemblages, the potential for PTS and TTS is considered to be very low. Fish assemblages at the nearest shoal, Goeree Shoal, may be exposed to piling noise approaching the TTS threshold, however given piling activities are expected to occur for less than 24 consecutive hours, the potential for impact is considered to be low.

8.4.3.4 Risk and Impact Summary and Key Management Controls

Table 8-19: Underwater Noise Evaluation of Impacts and Risks

Project Component/ Activity	Environmental Value/Sensitivity				Evaluation – Planned		
	Physical Environment	Threatened Species and Ecological Communities	Ecosystems, Communities and Habitats	Socio-economic and Cultural Environment	Magnitude	Sensitivity	Residual Impact
Evaluation – Planned Impacts							
Planned impacts resulting from underwater noise generated during the Crux project, including: • piling • VSP • operations, and • vessels		X	X		Minor	Medium	Minor
Key Management Controls							
Any VSP activities conducted at the development well will comply with 'Standard Management Procedures' set out in EPBC Act Policy Statement 2.1 – Interaction between Offshore Seismic Exploration and Whales: Industry Guidelines (DEWHA 2008c) (or the contemporary requirements at the time of the activity), specifically: • pre-start-up visual observations. Visual observations for the presence of whales by a suitably trained crew member will be carried out at least 30 minutes before the commencement of VSP. • start-up and normal operating procedures, including a process for delayed start-up, should whales be sighted. Visual observations by trained crew should be maintained continuously. • night time and low visibility procedures. Pile driving activities will follow standard industry controls for offshore piling which include: • safety zones – observation and shutdown zones • standard management and mitigation procedures including pre-start, soft start, normal operation, stand-by and shut-down procedures • trained crew members as observers. Maintenance of a minimum 1 km buffer from shoals within the in-field development area (**Figure 5-3**).						

8.4.3.5 Acceptability of Impacts and Risks

The acceptable levels of impact for the receptors that may credibly be impacted or at risk from the underwater noise aspect of the Crux project are summarised in **Table 8-20**. The method by which these acceptable levels were determined, along with a justification as to why these are acceptable, are discussed in **Section 7**.

Based on the outcomes of the evaluation of impacts and risks, Shell considers that the environmental risks and impacts that may result from the underwater noise aspect of the Crux project are acceptable.

Further discussion of the acceptability considerations outlined in **Section 7** in relation to the underwater noise aspect of the Crux project is provided below.

Table 8-20: Acceptable Levels of Impacts and Risks from Underwater Noise

Receptor Category	Receptor Sub-category	Acceptable Level of Impact	Are the Crux Project's Impacts and Risks of an Acceptable Level?
Ecosystems, Communities and Habitats	Benthic communities	No significant impacts to benthic habitats and communities. Impacts to non-sensitive benthic communities limited to a maximum of 5% of the project area.	Yes. Potential noise-related impacts will be concentrated around the Crux platform during piling. Biota associated with the communities around the Crux platform are broadly distributed in the wider region and are not considered to be unique or highly sensitive. Underwater noise from VSP undertaken during tieback well drilling will not result in significant impacts to benthic communities in the Crux in-field development area.
	Shoals and banks	No direct impacts to named banks and shoals. No loss of benthic habitats and communities at named banks or shoals as a result of indirect/offsite[11] impacts.	Yes. Modelling of underwater noise levels from piling indicates PTS will not occur at any of the shoals in the Crux in-field development area. TTS, from which fish are expected to recover, may credibly occur at the nearest shoal (Goeree Shoal) if a heavy piling hammer is used and piling is conducted for 48 consecutive hours. Underwater noise from VSP undertaken during tieback well drilling will not exceed impact thresholds at any shoals.
	Key Ecological Features	No significant impacts to environmental values of KEFs.	Yes. Underwater noise above impact thresholds for fish will not credibly occur at the Continental Slope Demersal Fish Communities KEF. The fish assemblages that are the key environmental value of this KEF will not be significantly impacted.
Threatened Species and Ecological Communities	Key fauna species	No mortality of threatened or migratory MNES fauna from the Crux project. Management of aspects of the Crux project must be aligned to conservation advice, recovery plans and threat abatement plans published by the DoEE. No significant impacts to threatened or migratory MNES fauna.	Yes. Potential noise-related impacts will be concentrated around the Crux platform during piling. This area is not important habitat for threatened or migratory MNES that may be impacted by underwater noise, such as cetaceans and marine turtles. Instantaneous PTS and TTS impact thresholds for these species will not be exceeded. Cumulative 24-hr PTS and TTS thresholds for low frequency cetaceans, however it is very unlikely that a low frequency cetacean would remain in the area long enough to result in PTS or TTS. Piling is a discrete, short

[11] As defined in the Matters of National Environmental Significance - Significant impact guidelines 1.1 (DoEE 2013).

Receptor Category	Receptor Sub-category	Acceptable Level of Impact	Are the Crux Project's Impacts and Risks of an Acceptable Level?
			duration activity; other sources of noise will not result in significant impacts to threatened and migratory MNES.
Socio-economic and Cultural Environment	Commercial fisheries	No negative impacts to exploited fisheries resource stocks which result in a demonstrated direct loss of income.	Yes. Potential impacts to fish from underwater noise are restricted to TTS and behavioural disturbance. These potential impacts will not result in impacts to commercial fishers.

Principles of ESD

The risks and impacts from underwater noise associated with the Crux project are consistent with the principles of ESD based on:

- the environmental values/sensitivities within the project area are not expected to be significantly impacted, and
- the precautionary principle has been applied, and studies undertaken where knowledge gaps were identified.

Relevant Requirements

Management of the impacts and risks from underwater noise associated with the Crux project are consistent with relevant legislative requirements, including:

- application of relevant guidelines:
  - VSP operations are consistent with the requirements of *EPBC Policy Statement – Interaction between offshore seismic exploration and whales* (DEWHA 2008c)
  - noise assessment consistent with the recommendations of the *Technical guidance for assessing the effects of anthropogenic sound on marine mammal hearing* (NOAA 2018), and
  - noise assessment consistent with the recommendations of the *Sound exposure guidelines for fishes and sea turtle* (Popper et al. 2014) was undertaken.
- management of impacts and risks are consistent with policies, strategies, guidelines, conservation advice, and recovery plans for threatened species (**Table 8-21**).

Matters of National Environmental Significance

Threatened and Migratory Species

The evaluation of impacts and risks indicates significant impacts[12] to threatened and migratory species will not credibly result from the planned direct impacts from the underwater noise aspects of the Crux project. Impacts are likely to be restricted to temporary behavioural disturbance of individual animals (most likely low frequency cetaceans).

[12] as described in Matters of National Environmental Significance - Significant impact guidelines (DoE 2013a)

Alignment of the Crux project with management plans, recovery plans and conservation advice for threatened and migratory fauna is provided in **Table 8-21**.

Commonwealth Marine Environment

The impacts and risks from underwater noise associated with the Crux project on the Ancient coastline at 125 m depth contour KEF and Continental Slope Demersal Fish Communities KEF do not significantly affect the environmental values of these KEFs.

Table 8-21: Summary of Alignment of the Impacts and Risks from Underwater Noise associated with the Crux Project with Relevant Requirements for EPBC Threatened Fauna

Sensitivity	EPBC Management Plans/Recovery Plans/Conservation Advices	Threats Relevant to the Project	Demonstration of Alignment as Relevant to the Project
Marine mammals	Significant impact guidelines for Critically Endangered, Endangered, Vulnerable and Migratory species (**Table 7-1**)	Underwater noise emissions	The impact assessment indicates that the impacts and risks from underwater noise to threatened or migratory marine mammals are likely to be restricted to behavioural disturbances of individual animals. PTS and TTS of threatened or migratory marine species is considered very unlikely. As such, the Crux project does not exceed any of the significant impact criteria for Threatened and Migratory marine species provided in **Table 7-1**.
	Conservation advice on sei whale (*Balaenoptera borealis*) (DoE 2015c)	Anthropogenic noise and acoustic disturbance	The risk of anthropogenic noise to cetaceans will be managed in accordance with: • VSP operations are consistent with the requirements of *EPBC Policy Statement – Interaction between offshore seismic exploration and whales* (DEWHA 2008c). A noise assessment consistent with the recommendations of the *Technical guidance for assessing the effects of anthropogenic sound on marine mammal hearing* (NOAA 2018) was undertaken.
	Conservation advice on fin whale (*Balaenoptera physalus*) (DoE 2015d)	Anthropogenic noise and acoustic disturbance	
	Conservation management plan for the blue whale: A recovery plan under the *Environment Protection and Biodiversity Conservation Act 1999* 2015–2025 (Commonwealth of Australia 2015a)	Noise interference	
	Conservation advice on humpback whale (*Megaptera novaeangliae*) (DoE 2015b)	Noise interference	
Marine reptiles	Significant impact guidelines for Critically Endangered, Endangered, Vulnerable and Migratory species (Table 7-1)	Underwater noise emissions	The impact assessment indicates that the impacts and risks from underwater noise to threatened or migratory marine turtles are likely to be restricted to behavioural disturbances of individual animals. PTS and TTS of threatened or marine turtles is not considered credible. As such, the Crux project does not exceed any of the significant impact criteria for Threatened and Migratory marine species provided in **Table 7-1**.
	Recovery Plan for Marine Turtles in Australia 2017–2027 (Commonwealth of Australia 2017a)	Noise interference	A noise assessment consistent with the recommendations of the S*ound exposure guidelines for fishes and sea turtle* (Popper et al. 2014) was undertaken.
Sharks and rays	Conservation advice on whale shark (*Rhincodon typus*) (DoE 2015l)	Habitat disruption from mineral exploration, production and transportation	A noise assessment consistent with the recommendations of the S*ound exposure guidelines for fishes and sea turtle* (Popper et al. 2014) was undertaken. This considered the potential impacts of underwater noise on whale sharks.

Sensitivity	EPBC Management Plans/Recovery Plans/Conservation Advices	Threats Relevant to the Project	Demonstration of Alignment as Relevant to the Project
Commonwealth marine area	Significant Impact Guidelines for the Commonwealth marine environment (**Table 7-1**)	Underwater noise	The impact assessment indicates that the underwater noise aspect of the Crux project will not exceed the Commonwealth marine environment significant impact criteria provided in **Table 7-1**.

Internal and External Context

Shell's ongoing consultation program will consider statements and claims made by stakeholders when undertaking the assessment of impacts and risks. Shell has also considered the internal context, including Shell's environmental policy and ESHIA requirements. The environmental performance outcomes, and the controls which will be implemented, are consistent with the outcomes from stakeholder consultation for the Prelude FLNG facility and Shell's internal requirements.

Acceptability Summary

The assessment of impacts and risks from underwater noise associated with the Crux project determined the residual impact and risk ranking was minor (**Table 8-19**). As outlined above, the acceptability of the impacts and risks from underwater noise associated with the Crux project has been considered in the context of:

- ESD
- relevant legislative requirements
- external context (i.e. stakeholder claims), and
- internal context (i.e. Shell requirements).

The residual impacts and risks are minor. Shell considers residual impacts of minor or lower to be acceptable if they meet legislative and Shell requirements. The discussion above demonstrates that these requirements have been met in relation to the underwater noise aspect of the Crux project.

Based on the points discussed above, Shell considered the impacts and risks from underwater noise associated with the Crux project to be acceptable.

8.4.3.6 Environmental Performance Outcomes

Threatened Species and Ecological Communities

No mortality of, or significant impacts to, threatened and migratory MNES species as a result of underwater noise from the Crux project.

8.4.4 Atmospheric Emissions

8.4.4.1 Project Context

Atmospheric emissions associated with the Crux project will be generated by a number of sources:

- combustion emissions from power generation and processing facilities
- periodic flaring of gas during commissioning/start-up and shutdown activities. A continuous small pilot flame will be necessary on the flare during operations for safety and GHG intensity reasons. This will comprise a continuous flow of small quantities of purge gas and off gas from gas dehydration.
- disposal of TEG regeneration off gas stream to flare
- disposal of separated reservoir CO_2 in the feed gas
- transportation, such as vessel and helicopter movements, and
- fugitive emissions.

Refer to **Section 5.7.5** for additional information on these sources.

This section evaluates the environmental impacts and risks associated with the atmospheric emissions aspect of the Crux project.

8.4.4.2 Description and Evaluation of Impacts and Risks

Given the offshore remote context, environmental sensitivities within the following groups may be impacted by atmospheric emissions arising from the Crux project, including:

- physical environment (air quality), and
- socio-economic and cultural environment

Potential impacts and risks associated with aspects of the Crux project with these are discussed below.

Physical Environment

Air quality

Gaseous emissions arising from the Crux project are anticipated to include atmospheric emissions of sulphur compounds (typically described as SO_X and H_2S), NO_X, carbon monoxide (CO), CO_2 and particulates (typically described as PM_{10} or $PM_{2.5}$). It is expected there will be some fugitive emissions, described as VOCs, from non-point source releases.

As described previously in **Section 5.7.5**, the majority of atmospheric emissions will be directed through to the operational Prelude FLNG facility. Only a minor (< 6% based on foundation project) proportion is attributable to the Crux project as a back-fill gas supply to Prelude. Therefore, it is important context that the majority (> 90%) of the air emissions profile have been subject to prior assessment and approval through the Prelude FLNG EIS and subsequent EPs. Emissions which occur on the Prelude FLNG facility will not be assessed again under this proposal.

The quantities of gaseous emissions are relatively small and will, under normal circumstances, be quickly dissipated into the surrounding atmosphere. In general terms, the sensitivity of local air quality in the in-field development area is considered low due to the absence of existing pollution sources and the absence of sensitive receptors. Considering the location of the Crux project in the open ocean, which is well-removed from nearest residential or sensitive populations of the WA coast, it is considered highly

unlikely that atmospheric emissions will result in significant impacts to ambient air quality at a local and regional scale.

While not a planned activity, it may be necessary to conduct unplanned venting of hydrocarbon gas (i.e. blowdown) to depressurise the production process onboard the Crux platform. Under normal circumstances, this hydrocarbon gas is flared. Unplanned venting would only occur if the flare was not available for use. Flaring is preferred to unplanned venting for safety and environmental reasons as:

- uncombusted hydrocarbon gas poses a significant safety risk, and
- unburned methane (the main component of the hydrocarbon gas) is a more potent greenhouse gas than carbon dioxide.

Atmospheric emissions will result in a minor deterioration in local air quality. While emissions of GHG will cause an incremental increase in global GHG concentrations, they are not considered to have a determinable local-scale impact. Taking into account the low sensitivity of the receiving environment subject to local and regional air quality changes (absence of receptors in the open offshore context), the residual impact is concluded to be low.

Socio-economic and Cultural Environment

Cumulative CO_2 and GHG Emissions

Shell understands and recognises the importance of climate change and is fully committed at all organisational levels to provide an active role in sustainable development and socially responsible project investments to provide more and cleaner energy.

Shell recognises the role of gas in providing more and cleaner energy in the energy transition. To this point, Shell is also an advocate for putting a market driven price on carbon as a sustainable framework to achieving the Paris Accord goals of reducing GHG emissions to keep climate change within 2°C. Further to this, Shell is committed to complying with legislative requirements including any future changes that may apply to Crux carbon emissions in future.

As part of early concept engineering, there are a range of inherent design and operational efficiencies that have been incorporated that support GHG efficiency gains, including:

- selection of NNM platform as opposed to FPSO concept, which contribute significant emissions reduction compared to this alternative
- leak detection and repair program to find and control fugitive emissions, and
- the selection of TEG off gas flaring over venting based on the approximately 25-fold improved GHG footprint of flaring hydrocarbons versus venting hydrocarbons.

Refer to **Section 8.4.9** for a further assessment of GHG emissions as relevant to contribution of cumulative impacts.

8.4.4.3 Risk and Impact Summary and Key Management Controls

Table 8-22: Atmospheric Emissions Evaluation of Impacts and Risks

Project Component/ Activity	Environmental Value/Sensitivity				Evaluation – Planned		
	Physical Environment	Threatened Species and Ecological Communities	Ecosystems, Communities and Habitats	Socio-economic and Cultural Environment	Magnitude	Sensitivity	Residual Impact
Evaluation – Planned Impacts							
Planned impacts resulting from atmospheric emissions arising from the Crux project, including: • decline in local or regional air quality, and • contribution to the incremental build-up of GHG in the atmosphere	X			X	Minor effect	Low	Minor
Evaluation – Unplanned Risks							
Project Component/ Activity	**Physical Environment**	**Threatened Species and Ecological Communities**	**Ecosystems, Communities and Habitats**	**Socio-economic and Cultural Environment**	**Significance**	**Likelihood**	**Residual Risk**
Unplanned impacts from venting of hydrocarbon gas.	X				Slight	Remote	Negligible
Key Management Controls							

All drilling rigs, vessels and Crux platform (as appropriate to vessel class) will comply with MARPOL Annex VI (Prevention of air pollution from ships), the *Navigation Act 2012*, the *Protection of the Sea (Prevention of Pollution from Ships) Act 1983* and subsequent Marine Orders. which requires vessels to have a valid International Air Pollution Prevention Certificate (for vessels > 400 tonnage) and use of low sulphur fuel, when possible.

Complete and submit annual National Greenhouse and Energy Reporting (NGER) reports during the operations stage of the project for the Kyoto Protocol listed (or applicable post-Kyoto agreement at the time of operations) GHG emissions on a CO_2 equivalency basis for each facility (as defined in Section 9 of the *National Greenhouse and Energy Reporting Act 2007* and National Greenhouse and Energy Reporting Regulations 2008) by fuel type, and the relevant requirements of the National Greenhouse and Energy Reporting (Safeguard Mechanism) Rule 2015.

GHG and NPI reporting records (or contemporary requirements at the time of the activities) will be complied with during the project.

Flaring during operations is optimised to enable the safe and economically efficient operation of the facility.

Selection of gas turbine generators during design process considers energy efficient (i.e. low emission) equipment.

TEG off gas will not be vented but sent to the flare for combustion as long as the flare is ignited.

8.4.4.4 Acceptability of Impacts and Risks

The acceptable level of impact for the receptors that may credibly be impacted or at risk from the atmospheric emissions aspect of the Crux project is summarised in **Table 8-23**. The methods by which this acceptable level was determined, along with a justification as to why it is acceptable, are discussed in **Section 7**.

Based on the outcomes of the evaluation of impacts and risks, Shell considers that the environmental risks and impacts that may result from the atmospheric emissions aspect of the Crux project are acceptable.

Further discussion of the acceptability considerations outlined in **Section 7** in relation to the atmospheric emissions aspect of the Crux project is provided below.

Table 8-23: Acceptable Levels of Impacts and Risks from Atmospheric Emissions

Receptor Category	Receptor Sub-category	Acceptable Level of Impact	Are the Crux Project's Impacts and Risks of an Acceptable Level?
Physical Environment	Air quality	No significant impacts to air quality during the Crux project.	Yes. Impacts to air quality from atmospheric emissions during the Crux project will be localised. Given the remoteness of the Crux project area, there is no potential for significant environmental impacts to occur.

Principles of ESD

The risks and impacts from atmospheric emissions from the Crux project are consistent with the principles of ESD based on:

- the environmental resources within the project area are not expected to be significantly impacted, and
- the precautionary principle has been applied, and studies undertaken where knowledge gaps were identified.

Relevant Requirements

Management of the impacts and risks from atmospheric emissions associated with the Crux project are consistent with relevant legislative requirements, including:

- compliance with international maritime conventions, including:
  - MARPOL:
    - Annex VI: Regulations for the prevention of air pollution from ships
- compliance with Australian legislation and requirements, including:
  - *Navigation Act 2012* and *Protection of the Sea (Prevention of Pollution from Ships) Act 1983*
    - Marine Order 97 (Marine Pollution Prevention – Air Pollution)
  - Relevant requirements of the National Pollutant Inventory (NPI) NEPM, National Greenhouse and Energy Reporting Act 2007, and National Greenhouse and Energy Reporting (Safeguarding Mechanism) Rule 2015 (or contemporary requirements at the time).
- implementation of recognised industry standard practice, such as:
  - preventative maintenance system
  - optimise flaring to enable the safe and efficient operation of the facility, and
  - equipment selection in design, to achieve emissions efficiencies.

Matters of National Environmental Significance

Threatened and Migratory Species

Atmospheric emissions will not credibly result in significant impacts to threatened or migratory species.

Commonwealth Marine Environment

The impacts and risks from the atmospheric emissions aspect of the Crux project on the Commonwealth marine environment do not exceed any of the significant impact criteria provided in **Table 7-1**.

Internal and External Context

Shell's ongoing consultation program will consider statements and claims made by stakeholders when undertaking the assessment of impacts and risks. Shell has also considered the internal context, including Shell's environmental policy and ESHIA requirements. The environmental performance outcomes, and the controls which will be implemented, are consistent with the outcomes from stakeholder consultation for the Prelude FLNG facility and Shell's internal requirements.

Acceptability Summary

The assessment of impacts and risks from atmospheric emissions determined the residual impact and risk ratings were Minor or lower (**Table 8-22**). As outlined above, the acceptability of the impacts and risks from atmospheric emissions associated with the Crux project has been considered in the context of:

- ESD
- relevant legislative requirements
- external context (i.e. stakeholder claims), and
- internal context (i.e. Shell requirements).

The residual impacts and risks are minor. Shell considers residual impacts of minor or lower to be acceptable if they meet legislative and Shell requirements. The discussion above demonstrates that these requirements have been met in relation to the atmospheric emissions aspect of the Crux project.

Based on the points discussed above, Shell considered the impacts and risks from atmospheric emissions associated with the Crux project to be acceptable.

8.4.4.5 Environmental Performance Outcomes

Physical Environment

No significant impacts to air quality as a result of atmospheric emissions during the Crux project.

8.4.5 Invasive Marine Species

8.4.5.1 Project Context

Aspects of the Crux project have the potential to introduce IMS to the project area, which may interact with environmental receptors. These aspects are described in **Section 5.7.6** and include:

- biofouling on the drilling rig, vessels and equipment sourced from outside Australian waters that will be immersed in the marine environment (e.g. drilling equipment, drilling rig anchors)
- ballast water discharges from vessels and drilling rigs, and
- transfer of IMS from the Prelude FLNG facility to the Crux flexible riser.

These aspects constitute potential vectors by which IMS may be introduced into the project area.

Establishment of IMS in the Crux project requires a sequence of events to occur:

- the potential IMS must be present on (e.g. biofouling) or in (e.g. ballast water) the vector
- the potential IMS must be released into the environment (e.g. ballast water discharge, release of propagules from biofouling), and
- the potential IMS must survive and reproduce (either sexual or vegetative reproduction) in the environment.

The introduction of IMS is recognised globally as a threat to marine biodiversity, and the International Maritime Organization (IMO) has developed guidelines for the management of biofouling and ballast water. Commonwealth, State and Territory authorities also regulate the risk of IMS from biofouling and ballast water. Vessels operating in Australia are required to meet these requirements, and vessels meeting these requirements pose an inherently low risk of harbouring IMS or releasing IMS into the environment.

The materials for the construction of the Crux infrastructure (e.g. platform, flowlines, risers, export pipeline etc.) will be new material that has not previously been submerged. Such materials will not host potential IMS and do not pose a direct biosecurity risk.

The offshore environment of the project area is relatively deep, and hard substrate habitats are very uncommon. Many potential IMS are sessile invertebrates that require hard substrate for attachment. In the unlikely event potential IMS are released into the project area, the IMS are unlikely to encounter suitable substrate for recruitment. Most potential IMS are adapted to coastal waters, such as ports and harbours. If a potential IMS were to become established in the project area, it is unlikely to survive in the relatively deep water offshore environment.

Spread of IMS along the Crux flexible riser to the export pipeline is not considered credible due to the water depth of the export pipeline. Credible potential IMS on the riser will be restricted to the part of the riser in surface waters at the Prelude FLNG facility (i.e. the immediate vicinity of the Prelude FLNG facility).

If potential IMS become established in the project area (i.e. on the Crux platform or the flexible riser connected to the Prelude FLNG), these IMS may become established on support vessels. These vessels may subsequently provide vectors for translocation of potential IMS. This sequence of events is considered extremely remote given the controls that are routinely applied to support vessels (e.g. anti-fouling coating, inspections, hull cleaning etc.), the remote offshore location and nature of typical vessel activities (e.g. short periods alongside the Crux platform during operations).

8.4.5.2 Description and Evaluation of Impacts and Risks

A range of environmental sensitivities within the following groups may be at risk from the introduction of potential IMS, including:

- ecosystems, communities and habitats
- threatened species and ecological communities, and
- socio-economic and cultural environment.

Potential impacts and risks associated with aspects of the Crux project with these are discussed below. As outlined in **Section 8.3.3**, the assessment considers only the residual impacts and risks following the application of controls.

Ecosystems, Communities and Habitats

Benthic Communities

Benthic communities within the project area are characterised by relatively sparse assemblages of filter feeding and deposit feeding organisms. The seabed within the entire project area does not receive sufficient photosynthetically active radiation to support benthic primary producer habitat, such as macroalgae and zooxanthellate corals. Very few potential IMS identified can credibly survive in the water depths of the project area. For example, of the non-oceanic species identified in the Australian Marine Pest Monitoring Manual (Department of Agriculture, Fisheries and Forestry 2010) indicated very few IMS (aside from planktonic oceanic species such as dinoflagellates) could credibly survive in the project area; only three (European clam, soft-shell clam and Northern Pacific sea star) were identified as potentially surviving in > 90 m water depth; none were identified as credibly surviving at > 200 m water depth. These three species are typically found in shallow, coastal waters. The project area is > 90 m water depth, with most of the area > 150 m water depth. In the highly unlikely event these species were introduced into the project area, they are unlikely to survive or become established due to the water depth.

Following construction of the Crux platform, it is possible that potential IMS may become established on the artificial habitat provided by the platform jacket and risers. However, this is considered highly unlikely as the potential vectors (e.g. vessels) will typically be near the platform for relatively short periods (up to a week) during the operational phase. In the unlikely event an IMS becomes established on the platform jacket, it is highly unlikely it will spread in the environment due to the water depth and remoteness of the area. Further, platform support vessels will typically be sourced from Australian waters; Australian ports are generally considered to pose a low risk of harbouring potential IMS compared to ports in other countries in the region (e.g. Indonesia and Singapore).

Most species within the project area will be widely distributed as similar habitats are broadly represented in the Timor Sea. An IMS may compete with native species if it were to become established in the project area. This may decrease the species diversity of benthic communities.

IMS are typically extremely difficult to eradicate once established and reproducing in an area. In the highly unlikely event an IMS becomes established in the project area, it would be almost impossible to remove.

Shoals and Banks

The shoals and banks in the region are typically shallower than the project area. As outlined above in **Benthic Communities**, most potential IMS prefer shallower habitats than the project area. Hence, shoals and banks in the region may be more vulnerable to

introduction of IMS, although the shoals and banks are also below the preferred depth range of many potential IMS.

The nearest shoal to the proposed location of the Crux platform is Goeree Shoal, which lies approximately 13 km to the north-west. Project vessels are very unlikely to spend any significant time in proximity to Goeree Shoal (or any other bank or shoal), and direct introduction of IMS to a shoal or bank is considered very unlikely.

In the highly unlikely event an IMS is introduced and becomes established in the project area, the IMS distribution may extend to include shoals and banks. Potential impacts to shoals and banks are expected to be similar to **Benthic Communities**, namely a potential reduction in species diversity.

Key Ecological Features

The Continental Slope Demersal Fish Communities KEF overlaps the export pipeline corridor. The depth of this overlapping area is > 200 m, which is too deep for IMS to credibly become established. No impacts to the environmental values of this KEF will credibly occur due to potential IMS.

Threatened Species and Ecological Communities

None of the EPBC Act listed threatened or migratory species will credibly be impacted in the unlikely event of an IMS introduction resulting from the Crux project. IMS are not identified as a threatening process for EPBC listed threatened or migratory species that may occur within the project area.

Socio-economic and Cultural Environment

Offshore Petroleum Exploration and Operations

The only socio-economic or cultural receptor within the project area that may credibly be impacted by the introduction of an IMS is the Prelude FLNG facility. The potential for IMS introduction to the Prelude FLNG facility from a project vessel is extremely unlikely.

Some potential IMS, such as green mussels, have been shown to form dense aggregations in pipes, such as seawater intakes for process cooling. Marine growth is a common problem on offshore facilities. It is routinely managed by cleaning or the use of biocides to reduce or remove marine growth. As such, impacts to the Prelude FLNG facility from an IMS introduction are not considered credible.

8.4.5.3 Risk and Impact Summary and Key Management Controls

Table 8-24: IMS Evaluation of Impacts and Risks

Project Component/ Activity	Environmental Value/Sensitivity				Evaluation – Unplanned		
	Physical Environment	Threatened species and Ecological Communities	Ecosystems, Communities and Habitats	Socio-economic and Cultural Environment	Significance	Likelihood	Residual Risk
Evaluation – Unplanned							
Unplanned risks associated with the introduction of IMS as a result of the Crux project			X	X	Major	Extremely remote	Moderate

Key Management Controls
Ballast water exchange operations will comply with the IMO International Convention for the Control and Management of Ships' Ballast Water and Sediments 2004 (as appropriate to vessel class), Australian Ballast Water Management Requirements (DAWR 2017) , *Protection of the Sea (Harmful Anti-fouling Systems) Act 2006* and *Biosecurity Act 2015*, including: • all ballast water exchanges conducted > 12 nm from land • vessel Ballast Water Management Plan stipulating that ballast water exchange records will be maintained, and • completion of DAWR Ballast Water Management Summary sheet for any ballast water discharge in Australian waters). Biofouling management for vessels in accordance to the IMO Guidelines for the Control and Management of Ships Biofouling to Minimise the Transfer of Invasive Aquatic Species. The International Convention on the Control of Harmful Anti-fouling Systems on Ships will be complied with, including vessels (of appropriate class) having a valid International Anti-fouling Systems Certificate. Compliance with the Commonwealth *Biosecurity Act 2015,* WA *Fish Resources Management Act 1994* and *Aquatic Resources Management Act 2016*, NT *Fisheries Act* and associated regulations. Alignment with the *National biofouling management guidance for the petroleum production and exploration industry* and the WA DPIRD *Biofouling Biosecurity Policy*. Maintenance of a minimum 1 km buffer from shoals within the in-field development area (**Figure 5-3**).

8.4.5.4 Acceptability of Impacts and Risks

The acceptable levels of impact for the receptors that may credibly be at risk from the IMS aspect of the Crux project are summarised in **Table 8-25**. The method by which these acceptable levels were determined, along with a justification as to why these are acceptable, are discussed in **Section 7**.

Based on the outcomes of the evaluation of impacts and risks, Shell considers that the environmental risks that may result from the IMS aspect of the Crux project are acceptable.

Further discussion of the acceptability considerations outlined in Section 7 in relation to the IMS aspect of the Crux project is provided below.

Table 8-25: Acceptable Levels of Impacts and Risks from Physical Presence and Vessel Movements

Receptor Category	Receptor Sub-category	Acceptable Level of Impact	Are the Crux Project's Impacts and Risks of an Acceptable Level?
Ecosystems, Communities and Habitats	Benthic communities	No significant impacts to benthic habitats and communities. Impacts to non-sensitive benthic communities limited to a maximum of 5% of the project area.	Yes. The introduction of an IMS as a result of the Crux project is unlikely to survive given the water depth of the Crux project area. Shell will take industry-standard measures to reduce the likelihood of an IMS being introduced as a result of the Crux project. If an IMS were to be become established, it would be very difficult to eliminate, however it is unlikely to result in significant impacts to benthic habitats and communities.
	Shoals and banks	No direct impacts to named banks and shoals. No loss of benthic habitats and communities at named banks or	Yes. While the shoals are likely to be more susceptible to an IMS becoming established due to their relatively shallow depth, the implementation of a 1 km buffer around the shoals makes the likelihood of an IMS becoming established extremely low. Shell

Receptor Category	Receptor Sub-category	Acceptable Level of Impact	Are the Crux Project's Impacts and Risks of an Acceptable Level?
		shoals as a result of indirect/offsite[13] impacts.	will take industry-standard measures to reduce the likelihood of an IMS being introduced as a result of the Crux project.
	Key Ecological Features	No significant impacts to environmental values of KEFs.	Yes. The portion of the Continental Slope Demersal Fish Communities KEF within the Crux project area is small (approximately 0.04%) and relatively deep (>150 m water depth). In the unlikely event an IMS was introduced, it would be very unlikely to survive.

Principles of ESD

The risks and impacts from the introduction of IMS resulting from the Crux project are inherently inconsistent with some of the principles of ESD based on the following:

- the introduction of an IMS poses a risk to the biological diversity and ecological integrity of benthic communities in the vicinity of the Crux project.

Shell will apply a range of controls to ensure that the risk of IMS introduction is reduced to a level that is acceptable and ALARP. These include a range of industry best practices that have been developed through extensive industry experience preventing establishment and managing incursions of IMS. Following successful application of these controls, Shell considers the residual risk to be consistent with the principles of ESD.

Relevant Requirements

Management of the impacts and risks from an introduction of IMS resulting from the Crux project are consistent with relevant legislative requirements, including:

- compliance with international maritime conventions, including
  - The International Convention for the Control and Management of Ships' Ballast Water and Sediments
  - The International Convention on the Control of Harmful Anti-Fouling Substances, and
  - IMO 2011 Guidelines for the control and management of ships' biofouling to minimise the transfer of invasive aquatic species.
- compliance with Australian legislation and requirements, including:
  - *Protection of the Sea (Harmful Anti-fouling Systems) Act 2006*:
    - Marine Order 98 – Marine Pollution prevention – anti-fouling systems
  - *Biosecurity Act 2015*:
    - National Biofouling Management Guidelines, and
    - Australian Ballast Water Management Requirements.
  - NT *Fisheries Act*

[13] As defined in the Matters of National Environmental Significance - Significant impact guidelines 1.1 (DoE 2013a).

- WA *Fish Resources Management Act 1994*, subsequent Fish Resources Management Regulations 1995 and the *Aquatic Resources Management Act 2016*, and
- the WA DPIRD Biofouling Biosecurity Policy.

Matters of National Environmental Significance

Threatened and Migratory Species

The policies, strategies, guidelines, conservation advice and recovery plans for MNES that may occur within the potential area affected by an IMS do not identify IMS as a threat.

Commonwealth Marine Environment

The impacts and risks from the introduction of IMS will not result in impacts to the environmental values of the Continental Slope Demersal Fish Communities KEF.

Introduction of IMS as a result of the Crux project will not credibly impact upon AMPs.

Internal and External Context

Shell's ongoing consultation program will consider statements and claims made by stakeholders when undertaking the assessment of impacts and risks. Shell has also considered the internal context, including Shell's environmental policy and ESHIA requirements. The environmental performance outcomes, and the controls which will be implemented, are consistent with the outcomes from stakeholder consultation for the Prelude FLNG facility and Shell's internal requirements.

Acceptability Summary

The assessment of impacts and risks from the introduction of IMS as a result of the Crux project determined the residual impact and risk rating was Moderate or lower (**Table 8-24**). As outlined above, the acceptability of the impacts and risks from the introduction of IMS as a result of the Crux project has been considered in the context of:

- ESD
- relevant legislative requirements
- external context (i.e. stakeholder claims), and
- internal context (i.e. Shell requirements).

The residual impacts and risks are moderate. Shell considers residual impacts of moderate to be acceptable if (**Section 7**):

- all practicable measures have been identified commensurate with the risks and impacts
- internal context – the proposed controls and residual risk level are consistent with Shell policies, procedures and standards
- external context – consideration of the environment consequence and stakeholder expectations, and
- other requirements – the proposed controls and residual risk level are consistent with national and international standards, laws and policies.

The discussion above demonstrates that these requirements have been met in relation to the risk of IMS introduction for the Crux project.

Based on the points discussed above, Shell considered the impacts and risks from the introduction of IMS from the Crux project to be acceptable.

8.4.5.5 Environmental Performance Outcomes

Ecosystems, Communities and Habitats

No IMS of concern established in the natural environment (beyond the installed project infrastructure) as a result of the Crux project.

8.4.6 Waste Management

8.4.6.1 Project Context

A range of aspects of the Crux project will result in the generation of hazardous and non-hazardous wastes and recyclable materials during all phases of the Crux project. These will include domestic wastes (e.g. recyclable material such as glass, plastics, paper and cardboard) and industrial wastes (e.g. waste lubricants, used filters and chemical storage materials). These will be routinely transported to shore for recycling or disposal. The planned management of these wastes will not result in any impacts to the offshore marine environment; however, improper storage and handling of these solid wastes may result in accidental releases to the marine environment. These unplanned events may result in risks and impacts to the marine environment. Shell's extensive operational experience indicates most accidental releases of solid wastes to the marine environment are typically relatively small, one-off events.

Some waste streams are discharged to the marine environment. Examples include utility discharges (e.g. sewage, putrescible waste), pipeline hydrotest discharge and PFW, drilling fluids and cuttings. Refer to **Section 8.4.7** for a discussion of planned waste discharges to the marine environment. Minor accidental releases of liquid wastes may also occur; these are also considered in **Section 8.4.7**.

The potential environmental impacts from the loss of solid wastes to the marine environment depend on the nature and amount of the waste, and the sensitivity of the environmental receptors that may be impacted. Some non-hazardous wastes such as paper and cardboard will readily degrade in the marine environment and pose little environmental risk. Other non-hazardous wastes are more persistent in the environment, particularly plastics. Hazardous wastes in the marine environment may result in acute and chronic toxic effects or accumulate in sediments. Accidental loss of solid waste to the environment is most likely to occur at the Crux platform location but may credibly occur anywhere within the project area. Shell has applied the precautionary principle and considered the loss of solid waste for the entire project area.

8.4.6.2 Description and Evaluation of Impacts and Risks

Physical Environment

The loss of hazardous and non-hazardous solid waste may have a localised, temporary effect on water and sediment quality, depending on the nature of the waste. Chemicals (e.g. oiled wastes, solid chemicals etc.) may result in acute toxic effects, however given the offshore receiving environment and the nature of most potential waste spills, any such effects will be of short duration and highly localised.

Ecosystems, Communities and Habitats

The potential for accidental spills of hazardous and non-hazardous solid wastes to impact upon ecosystems, communities and habitats is considered remote. Habitats within the project area are not considered to be particularly sensitive and are well represented in the region. Accidental loss of hazardous and non-hazardous solid wastes will not credibly result in impacts to the shoals and banks in the region.

The Continental Slope Demersal Fish Communities KEF is partially overlapped by the export pipeline corridor. Physical habitat modification has been identified as a threat for this KEF, however fishing gear (particularly trawl fishing) is the associated threatening process.

Threatened Species and Ecological Communities

Key Fauna Species

Marine debris has been identified as a threat for a range of vertebrate fauna species, including marine turtles, birds, marine mammals and sharks and rays. Marine debris is listed as a key threatening process under the EPBC Act. Persistent wastes such as plastics are of concern, as the threat to fauna may remain long after the waste is spilled. Potential impacts of marine debris on key fauna species include (DEWHA 2009c):

- entanglement, potentially resulting in restricted mobility, drowning, starvation, smothering and wounding
- ingestion (particularly of plastics) leading to physical blockage of digestive systems, leading to starvation, and
- acute or chronic toxic effects.

Given the typically small volumes of hazardous or non-hazardous wastes released, potential impacts to key fauna species are expected to be restricted to individual animals. Many of the vertebrate species considered vulnerable to wastes occur seasonally or are expected to occur in low densities (e.g. transiting the area).

8.4.6.3 Risk and Impact Summary and Key Management Controls

Table 8-26: Waste Management Evaluation of Impacts and Risks

Project Component/ Activity	Environmental Value/Sensitivity				Evaluation – Unplanned		
	Physical Environment	Threatened Species and Ecological Communities	Ecosystems, Communities and Habitats	Socio-economic and Cultural Environment	Significance	Likelihood	Residual Impact
Evaluation – Unplanned Risks							
Unplanned risks resulting from an accidental release of hazardous or non-hazardous solid waste to the marine environment	X	X	X		Slight	Medium	Slight
Key Management Controls							
All discharge of waste from vessels will comply with relevant MARPOL 73/78, *Navigation Act 2012* and *Protection of the Sea (Prevention of Pollution) Act 1983* and subsequent Marine Order requirements (as appropriate for vessel classification). Waste management procedures will be implemented for the Crux project that: • provide for waste segregation and storage • safe handling and transport of waste • appropriate waste classification and disposal, recycling and landfill The disposal of non-hazardous and hazardous wastes will be tracked to confirm they are disposed of at an appropriately licensed waste facility.							

8.4.6.4 Acceptability of Impacts and Risks

The acceptable levels of impact for the receptors that may credibly be impacted or at risk from the waste management aspect of the Crux project are summarised in **Table 8-27**.

The method by which these acceptable levels were determined, along with a justification as to why these are acceptable, are discussed in **Section 7**.

Based on the outcomes of the evaluation of impacts and risks, Shell considers that the environmental risks and impacts that may result from the waste management aspect of the Crux project are acceptable.

Further discussion of the acceptability considerations outlined in **Section 7** in relation to the waste management aspect of the Crux project is provided below.

Table 8-27: Acceptable Levels of Impacts and Risks from Waste Management

Receptor Category	Receptor Sub-category	Acceptable Level of Impact	Are the Crux Project's Impacts and Risks of an Acceptable Level?
Threatened Species and Ecological Communities	Key fauna species	No mortality of threatened or migratory MNES fauna from the Crux project. Management of aspects of the Crux project must be aligned to conservation advice, recovery plans and threat abatement plans published by the DoEE. No significant impacts to threatened or migratory MNES fauna.	Yes. Shell implements MARPOL standards in relation to managing wastes, which reduce the likelihood of wastes being accidentally released to the marine environment. Given the remote location of the Crux in-field development area, any accidental release of wastes to the environment would not be expected to interact with a large number of threatened or migratory MNES species.

Principles of ESD

The risks and impacts from wastes are consistent with the principles of ESD based on:

- the environmental values/sensitivities within the project area are not expected to be significantly impacted, and
- the precautionary principle has been applied to the risk assessment.

Relevant Requirements

Management of the impacts and risks from wastes during the Crux project are consistent with relevant legislative requirements, including:

- compliance with international maritime conventions, including:
  - MARPOL:
    - Annex V: regulations for the prevention of pollution by garbage from ships.
- compliance with Australian legislation and requirements, including:
  - *Navigation Act 2012* and *Protection of the Sea (Prevention of Pollution) Act 1983*:
    - Marine Order 94 – Marine pollution prevention – packaged harmful substances, and
    - Marine Order 95 – Marine pollution prevention – garbage.
- management of impacts and risks are consistent with policies, strategies, guidelines, conservation advice, and recovery plans for threatened species (**Table 8-28**).

Matters of National Environmental Significance

Threatened and Migratory Species

The evaluation of impacts and risks indicates significant impacts[14] to threatened and migratory species will not result from the unplanned direct impacts from the waste management aspect of the Crux project.

An unplanned release of waste into the marine environment is unlikely to occur and may result in injury to or death of individual animals. This unplanned event is not considered to have the potential for significant impacts to threatened or migratory species due to the low likelihood of wastes being released and the limited number of animals that would potentially be impacted.

Alignment of the Crux project with management plans, recovery plans and conservation advice for threatened and migratory fauna is provided in **Table 8-28**.

Commonwealth Marine Environment

The impacts and risks from the waste management aspect of the Crux project on the Commonwealth marine environment do not exceed any of the significant impact criteria provided in **Table 7-1**.

The impacts and risks from the accidental loss of hazardous and non-hazardous solid waste during the Crux project on the Continental Slope Demersal Fish Communities do not significantly affect the environmental values of the KEF.

[14] as described in Matters of National Environmental Significance - Significant impact guidelines (DoE 2013a)

Table 8-28: Summary of Alignment of the Impacts and Risks from Waste Management with Relevant Requirements for EPBC Threatened Fauna

Sensitivity	EPBC Management Plans/Recovery Plans/Conservation Advices	Threats Relevant to the Project	Demonstration of Alignment as Relevant to the Project
All vertebrate fauna	Threat abatement plan for the impacts of marine debris on vertebrate marine life (DEWHA 2009c)	Marine debris	The Crux project will manage waste in accordance with standard maritime requirements, international conventions (MARPOL), relevant Marine Orders and Shell's internal management system requirements. This management reduces the likelihood of the accidental release of hazardous and non-hazardous wastes into the marine environment. The quantities and nature of wastes that may be accidentally released into the environment are unlikely to result in significant impacts to threatened or migratory species.
Marine mammals	Conservation advice on sei whale (*Balaenoptera borealis*) (DoE 2015c)	Pollution (persistent toxic pollutants)	
	Conservation advice on fin whale (*Balaenoptera physalus*) (DoE 2015d)	Pollution (persistent toxic pollutants)	
	Conservation management plan for the blue whale: A recovery plan under the *Environment Protection and Biodiversity Conservation Act 1999* 2015–2025 (Commonwealth of Australia 2015a)	Habitat modification including presence of oil and gas platforms/rigs, marine debris infrastructure and acute/chronic chemical discharge	
	Conservation advice on humpback whale (*Megaptera novaeangliae*) (DoE 2015b)	Entanglement – marine debris	
	Significant impact guidelines for Critically Endangered, Endangered, Vulnerable and Migratory species (**Table 7-1**)	Marine debris	
Marine reptiles	Recovery Plan for Marine Turtles in Australia 2017– 2027 (Commonwealth of Australia 2017a)	Marine debris	
	Conservation advice on leatherback turtle (*Dermochelys coriacea*) (DEWHA 2009a)	Marine debris	
	Significant impact guidelines for Critically Endangered, Endangered, Vulnerable and Migratory species (**Table 7-1**)	Marine debris	
Sharks and rays	Conservation advice on whale shark (*Rhincodon typus*) (DoE 2015l)	Marine debris	
	Significant impact guidelines for Critically Endangered, Endangered, Vulnerable and Migratory species (**Table 7-1**)	Marine debris	
Commonwealth marine environment	Significant Impact Guidelines for the Commonwealth marine environment (**Table 7-1**)	Marine debris	The impact assessment indicates that the waste management aspect of the Crux project will not exceed the Commonwealth marine environment significant impact criteria provided in **Table 7-1**.

Internal and External Context

Shell's ongoing consultation program will consider statements and claims made by stakeholders when undertaking the assessment of impacts and risks. Shell has also considered the internal context, including Shell's environmental policy and ESHIA requirements. The environmental performance outcomes, and the controls which will be implemented, are consistent with the outcomes from stakeholder consultation for the Prelude FLNG facility and Shell's internal requirements.

Acceptability Summary

The assessment of impacts and risks from underwater noise determined the residual impact and risk rankings were all minor or lower (**Table 8-26**). As outlined above, the acceptability of the impacts and risks from the accidental loss of hazardous and non-hazardous solid waste during the Crux project has been considered in the context of:

- ESD
- relevant legislative requirements
- external context (i.e. stakeholder claims), and
- internal context (i.e. Shell requirements).

The residual impacts and risks are slight. Shell considers residual impacts of minor or lower (i.e. slight) to be acceptable if they meet legislative and Shell requirements. The discussion above demonstrates that these requirements have been met in relation to waste management aspect of the Crux project.

Based on the points discussed above, Shell considered the impacts and risks from the accidental loss of hazardous and non-hazardous solid waste during the Crux project to be acceptable.

8.4.6.5 Environmental Performance Outcomes

Threatened Species and Ecological Communities

No mortality of, or significant impacts to, threatened and migratory MNES species as a result of unplanned waste discharge to sea during the Crux project.

8.4.7 Liquid Discharges

8.4.7.1 Project Context

A range of aspects of the Crux project will result in the discharge of liquid waste streams to the marine environment. These aspects are described in **Section 5.7.1** and include:

- PFW
- wastewater
- cooling water
- hydrotest water
- drilling fluids and cuttings, and
- minor accidental releases of chemicals/hydrocarbons to the environment.

Descriptions of the characteristics of each of these liquid discharge streams are provided in **Table 8-29**. Note that accidental releases with a moderate or greater consequence magnitude are considered separately in **Section 8.4.8**. These spills are primarily large volume accidental hydrocarbon releases that have the potential to cause widespread environmental damage.

A number of other small planned or accidental liquid discharges may occur during the project life, including hydraulic fluids from the BOP and excess cement during development drilling, lubrication fluids from planned maintenance of the subsea integration system and flushing fluids associated with decommissioning activities. These discharges are expected to be for a short duration and/or relatively minor in nature. Therefore, any potential impacts are expected to occur within the area influenced by the larger planned discharges and are unlikely to result in impacts to the environment that are not assessed within this OPP. The full range of potential planned discharge sources will be further assessed and defined as the engineering design progresses and detailed in activity-specific EPs.

Table 8-29: Summary of Key Liquid Discharge Stream Characteristics

Discharge Stream	Description	Discharge Location	Project Stage and Duration	Indicative Volume*
PFW	PFW consists of water recovered from the reservoir along with the hydrocarbon and typically includes: hydrocarbons (including BTEX, PAH and naphthalene, phenanthrene and dibenzothiophene (NPD) compounds) metals, and production chemicals PFW is generally warmer and more saline than the receiving waters. The composition of the produced water discharge will vary over time as reservoir and production characteristics change.	Above the sea surface from the Crux platform†	During commissioning and operational phase – continuous discharge	Early operations – approximately 238 m^3/day Late operations – up to 3,180 m^3/day
Wastewater and cooling water	Utility discharge streams including utility discharges from vessels such as domestic sewage, greywater, cooling water, reverse osmosis (RO) brine, bilge and deck drainage.	Crux platform (when manned) Project vessels Drilling rig	During all phases, with increased volumes during development drilling, installation, commissioning and decommissioning	Wastewater – approximately 14 m^3/day to 120 m^3/day per vessel Cooling water – 5–10 m^3/day per vessel
Hydrotest water	Hydrotest water is used to assess the structural integrity of subsea infrastructure. Hydrotest water will be treated seawater and may contain biocide, dye (to aid in leak detection), oxygen scavenger, corrosion inhibitors and scale inhibitors.	Export pipeline – seabed at either the Crux platform or Prelude FLNG facility Flexible riser – Prelude FLNG; Crux platform topsides and rigid riser: Crux platform (either subsea or surface) Future tiebacks – either at Crux platform or at tieback field location	One-off discharge for each component during commissioning phase, with the longest discharge duration approximately 44 hours (for the export pipeline)	Export pipeline – 47,500 m^3 Flexible riser – 100 m^3 Crux topsides/riser – 500 m^3 Future tiebacks – < 10,000 m^3
Drilling fluids and cuttings	Drilling of the production wells will generate cuttings from the from the well. Drilling fluids (water-based and synthetic) will be used to cool and lubricate the drill bit,	Wells – from the MODU at the Crux platform location Platform foundations (if required) – at the seabed at	During development drilling and installation – continuously during drilling of each well	Wells – < 5,000 m^3 per well (five wells in total for foundation development) Platform foundations –

Discharge Stream	Description	Discharge Location	Project Stage and Duration	Indicative Volume*
	maintain overbalance, and remove cuttings from the well. Cuttings and drilling fluids are circulated to the drilling rig by a riser (lower sections). Cuttings will be processed onboard the drilling rig to recover drilling mud, and then discharged to the sea. Some residual drilling fluids will adhere to the drill cuttings. The platform foundations (if required) may also be drilled. These may be drilled without a riser or muds, and cuttings will be discharged at the seabed.	the Crux platform location Future tiebacks – well location within the in-field development area	(approximately 34 days per well)	approximately 1,130 m^3 per hole
Minor accidental releases	The Crux platform, drilling rig and project vessels will have a range of chemicals and hydrocarbons stored in small quantities (e.g. cleaning products, hydraulic fluid etc.). Accidental spills of these may occur, potentially leading to unintentional discharge to the marine environment	Crux platform, project vessels and drilling rig	During all phases	Small (typically < 20 L)

* The discharge volumes are based on engineering information available at the early stage of the project. While they are approximate and likely to be refined as the project concept definition progresses, they are considered appropriate to inform a robust assessment of potential impacts and risks at an OPP level of assessment. Further definition and assessment will be detailed in the activity-specific EPs.

† The discharge location of the PFW stream is yet to be finalised. The PWF handling process at the time of submitting this OPP involves discharging the PFW at the sea surface, however this may be subject to change (e.g. shallow subsurface discharge via a caisson). The modelling studies of PFW discharge include a sensitivity analysis of the effect of surface versus shallow subsea discharge (refer to **Appendix E**). This sensitivity analysis indicated there are not significant differences in the behaviour, mixing or fate of the PFW plume between surface and shallow subsea discharge.

8.4.7.2 Overview of Planned Discharge Modelling

Numerical modelling studies were commissioned by Shell to inform the assessment of impacts and risks from key planned liquid discharges, including:

- drilling fluids and cuttings (RPS 2018a)
- PFW (RPS 2018b), and
- hydrotest water (RPS 2018c).

The assumed constituents in the PFW are provided in **Table 8-30**. These were based on measured PFW concentrations for contaminants for which species protection concentration thresholds have been published by ANZECC & ARMCANZ. The measured values were derived from Shell's Auriga-1 exploration well, which targeted hydrocarbons that may be produced by the Crux platform.

Hydrocarbons in the PFW stream can be considered as two discrete categories:

- partially soluble hydrocarbons – these are low molecular weight hydrocarbons that are partially soluble in water, such as light weight PAHs (e.g. benzene). These compounds are typically the most toxic hydrocarbons when introduced into the marine environment. These compounds are not significantly reduced by primary or secondary PFW treatment.
- insoluble hydrocarbons – these are non-polar hydrocarbons that are not significantly soluble in water. Most hydrocarbon compounds fall within this category. The PFW treatment system that will be used on Crux is intended to remove these compounds from the PFW stream, however very fine droplets of insoluble hydrocarbons may remain after treatment. These will be discharged with the PFW stream.

Table 8-30: Assumed Constituents of PFW Discharge

Constituent	Assumed Concentration (mg/L[15])
Benzene	240
Naphthalene, phenanthrene, dibenzothiophene (NPD)	10.7
Phenol	0.757
Cadmium (Cd)	4.6×10^{-3}
Chromium (III/IV) (Cr)	2.48×10^{-2}
Copper (Cu)	9.2×10^{-3}
Lead (Pb)	4.6×10^{-3}
Nickel (Ni)	1.91×10^{-2}
Zinc (Zn)	2.94×10^{-2}

Reports documenting these modelling studies are provided in **Appendix D** to **Appendix F**. The planned discharges were modelled based on the context provided in **Section 5.7**, with discharge locations, characteristics and volumes based on the current design of the Crux project (described in **Table 8-29**).

A custom composite regional hydrodynamic model for the project area, comprising both tidal (HYDROMAP) and mesoscale (HYCOM) models, was used to inform the modelling studies. The tidal, mesoscale and composite models were validated against oceanographic observations, including data collected within the project area, and showed strong agreement with oceanographic observations (RPS 2018e). This confirmed the model was suitable for predicting the fate of liquid discharges.

Each of the modelling studies used a stochastic modelling approach, where the release was repeatedly simulated using different metocean conditions. This process consisted of 100 deterministic model runs from three seasons – summer, winter, and a transitional season. The aggregated deterministic results (300 deterministic runs for each release scenario) constitute the stochastic data set, from which probabilities of contact above thresholds are determined. A stochastic modelling approach was used to inform the risk assessment[16]. This approach is inherently conservative, with the actual area affected by the planned discharges expected to be significantly smaller than the area identified by the stochastic modelling.

[15] Concentrations of contaminants are often expressed in parts per million (ppm). The ppm and mg/L units are interchangeable if ppm is refering to a mass per unit volume.

[16] A similar stochastic approach was applied to the modelling of worst-case hydrocarbon spills. Refer to **Section 8.4.8** and **Appendix G** for further information.

Liquid Discharge and Hydrocarbon Spill Modelling
Numerical models of discharges to the environment have been used to predict the fate of several liquid discharges and hydrocarbon spills in this OPP. These types of computer simulations are regularly used in assessing potential environmental impacts and risks (NOPSEMA 2018d). Modelling results are used to identify which environmental receptors may be impacted, and what the nature of contact with a discharge may be (e.g. the concentration of a discharge, the weathered state of a hydrocarbon etc.).

Two approaches to modelling studies have been implemented to inform the impact assessments of liquid discharges and hydrocarbon spills in this OPP:

- deterministic, and
- stochastic.

These modelling approaches are related and are described further below.

Deterministic Modelling
Deterministic numerical modelling can be used to predict the fate of a discrete liquid discharge or hydrocarbon spill. The outputs of a deterministic model are completely dependent on the inputs. If the inputs to a deterministic model are unchanged, the output will be exactly the same every time the model is run (i.e. there is no variability in the results given the same starting conditions).

If the input parameters are consistent with environmental conditions, and the model is a realistic simulation of environmental processes, outputs from the deterministic model will provide a realistic indication of the fate of the discharge. This makes deterministic models useful where there is a high degree of confidence in the initial conditions, but unreliable where the initial conditions may vary, such as dynamic meteorological and oceanographic conditions in the project area. Hence, Shell has also applied a stochastic modelling approach to modelling studies of liquid discharges and hydrocarbon spills.

Stochastic Modelling
Given modelling is used to predict the fate of a discharge in the environment, and the environmental conditions at the time of discharge are unknown and have a significant effect on the fate of a discharge, single deterministic model runs are not a reliable method to identify the environmental receptors that may be affected. This deficiency of deterministic modelling can be mitigated by using a stochastic modelling approach which incorporates uncertainty, providing a more reliable method to identify environmental receptors that may be affected. Stochastic oil spill modelling is created by overlaying a great number (often hundreds) of individual (i.e. deterministic), computer-simulated hypothetical releases (NOPSEMA, 2018d). Stochastic modelling is a common means of assessing the potential risks from liquid discharges such as PFW and hydrocarbon spills.

The modelling studies used to inform this OPP applied a stochastic modelling approach, which consisted of combining three hundred deterministic model runs for each of the release scenarios. These three hundred runs were aggregated to constitute the stochastic data set for each of the release scenarios. Variability in the metocean conditions was incorporated into the deterministic models by varying the time of the release within a ten year hindcast metocean model. This composite hydrodynamic model comprised mesoscale, wind and tidal currents and was validated against measured metocean conditions recorded in the Crux in-field development area.

Stochastic modelling has been used to identify environmental receptors that may be contacted by discharges or spills above a given dilution or threshold. Given the variability in the stochastic data sets, this process for identifying receptors is highly conservative; the number of receptors considered in the risk and impact assessments is significantly higher that would be affected by a single spill. The nature of exposure is based on the worst-case deterministic run that contacted each receptor.

Shell considers all environmental receptors identified as potentially being contacted, regardless of the likelihood. This approach is will identify more receptors than would be impacted by a given release, and hence it is environmentally conservative.

All models considered far-field effects, which is a suitable approach for estimating the fate of discharges in the environment given the nature and scale of the planned discharges. Near-field modelling was also undertaken for PFW and hydrotest discharges due to the nature of these discharges. Both types of model were run in these instances to simulate the different spatial scales at which processes influencing plume dilution operate.

An impact threshold was identified for each of the modelled discharge streams. These were based on relevant literature and accepted industry practices. These thresholds are discussed further in the sections below, and in the modelling technical appendices (**Appendix D** to **Appendix F**).

This approach was also applied to the assessment for significant unplanned releases of hydrocarbons; refer to **Section 8.4.8** for further information.

8.4.7.3 Description and Evaluation of Impacts and Risks

Physical Environment

Water Quality

Produced Formation Water

PFW will be discharged from the Crux platform and will contain a range of potential residual contaminants, which is expected to include salts, hydrocarbons, metals and production chemicals. The likely PFW constituents and their concentrations was informed by Shell's Auriga-1 exploration well, which targeted the Crux field, and Prelude operational experience. Concentrations for a range of these potential constituents used to inform the PFW modelling studies (RPS 2018b) are provided in **Appendix E**. Based on the threshold concentrations for these constituents, as defined in the ANZECC & ARMCANZ) (2000) guidelines, the required dilution factor to reach the 99% species protection level trigger for all constituents is < 1:500. Stochastic modelling results indicated that a 1:500 dilution (i.e. reaching 99% species protection level trigger) to occur within 999 m from the discharge point.

Maximum concentrations of PFW are expected to occur between 14-55 m water depth, which is the trapping depth of the PFW plume based on the modelling studies. This depth (and hence the vertical depth at which PFW dilutions occur) is highly dependent on the metocean conditions at the discharge location (RPS 2018b). Based on the modelling results, Shell expects most mixing of the PFW to occur in the top 100 m of the water column.

The PFW discharge is expected to be warmer and more saline than the receiving environment, with the discharge denser (i.e. negatively buoyant) than the receiving seawater.

Based on operational experience in the region (e.g. Prelude FLNG facility), potential contaminants such as naturally occurring radioactive materials (NORMs) and organic acids (e.g. acetic acid) are not expected to occur in quantities that may result in environmental impacts.

Modelling of PFW discharges was undertaken for both early phase (discharge rate of 287 m^3/day) and late phase (3,180 m^3/day) forecast maximum discharge rates using the methods outlined in **Section 8.4.7.2**. Near-field modelling results indicated the produced water plume would initially sink and undergo turbulent mixing.

Far-field stochastic modelling results indicated that high dilutions are expected to be achieved during the early operations phase (**Figure 8-5**), with 1:500, 1:2,000 and 1:4,000 dilutions expected to occur within 67 m, 356 m and 873 m, respectively, from the discharge location for all seasons (RPS 2018b). Stochastic modelling results for late phase operations indicated these dilutions would be achieved at increased distances from the discharge location due to the increased discharge rate (**Figure 8-6**). Maximum distances at which 1:500, 1:2,000 and 1:4,000 dilutions are expected are 999 m, 4,696 m and 7,814 m respectively. No named shoals or KEFs were predicted to be exposed to dilutions lower than 1:5,000.

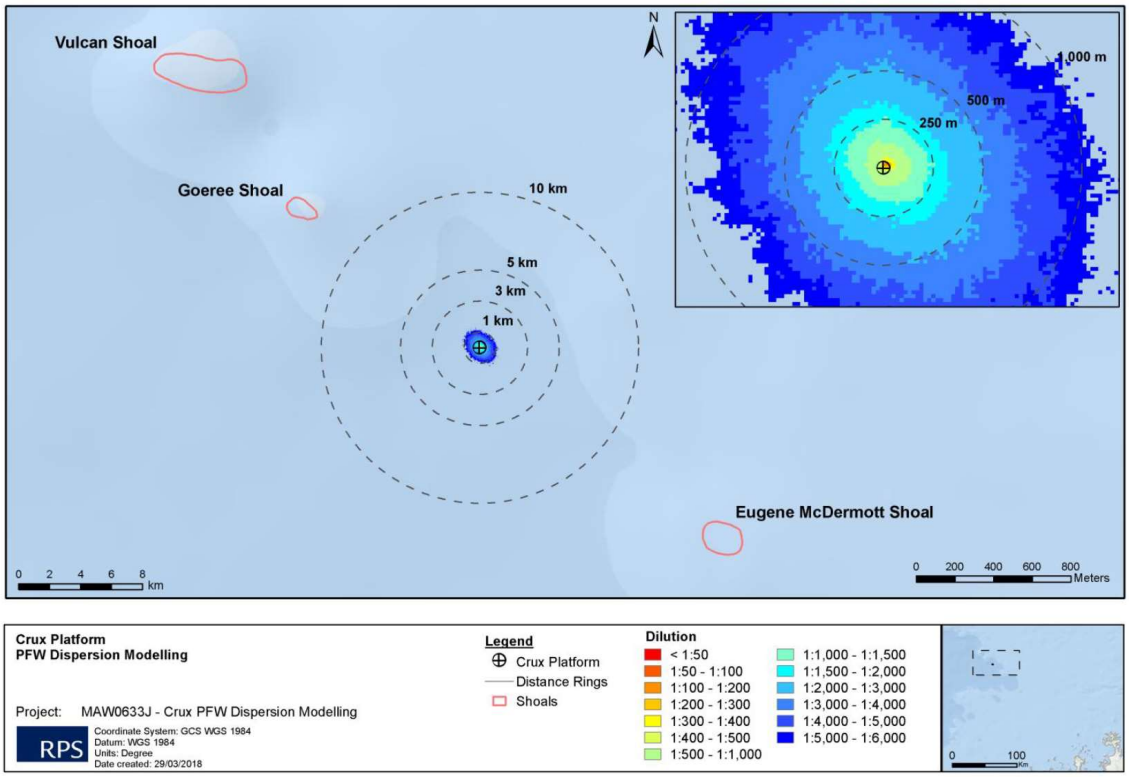


Figure 8-5: Predicted Annualised Minimum Dilutions for the Early Operations Phase Flow Rate of PFW

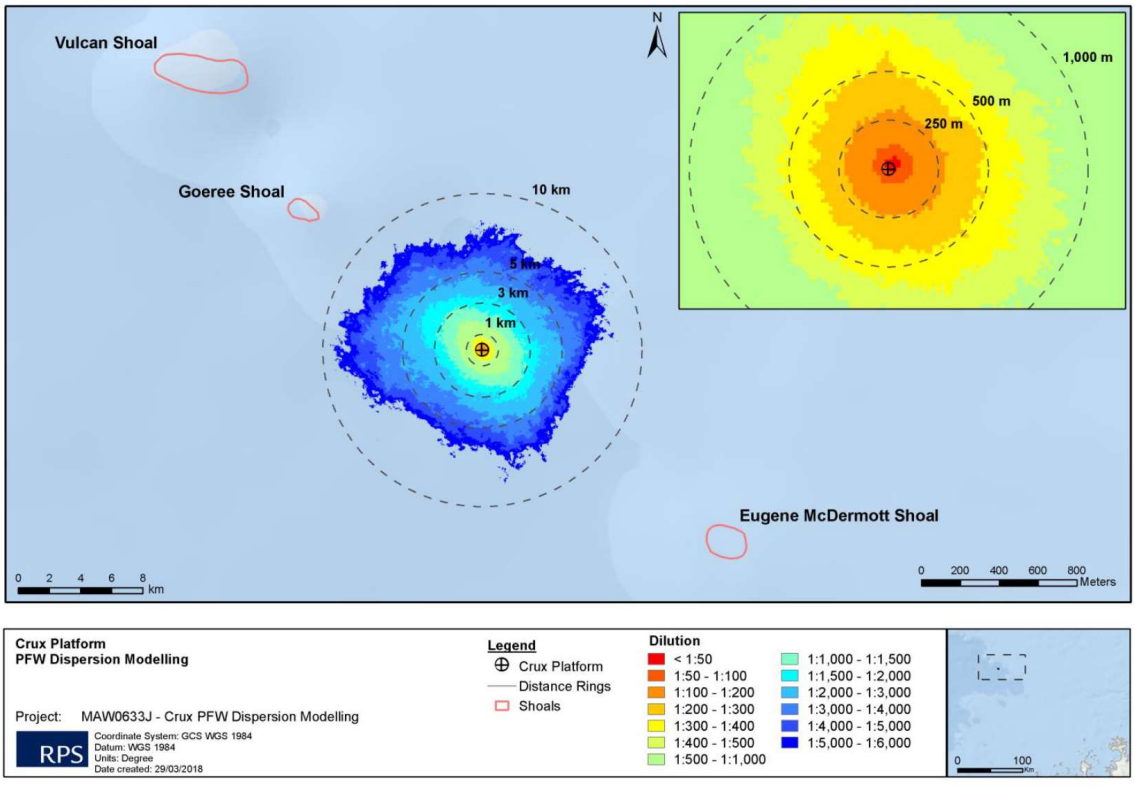


Figure 8-6: Predicted Annualised Minimum Dilutions for the Late Operations Phase Flow Rate of PFW

The salts within the PFW are expected to be similar in composition to the receiving seawater. Anions are expected to predominantly comprise sodium, calcium, magnesium and potassium. Cations are expected to comprise chloride, sulphate, bromide and bicarbonate. These ions (and their associated salts) are commonly found in seawater.

Hydrocarbons in the PFW will consist of both relatively low and high molecular weight compounds. Hydrocarbon solubility generally decreases with increasing molecular weight, and aromatic hydrocarbons also tend to have increased water solubility compared to non-aromatic hydrocarbons of equivalent molecular weight (Neff et al. 2011). As such, low molecular weight aromatic hydrocarbons are typically the most available in PFW. These compounds include BTEX, low-molecular weight PAHs, which include NPD and phenols. Low molecular weight hydrocarbons are of particular interest, as these tend to have the greatest potential for toxicity (Neff et al. 2011). Higher molecular weight compounds typically pose less environmental risk and are largely recovered during the production and PFW treatment processes onboard the Crux platform. Residual high molecular weight hydrocarbons will occur as very fine entrained oil droplets.

BTEX compounds are the most common hydrocarbon component of PFW. BTEX are highly volatile and do not persist in the environment; evaporation and dilution will rapidly reduce the concentration of BTEX in the receiving environment (Ekins et al. 2005, International Association of Oil and Gas Producers (IOGP) 2005. Neff et al. 2011). Other degradation processes such as biodegradation and photodegradation are expected to further reduce BTEX concentrations in the environment (Neff et al. 2000). BTEX is known to be toxic to marine organisms and has been shown to result in developmental defects (Fucik et al. 1995) but does not significantly bioaccumulate (Neff 2002). As such, potential impacts from the decrease in water quality due to BTEX will be localised to within a few hundred metres of the Crux platform during late phase operations.

PAHs are less volatile and soluble than BTEX and have greater potential to accumulate in the marine environment (Neff et al. 2011). PAHs can be broadly divided into two types; low molecular weight and those of high molecular weight. PAHs dissolved in PFW are predominantly low molecular weight and, while toxic, they are not mutagenic nor carcinogenic (although their metabolic by-products may be) (IOGP 2005). Higher molecular weight PAHs are rarely detected in treated PFW due to their low aqueous solubility. These compounds are primarily associated with dispersed oil droplets which are removed by the production process and produced water treatment system (Neff et al. 2011; Schmeichel 2017). PAHs are generally removed from the water column through volatilisation to the atmosphere upon reaching the sea surface, particularly the lower molecular weight fractions (Schmeichel 2017). PAHs can also degrade in the water column with half-lives ranging from less than a day to several months, with the more abundant and lower molecular weight compounds being more degradable (IOGP 2002).

The various trace metals that may be present in low concentrations in the PFW stream are generally in a low oxidative state and on release to the marine environment rapidly oxidise and precipitate into solid forms, which will be transported away from the discharge location while suspended in the water column (discussed further below in **Sediment Quality**). While concentrations of trace metals in PFW can be significantly greater than those in the marine environment, they are rapidly reduced through dilution and mixing processes, and other physicochemical reactions to levels that pose a low risk to the receiving environment (IOGP 2005).

A range of process chemicals may be introduced into wells and subsequently discharged to the sea as a component of the produced water. Some of the process chemicals will be in concentrations below that which are toxic to marine fauna, such as scale inhibitors, while others may be at concentrations that have potential to cause impact or contribute to the aquatic toxicity of the PFW, such as corrosion inhibitors and biocides (Neff 2002). The ecotoxicological impacts of process chemicals in PFW discharges was comprehensively investigated in a study by Henderson et al. (1999). The study tested 11 commonly used process chemicals (including biocides, corrosion inhibitors and demulsifiers) for their acute toxicity to marine bacterium, both directly in aqueous

preparations and following their partitioning between oil and water phases. The study results indicated that toxicity of the PFW was not significantly altered by the presence of most process chemicals used in typical concentrations. A review of the study by Schmeichel (2017) notes that process chemicals make a small contribution to the overall acute toxicity profile of PFW discharges and even chemicals which are classified as highly toxic may not actually present an acute toxicity risk at dosages representing normal operating conditions. As such, production chemicals in the PFW discharge will not result in more than slight potential impacts to water quality.

The decrease in water quality from potential contaminants in the treated PFW discharge stream may result in impacts to plankton. Research indicates that zooplankton exposed to low molecular weight hydrocarbons exhibit acute toxic effects (Almeda et al. 2013; Jiang et al. 2010) and developmental defects in fish (Fucik et al. 1995). In particular, PAHs are of concern due to their solubility, toxicity and relatively persistent compared to BTEX. The concentrations and durations of exposure required to induce these effects is unlikely to occur in the in-field development area due to the rapid dilution of PFW and the well mixed open ocean environment.

Wastewater and Cooling Water

Wastewater discharges from utilities onboard vessels and the Crux platform (when manned) such as sewage, greywater, bilge, RO brine, cooling water and deck drainage may result in increased levels of nutrients, chemicals and metals in the receiving environment. These discharges may also result in changes such as increased or decreased salinity, and changes to water temperature. Increased nutrients may enhance local planktonic productivity. Trace amounts of potential contaminants such as surfactants, hydrocarbons and metals may result in toxic effects on planktonic biota. Physical changes, such as changes to temperature (e.g. localised increase in temperature from cooling water discharges) or salinity (e.g. increased salinity from RO brine) will be localised to the discharge point and temporary. Given the relatively small volumes and transient nature of wastewater discharges, along with the well mixed offshore receiving environment, the potential for environmental impacts to water quality is slight.

Hydrotest Water

The discharge of hydrotest water associated with the project will result in a total of approximately 48,600 m^3 of treated seawater being released to the marine environment. The majority of this (approximately 47,500 m^3) will be discharged at the seabed from either the Crux or Prelude end of the export pipeline. The chemicals added to the treated seawater will result in the discharge of residual chemicals to the marine environment. These chemicals may include biocides, dyes, corrosion inhibitors and scale inhibitors; these residual chemicals may result in a temporary decrease in water quality in the water column affected by the discharge. This decrease in water quality may result in impacts to marine biota (discussed below in **Ecosystems, Communities and Habitats** and **Threatened Species and Ecological Communities**).

Shell commissioned RPS (2018c) to undertake a modelling study to better understand the potential fate of discharged hydrotest water in the environment; the report is provided as **Appendix F**. While the discharge location of the hydrotest water has not been determined and may be at either the Crux or Prelude ends of the export pipeline, the modelling study assumed the discharge to occur within the in-field development area. This is a “worst-case” discharge location due to the higher sensitivity of the receiving environment, due to:

- the closer proximity to benthic features such as shoals and banks that support relatively diverse biological communities, and

- the shallower benthic environment in general in the in-field development area, which supports more diverse benthic communities than the Prelude end of the export pipeline (Fugro 2017).

The biocide concentration was the parameter modelled, as this component of the treated seawater has the greatest potential for environmental impacts. The modelling was based on the complete discharge of treated seawater from the export pipeline, with the concentration of biocide at the time of discharge assumed to be 500 ppm; this is a conservative assumption as the actual concentration is expected to be significantly lower than this. The modelling also assumed the biocide is not consumed in the environment (i.e. it does not get consumed as it reacts with material); which is an additional conservative assumption upon which the modelling results are based.

An impact threshold of 1 ppm of biocide was defined; it was assumed that concentrations below this threshold would not result in significant environmental impacts. This threshold is consistent with published acute toxicity test data for aquatic species for typical biocides that may be used. For example, the Wheatstone Project Offshore Facilities and Produced Formation Water Discharge Management Plan: Stage 1 (Chevron, 2015) identified an acute toxicity threshold of 1 ppm for Hydrosure, a representative biocide product. The Safety Data Sheet for Hydrosure O-3670R states the 96-hour LC50[17] as 3.09 mg/L (3.09 ppm) for fish in marine waters, with a 48-hour EC50[18] of 5.66 mg/L (5.66 ppm) for aquatic invertebrates (Champion Technologies, 2013). Sano et al (2005) assessed the potential toxicity effects of glutaraldehyde, another representative biocide, and reported a 24-hour LC50 of 4.7 mg/L (4.7 ppm) for the aquatic invertebrate *Ceriodaphnia dubia*. Note that ecotoxicological studies are typically undertaken using constant doses for periods ranging from 24 to 96 hours under controlled conditions. This approach is in contrast to the natural environment, where the concentration and exposure durations can vary widely. For the purpose of this assessment, selection of an impact threshold of 1 ppm provides a conservative basis to evaluate the potential effects of biocide in the receiving environment.

Near-field stochastic modelling results indicated the velocity of the discharge plume will generate an initial turbulent mixing zone at the release location, followed by the marginally negatively buoyant plume sinking to the seabed and spreading in all directions from the discharge location. The stochastic modelling did not indicate that the 1 ppm threshold would be reached within the domain of the near-field model in any season. Far-field stochastic modelling indicated that the maximum and average distance from the discharge location that the 1 ppm threshold would be reached in any season was 5,727 m and 5,263 m, respectively (**Figure 8-7**). Both the near-field and far-field stochastic results indicated that ambient currents provide the greatest influence on the advection and dilution of the treated seawater plume in the environment. Note that the stochastic modelling results did not indicate any shoals or banks would be contacted above impact thresholds (**Figure 8-7**).

The discharge of hydrotest water may result in the re-suspension of sediments in the immediate surrounds of the release location. Sediments at the Crux end of the export pipeline are characterised by sand and gravel fractions, while the Prelude end of the export pipeline is characterised by sands with a higher portion of muds. Discharge at either end of the export pipeline may initially re-suspend finer sediments, which will result in increased turbidity within the plume. Re-suspension will taper off as fine sediments

[17] The LC50 value is the leathal concentration required to kill 50% of a population in the given time

[18] The EC50 is the median effective concentration. It is the concentation at which 50% immobilisation of the test organism is observed in the given time.

become exhausted around the discharge point. Near-field modelling indicated the velocity of the discharge will slow upon exiting the export pipeline due to turbulent mixing, and hence the potential for sediment re-suspension is concentrated around the discharge location.

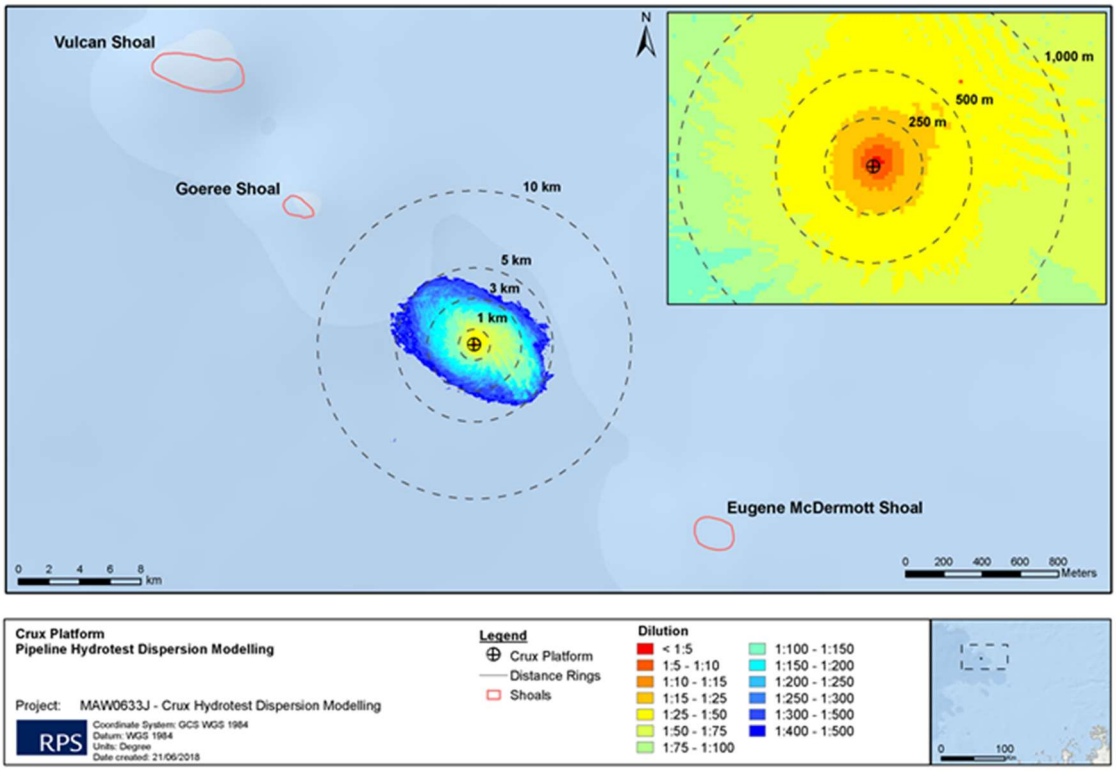


Figure 8-7: Predicted Annualised Dilutions of Hydrotest Water

Drilling Fluids and Cuttings

The discharge of drill cuttings will impact the physical properties of the receiving marine environment. The offshore receiving environment typically has low turbidity (AECOM 2016), and the discharge of drill cuttings from the drilling rig will result in a temporary increase in turbidity and total suspended solids (TSS). The nature of the change in turbidity is dependent on the characteristics of the cuttings, primarily size and density. The particle size distribution of cuttings will vary based on the geology of the formations being drilled, the characteristics of the drilling equipment, and the design of the well. Cuttings typically range from coarse gravel (> 32 mm) to silt (< 63 µm). Coarse particles will typically settle rapidly and have little potential to impact water quality (IOGP 2016). As cuttings particle size decreases, the settling velocity will typically decrease, and the ratio of residual drilling fluids to cutting size increases. This will result in a turbid plume that will decrease as the plume is diluted and the suspended particles are deposited (**Figure 8-8**; Continental Shelf Associates 2006). Results from the modelling of drill cuttings and fluids discharges for the Crux foundation wells indicated dilution is expected to occur rapidly due to the currents in the open ocean environment (RPS 2018a).

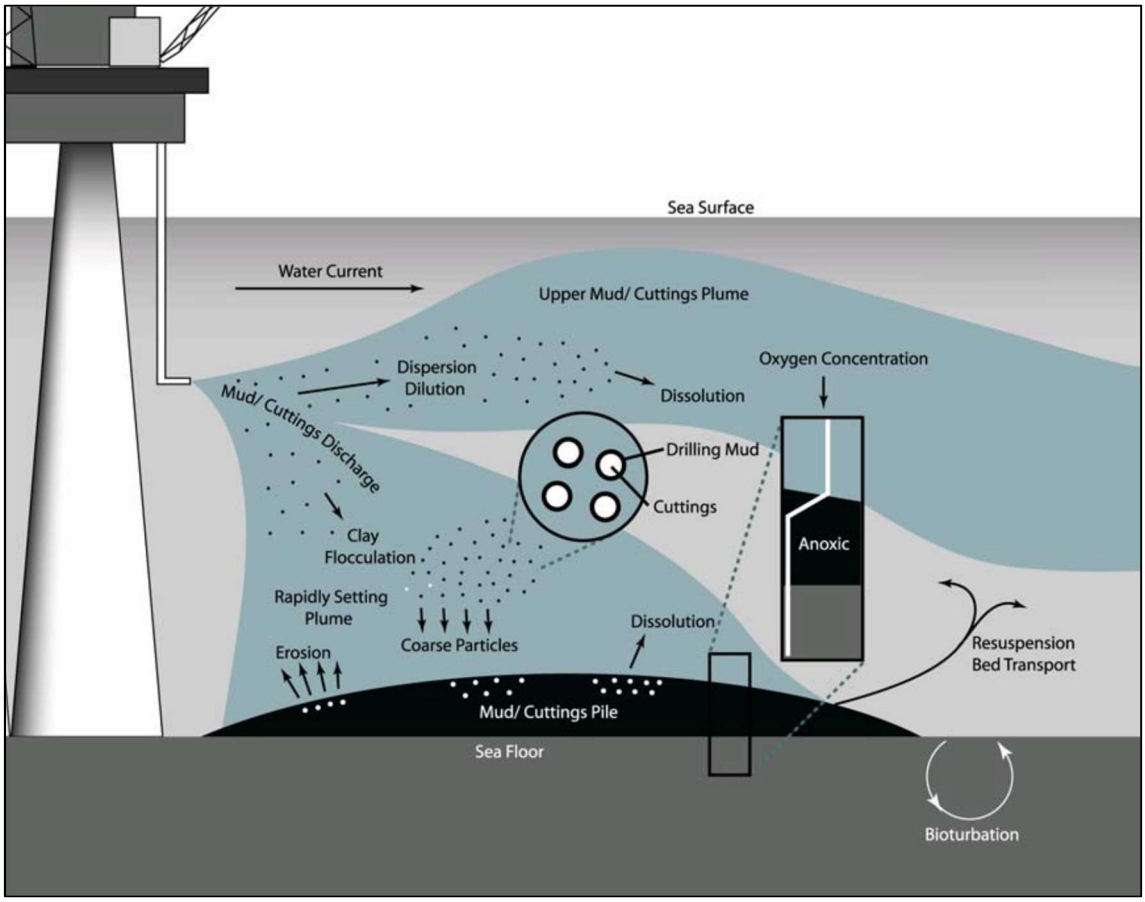


Figure 8-8: Generalised Schematic of the Fates of Drill Cuttings and Fluids Discharges

Dissolved components of the plume, particularly the salts and water-soluble drilling fluid organic additives, dilute rapidly by mixing in the water column. Most of the organic additives in water-based and synthetic-based muds are strongly adsorbed to inorganic cuttings particles and are deposited to the sediments rather than being available in the water column.

Studies by Smit et al. (2008) indicated that phytoplankton and filter-feeding zooplankton typically exhibit greater effects from suspended solids from drilling and suggested that these biota are less well-adapted to relatively high concentrations of suspended sediments than benthic biota. Smit et al. (2008) suggested that impacts to zooplankton were primarily the result of physical effects to filter-feeding and respiration organs, while impacts to phytoplankton were the result of reduced light levels. Concentrations at which impacts to phytoplankton are highly localised and unlikely to occur > 25 m from the discharge point (IAOGP 2016, Smith et al. 2004). Studies of zooplankton indicated effects of drilling fluids and cuttings at concentrations > 100 mg/L are unlikely, based on 96-hr exposure duration experiments. Concentrations above > 100 mg/L for more than 96 hours during Crux project drilling activities would only occur in the immediate vicinity of the discharge location.

The foundation wells as the Crux platform location are not close to any sensitive environmental receptors; the nearest shoal (Goeree Shoal) lies approximately 13 km away. Impacts to water quality from the drilling of the foundation wells will not result in significant impacts to the banks and shoals within the Crux in-field development area. The absence of benthic primary producers in this environment and the relatively short duration of the discharge (i.e. only during drilling activities) limits the potential for decreased water quality to impact upon receptors such as plankton or benthic communities.

Tieback wells may occur in relatively close proximity to shoals and banks, with the closest possible discharge point approximately 2 km from the boundary of a shoal (i.e. 1 km buffer plus the MODU anchor chain; refer to **Will a One Kilometre Buffer Protect the Shoals?** for further information on the buffer). Impacts to water quality from the discharge of drilling fluids and cuttings typically occur within close proximity of the discharge point. As outlined above, very fine cuttings form a very small portion of the total amount of cuttings and fluids discharges as they tend to clump together to form larger particles that sink relatively quickly. There is the potential for the suspended sediment plume from these fine cuttings being advected over the shoals, however potential turbidity levels are expected to be very low. This reduction in light available is typically intermittent and brief (IOGP 2016). Increased turbidity from natural events (e.g. cyclones) occurs in the Timor Sea, and the biota of the shoals are adapted to short-duration increases in turbidity. A review by Erftemeijer et al. (2012) on the effects of turbidity and sedimentation on corals indicated that corals exposed to low levels of suspended sediments typically recovered rapidly. Given the levels of suspended sediments from drilling during the Crux will approach natural levels within 2 km (RPS 2018a), no impacts to sensitive benthic habitats, such as corals, of the shoals within the Crux in-field development area are expected to occur.

Minor Accidental Releases

Given the relatively small volumes of chemicals that may be released because of accidental spills, the potential impacts to water quality will be localised and of short duration. Potential impacts will be a result of the nature of the spilled material, and may include:

- acute toxic effects to marine biota
- changes in water quality parameters (e.g. pH, salinity etc.), and
- changes in aesthetic quality (e.g. visual disturbance).

Any accidental releases within the project area will mix and dilute rapidly in the open ocean. Consequently, these potential impacts will be highly localised (i.e. to the immediate vicinity of the release location) and of short duration.

There are several scenarios that could potentially result in the release of large volumes of hydrocarbons (e.g. marine diesel, gas and condensate) to the marine environment. These are linked to major failures, and hence are beyond the scope of minor accidental releases. Refer to **Section 8.4.8** for the assessment of these unplanned hydrocarbon spills.

Sediment Quality

Liquid discharges with the potential to impact sediment quality include PFW, and drilling fluids and cuttings. Other liquid discharges were not considered to credibly result in impacts to sediments due to their transient nature (e.g. hydrotest discharge), low potential to harbour contaminants (e.g. wastewater and cooling water) or small volumes (e.g. minor accidental releases and utility discharges).

Produced Formation Water

The PFW discharge will contain a range of potential residual constituents. There are several processes by which these may become incorporated into the sediment, including:

- sedimentation of solids in the PFW
- dissolved contaminants forming precipitates, which settle to the seabed, and

- adsorption of contaminants onto natural suspended solids, which settle to the seabed.

The production process onboard the Crux platform will remove most solids from the produced water prior to discharge, and condensed water will not contain solids. Therefore, the mass of solids discharged in the PFW is expected to be very low. The remaining solids will be very fine in size, and hence will have low settling velocities. Given the water depth at the discharge location, the predicted behaviour of the plume, the surface discharge point, and the low settling velocities, residual solids will disperse widely and are unlikely to result in a decrease in sediment quality at the discharge location.

Dissolved materials (particularly metals) in the PFW may form precipitates once released into the environment due to changes in pH and availability of reactants (e.g. oxygen, sulphide etc.). While the exact composition of the PFW cannot reasonably be characterised prior to commencing production (and may change character as reservoirs become depleted), metals commonly encountered at elevated levels in PFW include barium, iron and manganese (Neff et al. 2011). Solids formed by precipitation are initially very small and will have low settling velocities. As with solids, precipitates are unlikely to be deposited near the discharge location and will disperse widely.

Some of the potential constituents in the PFW, such as metals and hydrocarbons, may become adsorbed onto the surface of suspended solids present in the receiving environment. Water quality studies in the project area have shown that natural suspended sediment levels are very low (AECOM 2016), refer to **Appendix A**.

This is consistent with the low observed rates of natural deposition in the region (Glenn 2004). The results of Glenn (2004) also showed that sediments locally derived from the water column are generally very fine (i.e. silt and clay sized particles). The low natural suspended sediment load indicates the potential for adsorption of potential contaminants is limited. Due to the small particle size, the potential for adsorbed contaminants to be deposited at the discharge location is low; particles with adsorbed contaminants are expected to be widely diluted and dispersed, resulting in no measurable impact to sediment quality in the region.

Each of the mechanisms discussed above by which contaminants in the PFW may be incorporated into sediments is considered to result in no more than a slight effect on sediment quality. This is consistent with monitoring results for other offshore facilities, which generally show that natural dispersion processes appear to control the concentrations of potential contaminants from PFW in sediments to slightly above background concentrations (Neff et al. 2011). The discharge of PFW is expected to be relatively low for the majority of the production period, before increasing significantly as reservoirs become depleted. Therefore, the period with the greatest potential for impact is concentrated at the end of field life.

Drilling Fluids and Cuttings

Drill cuttings will be discharged from the drilling rig after being treated by solids control equipment to reduce the concentration of residual drilling fluids. Recovered drilling fluids are returned to the drilling rig mud pit and recirculated. In the case of the initial foundation well and wells associated with future subsea tie backs, cuttings from the upper well sections may be discharged directly to the seabed or recovered using a riserless mud recovery systems. The majority of drill cuttings and residual fluids will be deposited in the area around the discharge location and will form a cuttings pile. The accumulation of cuttings will physically modify the sediments by modifying the particle size distribution. Stochastic modelling results indicate the cuttings pile may reach a thickness of up to 374 mm for a single well (RPS 2018a), which will be largely comprised of coarse cuttings directly under the discharge location.

The five planned foundation wells at the Crux platform will result in deposition of cuttings at the base of the Crux platform. Sediments at this location will be considerably modified by the discharges of drilling fluids and cuttings, however modelling studies indicate impacts to sediment will decline with increasing distance from the wells. Stochastic modelling for the cumulative deposition of drilling fluids and cuttings indicated the maximum thickness would be up to 1.888 m as the base of the platform, with cumulative cuttings from five wells reaching the 1 mm thickness threshold at a maximum distance of 659 m from the Crux platform location.

Cuttings from an individual tieback well are expected to become progressively finer with increasing distance from the well location, with the thickness of deposited cuttings expected to be ≤ 1 mm (considered to represent a low ecological threshold) within 318 m of the discharge location (single well) (RPS 2018a). Deposition ≥ 10 mm thickness (representative of a high ecological threshold) for a single tieback well was predicted to extend up to approximately 62 m from the release location and cover an area of approximately 7,000 m^2 (or 0.7 ha). Cuttings > 0.25 mm in diameter are predicted to typically be deposited within 250 m of the discharge location for a single tieback well (RPS 2018a).

The coarser sediments deposited directly under the discharge location are unlikely to be resuspended by currents and will gradually be buried by naturally deposited sediments over time. Finer sediments deposited further away may be reworked by currents and transported via saltation or as suspended sediments.

The deposition of the drill cuttings and fluids may lead to a decrease in sediment quality in the affected area. The stochastic modelling showed that for the foundation wells, in which five production wells will be drilled from a single location (**Section 5.6.2**), deposition was expected to be ≤ 1 mm (low ecological threshold) within approximately 658 m of the discharge location and ≥ 10 mm (high ecological threshold) within approximately 248 m (RPS 2018a). However, for a single well (i.e. for future subsea tie backs), deposition thicknesses of ≤ 1 mm and ≥ 10 mm were predicted to be within approximately 326 m and 68 m, respectively.

WBMs will be used where practicable; SBMs will be used where required to meet technical and safety requirements. WBMs will constitute most of drilling fluids discharged to the marine environment. Cuttings may contain potential contaminants derived from the geological formations from which they are generated; however, the potential for cuttings to be a source of contaminants is low compared to residual WBM and SBM drilling fluids. The residual WBMs may include potential contaminants such as metals (predominantly barium, a component of the commonly used weighting agent barium sulphate), as well as residual organic matter. Microbial degradation of residual organic matter can lead to depletion of oxygen in sediments within the cuttings pile, although this is unlikely to impact upon biota.

Cuttings with SBMs tend to clump together in large particles that settle rapidly to the seabed (Neff et al. 2000) and are more likely to be concentrated around the release location than cuttings with residual WBMs. SBMs may contain a range of synthetic hydrocarbons such as paraffins and olefins, which have low potential for toxicity and bioaccumulation, but may persist in the environment. Cuttings with residual SBMs are expected to have a higher concentration of residual organic matter compared to WBMs. The seabed affected by cuttings with residual SBM have greater potential for oxygen reduction via microbial degradation and associated changes to sediment chemistry (e.g. modified reduction/oxidation (redox) potential).

Upon completion of a well, excess WBM may be discharged to the ocean from the drilling rig and pose little environmental risk or impact beyond a localised, temporary sediment

plume. Excess SBMs will not be discharged to the ocean and may either be reused or disposed of onshore.

Ecosystems, Communities and Habitats

Benthic Communities

Produced Formation Water

Given the discharge of PFW is at the sea surface and is expected to mix rapidly upon release, benthic communities are not expected to be directly contacted by the PFW plume. Changes to sediment quality because of the discharge of PFW are expected to be slight, which may have consequent slight effects on benthic fauna. These slight impacts are expected to be concentrated around the Crux platform and will be significantly smaller than other sources of impact (e.g. physical disturbance during installation of the Crux platform, export pipeline and subsea integration system and discharge of drilling fluids and cuttings).

Hydrotest Water

The residual biocide in the hydrotest treated seawater has the potential to be acutely toxic to a range of marine biota associated with benthic habitats, including fish, molluscs, and echinoderms (Chevron Australia 2015). Other components of the treated seawater, such as dye, scale inhibitor and corrosion inhibitor are expected to be less toxic than the biocide (INPEX 2010; ConocoPhillips 2018). The biocides routinely used in the oil and gas industry do not bioaccumulate and are expected to be consumed by microorganisms (e.g. bacteria) once discharged to the marine environment.

Stochastic modelling (described above in **Section 8.4.7.2**) indicated the area which may be exposed to hydrotest water below the 1:500 dilution (i.e. dilution required to reach the 1 ppm impact threshold) in the in-field development area extends in all directions from the discharge location (**Figure 8-7**). The maximum distance from the release location recorded in the 300 model runs that comprised the stochastic results at which the 1:500 dilution was achieved was approximately 5.7 km (average of 5.3 km). Benthic habitat mapping indicated the area potentially affected consists of gravelly sands with burrowing macrofauna or no macrobiota (Fugro 2017). While not modelled, the distance at which the 1:500 dilution could occur at the Prelude end of the export pipeline is expected to be similar based on the similar nature of the discharge and oceanographic setting. The benthic habitats at the Prelude end of the export pipeline are characterised by muddy sands with burrowing macrofauna or no macrobiota (Fugro 2017).

The burrowing macrofaunal and no macrobiota habitats that may be impacted by the hydrotest water discharge, and associated fauna groups, are widely distributed in the region and are not considered to be of high conservation value. The discharge of hydrotest water will not physically modify benthic habitats (apart from potential localised scouring around the discharge location), although benthic biota associated with these habitats may experience acute toxic effects resulting in injury or mortality. Given the scale of disturbance and the near-seabed currents in the in-field development area, recovery from the effects of hydrotest discharge is expected to occur through natural recruitment.

Modelling results indicated that the hydrotest discharges above impact thresholds could not credibly reach any KEFs or shoals/banks, nor could it reach the shallower benthic communities associated with the outcropping in the north-eastern part of the in-field development area (**Figure 8-7**).

Drilling Fluids and Cuttings

The discharge of drill cuttings and residual fluids will impact upon benthic communities due to the potential physical and chemical changes to sediments (refer to **Sediment**

Quality above). The deposition of cuttings has the potential to smother sessile benthic organisms, with effects predicted to occur at deposition thicknesses of greater than 6.5 mm (IOGP 2016). Sedimentation is an ongoing natural process, and benthic organisms exhibit adaptations to respond to increased sediment deposition. Natural sedimentation rates Northwest Australia were estimated by Glenn (2004) ranged from approximately 0.17 mm and 2.23 mm per year.

Stochastic modelling results for the five well foundation development drilling program indicated deposition of drilling cuttings and fluids was expected to be ≤ 1 mm and ≥ 10 mm within approximately 658 m and 248 m of the discharge location, respectively (RPS 2018a). For a single well the deposition thickness of ≤ 1 mm and ≥ 10 mm were predicted to be within approximately 326 m and 68 m, respectively. Benthic communities subject to deposition between 1 mm and 10 mm thickness are less likely to experience mortality but may experience sub-lethal impacts (IOGP 2016), such as impaired feeding due to clogging of filter feeding organs and increased energy expenditure from removing sediment from burrows. Recognising that sediment deposition from drill cuttings and fluids is in addition to natural processes, benthic communities subject to deposition of drill cuttings and fluids of < 1 mm thickness are unlikely to experience impacts from physical deposition of cuttings, as this thickness is consistent with natural sedimentary deposition rates.

Changes in sediment chemistry may impact upon benthic communities, particularly changes in oxygen demand from biodegradation of organic compounds in residual drilling fluids. Trannum et al. (2010) examined the effects of cuttings with residual WBMs and found a significant reduction in abundance and diversity of benthic infauna with increasing cuttings thickness compared to natural sediment and suggested that changes in sediment chemistry were a significant factor. Increased oxygen demand resulting from aerobic degradation of organic compounds in the WBM were suggested as a cause, along with fluxes in silicon and phosphorous (Trannum et al. 2010). The effects at low sediment thickness (< 10 mm) were much less apparent than relatively high rates of burial; these results are consistent with findings from other investigations of potential impacts of WBMs (Smit et al. 2006). The increased oxygen demand will diminish over time as organic material is consumed and will approach natural conditions.

The recovery of the area subject to deposition ≥ 10 mm thickness will potentially take many years, depending on natural sedimentary processes. Recovery may be linked to the deposition of relatively fine natural sediments on the coarse sediments in the cuttings pile to create suitable habitat. Studies of the recovery of benthic communities on visible cuttings piles (consistent with the area subject to drill cuttings and fluids deposition ≥ 10 mm) indicated considerable recovery within three years (particularly where deposition was thinner), however the benthic communities had not yet recovered to be similar to pre-discharge conditions or the surrounding unaffected seabed.

The benthic communities at the Crux platform comprise sparse epibenthic burrowing macrofauna on soft sediment substrates (Fugro 2017a). These are widely represented in the region and are not of high environmental value. Modelling studies (RPS 2018a) indicate these existing communities at the base of the Crux platform will be affected by the discharge of drill cuttings and fluids out to a range of approximately 326 m from the discharge point (e.g. some reduction in species diversity and abundance). High levels (> 10 mm) of burial will occur out to a radius of approximately 68 m; sessile benthic fauna within this range are expected to be completely removed.

Sensitive benthic habitats, such as the shoals within the Crux in-field development area or the Continental Slope Demersal Fish Communities KEF will not be impacted by the discharge of drilling fluids and cuttings. The 1 km buffer around the shoals ensures that sediment deposition and suspended sediment plumes will not reach benthic habitats at the shoals (refer to the preceding section **Water Quality** and **Will a One Kilometre**

Buffer Protect the Shoals? for further information). The distance between the Crux in-field development area and the Continental Slope Demersal Fish Communities KEF (approximately 73 km from the Crux platform) ensures there will be no impacts to the environmental values of the KEF from drilling fluids and cuttings.

Threatened Species and Ecological Communities

Key Fauna Species

Produced Formation Water

Most threatened fauna species within the area predicted to be influenced by the PFW discharge are air breathing vertebrates, which are unlikely to be directly affected as their skin is relatively impermeable and breathe air. Hence, direct impacts are not considered credible. Indirect impacts, such as altered prey abundance or ingestion of bioaccumulated toxic compounds is considered to be of no effect given the localised area predicted to be impacted by PFW, the typically temporary or transitory presence of threatened fauna species, and the nature and scale of impacts to the marine ecosystem within the PFW discharge plume (i.e. minor impacts to plankton). Other fauna (e.g. pelagic and demersal fish) are expected to move away from areas if high concentrations of produced water, which will be localised to the vicinity of the release location. Hence potential impacts to these receptors are expected to be slight at worst. Anecdotal evidence from existing oil and gas platforms indicates this potential impact is unlikely, with well-developed marine communities, including mobile fauna such as fish, observed on platforms discharging PFW to the sea.

Hydrotest Water

Mobile benthic fauna such as fish and cephalopod molluscs may move away from the area affected by the plume, which may reduce potential impacts to these fauna. Potential impacts to fish assemblages are expected to be minor, and of no consequence to commercial fisheries in the region. Fauna of high conservation value (e.g. cetaceans, birds and marine reptiles) are typically concentrated in surface waters and will not be directly exposed to the hydrotest discharge plume.

Drilling Fluids and Cuttings

The discharge of drill cuttings and fluids will impact upon seabed habitat below the cuttings pile, particularly where the thickness of the deposition is ≥ 10 mm. This is not expected to result in impacts to key fauna species, as many key fauna are associated with surface waters and the water column (e.g. marine mammals, birds and marine reptiles). Given the depth of the in-field development area and the lack of benthic foraging habitat, marine turtles are not expected to be affected by the impacts to benthic habitats from the discharge of drill cuttings and fluids.

The localised, temporary decrease in water quality from the discharge of drill cuttings and fluids may temporarily displace pelagic marine fauna from the plume; this short-term, behavioural impact is considered to be negligible.

Socio-economic and Cultural Environment

Liquid discharges from the Crux project have little potential to impact upon socio-economic receptors (with the exception of low probability unplanned hydrocarbon spills; refer to **Section 8.4.8**). There is currently little exploitation of natural (e.g. hydrocarbons or minerals) or biological resources (e.g. fisheries or nature-based tourism) in the project area. While the discharge of PFW may lead to the introduction of contaminants with the potential for bioaccumulation, this is not expected to occur in organisms beyond the immediate area of the Crux platform (e.g. organisms living attached to the platform jacket); all unauthorised vessels, including fishing vessels, will be prohibited from the 500 m petroleum safety zone around the platform. Following cessation of discharges

from the Crux platform (i.e. after operations have ceased), concentrations of potential contaminants in sediments are expected to decrease over time. The potential for sediment contaminants to bioaccumulate in exploited biological resources (such as fish) following decommissioning is considered to be very low given the nature of environment.

8.4.7.4 Risk and Impact Summary and Key Management Controls

Table 8-31: Liquid Discharges Evaluation of Impacts and Risks

Project Component/ Activity	Environmental Value/Sensitivity				Evaluation – Planned		
	Physical Environment	Threatened Species and Ecological Communities	Ecosystems, Communities and Habitats	Socio-economic and Cultural Environment	Magnitude	Sensitivity	Residual Impact
Evaluation – Planned Impacts							
Planned impacts resulting from planned liquid discharges from the Crux project, including: • PFW (including non-routine discharges of off-specification PFW) • wastewater • hydrotest water, and • drilling fluids and cuttings.	X	X	X		Minor	Medium	Minor
Evaluation – Unplanned Risks							
Project Component/ Activity	**Physical Environment**	**Threatened Species and Ecological Communities**	**Ecosystems, Communities and Habitats**	**Socio-economic and Cultural Environment**	**Significance**	**Likelihood**	**Residual Risk**
Unplanned risks resulting from accidental liquid discharges during the Crux project, including: • minor accidental releases of chemicals/ hydrocarbons to the environment.	X		X		Moderate	Medium	Moderate

Key Management Controls
Utility Discharges
All planned discharges from vessels will comply with relevant requirements of MARPOL 73/78, the *Navigation Act 2012*, *Protection of the Sea (Prevention of Pollution from Ships) Act 1983* and any subsequent Marine Orders requirements (as appropriate for vessel classification).
The Crux platform deck drainage shall be managed to reduce impacts on the environment.
Oily bilge water from machinery space drainage is treated to a maximum concentration of 15 ppm oil-in-water prior to discharge from vessels, as specified in MARPOL 73/78 (Annex I).
Offshore discharge of sewage from vessels will be in accordance with Marine Order 96.
Food wastes will be macerated to < 25 mm particle size whilst operational prior to discharge to sea, in accordance with Marine Order 95.
Chemical Discharges
For chemicals planned to be used in production and process (including in the subsea facilities and well) and for hydrotesting, and which will be discharged to the marine environment, will be selected in accordance with the Chemical Management Process for chemical selection and assessment of effects on the environment.
Produced Water Discharges
An environmental monitoring program and adaptive management framework will be developed for PFW.
The oil-in-water concentration of PFW will be continuously monitored by an online analyser, while available, which will be fitted with an alarm that activates if the oil-in-water concentration is > 30 mg/L.
Drilling Fluid and Mud Discharges
No planned discharge of whole SBM will occur during development drilling.
When using SBM, the solids control equipment will reduce the residual base fluid on cuttings content prior to discharge overboard. Residual base fluid on cuttings will be less than 10% w/w averaged over all well sections using SBM.

8.4.7.5 Acceptability of Impacts and Risks

The acceptable levels of impact for the receptors that may credibly be impacted or at risk from the liquid discharges aspect of the Crux project are summarised in **Table 8-32**. The method by which these acceptable levels were determined, along with a justification as to why these are acceptable, are discussed in **Section 7**.

Based on the outcomes of the evaluation of impacts and risks, Shell considers that the environmental risks and impacts that may result from the liquid discharges aspect of the Crux project are acceptable.

Further discussion of the acceptability considerations outlined in **Section 7** in relation to the liquid discharges aspect of the Crux project is provided below.

Table 8-32: Acceptable Levels of Impacts and Risks from Liquid Discharges

Receptor Category	Receptor Sub-category	Acceptable Level of Impact	Are the Crux Project's Impacts and Risks of an Acceptable Level?
Physical environment	Water quality	No significant impacts to water quality beyond 1 km of the Crux platform or drilling locations.	Yes. Liquid discharges have the potential to result in reduced water quality at the discharge location, however discharges will dilute in the open ocean environment. Modelling studies indicate that the potential for significant impacts to water quality are highly localised around the discharge location, which is consistent with industry monitoring studies. Shell will implement measures to reduce the potential for impacts to water quality form routine discharges, including PFW treatment systems

Receptor Category	Receptor Sub-category	Acceptable Level of Impact	Are the Crux Project's Impacts and Risks of an Acceptable Level?
			and controls relating to the discharge of drilling fluids and cuttings.
	Sediment quality	No significant impacts to sediment quality beyond 1 km of the Crux platform or drilling locations.	Yes. The discharge of drilling fluids and cuttings and PFW may result in a decrease in sediment quality at drilling locations and the Crux platform. Modelling studies indicate that the potential for significant impacts to sediment quality are highly localised around the discharge location, which is consistent with industry monitoring studies. Shell will implement measures to reduce the potential for impacts to sediment quality form routine discharges, including PFW treatment systems and controls relating to the discharge of drilling fluids and cuttings.
Ecosystems, communities and habitats	Benthic communities	No significant impacts to benthic habitats and communities. Impacts to non-sensitive benthic communities limited to a maximum of 5% of the project area.	Yes. The benthic communities (excluding shoals) within the Crux in-field development area that may be impacted by liquid discharges are broadly represented in the region and are not of high environmental value. The 1 km buffer around shoals within the Crux in-field development will protect these sensitive environmental features.
	Shoals and banks	No direct impacts to named banks and shoals. No loss of benthic habitats and communities at named banks or shoals as a result of indirect/offsite[19] impacts.	Yes. Most project activities will take place a considerable distance from the shoals. The Crux platform, which will be the location of PFW and drilling-related discharges, is approximately 13 km from the nearest shoal (Goeree Shoal). Tieback wells may be drilled in closer proximity to banks and shoals. Liquid discharges from tieback wells are of relatively short duration and will not significantly impact upon the shoals due to the 1km buffer that will be applied around these features.
	Key Ecological Features	No significant impacts to environmental values of KEFs.	Yes. The Continental Slope Demersal Fish Communities KEF is not situated near any planned liquid discharge locations. Modelling studies indicate there is no potential for liquid discharges to impact upon the environmental values of this KEF.

[19] As defined in the Matters of National Environmental Significance - Significant impact guidelines 1.1 (DoEE 2013).

Principles of ESD

The risks and impacts from liquid discharges from the Crux project are consistent with the principles of ESD based on:

- the environmental resources within the project area are not expected to be significantly impacted, and
- the precautionary principle has been applied, and studies undertaken where knowledge gaps were identified.

Matters of National Environmental Significance

Threatened and Migratory Species

The evaluation of impacts and risks indicates significant impacts[20] to threatened and migratory species will not credibly result from the liquid discharges aspect of the Crux project (note that unplanned spills are considered in **Section 8.4.8**).

Alignment of the Crux project with management plans, recovery plans and conservation advice for threatened and migratory fauna is provided in **Table 8-33**.

Commonwealth Marine Environment

Liquid discharges during the Crux project, such as hydrotest water, drilling fluid and cuttings and PFW, have the potential to impact upon the Commonwealth marine environment. In particular, sediment quality and water quality in the vicinity of liquid discharges may be degraded. As outlined in the description and evaluation of impacts and risks for liquid discharges (**Section 8.4.7.3**), impacts in the immediate vicinity of discharge locaitons (e.g. < 100 m) may be substantial. However, these impacts are not considered to be significant when considered against the significant impact criteria for the Commonwealth marine environment (**Table 7-1**). In particular, the nature and scale of impacts and risks from liquid discharges is not considered sufficient to:

- modify, destroy, fragment, isolate or disturb an important or substantial area of habitat such that an adverse impact on marine ecosystem functioning or integrity in a Commonwealth marine area results, or
- result in persistent organic chemicals, heavy metals, or other potentially harmful chemicals accumulating in the marine environment such that biodiversity, ecological integrity, social amenity or human health may be adversely affected.

While the potential for impacts from liquid discharges to the Commonwealth marine environment cannot be eliminated, Shell will manage liquid discharges to limit the spatial extent of such impacts. This is reflected in the acceptable levels of impacts to water and sediment quality:

- No significant impacts to sediment quality or water quality from liquid discharges during the Curx project.
- Substantial impacts to sediment quality and water quality from the Crux project restricted to within < 1,000 m from the discharge source at least 95% of the time.

Substantial impacts are considered to be an exceedance of the 95% species protection levels for marine sediments and water derived from either ANZECC & ARMCANZ (2000) or discharge-specific whole effluent toxicity (WET) testing result using the ANZECC &

[20] As described in Matters of National Environmental Significance - Significant impact guidelines (DoE 2013a).

ARMCANZ methodology. The ANZECC & ARMCANZ water quality guidelines are widely used throughout Australia and are routinely referred to in PFW monitoring programs.

The ANZECC & ARMCANZ water quality framework recommends monitoring programs be designed based on defining management aims and determining appropriate trigger values. Shell's management aims are to ensure that impacts from the discharge of PFW are within the acceptable level of impact. To identify suitable trigger values, Shell examined the ecosystem condition of the receiving waters around the Crux platform. The three ecosystem conditions recognised by ANZECC & ARMCANZ (2000) are:

- high conservation/ecological value systems – effectively unmodified or other highly-valued ecosystems, typically (but not always) occurring in national parks, conservation reserved or in remote and/or inaccessible locations.
- slightly to moderately disturbed systems – ecosystems in which aquatic biological diversity may have been adversely affected to a relatively small but measurable degree by human activity. The biological communities remain in a healthy condition and ecosystem integrity is largely retained.
- highly disturbed systems – these are measurably degraded ecosystems of lower ecological value.

While remote, the Crux project area does not overlap any marine protected areas, and the presence of the Prelude FLNG at the western end of the export pipeline in an existing environmental disturbance. Prior to the discharge of PFW, the drilling of the foundation wells and construction of the Crux platform will disturb the environment. The lack of sensitive habitats within the area predicted to be affected by PFW discharge, along with the widespread distribution of such habitat in the region, indicates this area is not of high conservation value. Nor is the Crux project area a highly disturbed ecosystem. Hence, Shell concludes the ecosystem condition for the PFW discharge receiving environment is slightly to moderately disturbed. ANZECC & AMCANZ guidelines (2000) suggest that 95% species protection level triggers and direct toxicity assessment (DTA) (i.e. WET testing) be used for monitoring programs in slightly to moderately disturbed ecosystems. Shell's proposed controls and EPO are consistent with this approach.

Results from modelling studies suggest that the liquid discharges from the Crux project will not significantly impact upon the KEFs or shoals within or around the Crux project area.

Table 8-33: Summary of Alignment of the Risks and Impacts from Liquid Discharges from the Crux Project with Relevant Requirements for EPBC Threatened Fauna

Sensitivity	EPBC Management Plans/Recovery Plans/Conservation Advices	Threats Relevant to the Project	Demonstration of Alignment as Relevant to the Project
Marine mammals	Significant impact guidelines for Critically Endangered, Endangered, Vulnerable and Migratory species (Table 7-1)	Liquid discharges	The application of chemical selection process and proposed management of PFW discharges reduces the risk of persistent toxic pollutants being introduced to the marine environment.
	Conservation advice on *Balaenoptera borealis* (sei whale) (DoE 2015c)	Pollution (persistent toxic pollutants)	
	Conservation advice fin whale (*Balaenoptera physalus*) (DoE 2015d)		
Marine reptiles	Significant impact guidelines for Critically Endangered, Endangered, Vulnerable and Migratory species (Table 7-1)	Liquid discharges	
	Recovery plan for marine turtles in Australia (Commonwealth of Australia 2017a)	Chemical and terrestrial discharge	
Sharks and rays	Significant impact guidelines for Critically Endangered, Endangered, Vulnerable and Migratory species (Table 7-1)	Liquid discharges	
	Conservation advice on *Rhincodon typus* (whale shark) (DoE 2015l)	Habitat disruption from mineral exploration, production and transportation	
Commonwealth marine environment	Significant impact guidelines for Commonwealth marine environment (Table 7-1)	Liquid discharges	The discharge of PFW may exceed the significant impact criteria for the Commonwealth marine environment. Shell has sought to reduce the potential for these criteria to be exceeded through the selection of the PFW treatment system; the proposed PFW treatment is the best feasible option available for the NNM Crux platform. Shell's proposed EPO for PFW discharges limits the spatial extent of impacts to the vicinity of the Crux platform and makes use of the ANZECC & ARMCANZ water quality guidelines (2000)

Relevant Requirements

Management of the impacts and risks from liquid discharges associated with the Crux project are consistent with relevant legislative requirements, including:

- compliance with international maritime conventions, including:
  - MARPOL:
    - Annex I: regulations for the prevention of pollution by oil
    - Annex II: regulations for the control of pollution by noxious liquid substances in bulk
    - Annex III: regulations for the prevention of pollution by harmful substances carried by sea in packaged form, and
    - Annex IV: regulations for the prevention of pollution by sewage from ships
- compliance with Australian legislation and requirements, including:
  - *Navigation Act 2012* and *Protection of the Sea (Prevention of Pollution from Ships) Act 1983*:
    - Marine Order 91 (Marine pollution prevention – oil)
    - Marine Order 93 (Marine pollution prevention – noxious liquid substances)
    - Marine Order 94 (Marine pollution prevention – packages harmful substances), and
    - Marine Order 96 (Marine pollution prevention – sewage).
- management of impacts and risks are consistent with policies, strategies, guidelines, conservation advice, and recovery plans for threatened species (**Table 8-33**)
- implementation of recognised industry standard practice, such as:
  - no discharge of whole SBMs
  - use of solids control equipment on the drilling rig, and
  - treatment of PFW to < 30 mg/L residual oil.

Internal and External Context

Shell's ongoing consultation program will consider statements and claims made by stakeholders when undertaking the assessment of impacts and risks. Shell has also considered the internal context, including Shell's environmental policy and ESHIA requirements. The environmental performance outcomes, and the controls which will be implemented, are consistent with the outcomes from stakeholder consultation for the Prelude FLNG facility and Shell's internal requirements.

Acceptability Summary

The assessment of impacts and risks from liquid discharges determined the residual impact and risk ratings were all Minor or lower (**Table 8-31**). As outlined above, the acceptability of the impacts and risks from liquid discharges associated with the Crux project has been considered in the context of:

- ESD
- relevant legislative requirements
- external context (i.e. stakeholder claims), and
- internal context (i.e. Shell requirements).

The residual impacts and risks are moderate. Shell considers residual impacts of moderate to be acceptable if (**Section 7**):

- all practicable measures have been identified commensurate with the risks and impacts
- internal context – the proposed controls and residual risk level are consistent with Shell policies, procedures and standards
- external context – consideration of the environment consequence and stakeholder expectations, and
- other requirements – the proposed controls and residual risk level are consistent with national and international standards, laws and policies.

The discussion above demonstrates that these requirements have been met in relation to the impacts and risk of liquid discharges for the Crux project.

Based on the points discussed above, Shell considered the impacts and risks from liquid discharges associated with the Crux project to be acceptable.

8.4.7.6 Environmental Performance Outcomes

Physical and Biological Environment

No significant impacts to sediment quality or water quality from liquid discharges during the Crux project.

Substantial impacts[21] to sediment quality and water quality from the Crux project restricted to within < 1,000 m from the discharge source at least 95% of the time.

Direct impacts to benthic habitats from the Crux project will be limited to < 5% of the total project area.

No mortality of, or significant impacts to, threatened and migratory MNES species as a result of liquid discharges during the Crux project.

Impacts from liquid discharges from the Crux project on the Continental slope demersal fish communities KEF will not exceed the Commonwealth marine environment significant impact criteria listed in **Table 7-1**.

No direct impacts to the biological communities at Goeree Shoal, Eugene McDermott Shoal and Vulcan Shoal will occur as a result of liquid discharges from the Crux project.

[21] Substantial impacts are considered to be an exceedance of the 95% species protection levels for marine sediments and water derived from either ANZECC & ARMCANZ (2000) or discharge-specific whole effluent toxicity (WET) testing result using the ANZECC & ARMCANZ methodology.

8.4.8 Unplanned Spills

8.4.8.1 Project Context

The Crux project will involve the production and transport of large volumes of gas and condensate. Additionally, considerable volumes of hydrocarbons will be present onboard vessels for use as fuel. Several unplanned events (i.e. accidents or emergencies) resulting in the potential large-scale releases of these hydrocarbons were identified for the Crux project, including:

- a loss of well control (a well blowout) during drilling and operations
- a loss of process storage tank containment on the Crux platform
- a loss of subsea containment from the export pipeline, and
- a loss of fuel from a vessel.

A worst-case scenario resulting from each of these events has been considered in this environmental risk assessment. Each of these scenarios is discussed further below. Each of these scenarios can result in smaller spills than the worst-case credible spills discussed below. Smaller unplanned spill scenarios, such as incidental spills from vessels, are considered in **Section 8.4.7**; the potential consequences of these spills are much smaller than the large volumes hydrocarbon releases considered below.

Loss of Well Control

The Crux project involved drilling and completion of, and production from, a series of subsea wells. Shell engineering standards require a range of features which manage the risk of a loss of well control to very low levels. However, there is a possibility that a loss of well control may occur during drilling and operation of the Crux platform. While the likelihood is very small, a complete loss of well control (a well blowout) has the potential to release significant volumes of condensate into the environment. Such a release could result in significant environmental damage.

The likelihood and potential release volumes of a loss of well containment will change during different phases of the Crux project. Industry statistics from wells using similar controls that will be applied during development drilling of, and production from, the well within the scope of this OPP indicate the likelihood of a well blowout are:

- development drilling and completions – $2.5 \times 10^{-4} Q^{-0.3}$ per well, and
- production – $6.9 \times 10^{-5} Q^{-0.3}$ per well per year.

Where Q is the mass of spilled hydrocarbons in tonnes (Det Norske Veritas 2011).

These functions are shown in **Figure 8-9**, and are consistent with observed well blowout data observations in Australia and similar jurisdictions around the world. Most loss of well control incidents do not result in a worst-case well blowout scenario, and typically release relatively small masses of hydrocarbons. The likelihoods of a well blowout from development drilling and production are considerably lower than a loss of containment from an exploration well, as are the release masses (**Figure 8-9**); exploration wells will not be drilled during the Crux project.

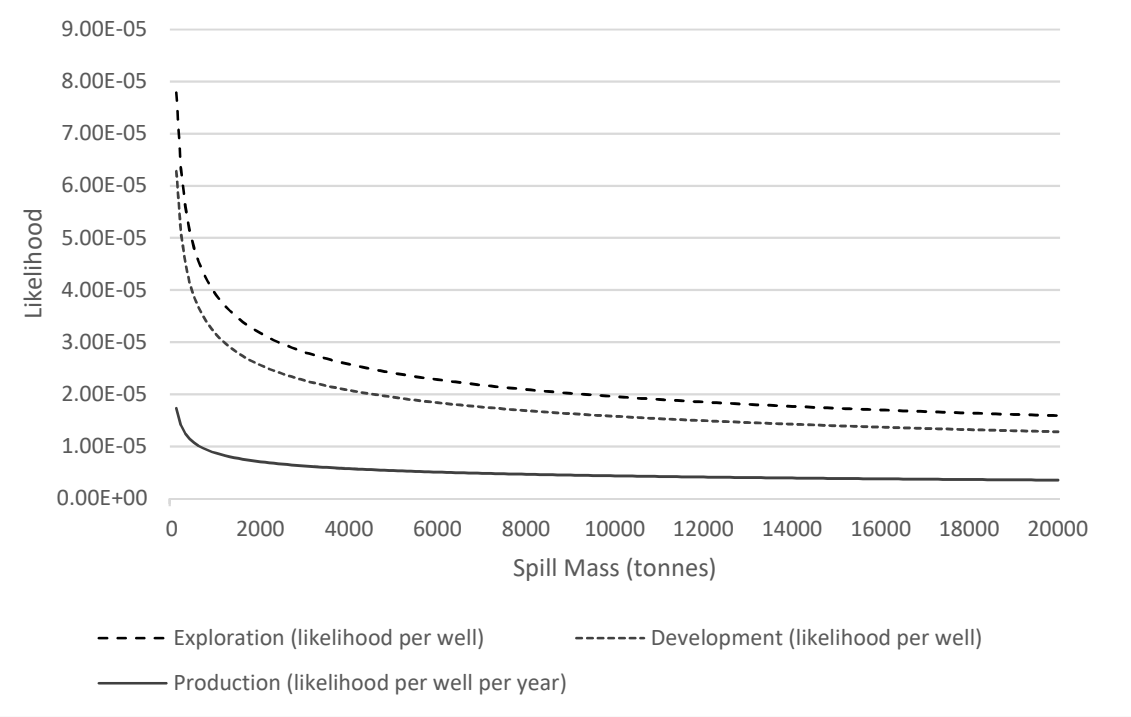


Figure 8-9: Estimated Likelihood and Mass of Well Blowouts for Exploration, Development and Production Wells (after Det Norske Veritas 2011)

Shell has extensive experience with safe and environmentally responsible drilling and reservoir engineering worldwide. Shell has developed a detailed understanding of the Crux field through historical seismic surveys and drilling. The offshore oil and gas industry has improved environmental performance since the Macondo and Montara catastrophes, and Australian regulations require that all environmental risks be managed to a level that is ALARP and acceptable. This is done through NOPSEMA's EP framework. All petroleum activities considered in this OPP will be undertaken under an accepted EP. All wells will be drilled and operated in accordance with an accepted WOMP in accordance with the OPGGS Act.

Shell has determined the worst-case credible spill scenario that could occur from the wells within the scope of this OPP. This scenario is a complete well blowout of a Crux production well during development drilling. This scenario consists of an 80-day uncontrolled release of 206,225 m^3 of condensate (2,578 m^3 per day). The duration is based on the credible worst-case time required to control the well (either by capping or drilling of a relief well) and the volume is based on the maximum credible rate of release derived from the proposed well design and reservoir characteristics. The release location is at the seabed at the Crux platform. While this scenario is very unlikely, using the worst-case credible spill as the basis for the risk assessment provides an environmentally conservative assessment of the potential impacts and risks posed by the Crux project. Shell commissioned numerical modelling to inform the risk assessment; refer to **Section 8.4.8.2** for further information on this worst-case credible spill scenario and associated modelling.

Loss of Process Storage Tank Containment

The Crux platform will process well fluids, before exporting the hydrocarbon fractions to the Prelude FLNG facility. The process equipment on the Crux platform will store considerable volumes of condensate, that may be released to the environment in the event of loss of containment from process infrastructure.

A significant loss of containment from process equipment is highly unlikely and represents a significant safety risk to personnel onboard the platform. The offshore oil and gas industry routinely implements safety by design to reduce the likelihood of a process loss of containment and reduce personnel exposure to significant risks (a key safety benefit of the NNM design of the Crux platform). This is reflected in industry statistics, which indicate a significant release of liquid hydrocarbons from offshore process equipment is very low, particularly for unmanned platforms (Det Norske Veritas 2011; IOGP 2010a).

Shell has determined the worst-case credible release from the Crux platform based on the preliminary design of the platform and associated processing equipment. This scenario consists of a short-term (< 1 hour) release of 88 m^3 of Crux condensate above the sea surface at the Crux platform location. This is the largest single vessel volume on the Crux platform at this time in the design process. As outlined above in **Loss of Well Control**, this is considered to provide an environmentally conservative assessment of potential impacts and risks from a loss of containment from process equipment. Shell commissioned numerical modelling to inform the risk assessment; refer to **Section 8.4.8.2** for further information on this worst-case credible spill scenario and associated modelling.

Loss of Containment from Crux Export Pipeline

The export pipeline will contain a significant volume of gas and condensate during production operations. A loss of containment from the pipeline may lead to the release of condensate to the marine environment. Pipeline loss of containment events can range from small 'pinhole' leaks (e.g. due to localised corrosion) through to complete rupture of the pipeline (e.g. due to significant mechanical impacts such as a drilling rig anchor being dragged over the export pipeline). Shell has extensive experience in the safe design and operation of subsea pipelines, and the oil and gas industry routinely implements a range of design standards and operational inspections to ensure pipeline integrity. This is reflected in the very low likelihoods of significant hydrocarbon releases from pipelines in jurisdictions similar to Australia (Det Norske Veritas 2011; IOGP 2010b).

Shell has determined the worst-case credible release from the export pipeline based on the preliminary design of the pipeline and the proximity of sensitive environmental receptors. This scenario consists of the short-term (< 6 hour) release of the entire contents (2,037 m^3 of Crux condensate) of the export pipeline from the point at which the pipeline is closest to a submerged shoal (Heyward Shoal) which was considered to represent the location which could potentially result in the worst-case environmental impact. This scenario accounts for a shut down time of 15 minutes at full flow rates, and time required for the release to equalise to outside pressure at 199 m at which the release was simulated. As outlined above in **Loss of Well Control**, this is considered to provide an environmentally conservative assessment of potential impacts and risks from a loss of containment from the export pipeline. Shell commissioned numerical modelling to inform the risk assessment; refer to **Section 8.4.8.2** for further information on this worst-case credible spill scenario and associated modelling.

Loss of Fuel from Vessel

The Crux project will require considerable use of a range of project vessels, from small platform support vessels to heavy lift and pipeline installation vessels. The frequency and duration of vessel activities will vary considerably depending on the project phase. Installation and decommissioning will be peak periods of vessel activity, and vessels will include heavy lift and construction vessels. The commissioning and operations phases (the longest phases of the Crux project) will involve relatively low vessel activity, comprised primarily of platform support vessels.

The nature and scale of the environmental risks and impacts from a loss of fuel from a vessel varies significantly based on the vessel type and activities. Vessels such as heavy lift and pipeline vessels typically store relatively large quantities of fuel. Often these types of vessels are fuelled using relatively heavy fuel oils, such as intermediate fuel oil (IFO). Smaller vessels, such as platform support vessels, typically store smaller quantities of fuel. Smaller vessels are typically fuelled using lighter fuel oils such as marine diesel, which are less persistent in the environment than heavier fuel oils.

Shell has determined the worst-case credible release from a loss of fuel from a vessel is a short-term (1 hour) release of 1,000 m^3 of IFO at the Crux end of the export pipeline. This scenario represents the loss of a significant volume of persistent fuel oil from a pipelay vessel. This scenario was identified as credibly arising from a collision with a large vessel (e.g. bulk carrier). Based on the shipping activity in the region and standard maritime practices, this scenario is considered extremely unlikely. As outlined above in **Loss of Well Control**, this worst-case credible spill scenario is considered to provide an environmentally conservative assessment of potential impacts and risks from a loss of containment from a loss of fuel from a vessel. Shell commissioned numerical modelling to inform the risk assessment; refer to **Section 8.4.8.2** for further information on this worst-case credible spill scenario and associated modelling.

8.4.8.2 Overview of Unplanned Spill Modelling

Numerical modelling studies were commissioned by Shell for the worst-case credible spill scenarios outlined above. The characteristics of each scenarios used in the modelling are provided in **Table 8-34**.

Table 8-34: Summary of Modelled Hydrocarbon Spill Scenarios

Scenario	Location Name	Latitude	Longitude	Depth (m)	Hydrocarbon Type	Duration	Total Volume (m^3)
Loss of well control	Platform	12° 57' 52.46"	124° 26' 33.21"	169	Crux condensate	80 days	206,225
Loss of process tank containment on Crux platform	Platform	12° 57' 52.46"	124° 26' 33.21"	Surface	Crux condensate	Instant	88
Loss of containment from export pipeline	Near Heywood Shoal – export pipeline	13° 15' 29.00"	123° 54' 39.00"	199	Crux condensate	< 6 hours	2,037
Loss of fuel from vessel	Platform	12° 57' 52.46"	124° 26' 33.21"	Surface	IFO-180	1 hour	1,000

A similar approach was applied to the hydrocarbon spill modelling as was used for the liquid discharges modelling described in **Section 8.4.7.2** (refer to the blue box describing the approaches to deterministic and stochastic modelling). The same validated composite regional hydrodynamic model for the project area (RPS 2018e). The tidal, mesoscale and composite models were validated against oceanographic observations, including data collected within the project area, and showed strong agreement with oceanographic observations (RPS 2018e). This confirmed the model was suitable for predicting the fate of hydrocarbon spills.

Each of the four spill scenarios was modelled using a stochastic modelling approach, where the release was repeatedly simulated deterministic model using different metocean conditions. A total of 300 deterministic model runs were undertaken for each worst-case credible spill scenario (100 during summer, 100 during winter and 100 during transitional season). The aggregated deterministic results (300 deterministic runs for each release scenario) constitute the stochastic data set, from which probabilities of contact above thresholds are determined. Shell considers all environmental receptors identified as potentially being contacted, regardless of the likelihood. This will identify more receptors than would be impacted by a given release, and hence it is environmentally conservative.

A single representative deterministic run was selected from the stochastic set based on the maximum oil volume accumulated across all shoreline receptors. This deterministic run for each of four scenarios has been presented as a time-series compilation of figures. This time-series compilation of figures provides an indication of how hydrocarbons released from a single worst-case spill event may behave in the environment. The time-series figure compilations include floating, entrained, dissolved and accumulated hydrocarbons.

Hydrocarbon Characteristics

Crux Condensate

Crux condensate is relatively volatile (> 90% volatile hydrocarbons by mass), non-viscous hydrocarbon mixture. Soluble aromatic hydrocarbons contribute approximately 12.3% by mass of the whole condensate, with a large proportion (9.8%) in the C4–C10 range of hydrocarbons. These compounds will evaporate rapidly, reducing the potential for dissolution of a proportion of them into the water. The physical properties and boiling points of Crux condensate are presented in **Table 8-35** and **Table 8-36** respectively.

Table 8-35: Physical Properties of the Hydrocarbons used in the Modelling

Physical Properties	Crux Condensate	IFO-180
Density (kg/m^3)	783.6 (at 15 °C)	967.0 (at 25 °C)
API	49.0	14.8
Dynamic viscosity (cP)	1.052 (at 20 °C)	2,324 (at 15 °C)
Pour point (°C)	9.0	-10.0
Hydrocarbon property category	Group I	Group IV
Hydrocarbon persistence classification	Non-persistent	Persistent (heavy)

Table 8-36: Boiling-point Breakdown of the Hydrocarbons used in the Modelling

Oil Type	Volatiles (%)	Semi-Volatiles (%)	Low Volatiles (%)	Residual (%)	Aromatics (%)
Boiling point (°C)	< 180 C4 to C10	180–265 C11 to C15	265–380 C16 to C20	> 380 > C20	Of whole oil < 380 BP
	Non-persistent			*Persistent*	-
Crux condensate	54.8	22.8	14.6	7.8	12.3
IFO-180	1.0	14.4	20.8	63.8	5.9

Intermediate Fuel Oil

IFO-180 has a high density (967 kg/m^3) and a high viscosity (2,324 cP), with a low portion of volatile component (**Table 8-35** and **Table 8-36**). Once released to the environment, most of the oil will spread and form a surface slick, with the small portion of volatile components evaporating.

Given the low viscosity of IFO, it is unlikely to become entrained under most wind and wave conditions (RPS 2018d). IFO-180 can form stable water-in-oil emulsions (also referred to as "chocolate mousses") in which seawater droplets become suspended into the oil matrix (Fingas and Fieldhouse 2004). The formation of emulsions requires physical mixing (i.e. wave action), with the stability of the emulsion influenced by the properties of the IFO (which will change as the oil weathers). Emulsions are expected to become less stable over time as the water content reduces. Emulsification will affect the spreading and weathering of the oil and increase the volume of oily material and may the affect natural degradation rate (Fingas and Fieldhouse 2004).

The IFO will continue to degrade in the environment through weathering processes and microbial action. Residual oil may remain as floating oil, form tarballs, and become deposited to the seabed if subject to high suspended sediment loads (such as those observed in nearshore environment) (International Tanker Owners Pollution Federation 2011a). High suspended sediment loads and therefore sedimentation of oil is not expected in the offshore marine environment.

Hydrocarbon Impact Thresholds

Spilled hydrocarbons can exist as a range of fates, or phases, in the marine environment. These are floating, entrained, dissolved and accumulated (i.e. stranded onshore) hydrocarbons. Each of these fates, or phases, can interact with the environment in diverse ways due to different pathways to receptors and impact mechanisms.

A series of impact thresholds for floating, entrained, dissolved and accumulated hydrocarbons were determined. These thresholds were applied to the hydrocarbon spill modelling studies and used to inform the assessment of potential impacts and risks. Three thresholds were applied to each fate, or phase, (low exposure, moderate exposure and high exposure); these are described in **Table 8-37** (RPS 2018d).

Table 8-37: Summary of the Zones of Exposure and Thresholds

Exposure Zone	Threshold	Justification
Floating Hydrocarbon Threshold		
Exposure zone Low exposure (1 g/m^2–10 g/m^2)	1 g/m^2	The 1 g/m^2 threshold represents the practical limit of observing hydrocarbon sheens in the marine environment and therefore has been used to define the outer boundary of the low exposure zone. This threshold is considered below levels which would cause environmental harm and is more indicative of the areas perceived to be affected due to its visibility on the sea-surface. This exposure zone is not considered to be of significant biological impact but may be visible to the human eye. This exposure zone represents the area contacted by the spill and defines the conservative outer boundary of the area of influence from a hydrocarbon spill.
Adverse exposure zone Moderate exposure (10 g/m^2–25 g/m^2)	10 g/m^2	Ecological impact has been estimated to occur at 10 g/m^2 as this level of oiling has been observed to mortally impact birds and other wildlife associated with the water surface (French et al. 1996; French 2000).

Exposure Zone	Threshold	Justification
		The 10 g/m^2 threshold has been selected to define the moderate exposure zone. Contact within this exposure zone may result in impacts to the marine environment.
Adverse exposure zone High exposure (> 25 g/m^2)	25 g/m^2	The 25 g/m^2 threshold is above the minimum threshold observed to cause ecological impact. Studies have indicated that a concentration of surface oil 25 g/m^2 or greater would be harmful for the majority of birds that contact the hydrocarbon at this concentration (Koops et al. 2004; Scholten et al. 1996). Exposure above this threshold is used to define the high exposure zone.
Shoreline Hydrocarbon Threshold		
Exposure zone Low exposure (10 g/m^2–100 g/m^2)	10 g/m^2	In previous risk assessment studies by French-McCay et al. (McCay et al. 2005a, 2005b), a threshold of 1 g/m^2 was used to assess the potential for shoreline contact (by oil stranding on shorelines/beaches). It is a conservative threshold used to define regions of socio-economic impact, such as the need for shore clean-up on man-made concrete/stone walls or on amenity beaches. A less conservative threshold of 10 g/m^2 has been defined as the zone of potential 'low' exposure. This exposure zone represents the area visibly contacted by the spill and defines the outer boundary of the area of influence from a hydrocarbon spill.
Adverse exposure zone Moderate exposure (100 g/m^2–1,000 g/m^2)	100 g/m^2	French *et al.* (1996) and French-McCay (2009) have defined an oil exposure threshold of 100 g/m^2 for shorebirds and wildlife (furbearing aquatic mammals and marine reptiles) on or along the shore, which is based on studies for sub-lethal and lethal impacts. The 100 g/m^2 threshold has been used in previous environmental risk assessment studies (French et al. 2011; French-McCay 2004; French-McCay 2003; French-McCay et al. 2012; National Oceanic and Atmospheric Administration 2013). This threshold is also recommended in AMSA's foreshore assessment guide as the acceptable minimum thickness that does not inhibit the potential for recovery and is best remediated by natural coastal processes alone (AMSA 2015). Thresholds of 100 g/m^2 and 1,000 g/m^2 will define the zones of potential 'moderate' and 'high' exposure on shorelines, respectively. Contact within these exposure zones may result in impacts to the marine environment.
Adverse exposure zone High exposure (> 1,000 g/m^2)	1,000 g/m^2	
Entrained Hydrocarbon Threshold		
Exposure zone Low exposure (10 parts per billion (ppb)–100 ppb)	10 ppb	The 10 ppb threshold represents the lowest concentration and corresponds generally with the lowest trigger levels for chronic exposure for entrained hydrocarbons in the ANZECC & ARMCANZ (2000) water quality guidelines. Due to the requirement for relatively long exposure times (> 24 hours) for these concentrations to be significant, they are likely to be more meaningful for juvenile fish, larvae and planktonic organisms that might be entrained (or otherwise moving) within the entrained plumes, or when entrained hydrocarbons adhere to organisms or is trapped against a shoreline for periods of several days or more. This exposure zone is not considered to be of significant biological impact. This exposure zone represents the area contacted by the spill and conservatively defines the outer boundary of the area of influence from a hydrocarbon spill.
Adverse exposure zone Moderate exposure (100 ppb–500 ppb)	100 ppb	The 100 ppb threshold is considered conservative in terms of potential for toxic effects leading to mortality for sensitive mature individuals and early life stages of species. This threshold has been defined to indicate a potential zone of

Exposure Zone	Threshold	Justification
		acute exposure, which is more meaningful over shorter exposure durations. The 100 ppb threshold has been selected to define the moderate exposure zone. Contact within this exposure zone may result in impacts to the marine environment.
Adverse exposure zone High exposure (> 500 ppb)	500 ppb	The 500 ppb threshold is considered conservative high exposure level in terms of potential for toxic effects leading to mortality for more tolerant species or habitats. This threshold has been defined to indicate a potential zone of acute exposure, which is more meaningful over shorter exposure durations. The 500 ppb threshold has been selected to define the high exposure zone.
Dissolved Aromatic Hydrocarbon Threshold		
Exposure zone Low exposure (6 ppb–50 ppb)	6 ppb	The threshold value for species toxicity in the water column is based on global data from French *et al.* (1999) and French-McCay (2003, 2002), which showed that species sensitivity (fish and invertebrates) to dissolved aromatics exposure > 4 days (96-hour LC_{50}) under different environmental conditions varied from 6 ppb–400 ppb, with an average of 50 ppb. This range covered 95% of aquatic organisms tested, which included species during sensitive life stages (eggs and larvae). Based on scientific literature, a minimum threshold of 6 ppb used to define the low exposure zones (Clark 1984; Engelhardt 1983; Geraci and St Aubin 1988; Jenssen 1994; Tsvetnenko 1998). This exposure zone is not considered to be of significant biological impact. This exposure zone represents the area contacted by the spill and conservatively defines the outer boundary of the area of influence from a hydrocarbon spill.
Adverse exposure zone Moderate exposure (50 ppb–400 ppb)	50 ppb	A conservative threshold of 50 ppb was chosen as it is more likely to be indicative of potentially harmful exposure to fixed habitats over short exposure durations (French-McCay 2002). French-McCay (2002) indicates that an average 96-hour LC_{50} of 50 ppb could serve as an acute lethal threshold to 5% of biota. The 50 ppb threshold has been selected to define the moderate exposure zone. Contact within this exposure zone may result in impacts to the marine environment.
Adverse exposure zone High exposure (> 400 ppb)	400 ppb	A conservative threshold of 400 ppb was chosen as it is more likely to be indicative of potentially harmful exposure to fixed habitats over short exposure durations (French-McCay 2002). French-McCay (2002) indicates that an average 96-hour LC_{50} of 400 ppb could serve as an acute lethal threshold to 50% of biota. The 400 ppb threshold has been selected to define the high exposure zone.

Summary of Unplanned Spill Modelling Results

Loss of Well Control

The worst-case deterministic run, determined to be the deterministic model run from the stochastic set with the greatest volume of hydrocarbons accumulating on shorelines, is shown in **Figure 8-10**. This deterministic run resulted in approximately 9.3 m^3 of hydrocarbon accumulation on the shoreline within and around the Djukbinj National Park in the NT.

This worst-case deterministic run indicated that hydrocarbons on the sea surface mainly drifted southwest of the release location. The potential floating oil exposure zones (low threshold) was limited to within 15 km of the release location, with the moderate and high thresholds not exceeded. The entrained oil and dissolved aromatic hydrocarbons were shown to move east and northeast of the release location. Low, moderate and high entrained hydrocarbons were observed up to 1,155 km, 1,048 km and 890 km, respectively, from the release location. Low, moderate and high dissolved aromatic hydrocarbons were observed up to 1,071 km, 597 km and 364 km, respectively, from the release location.

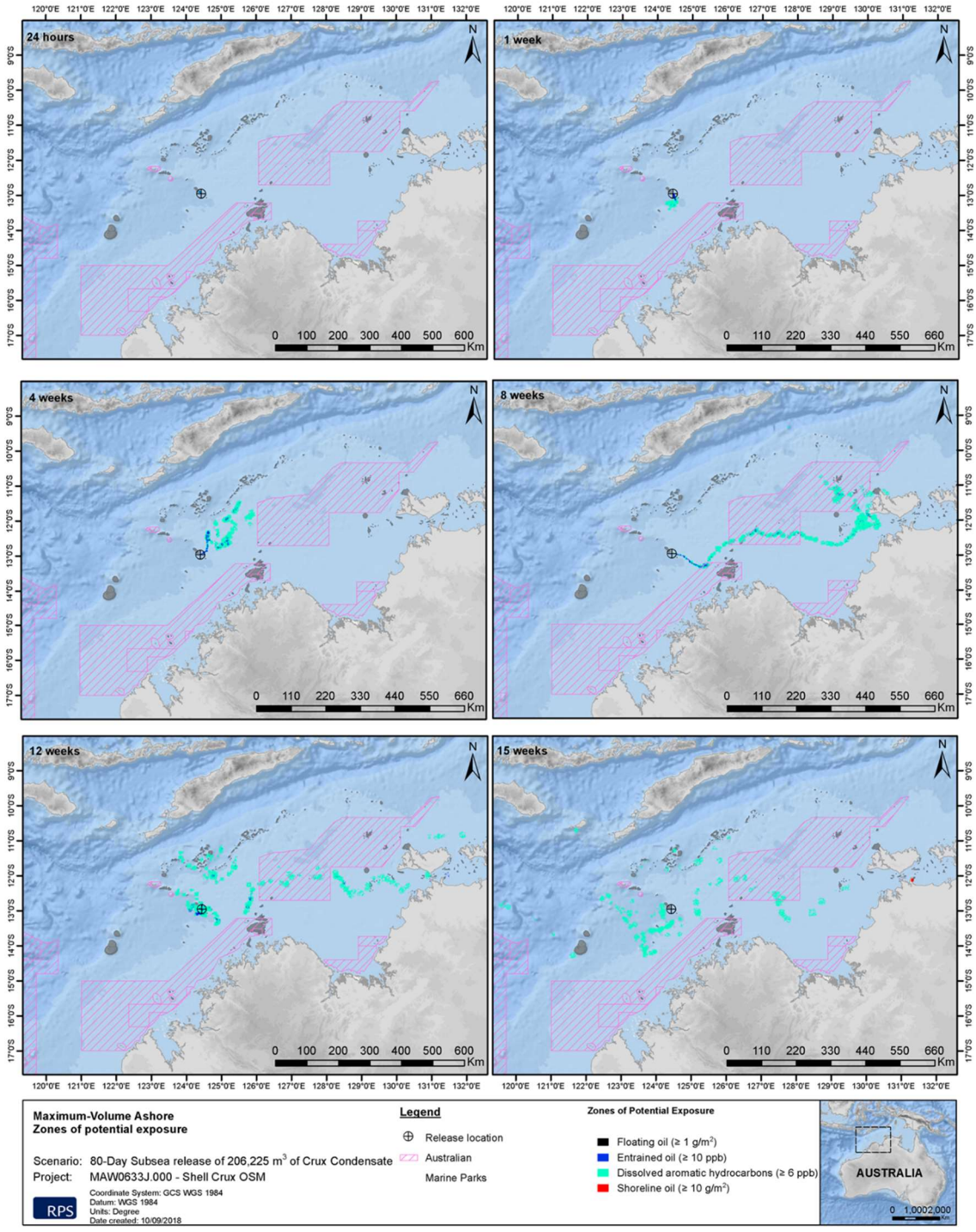


Figure 8-10: Time-varying Areal Extent of Potential Exposure at Floating, Entrained, Dissolved Hydrocarbon and Shoreline Hydrocarbon Low Exposure Threshold Concentrations Resulting from an 80-day Subsurface Release of Crux Condensate at a Development Well

Key results from the stochastic modelling studies for a worst-case loss of well control showed:

- floating hydrocarbons (**Figure 8-11**) were relatively localised to the release location due to the seabed release and the resulting entrainment of the condensate as very fine drops with low rising velocity. Modelling results indicated floating hydrocarbons would only occur above the low exposure threshold; no exceedance of the moderate or high floating hydrocarbon thresholds were predicted. The maximum distance to the outer extent of the low floating oil threshold is predicted to vary between seasons, extending to within 577 km, 387 km and 93 km during transitional, summer and winter conditions, respectively. Floating oil concentrations above the moderate threshold occurred only during the transitional season. The high floating oil threshold was not exceeded during any season.
- the potential for shoreline accumulation is very low, with potential shoreline accumulation predicted to occur at isolated location along the NT coastline during the summer season.
- entrained hydrocarbons (**Figure 8-11**, **Figure 8-12** and **Figure 8-13**) were predicted to extend in all directions. The maximum distance to the outer extent of the low entrained oil threshold is predicted to vary between seasons, extending up to 3,292 km, 2,589 km and 2,170 km during winter, transitional and summer conditions, respectively. The maximum extent is forecast to be slightly reduced for the moderate (100 ppb) and high (≥ 500 ppb) thresholds for all the seasons. Most of the spilled liquid hydrocarbons from a worst-case loss of well control will exist in the entrained phase.
- dissolved hydrocarbons (**Figure 8-11**, **Figure 8-12** and **Figure 8-13**) were predicted to follow a similar distribution to entrained hydrocarbons and extend in all directions. The maximum distance to the outer extent of the dissolved aromatic hydrocarbon low threshold (6 ppb) is predicted to vary between seasons, extending up to 3,280 km, 2,364 km and 1,764 km during winter, transitional and summer conditions, respectively. The maximum extent is forecast to be slightly reduced for the moderate (50 ppb) and high (≥ 400 ppb) thresholds for all the seasons.
- the loss of well control scenario will generate a plume of buoyant gas and condensate, which will rise rapidly through the water column (RPS 2018d). The resulting turbulent mixing of the gas and condensate with the water is predicted to entrain liquid hydrocarbons in the water column. Modelling results indicated these liquid hydrocarbon drops will be very small (< 30 µm) and will rise very slowly towards the sea surface (approximately 4.3 m per day). The droplets are expected to remain entrained in near-surface waters due to wind and wave action, although may form thin floating slicks under sufficiently calm conditions (RPS 2018d).
- the metocean conditions significantly affected the distribution of entrained and dissolved hydrocarbons. The strong mesoscale flow to the south-west during winter months associated with the ITF moved the majority of dissolved and entrained hydrocarbons in this direction for released during this season. The weakening of the ITF during transitional and summer months lead to increased probabilities of entrained and dissolved hydrocarbons moving east from the release location.

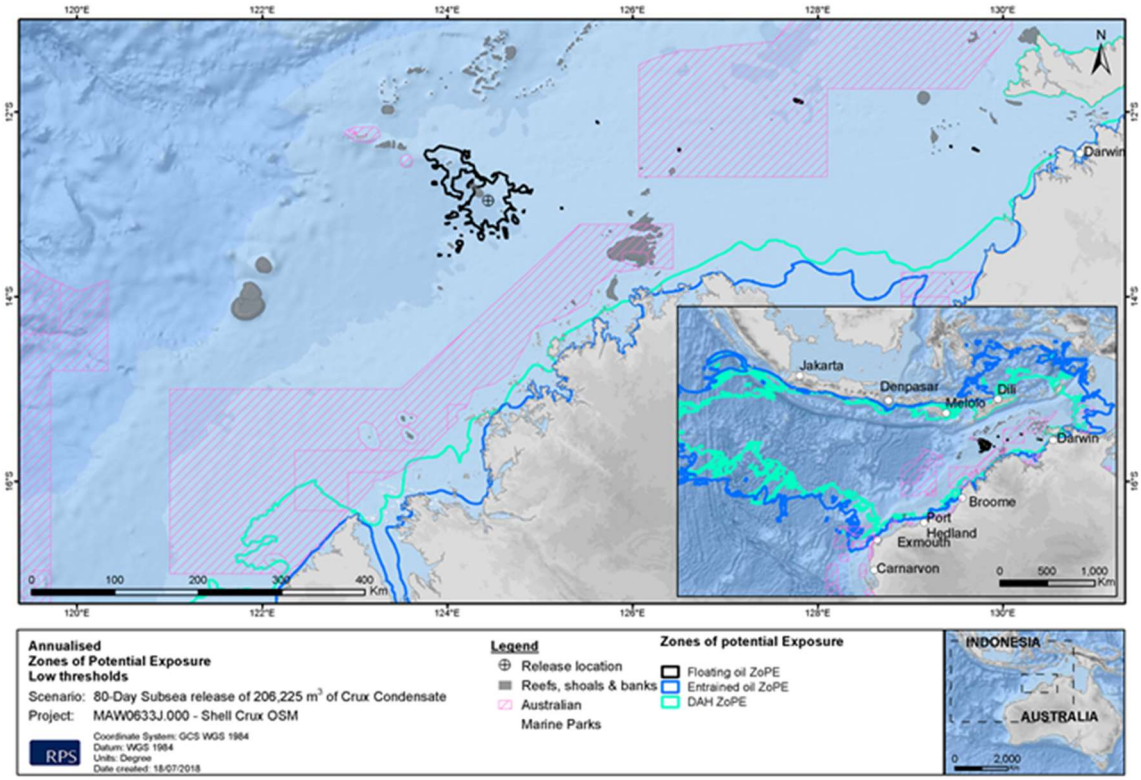


Figure 8-11: Predicted Annualised Low Exposure Threshold for Floating, Entrained and Dissolved Hydrocarbons from an 80-day Subsurface Release of Crux Condensate at a Development Well

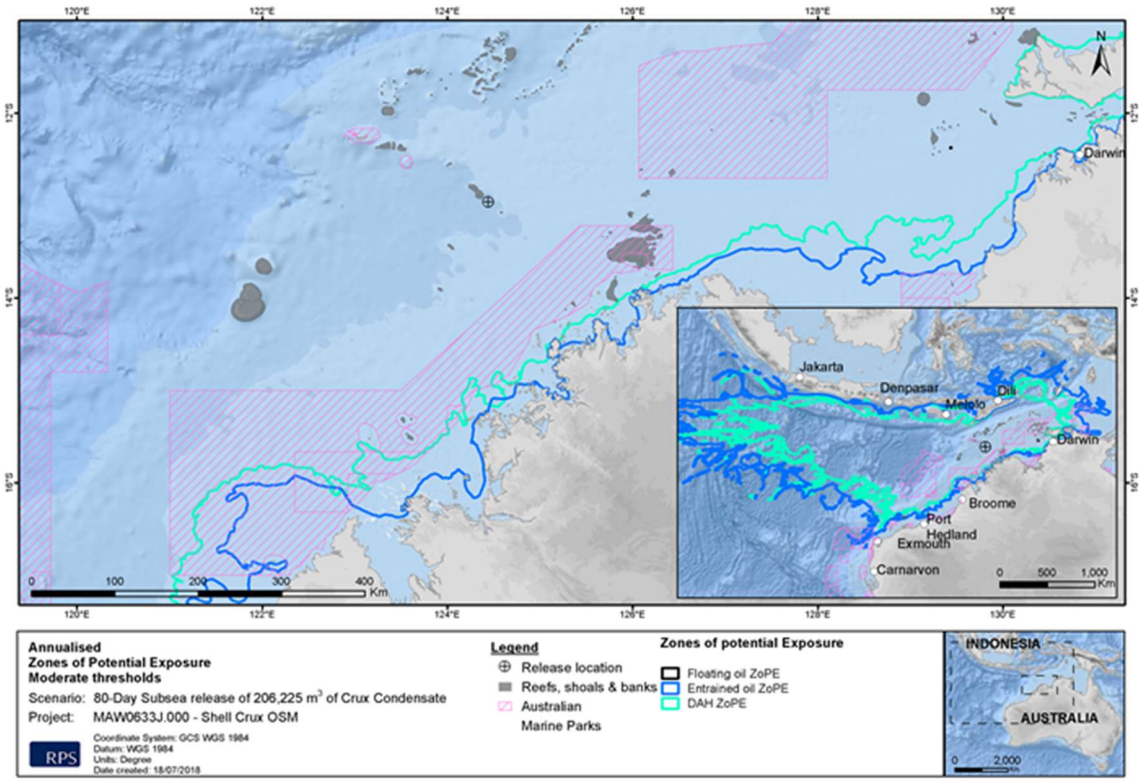


Figure 8-12: Predicted Annualised Moderate Exposure Threshold for Floating, Entrained and Dissolved Hydrocarbons from an 80-day Subsurface Release of Crux Condensate at a Development Well

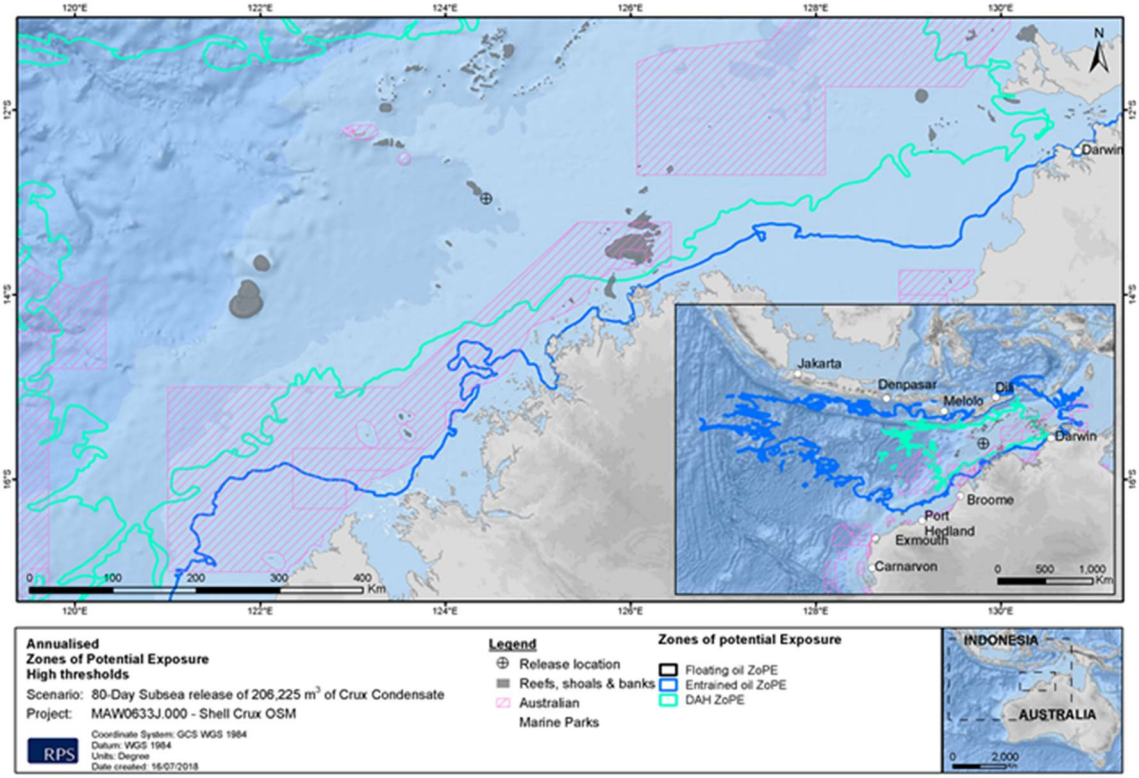


Figure 8-13: Predicted Annualised High Exposure Threshold for Floating, Entrained and Dissolved Hydrocarbons from an 80-day Subsurface Release of Crux Condensate at a Development Well

Loss of Process Storage Tank Containment

The worst-case deterministic run, determined to be the deterministic model run from the stochastic set with the greatest volume of hydrocarbons accumulating on shorelines, is shown in **Figure 8-14**. This deterministic run resulted in approximately 2 m^3 of hydrocarbon accumulation on the shorelines within the Ashmore Reef and Cartier Island and Surrounding Commonwealth Waters KEF.

This worst-case deterministic run indicated that hydrocarbons on the sea surface mainly drifted north-west of the release location. The potential floating oil exposure zones were shown up to 57 km, 8 km and 1 km of the release location at the low, moderate and high thresholds, respectively. The entrained oil and dissolved aromatic hydrocarbons were shown to move west of the release location. Low entrained hydrocarbons were recorded up to 304 km from the release location. Low dissolved aromatic hydrocarbons were observed up to 1 km from the release location.

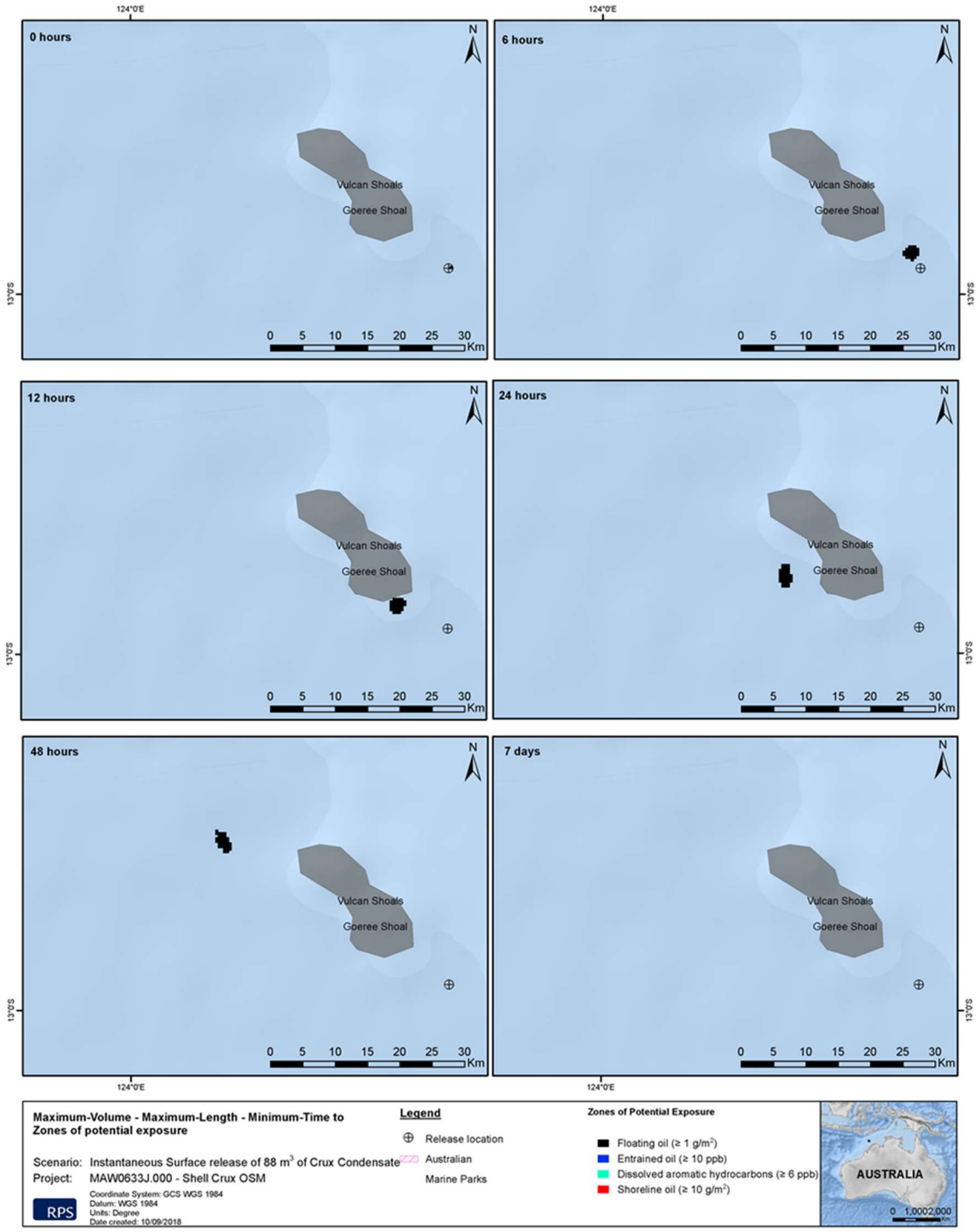


Figure 8-14: Time-varying Areal Extent of Potential Exposure at Floating, Entrained, Dissolved Hydrocarbon and Shoreline Hydrocarbon Low Exposure Threshold Concentrations Resulting from an Instantaneous Release of Crux Condensate at the Crux Platform

Key results from the stochastic modelling studies for a worst-case loss of process storage tank containment showed:

- the surface release results in a high probability of formation of a floating hydrocarbon slick (**Figure 8-15** and **Figure 8-16**), which is expected to evaporate and weather rapidly due to the high portion of volatile hydrocarbons. The maximum distance to the outer extent of the low floating oil threshold is predicted to vary between seasons, extending to within 116 km, 115 km and 81 km during winter, summer and transitional conditions, respectively. The area affected by floating oil above the moderate and high floating oil thresholds was further reduced, with floating oil not predicted to extend beyond 17 km in any season.
- potential for accumulation of hydrocarbons on shorelines is predicted to be low, with a maximum accumulated volume of 2 m^3 forecast at Ashmore Reef and Cartier Island, and maximum local accumulated concentration on shorelines of 127 g/m^2 forecast at Ashmore Reef and Cartier Island.
- entrained oil concentrations were predicted to disperse in all direction from the release location (**Figure 8-15**, **Figure 8-16**, **Figure 8-17**), depending on metocean conditions. The maximum distance to the outer extent of the low entrained oil threshold is predicted to vary between seasons, extending up to 566 km, 541 km and 402 km during summer, winter and transitional conditions, respectively. The maximum extent is forecast to be reduced for the moderate and high thresholds for all the seasons.
- dissolved hydrocarbons (**Figure 8-15**, **Figure 8-16**, **Figure 8-17**) were predicted to follow a similar distribution to entrained hydrocarbons and extend in all directions from the release location. The maximum distance to the outer extent of the low dissolved aromatic hydrocarbon threshold is predicted to vary between seasons, extending up to 465 km, 427 km and 216 km during summer, winter and transitional conditions, respectively. The maximum extent is forecast to be reduced for the moderate (50 ppb) and high (≥ 400 ppb) thresholds for all the seasons.
- the surface release of Crux condensate from a loss of process tank containment will spread rapidly, with volatile components (approximately 55%) evaporating within the first 12 hours (RPS 2018d). The remaining components will continue to evaporate of the course of several days, leaving approximately 8% residual hydrocarbons by mass. Local wind and wave conditions may entrain floating hydrocarbons, although the resulting entrained droplets may resurface and reform floating slicks.
- as with the worst-case loss of well containment scenario, metocean conditions were a significant influence on the distribution of entrained and dissolved hydrocarbons. Unlike the worst-case loss of well containment scenario, the entrained and dissolved hydrocarbons were concentrated in surface waters due to the relatively large droplet size and different entrainment mechanisms (i.e. wave action on floating oil versus a turbulent subsea plume).

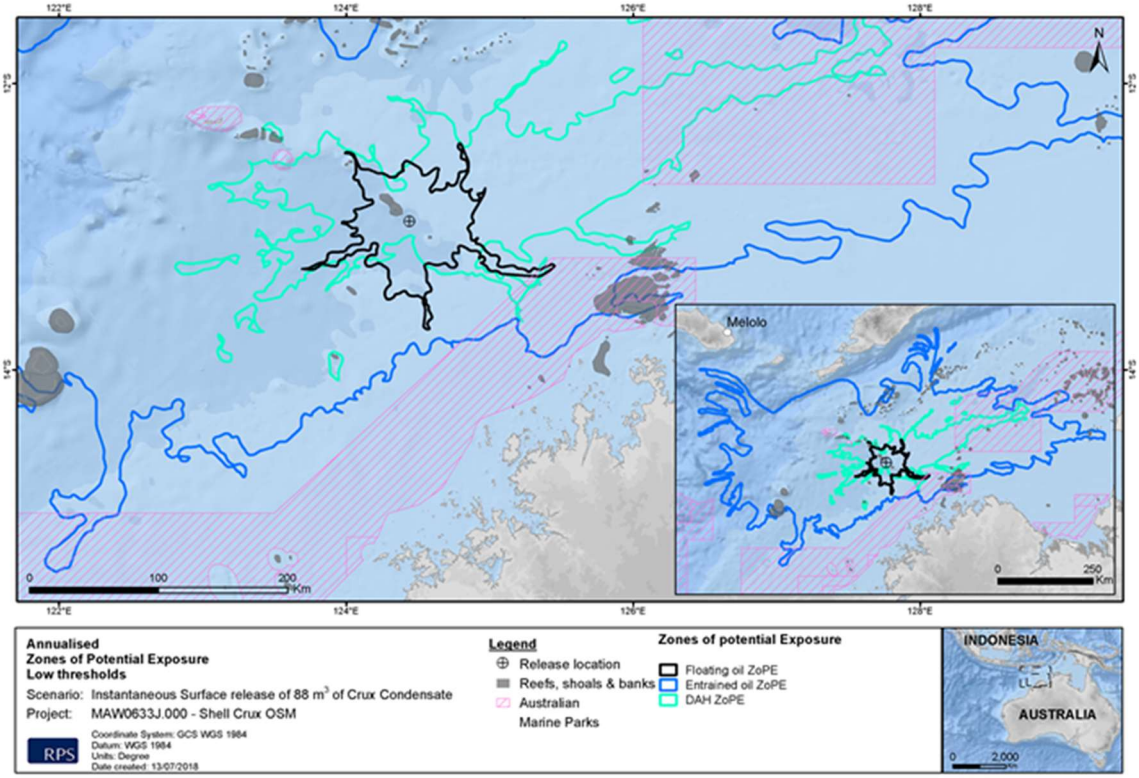


Figure 8-15: Predicted Annualised Low Exposure Threshold for Floating, Entrained and Dissolved Hydrocarbons from an Instantaneous Surface Release of Crux Condensate at the Crux Platform

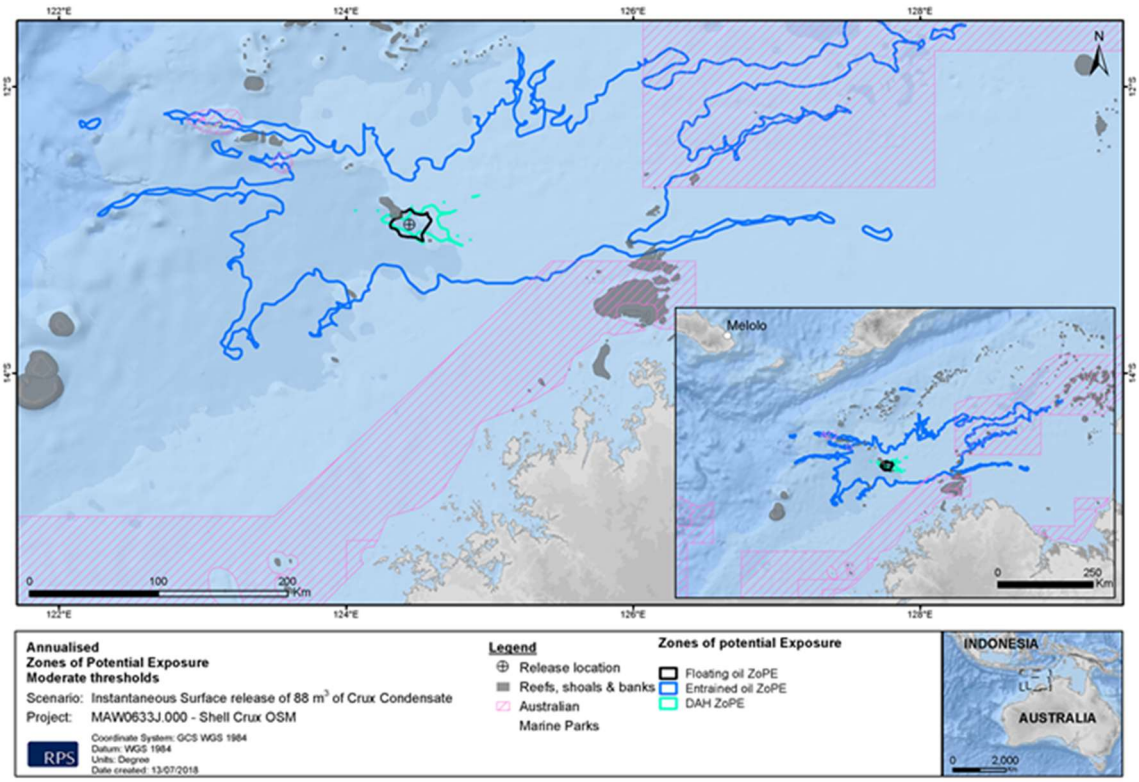


Figure 8-16: Predicted Annualised Moderate Exposure Threshold for Floating, Entrained and Dissolved Hydrocarbons from an Instantaneous Surface Release of Crux Condensate at the Crux Platform

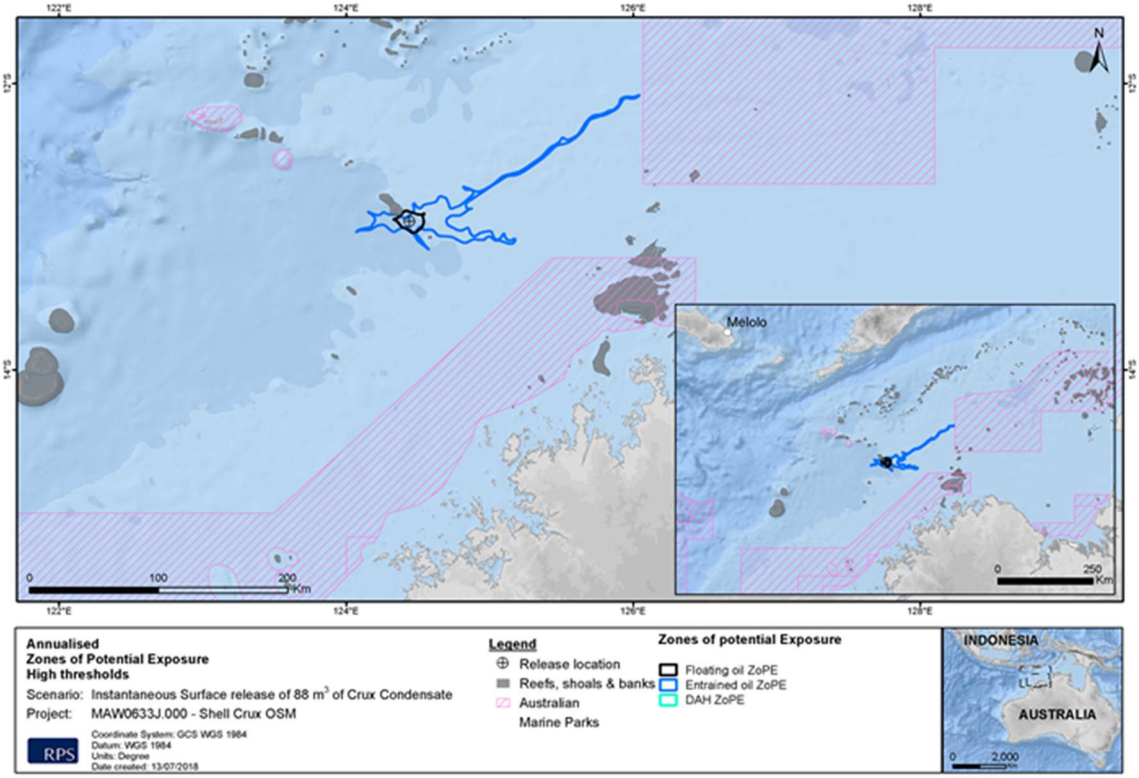


Figure 8-17: Predicted Annualised High Exposure Threshold for Floating, Entrained and Dissolved Hydrocarbons from an Instantaneous Surface Release of Crux Condensate at the Crux Platform

Loss of Containment from Crux Export Pipeline

The worst-case deterministic run, determined to be the deterministic model run form the stochastic set with the greatest volume of hydrocarbons accumulating on shorelines, is shown in **Figure 8-18**. This deterministic run resulted in approximately 116 m^3 of hydrocarbon accumulation on the shorelines within at Ashmore Reef and Cartier Island and Surrounding Commonwealth Waters KEF.

This worst-case deterministic run indicated that hydrocarbons on the sea surface mainly drifted north-west of the release location. The potential floating oil exposure zones were shown up to 312 km, 34 km and 14 km of the release location at the low, moderate and high thresholds, respectively. The entrained oil and dissolved aromatic hydrocarbons were shown to move west and south-west of the release location. Low, moderate and high entrained hydrocarbons were recorded up to 1,419 km, 1,323 km and 12 km, respectively, from the release location. Low and moderate dissolved aromatic hydrocarbons were observed up to 428 km, 276 km, respectively, from the release location.

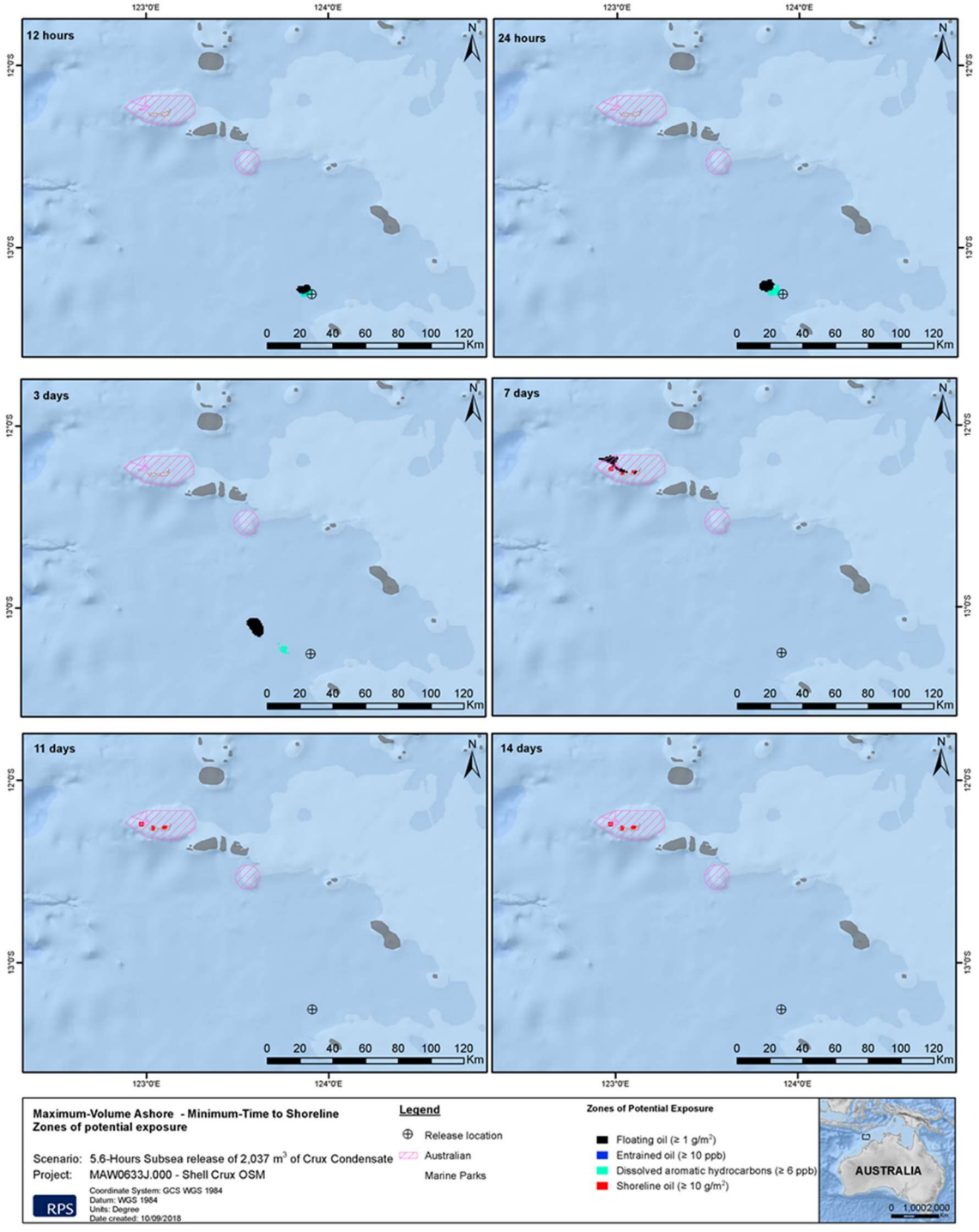


Figure 8-18: Time-varying Areal Extent of Potential Exposure at Floating, Entrained, Dissolved Hydrocarbon and Shoreline Hydrocarbon Low Exposure Threshold Concentrations Resulting from a 5.6-hour Subsurface Release of Crux Condensate from the Export Pipeline

Key results from the stochastic modelling studies for a worst-case loss of containment from the export pipeline showed:

- the maximum distance to the outer extent of the low floating oil threshold is predicted to vary between seasons, extending to within 581 km during summer and within 330 km during winter and transitional conditions. The maximum extent is forecast to be reduced for the moderate and high thresholds for all the seasons (**Figure 8-19**, **Figure 8-20** and **Figure 8-21**).
- potential for accumulation of hydrocarbons on shorelines is predicted to be low, although the worst-case maximum accumulated volume of 116 m^3 forecast at Ashmore Reef AMP would result in considerable hydrocarbon contamination. Maximum local accumulated concentration on shorelines of 3,131 g/m^2 forecast at Ashmore Reef AMP during a release starting in the transitional period.
- entrained oil concentrations were predicted to disperse in all direction from the release location (**Figure 8-19**, **Figure 8-20** and **Figure 8-21**), depending on metocean conditions. The maximum distance to the outer extent of the low entrained oil threshold is predicted to vary between seasons, extending up to 1,770 km, 1,419 km and 780 km during winter transitional and summer conditions, respectively. The maximum extent is forecast to be reduced for the moderate and high thresholds for all the seasons.
- dissolved hydrocarbons (**Figure 8-19**, **Figure 8-20** and **Figure 8-21**) were predicted to follow a similar distribution to entrained hydrocarbons and extend in all directions from the release location. The maximum distance to the outer extent of the low dissolved aromatic hydrocarbon threshold is predicted to vary between seasons, extending up to 1,770 km, 754 km and 671 km during winter, summer and transitional conditions, respectively. The maximum extent is forecast to be slightly reduced for the moderate and high thresholds for all the seasons.
- the loss of containment from the export pipeline will generate a buoyant plume of gas and condensate, although at considerably lower pressure than the worst-case loss of well containment. The subsequent turbulent mixing in the water column will result in larger entrained oil droplets (approximately 500 µm to 2.5 mm), which will rise towards the sea surface (approximately 1.6-10 cm per second). These droplets are more likely to result in floating slicks than those formed by a well blowout, although the floating slick may become entrained due to surface wind and wave conditions (RPS 2018d).
- as with the worst-case loss of well containment scenario, metocean conditions were a significant influence on the distribution of entrained and dissolved hydrocarbons. Unlike the worst-case loss of well containment scenario, the entrained and dissolved hydrocarbons were concentrated in surface waters due to the relatively large droplet size and different entrainment mechanisms (i.e. wave action on floating oil versus a turbulent subsea plume).

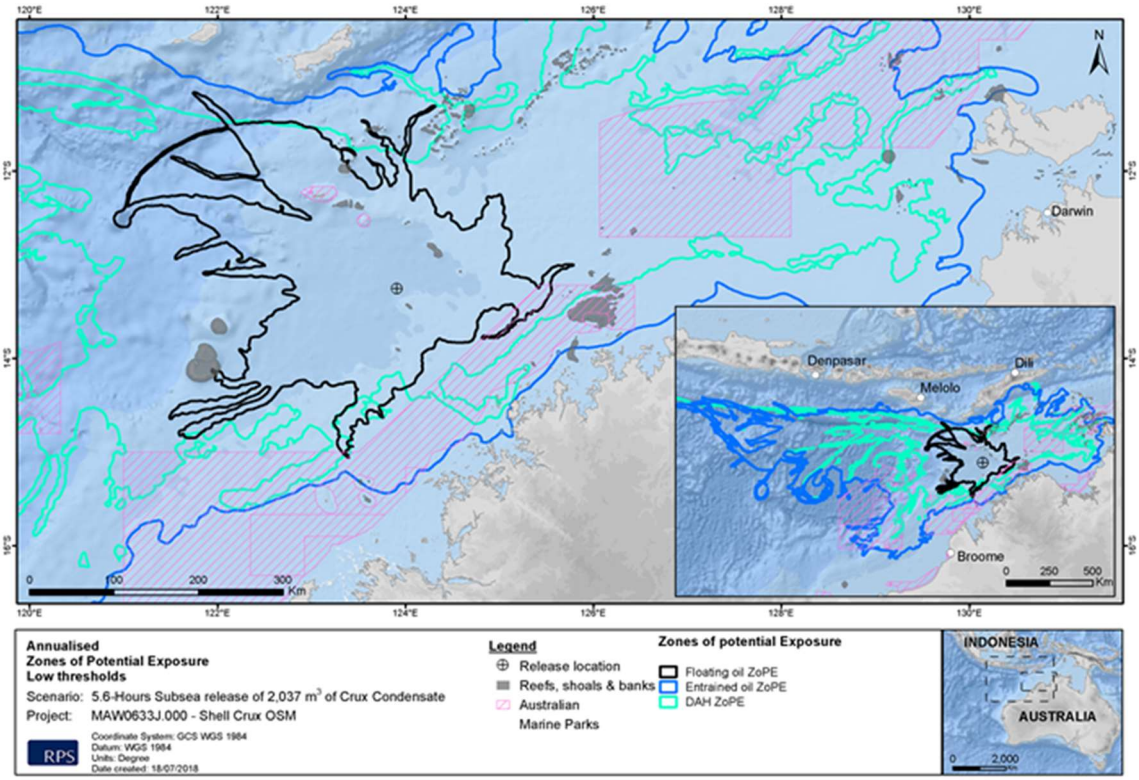


Figure 8-19: Predicted Annualised Low Exposure Threshold for Floating, Entrained and Dissolved Hydrocarbons from a 5.6-hour Subsurface Release of Crux Condensate from the Export Pipeline

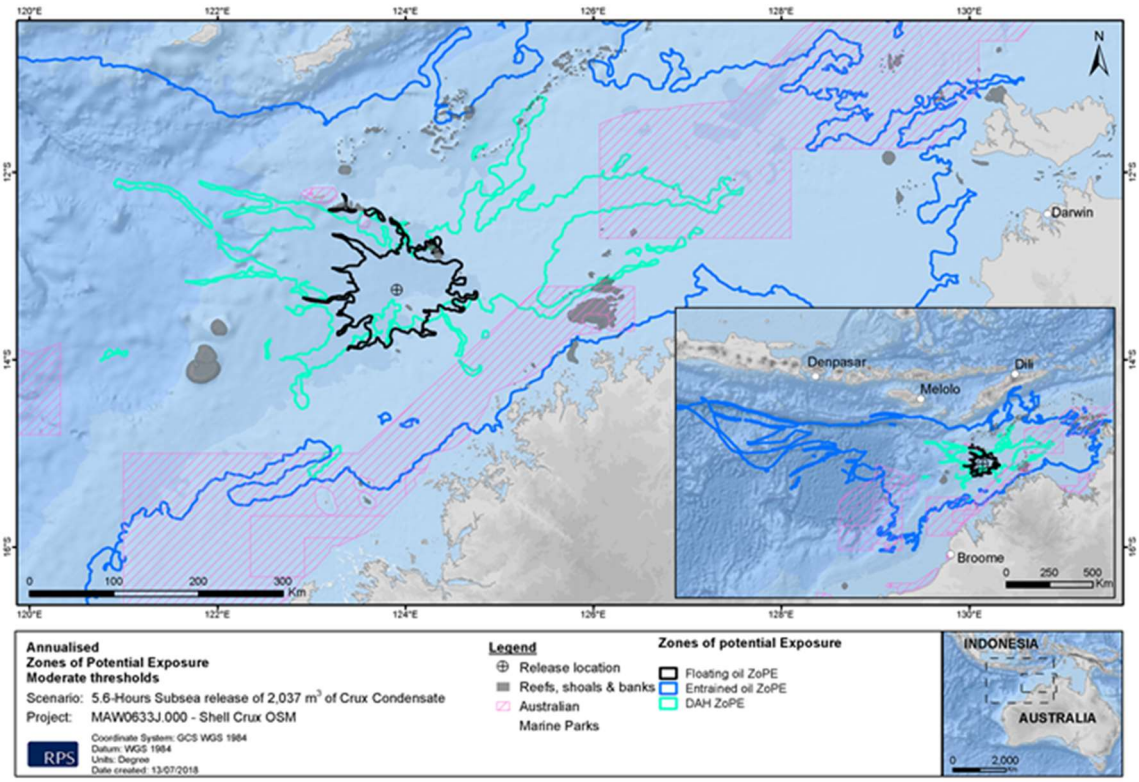


Figure 8-20: Predicted Annualised Moderate Exposure Threshold for Floating, Entrained and Dissolved Hydrocarbons from a 5.6-hour Subsurface Release of Crux Condensate from the Export Pipeline

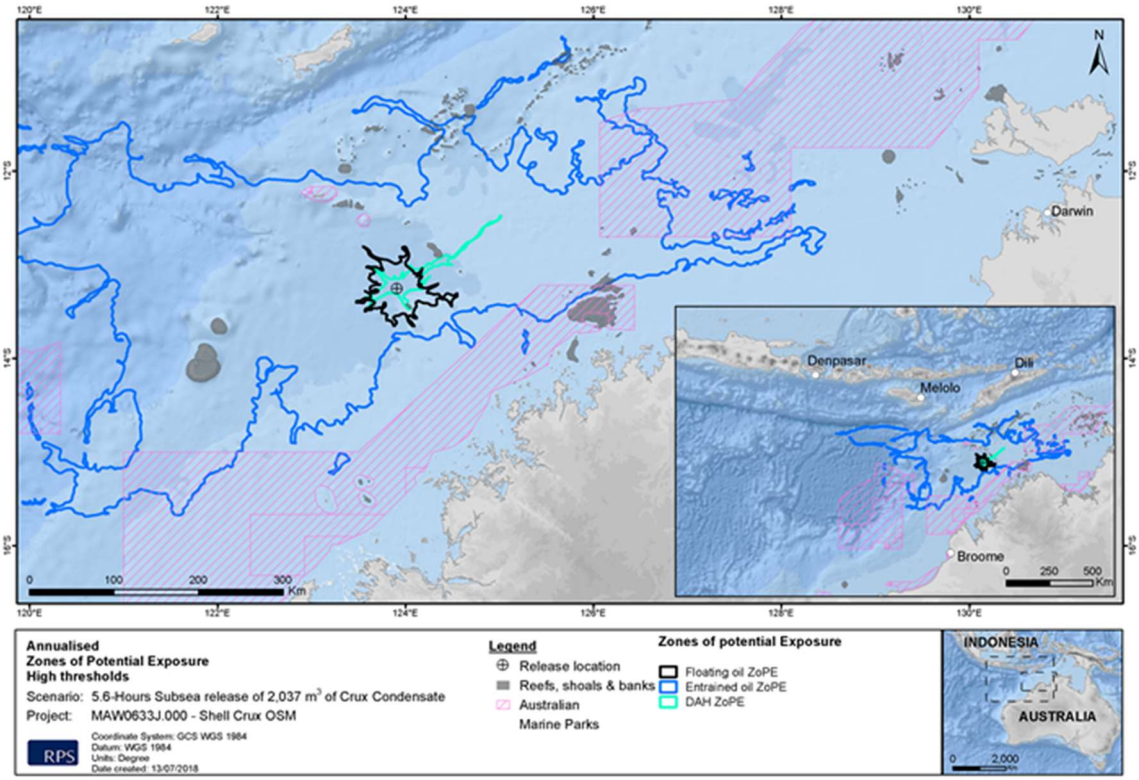


Figure 8-21: Predicted Annualised High Exposure Threshold for Floating, Entrained and Dissolved Hydrocarbons from a 5.6-hour Subsurface Release of Crux Condensate from the Export Pipeline

Loss of Fuel from Vessel

The worst-case deterministic run, determined to be the deterministic model run form the stochastic set with the greatest volume of hydrocarbons accumulating on shorelines, is shown in **Figure 8-22**. This deterministic run resulted in approximately 624 m^3 of hydrocarbon accumulation on the shorelines associated with the Bonaparte Archipelago/Bigge Island.

Hydrocarbons on the sea surface mainly drifted south of the release location. The potential floating oil exposure zones were shown up to 198 km, 190 km and 159 km of the release location at the low, moderate and high thresholds, respectively. There was no entrained oil or dissolved aromatic hydrocarbon exposure predicted at any threshold.

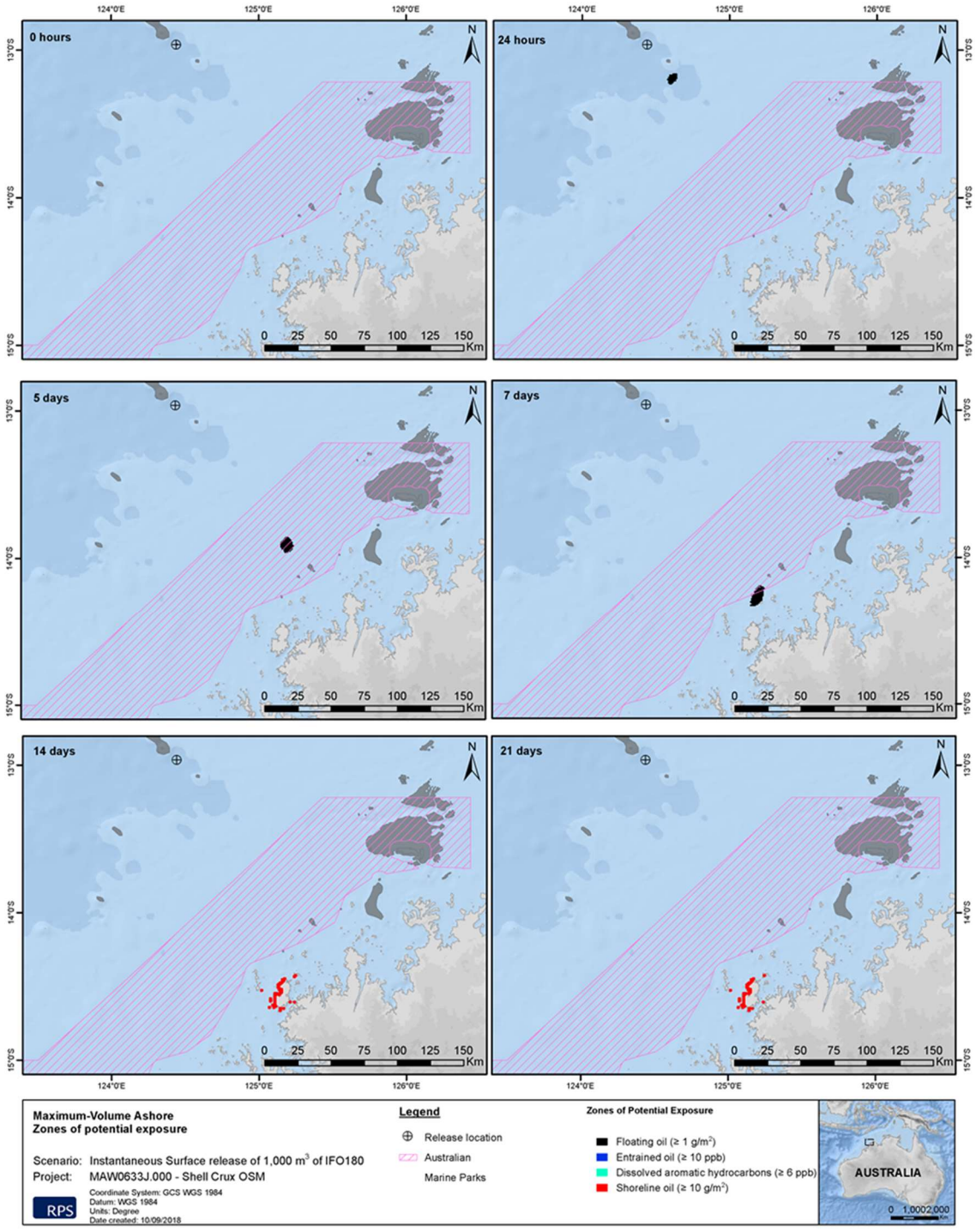


Figure 8-22: Time-varying Areal Extent of Potential Exposure at Floating, Entrained, Dissolved Hydrocarbon and Shoreline Hydrocarbon Low Exposure Threshold Concentrations Resulting from a 1-hour Surface Release of IFO at the Crux End of the Export Pipeline

Key results from the stochastic modelling studies for a worst-case loss of fuel from a vessel showed:

- floating IFO may disperse in all directions, depending on metocean conditions (**Figure 8-23**, **Figure 8-24** and **Figure 8-25**). The maximum distance to the outer extent of the low floating oil low threshold is predicted to vary between seasons, extending to within 1,853 km, 1,249 km and 985 km during winter, summer, and transitional conditions, respectively. The area potentially contacted above the moderate and high floating oil threshold was reduced, with floating oil not predicted to extend beyond 1,061 km, 727 km and 484 km, during winter, summer, and transitional conditions, respectively.
- potential for accumulation of oil on shorelines is predicted to be low, although the worst-case maximum accumulated volume of 771 m^3 forecast at Bonaparte Archipelago and Kimberley PMZ would result in considerable hydrocarbon contamination. Maximum local accumulated concentration on shorelines of 7,777 g/m^2 forecast at Bonaparte Archipelago, Kimberley PMZ and Kimberley Coast during a release starting in the summer period.
- entrained oil concentrations are expected to be localised to the release location. The high viscosity of IFO means the potential for entrainment during typical metocean conditions is relatively low. The maximum distance to the outer extent of the low entrained oil threshold is predicted to vary between seasons, extending up to 170 km, 102 km and 24 km during summer, transitional and winter conditions, respectively. The maximum extent is forecast to be greatly reduced for the moderate and high thresholds for all the seasons.
- dissolved hydrocarbons will be localised to the release location. The maximum distance to the outer extent of the low dissolved aromatic hydrocarbon threshold is predicted only in the summer season, extending up to 20 km.

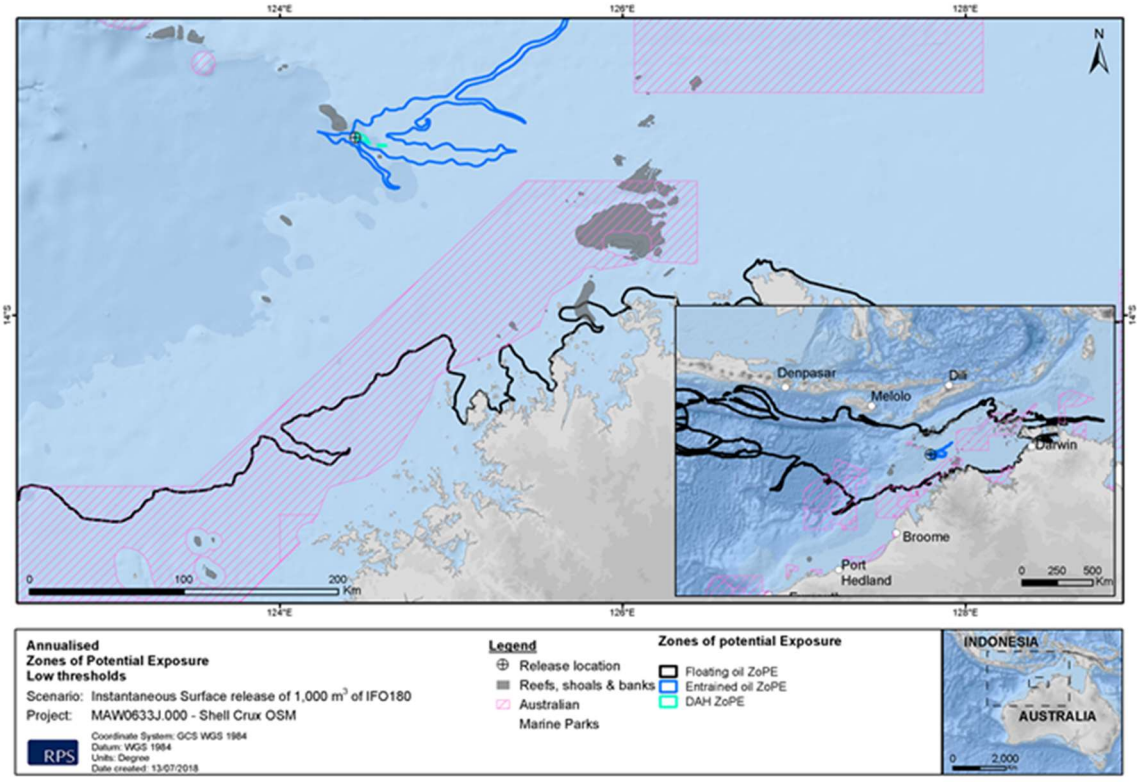


Figure 8-23: Predicted Annualised Low Exposure Threshold for Floating, Entrained and Dissolved Hydrocarbons from a 1-hour Surface Release of IFO-180 at the Crux End of the Export Pipeline

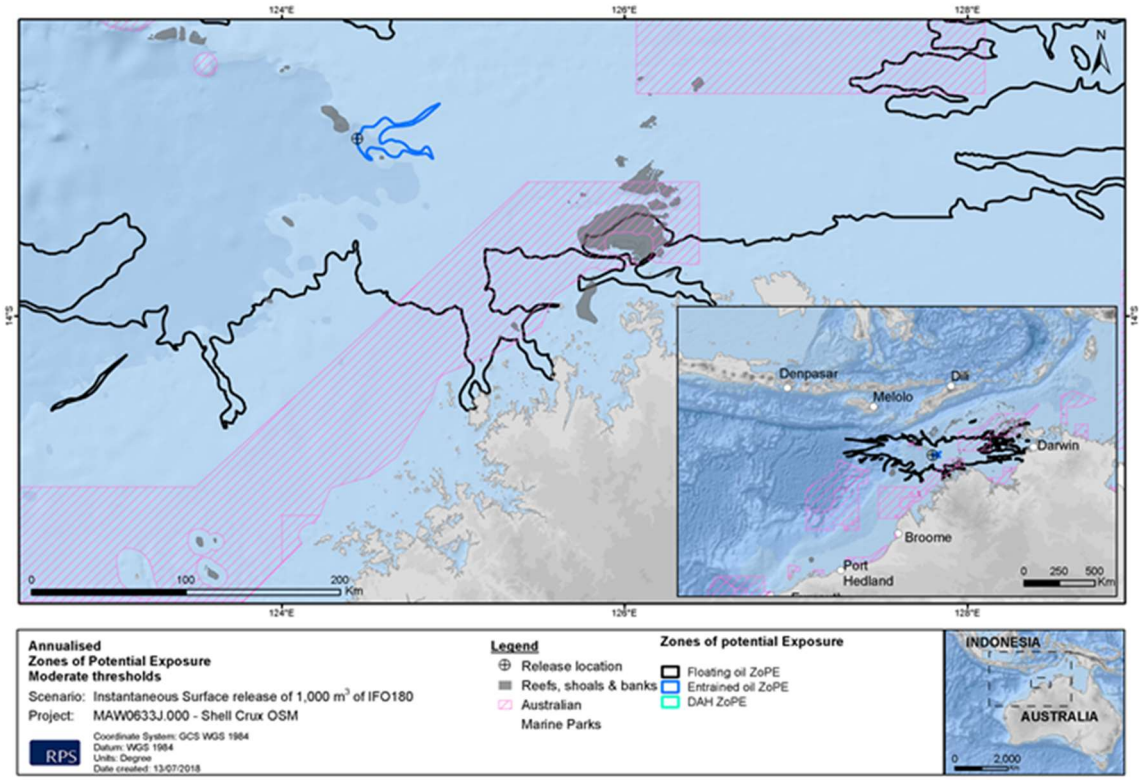


Figure 8-24: Predicted Annualised Moderate Exposure Threshold for Floating, Entrained and Dissolved Hydrocarbons from a 1-hour Surface Release of IFO-180 at the Crux End of the Export Pipeline

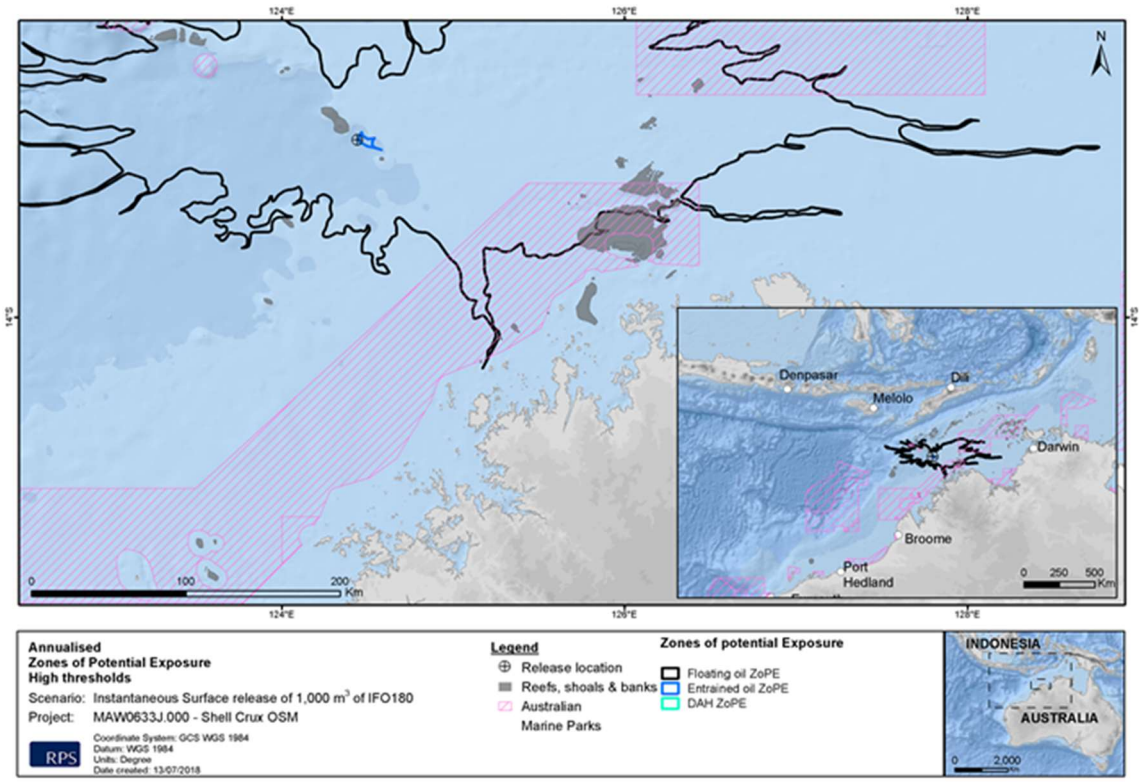


Figure 8-25: Predicted Annualised High Exposure Threshold for Floating, Entrained and Dissolved Hydrocarbons from a 1-hour Surface Release of IFO-180 at the Crux End of the Export Pipeline

8.4.8.3 Description and Evaluation of Impacts and Risks

Table 8-38: Summary of Hydrocarbon Spill Modelling Results for Receptors with ≥ 50 % Likelihood of Contact above Moderate or High Thresholds

Receptor Category	Hydrocarbon Phase Above Adverse Exposure Threshold			
	Floating	Accumulated	Entrained	Dissolved
Shoals and Banks				
Barracouta Shoals			1	1
Deep Shoal 1			1	
Echuca Shoal			1	
Eugene McDermott Shoal			1	1
Gale Bank			1	
Goeree Shoal			1	1
Heywood Shoal			1	1
Johnson Bank			1	
Vulcan Shoals			1	1
Woodbine Bank			1	1
Reefs and Offshore Islands				
Browse Island			1	
Seringapatam Reef			1	
Scott Reef North			1	
Scott Reef South			1	
Sandy Islet			1	
Mainland Coastlines				
No coastlines with likelihood of contact > 50%				
KEFs				
Ancient Coastline at 125 m depth contour			1	1
Ashmore Reef and Cartier Island and surrounding Commonwealth waters			1	1
Carbonate bank and terrace system of Sahul Shelf			1	1
Continental Slope Demersal Fish Communities			1	1
Seringapatam Reef and Commonwealth waters in the Scott Reef Complex			1	
BIAs				
Flatback turtle			1	1
Green turtle			1	1
Hawksbill turtle			1	
Loggerhead turtle			1	1
Olive ridley turtle			1	1
Habitat Critical to the Survival of a Species				
Green turtle			1	1
Heritage				
Ashmore Reef National Nature Reserve			1	1

Receptor Category	Hydrocarbon Phase Above Adverse Exposure Threshold			
	Floating	Accumulated	Entrained	Dissolved
Scott Reef and Surrounds – Commonwealth Area			1	
Ramsar Wetlands				
Ashmore Reef National Nature Reserve			1	1
Marine Parks				
Ashmore Reef AMP			1	
Cartier Island AMP			1	1
Kimberley AMP			1	
Oceanic Shoals AMP			1	1
Fisheries				
Northern Prawn Fishery			1	
NWSTF			1,3	1
Southern Bluefin Tuna Fishery	2, 3, 4		1, 3	1
Western Skipjack Fishery	2, 3, 4		1, 3	1
Western Tuna and Billfish Fishery	2, 3, 4		1, 3	1
Defence				
No defence areas with likelihood of contact > 50%				
Offshore Petroleum				
Montara Production Platform			1	1
Prelude FLNG			1	1
Indonesia and Timor-Leste Coastlines				
No Indonesian or Timorese coastlines with likelihood of contact > 50%				

Scenarios – loss of well control (1), loss of process storage tank containment (2), loss of containment from the export pipeline (3) and loss of fuel from vessel (4)

Physical Environment

Water Quality

Large volume releases of Crux condensate have the potential to result in increased concentrations of dissolved hydrocarbons, which include BTEX and PAHs. There low molecular weight compounds are known to be toxic to marine biota (refer to **Ecosystems, Communities and Habitats** and **Threatened Species and Ecological Communities** below for a discussion of these effects). BTEX compounds do not persist in the environment due to their volatility and will diminish once released into the environment. The concentration of BTEX is expected to be highest near the release location and will decline as the spilled hydrocarbon weathers. PAHs are less volatile than BTEX and are expected to persist for longer in the environment.

The decrease in water quality from worst-case hydrocarbon spill are expected to consist of short-term acute toxic effects to phytoplankton and zooplankton. Planktonic communities are characterised by relatively rapid turnover rates of short-lived biota. The high turnover rate will lead to rapid recovery as the spilled hydrocarbons decay in the environment. Within plankton communities, there is evidence from laboratory studies that some taxonomic groups, particularly zooplankton (e.g. copepods) may be more sensitive

to hydrocarbon pollution (Almeda et al. 2013; Jiang et al. 2010). Few reliable studies have shown any impacts of hydrocarbon spills on planktonic communities, with most studies concluding that impacts from hydrocarbon pollution cannot be distinguished from natural variability (Abbriano et al. 2011; Davenport et al. 1982; Varela et al. 2006).

The concentrations of hydrocarbons in the water column will decrease over time once the release has stopped due to processes such as dispersion, dilution, physical and biological degradation, and evaporation. For short duration release scenarios, these processes will begin to reduce the total amount of hydrocarbons in the water column shortly after the release. The worst-case loss of well containment will continue to release fresh hydrocarbons for the duration of the release, and the amount of hydrocarbons will increase until the release is stopped.

Sediment Quality

Sediment quality is not expected to be significantly affected by any of the worst-case scenarios that release Crux condensate. Hydrocarbon contaminants (e.g. PAHs) from surface releases are unlikely to reach the seabed due to the water depth and low natural sedimentation rates in the region. Hydrocarbon contaminants from the subsea releases (loss of well control and loss of pipeline containment) may contaminate sediments by advective transport of the plume that will be formed during the release (Romero et al. 2015). This is considered most likely to occur with the worst-case loss of well containment scenario due to the relatively long duration of the release. Any resulting contamination will be concentrated around, and down-current from, the wellhead. Due to the low density and volatile nature of the hydrocarbon, weathered condensate is unlikely to be deposited to the seabed.

The IFO release from a loss of fuel from a vessel scenario has a relatively low portion of volatiles, which are expected to evaporate quickly following release. The remaining IFO may sink to the seabed if exposed to considerable sedimentary particles, however this is considered very unlikely to occur in the open sea due to the low density of the residual IFO relative to seawater and the naturally low sedimentation rates. Residual IFO near shorelines may be exposed to higher sediment loads and be more likely to sink. Stranding of residual IFO on shorelines can lead to long-term contamination of sediments with high-molecular weight hydrocarbons. These compounds are typically much less toxic than low-molecular weight hydrocarbons.

Air Quality

The gas plume from the worst-case loss of well containment and loss of pipeline containments scenarios will result in a gas cloud upon reaching the surface. This potentially large gas cloud is expected to disperse rapidly in the open, offshore environment.

The formation of a gas cloud poses a significant health and safety risk from the formation of explosive mixtures and asphyxiation. Given the highly localised extent and expected short duration of the gas cloud, this risk is considered to be very low.

Ecosystems, Communities and Habitats

Benthic Communities

Seabed releases of Crux condensate may result in impacts to water quality and sediments in the vicinity of the release location (refer to sections **Water Quality** and **Sediment Quality** above). The seabed in the vicinity of these potential release locations (i.e. the project area) are characterised by unconsolidated sediments which host spare assemblages of filter feeding and deposit feeding organisms. These fauna may be subject to acute and chronic toxic effects from exposure to hydrocarbons, however the extent of the affected habitat is expected to be localised to the vicinity of the release

location. Bare sediment habitat is very widely represented in the Timor Sea, and the associated fauna assemblages are not considered to be particularly sensitive of or high conservation value.

Many benthic fauna species have planktonic larval phases (e.g. corals, echinoderms, sponges etc.). Organisms with planktonic larval phases typically produce very high numbers of larvae. A worst-case credible spill may result in increased mortality of planktonic larvae (which are subject to high natural mortality); however, this is not expected to result in population-scale impacts.

Filter feeding benthic communities may be vulnerable to entrained and dissolved hydrocarbons. Entrained hydrocarbons can be ingested by filter feeders, leading to increased exposure due to accumulation of ingested oil droplets (Payne and Driskell 2003). While typically less toxic than dissolved hydrocarbons, entrained oil may still cause toxic effects; entrained oil may also result in physical impacts such as clogging of filter feeding organs, potentially resulting in reduced feeding efficiency. Filter feeder, and sessile organisms in general, may be exposed to concentrations of dissolved hydrocarbons that result in acute and chronic toxic effects.

Results from modelling studies of the worst-case loss of well containment and pipeline release scenarios indicated that several offshore reefs and islands, and bank and shoals, may be contacted by hydrocarbons above impact thresholds. Refer to **Offshore Reefs and Islands** and **Shoals and Banks** below for a discussion of potential impacts to these receptors.

Nearshore benthic communities are typically more diverse than those found in the deep-water habitat of the project area, often due to the presence of primary producers, such as seagrasses, macroalgae, zooxanthellate corals and mangroves.

Most seagrasses within the area that may be affected by the worst-case hydrocarbon spill scenarios are subtidal, although there may be relatively small areas of intertidal seagrasses along the WA and NT coastlines. Seagrass in the subtidal and intertidal zones have different degrees of exposure to hydrocarbon spills. Subtidal seagrass is unlikely to be exposed to spilled hydrocarbons, as most hydrocarbons in subtidal environments will be concentrated at the surface. Intertidal seagrasses are vulnerable to smothering by floating oil slicks, which can lead to mortality if it coats their flowers, leaves and stems (Dean et al. 1998; Taylor and Rasheed 2011). Long-term impacts to seagrass are unlikely unless hydrocarbon is retained within the seagrass meadow for a sustained duration (Wilson and Ralph 2011). Toxicity effects can also occur due to absorption of soluble fractions of hydrocarbons into tissues (Runcie et al. 2010). The potential for toxicity effects of entrained hydrocarbons may be reduced by weathering processes that should serve to lower the content of soluble aromatic components before contact occurs.

Like seagrasses, the potential impacts to macroalgae depend on the exposure pathway; most macroalgae in the region are subtidal, although intertidal macroalgae may be present. Studies of subtidal macroalgal assemblages exposed to fuel oil spills have shown that impacts from exposure is slight (Edgar et al. 2002; Lobón et al. 2008). Effects of exposure to oil on intertidal macroalgae are more variable; some studies reported little evidence of impacts (Díez et al. 2009), while others show significant impacts (De Vogelaere and Foster 1994). Recovery of intertidal macroalgae has been shown to occur faster in areas where oil has been left to degrade naturally compared to areas subject to intensive clean-up operations (De Vogelaere and Foster 1994). Given the potential for shoreline contact is very low in all the worst-case spill scenarios, impacts to macroalgae are considered to be highly unlikely.

Subtidal and intertidal zooxanthellate corals occur widely throughout the Timor Sea, including around offshore reefs and islands, bank and shoals, and the mainland coast. Shallow subtidal and intertidal corals may be coated by stranded floating hydrocarbons

during low tides, which may subsequently be re-floated by subsequent incoming tides. Impacts from physical coating of corals appears to also depend on coral morphology. Coral species more likely to retain oil coatings (e.g. due to polyp morphology, or gross morphology with high surface area to volume ratios such as branching corals) have been shown to be more susceptible to impacts (Shigenaka 2001). Exposure to dissolved and entrained hydrocarbons may result in acute and chronic toxic effects, with longer exposure durations typically leading to greater potential for mortality (Shigenaka 2001). Corals may also ingest entrained oil particles, potentially leading to update of hydrocarbons into coral tissue (Loya and Rinkevich 1980).

Intertidal mangrove habitats occur throughout much of Kimberley and NT coastline, and are highly susceptible to oil pollution (NOAA 2014). Given the distance between potential release locations and the nearest mangroves, any spilled hydrocarbons reaching mangroves will be highly weathered. Mangroves are vulnerable to contact with floating hydrocarbons, such as weathered IFO, which may coat prop roots and pneumatophores (aerial roots that support oxygen uptake) (Duke and Archibald 2016). Exposure can result in direct effects such as yellowed leaves, defoliation and mortality, and indirect effects such as reduced recruitment and increased sensitivity to other stressors (NOAA 2014). Like seagrasses, mangroves can also be impacted by entrained and dissolved aromatic hydrocarbons either in the water or sediment

Shoals and Banks

The Timor Sea region hosts numerus named shoals and banks, a number of which were identified by the stochastic modelling as being contacted by entrained and dissolved hydrocarbons from worst-case credible spill scenarios. Modelling results indicated shoals relatively close to the release locations are at greatest likelihood of being impacts. These include Goeree Shoal, Eugene McDermott Shoals, Vulcan Shoal, Barracouta Shoals, Heywood Shoals and Echuca Shoals. In the unlikely event of a significant hydrocarbon spill, these benthic features may be contacted by entrained and dissolved hydrocarbons above impact thresholds. The shortest modelled time to contact was ≤ 4 hour, providing relatively little time for hydrocarbons to weather.

Studies of the shoals and banks in the region show these areas host biological communities distinct from the surrounding relatively deep bare sediment habitat (e.g. Heyward et al. 2017, 2012, 1997) indicated the banks were broadly similar. Each bank hosted a range of light-dependent ecosystems characterised by benthic primary producers, such as coral and macroalgae. Surveys of shoals near the Crux project following the Montara oil spill indicated these communities did not exhibit obvious impacts as a result of the spill (Heyward et al. 2013, 2012, 2010). However, considerable natural variation both over time and between locations was observed (Heyward et al. 2013). Reviews of the ecological function of the shoals and banks in the Timor Sea east of the project area concluded there is a relatively high degree of connectivity between shoals and banks, with the banks acting as a series of “stepping stones” (Heyward et al. 2017, 2013). In the event of a disturbance to benthic communities as the result of a hydrocarbon spill, the upstream shoals and banks may act as a source of propagules or larvae, which may enhance recovery.

Contact with dissolved and entrained hydrocarbons above adverse exposure thresholds may result in mortality of benthic biota. The loss of habitat-forming biota such as corals, macroalgae or sponges could result in changes to habitats, with consequent changes to fauna assemblages. As described above in **Benthic Communities**, impacts to corals, seagrasses and macroalgae include acute and chronic toxicity which may result in non-lethal impacts (e.g. reduced feeding) and mortality.

The time required for recovery following disturbance will depend on the nature and scale of the impact. Shoals and banks in the region have been exposed to significant

intermittent disturbance for long periods of time, such as damage from cyclones and changes in water temperature associated with the El Niño-Southern Oscillation. Differences in benthic communities over time within and between shoals and banks (such as those observed by Heyward et al. 2013) may represent different phases of ecological succession.

Offshore Reefs and Islands

Several offshore reefs and islands were identified by the modelling study results as potentially being contacted by hydrocarbons above adverse exposure thresholds. These include Cartier Island, Ashmore Reef, Browse Island, Hibernia Reef, Scott Reef and Seringapatam Reef. These offshore islands and reefs often host biological communities that are distinct from coastal islands and the mainland. Like the **Shoals and Banks** described above, offshore reefs and islands typically host light-dependent ecosystems characterised by benthic primary producers. Potential impacts to submerged receptors associated with offshore reefs and islands will be similar to those described in **Shoals and Banks** above. Unlike shoals and banks, offshore reefs and islands may be exposed to floating hydrocarbons (in addition to entrained and dissolved hydrocarbons). While floating hydrocarbons from the Crux condensate release scenarios were not predicted to contact or accumulate on any offshore reefs or islands, stochastic modelling of the loss of vessel fuel scenario indicated a low probability of shoreline accumulation at several offshore islands and reefs, including the Bonaparte Archipelago, Bathurst Island and Browse Island.

The shorelines of offshore reefs and islands typically consist of intertidal reef flats and sandy beaches; shoreline types such as rocky shores, estuaries and mangroves typically do not occur. Given the modelling results estimated the minimum time to contact would be at least 144 hours for an emergent receptor (Hibernia Reef), any residual IFO reaching the shoreline of an offshore island or reef would be highly weathered. Stranding of floating oil on offshore islands and reefs may result in a band of weathered oil between the low- and high-water marks on shorelines and intertidal corals. This may result in impacts to fauna in these habitats, such as nesting turtles and wading birds. Refer to **Key Fauna Species** below for a discussion of potential impacts to these taxa.

WA and NT Mainland Coastline

The modelling studies identified potential shoreline contact along mainland Australian shores above the moderate shoreline exposure threshold for both the NT (Kakadu Coast, Cobourg Peninsula West Arnhem Land and Darwin Coast) and WA (Kimberley Coast). This was primarily from the loss of fuel from a vessel scenario, which comprised a fairly persistent hydrocarbon type (IFO). Minimum time to contact for these shoreline receptors ranged between 190 and 2,356 hours, indicating the IFO has considerable weathering time prior to reaching a shoreline.

Key Ecological Features

Modelling study results indicated several KEFs may be exposed to hydrocarbons above adverse impact thresholds (**Section 6.4.7**). KEFs with relatively high likelihoods of contact above impact thresholds include:

- ancient coastline at 125 m depth contour
- carbonate bank and terrace system of the Sahul Shelf
- continental slope demersal fish communities
- Ashmore Reef and Cartier Islands and surrounding Commonwealth waters
- Seringapatam Reef and Commonwealth waters in the Scott Reef complex, and
- pinnacles of the Bonaparte Basin.

All but two of these KEFs are entirely sub-tidal; discussion of potential impacts in this section is limited to sub-tidal features of the KEFs listed above. The exceptions of Ashmore Reef and Cartier Islands and surrounding Commonwealth waters and Seringapatam Reef and Commonwealth waters in the Scott Reef complex are considered above in **Offshore Reefs and Islands** and **Shoals and Banks**, respectively.

The sub-tidal KEFs may be exposed to entrained and dissolved above the adverse exposure thresholds. The environmental values of these sub-tidal KEFs are a function of their geomorphology and depth. A worst-case loss of well containment will not alter the geomorphology or depth characteristics of the sub-tidal KEFs. Given the nature of these KEFs (i.e. potentially more rugose and complex benthic habitats), there may be relatively diverse benthic communities associated with these habitats, such as filter feeding communities and demersal fish assemblages. These biological receptors may be impacted by dissolved and entrained hydrocarbon above adverse exposure thresholds, which may result in acute a or chronic toxic effects. KEFs are most likely to be contacted by the subsea loss of well control scenario, due to the large entrained hydrocarbon fraction. The sub-tidal KEFs are large environmental features. Modelling results indicated that no single deterministic run affected the entirety of a sub-tidal KEF; most runs typically affected a minor portion of any sub-tidal KEF. Given the nature of the KEFs and the scale of potential impacts, recovery of impacted parts of a KEF are expected to be facilitated by movement and recruitment of biota from the unaffected areas.

Threatened Species and Ecological Communities

Key Fauna Species

Marine Mammals

A range of cetaceans potentially occurring within the adverse exposure zones for the worst-case credible spill scenarios outlined in **Section 8.4.8.1**. These are described in **Section 6.5.5**. Cetaceans exposed to hydrocarbons may exhibit avoidance behaviour. Geraci (1988) documented apparent avoidance of floating by bottlenose dolphins, suggesting that cetaceans can detect and avoid surface slicks. However, observations during spills have recorded whales and dolphins traveling through and feeding in oil slicks. During the Deepwater Horizon spill cetaceans were routinely seen swimming in surface slicks offshore (and nearshore) (Aichinger Dias et al. 2017). Cetaceans observed during the spill response for the Montara oil spill included oceanic species such as false killer whales, bottlenose dolphins, spotted dolphins and spinner dolphins (Watson et al. 2009).

Cetaceans exposed to surface, entrained or dissolved aromatic hydrocarbons above adverse exposure thresholds may suffer external oiling, ingestion of oil and inhalation of toxic vapours (Deepwater Horizon Natural Resource Damage Assessment Trustees 2016). Cetaceans in coastal waters (e.g. coastal dolphin species and humpback whales at the northern limit of their migration) are at lower risk of impacts than cetaceans in offshore water due to the oil weathering before reaching coastal waters. Impacts from direct oiling from a spill of Crux condensate are considered unlikely due to the non-persistent nature of the hydrocarbon and the thick layer of skin and blubber of cetaceans. Impacts from direct exposure are expected to be irritation of eyes and mucous membranes. Entrained hydrocarbons may be ingested by cetaceans during feeding, particularly by baleen whales. Some species of baleen whale, such as blue whales, may be seasonally present during their migrations. However, significant feeding during migration is not expected (although opportunistic feeding may occur).

Dugongs are known to occur in coastal waters and around offshore islands within the adverse exposure zones identified by the stochastic spill modelling. There is a paucity of studies examining the effects of hydrocarbon spills on dugongs, although the direct

impacts of exposure to hydrocarbons may be similar to cetaceans. Like cetaceans, dugongs are expected to be resilient to direct impacts due to their thick skin and blubber. Suitable dugong habitat is associated with seagrass meadows, which are typically restricted to shallow waters around the mainland coast and islands. The distance of dugong habitat from the worst-case credible spill release locations means that oil reaching dugong habitat will be highly weathered.

Marine Reptiles

Stochastic modelling results indicated adverse exposure zones overlap the known distribution of several species of marine turtles and sea snakes. Saltwater crocodiles were also identified as potentially occurring within the adverse exposure zone; given the preferred habitat for salt water crocodiles are freshwater rivers and estuaries, impacts to this species from the worst-case hydrocarbon spills are not considered credible.

Marine turtles may be exposed to floating hydrocarbons when at the sea surface (e.g. breathing, basking etc.), and are not expected to avoid floating hydrocarbon slicks (NOAA 2010). Exposure to floating or entrained hydrocarbons may result in external oiling, which could result in impacts such as inflammation or infection (Gagnon and Rawson 2010l Lutcavage et al. 1995; NOAA 2010). Given the large portion of non-persistent hydrocarbons in Crux condensate, the loss of vessel fuel scenario is considered to pose the greatest risk of external oiling. Dissolved hydrocarbons may result in toxic effects on marine turtles, however their relatively impermeable skin reduces the potential for these impacts.

Several shoals and banks occur in the vicinity of the project area, which may be used as foraging areas by marine turtles (although none are recognised as BIAs). Impacts to benthic habitats and biota at these shoals and banks may result in a reduction of prey for marine turtles. Refer to **Shoals and Banks** above for further information on potential impacts to shoals and banks.

Stochastic modelling identified a number of shoreline habitats (sandy beaches and inter-nesting habitat) that may be exposed to hydrocarbons above adverse exposure thresholds. Many of these are classified as habitat critical for the survival of marine turtles in the Recovery Plan for Marine Turtles in Australia (Commonwealth of Australia 2017a). Significant breeding and nesting activity occurs at these locations throughout the region. Given the distance of these locations from the project area, worst-case credible spills of Crux condensate reaching these areas will be highly weathered and unlikely to result in impacts. The relatively persistent IFO from a worst-case loss of vessel fuel may result in shoreline accumulation on nesting beaches. Shorelines with the greatest potential for hydrocarbon accumulation were the Bonaparte Archipelago, Bigge Island, Joseph Bonaparte Gulf, the Kimberley Coast and Bathurst Island, all as a result of the loss of fuel from a vessel scenario. A spill reaching coastal waters during peak periods to turtle nesting may have increased potential to cause impacts. Nesting female turtles and hatchling turtles moving from the nest to the sea may be exposed to weathered IFO, potentially resulting in oiling. Given the highly weathered state of the oil, this is not expected to result in significant impacts.

Sea snakes have similar exposure pathways to spilled hydrocarbons as marine turtles (although sea snakes will not be exposed to shoreline hydrocarbon accumulation). Potential impacts are expected to be comparable and may include irritation of eyes and mucous membranes. Sea snake mortality has been linked to exposure to hydrocarbon spills, with dead sea snakes recovered from the region of the Montara oil spill showing high levels of petroleum hydrocarbons (including PAHs) in the trachea, lungs and stomach (Gagnon 2009). These results are consistent with exposure through ingestion and respiration of hydrocarbons. Ashmore Reef and Hibernia Reef are noted as being one of the few sites where the critically endangered leaf-scaled sea snake and short-

nosed sea snake have been recorded, along with other species of sea snake. Both the leaf-scaled and snort-nosed sea snakes have not been detected at Ashmore Reef since 2001, despite increased biological survey effort. Both locations were identified by the stochastic modelling as potentially being exposed to hydrocarbon above adverse exposure limits.

Birds

A number of seabird and migratory shorebird species have been identified as potentially occurring within the adverse exposure zone for the worst-case hydrocarbon spill scenarios contains. Additionally, a number of BIAs for several seabird and migratory shorebird species occur throughout the adverse exposure zone, centred around offshore and coastal islands and mainland shorelines.

Spill of Crux condensate are unlikely to pose a significant risk due to the non-persistent nature of the condensate, however a worst-case IFO spill may result in a considerable mass of persistent floating oil. Seabirds and migratory birds are particularly vulnerable to contact with floating hydrocarbons, which may mat feathers. This may lead to hypothermia from loss of insulation and ingestion of hydrocarbons when preening to remove hydrocarbons; both impacts may result in mortality (Hassan and Javed 2011).

Seabirds may encounter floating oil when foraging for food. Seabird foraging is typically concentrated around roosting locations, such as offshore and coastal islands. Potential roosting locations lie considerable distances from the project area; the nearest significant roosting location is Cartier Island, which lies approximately 105 km from the proposed Crux platform location. Ashmore Reef is a Ramsar-listed wetland and hosts significant seabird colonies and is an important stopping area for migratory shorebirds. Ashmore Reef lies approximately 155 km from the proposed Crux platform location. Floating hydrocarbons reaching these locations would be significantly weathered. Seabirds typically nest above the high-water mark and as such, are not likely to encounter stranded hydrocarbons.

Migratory shorebirds are seasonally abundant during summer months, and a spill during this period would have greater potential to impact migratory shorebirds. Migratory shorebirds are not likely to encounter floating oil at sea, but may be affected by shoreline accumulation of oil, or oil and shallow foraging habitats such as intertidal mudflats. Unlike seabirds, shorebird mortality due to hypothermia from matted feathers is relatively uncommon (Henkel et al. 2012). Indirect impacts, such as reduced prey availability and bioaccumulations of PAHs, may occur (Henkel et al. 2012).

Fish

Fish respire through gills, which may make them more vulnerable to dissolved hydrocarbon fraction that fauna with less permeable skins, such as cetaceans, marine reptiles and birds. Despite this apparent vulnerability, fish mortalities are rarely observed to occur because of hydrocarbon spills (Fodrie and Heck 2011; International Tanker Owners Pollution Federation 2011b), although instances of fish mortality from spills in confined areas (e.g. bays) have been recorded. These observations are consistent with fish moving away from hydrocarbons in the water (Hjermann et al. 2007). Stochastic modelling results indicated that hydrocarbons are likely to be concentrated in surface waters. As a result, demersal fish are unlikely to be directly affected unless near a subsea release, as these are likely to be associated with seabed features (e.g. **Shoals and Banks** and **Ecological Features**). Pelagic fish are more likely to encounter dissolved and entrained hydrocarbons above adverse exposure thresholds but are may move away from affected areas.

Exposure of fish to hydrocarbons may results in acute and chronic effects and may vary depending on a range of factors such as exposure duration and concentration, life history stage, inter-species differences and other environmental stressors (Westera and

Babcock 2016). Environmental monitoring of pelagic and demersal fishes immediately following the Montara oil spill indicated that fish were exposed to hydrocarbons, although no adverse effects were detected (Gagnon and Rawson 2012, 2011). Further sampling and testing over time indicated that fish captured in close proximity to the Montara wellhead were comparable to those collected from reference sites (Gagnon and Rawson 2012, 2011).

Most marine fish species produce very high numbers of eggs, which then undergo a planktonic larval development phase. Early life history stages of fish (planktonic eggs and larvae) may be more vulnerable to hydrocarbon pollution than juvenile and adults, as these early life history phases cannot actively avoid water with high concentrations of hydrocarbons. Fish embryos and larvae may exhibit genetic and developmental abnormalities from long-term exposure to low concentrations of hydrocarbons (Fodrie and Heck 2011), although such long exposures may not be representative of real world conditions. PAHs have also been linked to increased mortality and stunted growth rates of early life history (pre-settlement) of reef fishes, as well as behavioural impacts that may increase predation of post-settlement larvae (Johansen et al. 2017). Given the temporal and spatial scale of the worst-case credible spill scenarios (as shown by a single deterministic run), and the typically high supply of eggs and larvae, it is unlikely that any of the worst-case credible spill scenarios will result in significantly reduced recruitment of fish due to impacts during early life history phases. This conclusion is supported by studies of fish stocks following large-scale hydrocarbon spills, which have shown relatively little evidence of reduced recruitment at the scale of fish stocks/populations (Fodrie and Heck 2011).

Shark and Rays

Transitory and resident sharks may occur within the adverse exposure zones identified by the stochastic spill modelling. Whale sharks may occur within the project area (e.g. traversing the project area during migration to and from aggregation off Ningaloo Reef) and a BIA for foraging whale sharks overlaps with the project area. Tagging studies by Meekan and Radford (2010) have shown whale sharks traversing the Timor Sea following the seasonal aggregation off the Ningaloo Coast. Whale sharks may be exposed to entrained and dissolved hydrocarbons by contact with their gills and ingestion during feeding. The large volume filter feeding behaviour of whale sharks may result in a relatively high potential for exposure to entrained hydrocarbons compared to many other marine species (Campagna et al. 2011).

Tagging studies off Ningaloo Reef have shown that whale sharks disperse broadly (Meekan and Radford 2010; Wilson et al. 2006). Genetic studies of whale sharks have shown low genetic diversity, which suggests flow of genetic material through the movement of individual sharks over large spatial scales (Schmidt et al. 2009). On this basis, only a portion of the whale shark population in the Timor Sea would be within the area above the adverse exposure threshold at any one time and impacts such as toxic effects leading to mortality would be expected to affect a small number of individual animals.

Other oceanic (e.g. mako) and resident (e.g. reef) sharks will occur throughout the adverse exposure zone, although Heyward et al. (2017) noted that shark numbers were lower than expected, potentially due to fishing pressure. Potential impacts to other oceanic shark species are likely to be similar to fish (see **Fish** above). Any reduction of shark numbers may take longer to recover due to the relatively long lifespans and low reproductive output compared to finfish species.

Socio-economic and Cultural Environment

World Heritage

A small portion of the Kakadu World Heritage Area, approximately 806 km from the proposed Crux platform location, was overlapped by the floating, dissolved and entrained hydrocarbons above the moderate adverse exposure threshold from the loss of well containment and loss of vessel fuel scenarios. Modelling results indicate the likelihood of contact above adverse exposure thresholds was very low; the potential contact was at very low concentrations. No shoreline accumulation above adverse exposure thresholds was predicted to occur. On the basis of the nature and scale of the contact predicted by the modelling, no impacts to the world heritage values of the Kakadu World Heritage Area will occur.

National Heritage Places

The Kakadu National Heritage Place has the same extent at the Kakadu World Heritage Area discussed above in **World Heritage**; no impacts to the heritage values of the Kakadu National Heritage Place will occur as a results of a worst-case credible hydrocarbon spill.

Spill modelling results indicated that the shorelines of the West Kimberley National Heritage Place may be contacted by floating, accumulated, entrained and dissolved hydrocarbons above impact thresholds. The West Kimberley National Heritage Place contains a range of shoreline types, including rocky shores, sandy beaches and mangroves. Potential impacts to these are discussed above in **WA and NT Mainland Coastline**. Many of the heritage values of the West Kimberley National Heritage Place (refer to **Section 6.6.5**) lie inland and will not be impacted by a hydrocarbon spill. The modelling study results indicate probabilities of shoreline accumulation above the moderate adverse accumulation threshold within the West Kimberley and Kakadu National Heritage Places are very low, 1.8% and 0.6% respectively. The maximum modelled shoreline accumulation of spilled oil on both the West Kimberley and Kakadu National Heritage Place coastlines are < 45 g/m^2.

Commonwealth Heritage Places

Several offshore islands and reefs listed as Commonwealth Heritage Places were identified by the spill modelling results as potentially being contacted by hydrocarbons. These include:

- the Ashmore Reef National Nature Reserve Commonwealth Heritage Place
- Scott Reef and Surrounds Commonwealth Heritage Place, and
- Mermaid Reef – Rowley Shoals Commonwealth Heritage Place.

The heritage values of these reefs are primarily their outstanding natural values. Refer to **Offshore Reefs and Islands** above for a discussion of potential impacts to these natural values.

Ramsar Wetlands

Several Ramsar sites were identified in the results of the spill modelling studies as potentially being impacted by spilled hydrocarbons. Most of these are in the far-field of the model and are highly unlikely to be contacted by hydrocarbons above the moderate adverse exposure thresholds. The exception is Ashmore Reef, which is the closest Ramsar site to the project area. The migratory bird species associated with Ramsar sites are most vulnerable to floating oil, and oil accumulations along the shoreline. All four credible worst-case scenarios were identified as potentially resulting in shoreline accumulation at Ashmore Reef, however the likelihoods for contact by floating hydrocarbon sis very low (≤ 2.4%). Potential impacts of spilled hydrocarbons on

migratory shorebirds are discussed above in **Key Fauna Species**; refer to this section for further information.

Note the Protected Matters search tool report identified several Ramsar wetlands at Christmas Island, however given the distance to these receptors these Ramsar wetlands will not credibly be impacted.

Marine Parks

Modelling results of the worst-case credible spill scenarios indicated a range of Commonwealth, state and territory marine parks may be contacted above adverse exposure thresholds (**Table 8-38**). These parks contain a range of environmental values such as marine biota, representative marine habitats and unique sea scapes (e.g. KEFs). Environmental values for these marine parks are described in **Section 6.6.8** and discussed above in **Physical Environment**, **Ecosystems, Communities and Habitats**, and **Threatened Species and Ecological Communities**. Refer to these sections for discussion of potential impacts to these environmental values within marine parks.

Cultural Heritage

Aboriginal people have a long history of inhabitation across northern Australia, particularly coastal regions. As outlined above in **WA and NT Mainland Coastline**, potential shoreline contact above adverse exposure thresholds may occur. Hydrocarbon pollution and shoreline clean-up activities may result in disturbance to culturally significant sites. Given the nature of the worst-case credible spill scenarios, the potential for shoreline accumulation above which clean-up activities would be effective is very low.

Marine Archaeology

No impacts to marine archaeological features will occur because of a worst-case credible hydrocarbon spill. The nearest historic shipwreck, the Anne Millicent, lies approximately 108 km from the proposed Crux platform location.

Commercial Fisheries

A number of commercial fisheries operate within the adverse exposure zone determined from spill modelling results. The worst-case credible hydrocarbon spill scenarios may result in a range of impacts to commercial fishing activities, such as (International Tanker Owners Pollution Federation 2011b):

- displacement of fishing effort from areas affected by a spill or spill response activities
- damage to fish stocks due to mortality
- closure of fisheries by management agencies
- inability to sell catch due to perceived or actual fish tainting or contamination, and
- oiling of fishing gear, particularly by floating oil.

A significant hydrocarbon spill would likely result in the temporary closure of areas of fisheries within the area of adverse exposure. The spatial extent and duration of the closure would depend on the nature and scale of the pollution resulting from the hydrocarbon spill. Given the large spatial extent of managed fisheries in the area potentially contacted above adverse exposure thresholds, a spill is unlikely to result in complete closure of a fisher. Rather, the closure of areas to fishing is more likely to result in the displacement of fishing effort. Displacement from productive fishing areas may result in impacts to fishers such as increased costs and reduced catch per unit effort.

Exposure of fish to hydrocarbons may result in tainting, which may render landings unsuitable for human consumption. Tainting may occur even a low levels of hydrocarbon exposure. Monitoring of fish for taint immediately following capping of the Montara well detected differences between fish likely to have been exposed to hydrocarbons, however

these differences were not conclusively linked to oil contamination and fell within the range of "normal" fish odours (Rawson et al. 2011). Samples collected at the same monitoring locations two and four months after were not distinguishable (Rawson et al. 2011). These results are consistent with other studies of fisheries resources exposed to hydrocarbon pollution, which acknowledge the potential for impacts to fisheries resources and have shown little potential risk for consumers if suitable fisheries management actions are undertaken (Law and Hellou 1999; Law and Kelly 2004).

Fish caught in areas affected by a significant hydrocarbon spill may be perceived as being of poorer quality, even if no decrease in quality is evident. This may result in lower prices at the time of sale and subsequently lead to reduced income for commercial fishers.

Traditional Indonesian Fishing

Traditional Indonesian fishing activity occurs within the MoU box, which overlaps the export pipeline corridor and lies within the adverse exposure zones identified by the spill modelling results. Traditional fishing is concentrated around banks, shoals, island and reefs; refer to **Shoals and Banks** and **Offshore Reefs and Islands** for discussion of potential impacts to these receptors. The worst-case credible spill scenarios may impact upon the biological resources exploited by traditional Indonesian fishers, such as fish and benthic invertebrates (e.g. sea cucumbers and trochus shells). Impacts to these biological resources may result in effects on traditional fishers, such as reduced catch rates and displacement of fishing effort. Given the distance between the release locations and the reefs exploited by traditional Indonesian fishers, impacts to traditional Indonesian fishing activities are considered to be unlikely and would be minor.

Tourism and Recreation

There are currently no known tourism activities in the project area, or surrounding areas, due to the remoteness of the area. Some tourism activity tourism activities may occur at the remote offshore islands and reefs within the adverse exposure zones. These activities are expected to be exclusively nature-based tourism and impacts to the environmental values associated with these islands and reefs may impact upon tourism activities. Refer to **Offshore Reefs and Islands** for discussion on the potential impacts to these receptors.

Mainland coastline and islands will typically host more nature-based tourist activities than offshore islands. This activity is expected to be seasonal, with increased visitation during the winter dry season months. Refer to **WA and NT Mainland Coastline** above for a discussion of potential impacts to the natural receptors along these coastlines.

Impacts to tourism activities are expected to be minor based on the likelihood and nature of contact to environmental values that support tourism activities. Impacts to these values may result in displacement of tourism activity, and potentially minor loss of revenue for tourist operators (e.g. charter fishing cancellations due to fishery closures).

Military/Defence

Defence activities within the offshore NAXA are unlikely to be affected by the worst-case credible hydrocarbon spills. Activities may be temporary displaced from areas where spill response operations are underway. This would be highly localised and temporary in nature.

Ports and Commercial Shipping

Potential impacts to ports and commercial shipping from the worst-case credible spill scenarios are expected to be very minor and consist of temporary displacement of other users from areas where spill response activities are underway. These are expected to be concentrated around the release location.

Offshore Petroleum Exploration and Operations

Petroleum activities in the region include the Shell-operated Prelude FLNG facility, the INPEX-operated Ichthys facility and the Montara development (previously operated by PTTEP Australia, now Jadestone Energy). Other exploration activities are expected to occur in the Timor Sea throughout the life of the Crux project. Reduction in water quality as a result of a worst-case credible spill may affect the operation of these facilities if seawater at the facility is no longer suitable for intake (e.g. for use as cooling water or feed water for RO water generation). This may result in impacts to routine operations such as decreased production. A worst-case hydrocarbon spill response may result in competition for vessels and potentially drilling rigs (if well intervention or a relief well is required).

Indonesian and Timor-Leste Coastlines

The spill modelling results indicated there is the potential for several worst-case credible spill scenarios resulting in contact with the Indonesian and Timor-Leste coastlines above the moderate adverse exposure thresholds. The likelihood of contact was very low except for the entrained fraction from the worst-case well blowout scenario. The likelihood of this fraction contacting the Indonesian and Timor-Leste coastlines above the moderate entrained adverse exposure threshold were 17.1% and 14.7% respectively. Minimum times to contact were 28.2 days and 30.8 days for Indonesian and Timor-Leste respectively. Given the relatively long time to contact, soluble aromatic hydrocarbon fractions are unlikely to be present, leaving relatively low toxicity residual hydrocarbons such as paraffins. Potential impacts may include smothering of coastal infrastructure (e.g. aquaculture, fishing equipment), which may result in localised economic impacts.

8.4.8.4 Risk and Impact Summary and Key Management Controls

Table 8-39: Unplanned Spills Evaluation of Impacts and Risks

Project Component/ Activity	Environmental Value/Sensitivity				Evaluation – Unplanned		
	Physical Environment	Threatened species and Ecological Communities	Ecosystems, Communities and Habitats	Socio-economic and Cultural Environment	Significance	Likelihood	Residual Impact
Evaluation – Unplanned Risks							
Unplanned risks resulting from a worst-case credible spill scenario from: • loss of well control • loss of process storage tank containment • loss of containment from export pipeline, and • loss of fuel from vessel.	X	X	X	X	Massive	Remote	Major

Key Management Controls
Vessel specific controls will align with MARPOL 73/78, the *Navigation Act 2012,* the *Protection of the Sea (Prevention of Pollution from Ships Act 1983* and subsequent Marine Orders (as appropriate for vessel classification), which includes managing spills aboard, emergency drills and waste management requirements. All vessels involved in the project will have a valid Shipboard Oil Pollution Emergency Plan or Shipboard Marine Pollution Emergency Plan (as appropriate for vessel classification) which is maintained including: Spill Kit – Pollution Control Equipment container/ box is located at a strategic location, containing adequate equipment/material (minimum as per the Shipboard Oil Pollution Emergency Plan) to control spills of pollutants on board. All project vessels operating within the project area will adhere to the navigation safety requirements contained within the COLREGS, Chapter 5 of the SOLAS Convention, STCW Convention, the *Navigation Act 2012* and any subsequent Marine Orders, which specify standards for crew training and competency, navigation, communication, and safety measures. Offshore Vessel Inspection Database or equivalent reviewed prior to mobilisation of project vessels. Australian Hydrographic Service notified of location of installed infrastructure to facilitate inclusion on nautical charts. Australian Hydrographic Service advised of project activities and installed infrastructure to facilitate issuing Notices to Mariners. Accepted WOMP in place for all wells, in accordance with the OPGGS Act requirements, including: • installation of a BOP during drilling operations, and • regular testing of BOP Accepted EPs and OPEPs in place for all petroleum activities appropriate to the nature and scale of the credible hydrocarbon spill risks. The OPEP include an Operational and Scientific Monitoring Program will be initiated and implemented as appropriate to the nature and scale of the spill and the existing environment, as informed by a net environmental benefit assessment. The OPEP shall consider: • relief well planning and preparedness • interim source control (e.g. capping stacks) • oiled wildlife response, and • operational and scientific monitoring. Stakeholder consultation throughout the Crux project, including consultation consistent with the requirements of the OPGGS (E) Regulations for all subsequent petroleum activities and associated EPs. Where vessel dynamic positioning systems are required[22], they shall be in working order whilst within the Crux platform petroleum safety zone at all times. Development and implementation of a maintenance management system for the Crux platform, export pipeline and subsea infrastructure. Development of simultaneous operations (SIMOPS) plans where interactions with other activities (e.g. Prelude operations, backfill installations) may credibly occur. Concrete coating of the majority of the export pipeline reduces the risk of a dropped object damaging the pipeline.

8.4.8.5 Acceptability of Impacts and Risks

The acceptable levels of impact for the receptors that may credibly be impacted or at risk from the unplanned spills aspect of the Crux project are summarised in **Table 8-40**. The method by which these acceptable levels were determined, along with a justification as to why these are acceptable, are discussed in **Section 7**.

[22] The requirement for DP will be determined based on the activities the vessel will be undertaking and Shell's operational requirements. There may be instances where a Shell vessel operating within the petroleum safety zone does not require DP (e.g. environmental surveys away from the platform and subsea infrastructure).

In addition to the receptor-based acceptable levels of impact listed in **Table 8-40**, Shell considers any event that results in, or has the potential to result in, the unplanned release of Crux condensate or vessel fuel to be unacceptable.

Based on the outcomes of the evaluation of impacts and risks, Shell considers that the residual environmental risks of the unplanned spill aspect of the Crux project are acceptable.

Further discussion of the acceptability considerations outlined in **Section 7** in relation to the unplanned spills aspect of the Crux project is provided below.

Table 8-40: Acceptable Levels of Impacts and Risks from Unplanned Spills

Receptor Category	Receptor Sub-category	Acceptable Level of Impact	Are the Crux Project's Impacts and Risks of an Acceptable Level?
Physical environment	Water quality	No significant impacts to water quality beyond 1 km of the Crux platform or drilling locations.	Yes. Shell considers large-scale releases of hydrocarbons during the Crux project to be unacceptable. Such spills have potential to result in significant environmental impacts. Consequently, Shell will apply its considerable experience and knowledge in the offshore petroleum industry to ensure such a release during the Crux project never occurs. Shell has applied a conservative approach to the identification and modelling of the credible worst-case hydrocarbon spills. This information was used to inform the evaluation of the environmental impacts and risks, and is consistent with the precautionary principle. Shell will implement industry standard controls to manage the risk of unplanned hydrocarbon spills. The EPs for activities undertaken as part of the Crux project are required to have an Oil Pollution Emergency Plan (OPEP) commensurate to the nature and scale of the hydrocarbon pollution risks for the activity.
	Sediment quality	No significant impacts to sediment quality beyond 1 km of the Crux platform or drilling locations.	
Ecosystems, communities and habitats	Benthic communities	No significant impacts to benthic habitats and communities. Impacts to non-sensitive benthic communities limited to a maximum of 5% of the project area.	
	Shoals and banks	No direct impacts to named banks and shoals. No loss of benthic habitats and communities at named banks or shoals as a result of indirect/offsite[23] impacts.	
	Offshore reefs and islands	No impacts to offshore reefs and islands.	
	WA and NT mainland coastline	No impacts to WA and NT mainland coastline.	
	Key Ecological Features	No significant impacts to environmental values of KEFs.	
Threatened species and ecological communities	Marine mammals	No mortality of threatened or migratory MNES fauna from the Crux project. Management of aspects of the Crux project must be aligned to conservation advice, recovery plans and threat abatement plans published by the DoEE. No significant impacts to threatened or migratory MNES fauna.	
	Marine reptiles		
	Birds		
	Fish		
	Sharks and rays		

[23] As defined in the Matters of National Environmental Significance - Significant impact guidelines 1.1 (DoE 2013a).

Receptor Category	Receptor Sub-category	Acceptable Level of Impact	Are the Crux Project's Impacts and Risks of an Acceptable Level?
Socio-economic and cultural environment	Commonwealth Marine Area	No significant impacts to the Commonwealth marine area beyond 1 km from the Crux platform or drilling locations.	
	World Heritage Properties	No impacts to world heritage values.	
	National Heritage Places	No impacts to national heritage values.	
	Commonwealth Heritage Places	No impacts to Commonwealth heritage values	
	Declared Ramsar Wetlands	No impacts to ecological values of Ramsar wetlands	
	Marine Parks	No impacts to the values of marine parks	
	Commercial fisheries	No negative impacts to exploited fisheries resource stocks which result in a demonstrated direct loss of income.	
	Traditional Indigenous fishing	No negative impacts to exploited fisheries resource stocks.	
	Tourism and recreation	No negative impacts to nature-based tourism resources resulting in demonstrated loss of income.	

Principles of ESD

The risks and impacts from the worst-case credible spill scenarios are inherently inconsistent with some of the principles of ESD based on the following:

- environmental resources may be significantly impacted in the event a worst-case credible spill occurs, and
- a worst-case credible spill may prevent others exercising their right to access environmental resources.

Shell will apply a range of controls to ensure that a worst-case credible spill from the Crux project never occurs. These include a range of industry best practices that have been developed through extensive industry experience, including the lessons learned from significant unplanned releases such as the Macondo and Montara well blowouts. Following successful application of these controls, Shell considers the residual risk to be consistent with the principles of ESD. This consistency is achieved by:

- developing natural resources in an environmental responsible manner, resulting in income for government, generation of Australian jobs, and developing an increased understanding of the Timor Sea environment.
- application of the precautionary principle in the assessment of hydrocarbon spill scenarios by:

- using worst-case credible spill scenarios. Industry statistics indicate the vast majority of unplanned spills are significantly smaller than the worst-case credible spills.
- using a stochastic modelling approach for numerical modelling of the worst-case credible spill scenarios that includes a large number (300) of deterministic runs covering a range of metocean conditions, and
- using environmentally conservative adverse exposure zone thresholds.

Relevant Requirements

Management of the impacts and risks from unplanned hydrocarbon spills are consistent with legislative requirements, including:

- compliance with international maritime conventions, including:
  - STCW Convention
  - SOLAS Convention
  - COLREGS, and
  - MARPOL:
    - Annex I: prevention of pollution by oil and oily water.
- compliance with Australian legislation and requirements, including:
  - *Navigation Act 2012* and *Protection of the Sea (Prevention of Pollution from Ships) Act 1983*:
    - Marine Order 21 (Safety of Navigation and Emergency Procedures
    - Marine Order 27 (Radio Equipment)
    - Marine Order 30 (Prevention of Collisions)
    - Marine Order 71 (Masters and Deck Officers), and
    - Marine Order 91 (Marine pollution prevention – oil).
  - OPGGS (E) Regulations:
    - an accepted OPP for the Crux project
    - accepted WOMPs for all well activities, including drilling, operation, suspension and abandonment, and
    - accepted EPs and OPEPs for all petroleum activities associated with the Crux project.
- Implementation of recognised industry best practices, such as:
  - use of BOPs while drilling over-pressured formations with potential for flow, including regular function and pressure testing of the BOPs
  - design, construction and operation of Crux infrastructure in accordance with recognised industry standards
  - mutual aid agreement in place with other petroleum operators to assist with drilling rig availability for relief well drilling
  - agreements in place with oil spill response service providers;
  - leak detection system on export pipeline to detect major incidents, and
  - development of SIMOPS plans for activities that may interact with the Prelude FLNG facility.

Matters of National Environmental Significance

A worst-case hydrocarbon spill may result in significant impacts for several MNES. Shell will put in place a range of measures during all phases of the Crux project to ensure that spills of hydrocarbons that may result in significant impacts to threatened and migratory species do not occur. Shell considers the residual risk to these MNES to be acceptable, after application of the key management controls proposed in this OPP.

Threatened and Migratory Species

The evaluation of impacts and risks indicates that significant impacts to threatened and migratory species may occur in the event of a significant hydrocarbon spill. Pollution from hydrocarbon spills is recognised as a threat in management plans, recovery plans and conservation advice for a number of threatened and migratory species. Alignment of the Crux project with these documents is provided in **Table 8-41**.

Wetlands of International Importance

While considered very unlikely due to the distance from the Crux project area, results from the stochastic spill modelling studies indicated hydrocarbons above impact thresholds may contact the Ramsar wetland at Ashmore Reef.

Commonwealth Marine Environment

The evaluation of impacts and risks indicates that significant impacts to the Commonwealth marine environment may occur in the event of a significant hydrocarbon spill. The potential for widespread impacts to water quality may result in a number of marine species to be affected.

Table 8-41: Summary of Alignment of the Risks and Impacts from Unplanned Spills from the Crux Project with Relevant Requirements for EPBC Threatened Fauna

Sensitivity	EPBC Management Plans/Recovery Plans/Conservation Advices	Threats Relevant to the Project	Demonstration of Alignment as Relevant to the Project
Marine mammals	Significant impact guidelines for Critically Endangered, Endangered, Vulnerable and Migratory species (**Table 7-1**)	Unplanned spills	Shell has identified the potential for hydrocarbon pollution, and potential consequential habitats degradation, from large-scale hydrocarbon releases as a significant environmental risk. Shell has applied a range of controls that are intended to reduce the likelihood of such a release occurring, and mitigative controls to understand and reduce the severity of impacts should such as release occur. Large-scale hydrocarbon releases pose a significant safety risk for Shell personnel, and considerable effort will be applied to the Crux project design to reduce the inherent likelihood of large-scale hydrocarbon releases occurring.
	Conservation management plan for the blue whale: A recovery plan under the *Environment Protection and Biodiversity Conservation Act 1999* (Commonwealth of Australia 2015a)	Pollution (persistent toxic pollutants)	
	Conservation advice *Balaenoptera borealis* sei whale (DoE 2015c)		
	Conservation advice *Balaenoptera physalus* fin whale (DoE 2015d)		
	Conservation management plan for the southern right whale: A recovery plan under the *Environment Protection and Biodiversity Conservation Act 1999* (DSEWPaC 2012)		
Marine reptiles	Significant impact guidelines for Critically Endangered, Endangered, Vulnerable and Migratory species (**Table 7-1**)	Unplanned spills	
	Recovery plan for marine turtles in Australia (Commonwealth of Australia 2017a)	Chemical and terrestrial discharge	
	Conservation advice on short-nosed sea snake (*Aipysurus apraefrontalis*) (DSEWPaC 2010a) Conservation advice on leaf-scaled sea snake (*Aipysurus foliosquama*) (DSEWPaC 2010b)	Degradation of reef habitat	
Birds	Significant impact guidelines for Critically Endangered, Endangered, Vulnerable and Migratory species (**Table 7-1**)	Unplanned spills	
	Wildlife conservation plan for migratory shorebirds (Commonwealth of Australia 2015b)	Oil spills Modification of habitat from pollution	

Sensitivity	EPBC Management Plans/Recovery Plans/Conservation Advices	Threats Relevant to the Project	Demonstration of Alignment as Relevant to the Project
	National recovery plan for threatened albatrosses and giant petrels 2011-2016 (DSEWPaC 2011)		
	Conservation advice for *Sternula nereis* (fairy tern) (DSEWPaC 2011b)		
	Conservation advice *Numenius madagascariensis* eastern curlew (DoE 2015i)		
	Conservation advice *Calidris ferruginea* curlew sandpiper (DoE 2015h)		
	Conservation advice *Anous tenuirostris melanops* Australian lesser noddy (DoE 2015j)		
	Conservation advice *Calidris canutus* red knot (DoE 2016a)		
	Conservation advice *Calidris tenuirostris* great knot (DoE 2016b)		
	Conservation advice *Charadrius leschenaultii* greater sand plover (DoE 2016c)		
	Conservation Advice *Charadrius mongolus* lesser sand plover (DoE 2016d)		
	Conservation advice *Limosa lapponica menzbieri* bar-tailed godwit (northern Siberian) (DoE 2016e)		
Sharks and rays	Significant impact guidelines for Critically Endangered, Endangered, Vulnerable and Migratory species (**Table 7-1**)	Unplanned spills	
	Conservation advice *Rhincodon typus* whale shark (DoE 2015l)	Habitat disruption from mineral exploration, production and transportation	
	Recovery plan for the white shark (*Carcharodon carcharias*) (DSEWPaC 2013a)	Habitat modification/ degradation	
	Sawfish and river shark multispecies recovery plan (Commonwealth of Australia 2015c)		

Sensitivity	EPBC Management Plans/Recovery Plans/Conservation Advices	Threats Relevant to the Project	Demonstration of Alignment as Relevant to the Project
	Approved conservation advice for *Glyphis plyphis* (speartooth shark) (DoE 2014c)		
	Approved conservation advice for *Pristis clavata* (dwarf sawfish) (DEWHA 2009b)		
	Approved conservation advice for green sawfish (DEWHA 2008b)		
Commonwealth marine environment	Significant impact guidelines for Commonwealth marine environment (**Table 7-1**)	Unplanned spills	

Internal and External Context

Shell's ongoing consultation program will consider statements and claims made by stakeholders when undertaking the assessment of impacts and risks. Shell has also considered the internal context, including Shell's environmental policy and ESHIA requirements. The environmental performance outcomes, and the controls which will be implemented, are consistent with the outcomes from stakeholder consultation for the Prelude FLNG facility and Shell's internal requirements.

Shell has, and will continue to maintain, an appropriate spill response framework, which includes regular testing of the response arrangements. This response framework will be applied to all stages of the Crux project.

Acceptability Summary

The assessment of impacts and risks from the worst-case credible unplanned hydrocarbon spills determined the residual impact and risk rating is Major (**Table 8-39**). Given the significant consequence of the risks associated with these worst-case hydrocarbon spills, Shell has undertaken an extensive, conservative risk assessment and will apply a range of controls consistent with relevant requirements and industry best practice. As outlined above, the acceptability of the impacts and risks from unplanned spills associated with the Crux project has been considered in the context of:

- ESD
- relevant legislative requirements
- external context (i.e. stakeholder claims), and
- internal context (i.e. Shell requirements).

Based on the points discussed above, Shell considered the impacts and risks from worst-case unplanned spill scenarios from the Crux project to be acceptable following the application of the controls outlined in **Table 8-39.**

8.4.8.6 Environmental Performance Outcomes

No emergency events[24] associated with the unplanned release of Crux condensate or vessel fuel to the marine environment during the Crux project.

8.4.9 Cumulative Impacts

8.4.9.1 Project Context

This section provides a summary of cumulative impacts considered to be of primary relevance to the Crux project, as appropriate to the early stage evaluation of impacts and risks to be considered at an OPP level of assessment. Given the low likelihood of unplanned events that may arise during the Crux project (e.g. large hydrocarbon spills), unplanned events have not been considered in the assessment of cumulative impacts.

The preceding assessments in **Sections 8.4.1** to **8.4.8** inclusive, have addressed the interaction of the Crux project aspects with the receiving environment on a single-aspect basis. This section builds on those assessments and takes into account the potential for cumulative or additive effects to occur.

As described previously in **Section 6.6.16**, the nearest facility in proximity to the Crux project include the Montara FPSO facility located approximately 36 km north of the Crux platform. The Ichthys Project offshore facilities are located approximately 164 km to the

[24] emergency events are incidents which result in the mobilisation of the Shell emergency response team.

south-west of the proposed Crux platform, and the Prelude FLNG facility is approximately 165 km to the south-west of the Crux platform, representing the location where the export pipeline will feed into.

8.4.9.2 Description and Evaluation of Impacts

The potential for cumulative impacts resulting from the Crux project were considered from two perspectives:

- How might aspects from the Crux project compound with aspects of existing activities within the Timor Sea region? This focussed on the potential interactions with other oil and gas developments, including Prelude, Ichthys and Montara.
- How might an environmental receptor be affected by multiple aspects of the Crux project and other activities? This approach is receptor-based and differs from the aspect-based approach applied in **Sections 8.4.1** to **8.4.8**.

The cumulative impact assessments are presented below.

Aspect-based Cumulative Impacts

The aspects-based cumulative impact assessment considers how the aspects from the Crux project, and the associated environmental impacts, may interact with aspects from other activities in the region to result in increased environmental impacts. Other activities identified included:

- the Prelude FLNG facility
- the Montara production facility
- Ichthys offshore production facility, and
- commercial shipping.

The aspects identified that were common to these activities and the Crux project were:

- physical presence and vessel movements
- light emissions
- atmospheric emissions, and
- liquid discharges.

Each of these are considered in the sections below.

Physical Presence and Vessel Movements

Interactions with other marine users are considered remote, given the relatively minor physical scale of the project, combined with the relatively low level of activity within the open offshore waters of the project area, the potential cumulative impact of offshore petroleum safety zones restricting commercial fishing areas is understood. The petroleum safety zones associated with offshore projects are spatially small (typically 500 m radius) compared to the area available to commercial fisheries, and therefore not expected to represent a large area of displaced fishing effort relative to the available fishing zones.

The physical presence of Crux project facilities/infrastructure and vessels will not have a cumulative impact on marine fauna as it represents a small physical footprint in the context of an open marine environment where marine fauna transit the region.

Vessel movements will be associated with all stages of the Crux project, which is geographically separated from the Montara, Ichthys or Prelude facilities. There is pre-existing marine vessel traffic, including support vessels at the existing operational

facilities. The potential environmental impacts associated with vessels are considered to be largely similar for offshore oil and gas developments in terms of interactions with marine fauna and planned emissions and discharges.

The majority of the vessel movements will be within the vicinity of each project's facilities/infrastructure and equipment. The movement of vessels related to the Crux project will be contained within the in-field development area and the pipeline corridor, with transit to/from nearest port as required. Therefore, overlap of each project's vessel movements in the offshore marine environment is considered unlikely with typical industry navigational practice. Given the broad marine area and the open shipping navigational areas available for vessels in the offshore Browse Basin, this potential for impact 'in-field' is very low. Therefore, cumulative impacts at a local scale from associated with the project in combination with other activities are low. There may be a minor cumulative impact associated with the concurrent transit movement of vessels between Broome and/or Darwin to Crux and other offshore destinations, which may be experienced in or near to the ports of Broome or Darwin. This will be subject to normal marine operational practice of shipping coordination and interface with the respective port authorities and marine users. Therefore, the potential for significant cumulative impact from physical is low.

Light Emissions

Light emissions will be associated with the Crux project, albeit at relatively low levels given the NNM operational philosophy. Given the relative proximity of the Montara FPSO facility (approximately 36 km to the north) and taking into consideration the results of the light impact assessment, there may be some overlap in light emissions from the projects. As presented in **Section 8.4.2**, the extent of light propagation at ambient conditions may theoretically extend up to approximately 38 km, which are comparable to a moonless clear night. This may lead to an incremental increase in light emissions predominantly over open ocean waters, with potential for very slight additive increases at Goeree Shoal or Vulcan Shoal, these representing submergent receptors with limited influence from atmospheric light. However, these cumulative increases are expected to be minimal and are therefore not expected to have a significant cumulative impact on marine fauna.

Atmospheric Emissions

The evaluation of the atmospheric emissions relevant to the Crux project was previously provided in **Section 8.4.4**. In a cumulative context, it is appreciated that the generation of emissions arising from offshore developments are to be considered in the context of cumulative contributions.

CO_2 emissions from the Crux project contribute to total Australian emissions. The effects of global warming and associated climate change are the cumulative effect of many sources across the globe and it is the cumulative effects that ultimately influence climate change. As part of early concept engineering, there are a range of inherent design and operational efficiencies that have been incorporated that support CO_2 efficiency gains.

Shell is committed to enabling technologies that are practical, cost-effective and with outcomes to minimise CO_2 emissions through design and implementation. This will be guided through a Greenhouse Gas and Energy Management Plan as the project progresses.

Liquid Discharges

Planned discharges to the marine environment, such as PFW water, drill cuttings and fluids and wastewater, will be associated with the Crux project, with limited potential to interact with other users or facilities. Conservative modelling of the planned discharges for the Crux project predicted that the discharges would be below ANZECC & ARMCANZ guideline thresholds within a radius of approximately 1 km from the discharge location

(**Section 8.4.7**). Planned discharges from the Montara FPSO facility, as the nearest facility to the in-field development area, are localised and expected to disperse rapidly within close proximity to discharge points, with no expected cumulative effect from liquid discharges overlapping across the projects' area of influence. The Montara facility PFW discharges are regulated in accordance with the conditions of approval (EPBC 2002/755) under the EPBC Act, and associated Operations Environment Plan approvals by NOPSEMA. The in-field development area is an open ocean environment, within a localised impact zone as informed by modelling studies, and geographically from the nearest shoals/banks and other nearest offshore facilities.

A monitoring program will be established to verify that concentrations of planned discharges will meet relevant ANZECC & ARMCANZ guidelines (or within natural variation or background concentration) beyond the predicted mixing zone(s). Considering this, no significant cumulative impacts from planned discharges of PFW and other liquid discharges are expected.

Receptor-based Assessment of Cumulative Impacts

Water Quality

Water quality was identified as being impacted by the following aspects:

- physical presence and vessel movements, and
- liquid discharges.

As outlined in **Section 8.4.1**, the potential for impacts to water quality from the physical presence and vessel movements aspect are negligible and predominantly occur during the development drilling and construction phases of the project. Water quality will recover from impacts from the physical presence and vessel movement aspects rapidly following completion of the activity. Hence the potential for impacts to water quality from this aspect to interact with other aspects is very limited.

Section 8.4.7 described the discrete impacts of the liquid discharge streams that will occur during the Crux project. Many of these are separated temporally or spatially, and hence have negligible potential to interact.

Wastewater and cooling water discharges from vessel are typically small volumes and have relatively low potential for impacts. Given the Crux platform will be NNM, wastewater discharges from the platform will also be negligible. These liquid discharges have negligible potential to interact with other aspects and hence will not result in significant cumulative impacts.

PFW is a large volume continuous discharge during the operational phase of the Crux project. Given this discharge will only occur during the operational phase, it will not interact with other liquid discharges that have considerable potential for impacts to water quality, such as drilling fluids, cuttings and hydrotest water which are limited to discrete activity phases.

Based on the consideration of the potential interactions between aspects of the Crux project that may impact upon water quality, the cumulative impacts are of an acceptable level. Refer to **Section 7** for additional information on the acceptable level of impact to water quality.

Sediment Quality

Sediment quality was identified as being impacted by the following aspects:

- physical presence and vessel movements, and
- liquid discharges.

As outlined in **Section 8.4.1**, the potential for impacts to sediment quality from the physical presence aspect are negligible and predominantly occur during the development drilling and construction phases of the project. The presence of Crux project infrastructure may encourage the deposition, and inhibit the re-suspension, of fine sediments. Fine sediments have a greater surface are to volume ratio and have greater potential to bind potential contaminants such as metals, which are retained in situ. This modification of sedimentary processes may limit the transport of contaminated sediments. It may also result in elevated levels of contaminants in close proximity to potential contaminant sources (e.g. PFW discharge and drill cuttings at the Crux platform location).

The liquid discharges with the greatest potential to impact sediment quality are the discharges of PFW and drilling fluids/cuttings at the Crux platform location. While these activities will not occur simultaneously, the drill cuttings from the foundation wells will remain in situ around the Crux platform. Hence the potential sediment contamination from PFW discharges during the operational phase may result in cumulative impacts to sediment quality. The discharged cuttings at the Crux platform location are expected to have relatively low concentrations of potential contaminants based on the drilling related controls Shell will implement (preference to WBM, no whole SBM discharge, residual SBM < 10% by weight averaged over all sections using SBM). Modelling studies of the PFW plume indicate that it will dilute and mix prior to contacting the seabed, hence the potential for direct interaction with the PFW and the sediments at the base of the Crux platform is not considered credible. Suspended solids arising from the produced water (e.g. solids discharged in the PFW, precipitates formed by dissolved components of the PFW) are expected to be very fine. These fine sediments will have low settling velocities and will be advected away from the discharge location by the currents at the discharge location and are unlikely to be deposited in the area around the platform.

While there is the potential for sediments arising from the discharge of treated PFW to be deposited on top of sediments contaminated by drilling fluids and cuttings, the potential cumulative impacts are not expected to exceed the impacts outlined in the evaluation of impacts from liquid discharges (**Section 8.4.7**). This is based on the following points:

- sediment contamination from drilling fluids and cuttings will be concentrated at the Crux platform and tieback drilling locations.
- sediment contamination is expected to be low based on the controls implemented by Shell.
- the PFW plume will not interact directly with the sediments, and
- solids from the PFW stream are expected to be fine, and advected away from the discharge location by water movement.

Based on the consideration of the potential interactions between aspects of the Crux project that may impact upon sediment quality, cumulative impacts will be of an acceptable level. Refer to **Section 7** for additional information on the acceptable level of impact to sediment quality.

Benthic Communities

Benthic communities (excluding shoals and banks, which are considered separately below) were identified as being impacted by the following aspects:

- physical presence and vessel movements
- underwater noise, and
- liquid discharges.

Benthic communities at the base of the Crux platform will be impacted by the physical presence of the construction of the platform, the discharge of drilling fluid and cuttings, and the ongoing discharge of treated PFW from the platform. The impacts of these aspects of the activity will combine to result in cumulative impacts to benthic communities. The potential for significant cumulative impacts will be limited to the vicinity (i.e. < 100 m) from the Crux platform. The benthic habitats around the Crux platform are characterised by soft sediments with low density epifaunal communities. These are widely represented in the region, are not particularly sensitive.

Benthic habitats and communities along the export pipeline route will be modified by the presence of the pipeline. However, given the majority of the pipeline route is not in close proximity to other sources of impacts (e.g. Crux platform and Prelude FLNG), the potential for cumulative impacts is negligible.

The Continental Slope Demersal Fish Communities KEF lies within pipeline route but is distant form the Crux platform location (approximately 73 km). Shell is not aware of any other activities that have, or credibly will, impact upon the environmental values of this KEF in the Timor Sea; the Prelude, Ichthys and Montara production facilities all lie beyond the KEF and the area is not currently subject to trawl fishing activities. Cumulative impacts from the Crux project on the KEF are not considered credible.

IMR activities that have the potential to impact upon benthic habitats, such as span rectification if required, will be infrequent and highly localised; cumulative impacts from these activities are considered to be negligible.

The drilling of wells will result in disturbance of the seabed from the mooring anchors for the MODU, which will directly disturb the seabed at the anchoring locations. The seabed disturbance from the anchors will recover over time as natural sedimentary processes fill in the holes created by the anchors after they are removed. This disturbance has a negligible potential for cumulative impacts to benthic communities.

Underwater noise impacts are most likely to occur during piling and VSP, as these activities will generate high intensity noise that may propagate considerable distances. Other noise sources (e.g. vessel-related noise) have a low potential for impacts to benthic communities. The benthic communities in the Crux project area are not considered to be particularly sensitive to noise-related impacts and the activities that generate high intensity noise are of relatively short duration (i.e. hours to days). No other high intensity noise sources within the vicinity of the Crux project area have been identified, with noise from other operating petroleum facilities expected to have no potential for impact within the Crux project area. The potential for the underwater noise aspect of the Crux project to contribute to cumulative impacts to benthic habitats is negligible.

The benthic communities within the vicinity of the planned hydrotest discharge will already be impacted by the construction and operation of the Prelude FLNG facility. These benthic communities are also of low sensitivity and are broadly represented in the region. The hydrotest discharge is a one-off impact that is expected to dilute rapidly. The hydrotest water plume will not reach benthic habitats associated with the banks and shoals or the Continental Slope Demersal Fish Communities KEF. Given the non-persistent nature of the impacts from the discharge of hydrotest water, the potential for hydrotest water to result in cumulative impacts is negligible.

Based on the consideration of the potential interactions between aspects of the Crux project that may impact upon benthic communities, the cumulative impacts are of an acceptable level. Refer to **Section 7** for additional information on the acceptable level of impact to benthic communities.

Shoals and Banks

Sediment quality was identified as being impacted by the following aspects:

- underwater noise
- light, and
- liquid discharges.

The distance of the Crux platform from shoals and banks within the Crux in-field development area, along with Shell's implementation of a 1 km buffer around the shoals within which no activities will occur, means that cumulative impacts to banks and shoals are unlikely.

With the exclusion of VSP during the drilling of tieback wells in close proximity to banks and shoals, underwater noise impacts to banks and shoals are considered to be very unlikely due to the distance of these environmental receptors from the Crux platform. Noise from piling is unlikely to significantly impact the communities, although the 24-hour TTS threshold for fish may be exceeded at Goeree Shoal if a relatively heavy hammer is required for piling. As this impact is temporary, any fish impacted are expected to recover. VSP may be undertaken during drilling of tieback wells, which will result in acoustic emissions to the marine environment, however modelling studies indicated these would not exceed impact thresholds for fish, cetaceans or marine turtles (SVT 2018). Any tieback wells will be at least 1 km from the boundary of the shoals within the Crux in-field development area. Other activities that may impact upon the shoals (e.g. light and VSP noise from a MODU drilling a tieback well) will not occur simultaneously with piling; tieback wells are not expected to be required for a number of years after initial production commences from the Crux foundation wells.

Given the distances of potential light and liquid discharge sources from banks and shoals (> 13 km for the Crux platform, > 1 km for any tieback wells), these aspects will not credibly impact upon the biota of the banks and shoals. Results from modelling studies of drilling fluids and cuttings discharges indicated that impacts from sediment deposition will be limited to > 326 m (RPS 2018a). Suspended sediment plumes from drilling will not exceed impact thresholds at > 1 km (i.e. the buffer distance around the shoals). Hence cumulative impacts exacerbated by light or liquid discharges will not credibly occur.

Based on the consideration of the potential interactions between aspects of the Crux project that may impact upon shoals and banks, cumulative impacts will be of an acceptable level. Refer to **Section 7** for additional information on the acceptable level of impact to shoals and banks.

Threatened Species and Ecological Communities

A number of threatened and migratory under the EPBC Act were identified as potentially occurring within the Crux project area. These were identified as being impacted by the following aspects:

- physical presence and vessel movements
- underwater noise
- light
- waste management, and
- liquid discharges.

Migratory species are of particular concern when assessing cumulative impacts, as impacts to critical habitats that are distant from the Crux project area may make them

more vulnerable. For example, loss of critical nesting and foraging habitats for migratory birds that nest in east Asia may make these species more vulnerable to impacts in their migratory corridors.

The planned impacts to threatened from the Crux project are very low, and do not exceed the significant impact triggers for threatened and migratory species outlined in **Section 7**. Where applicable, aspects of the Crux project are aligned to conservation advice, threat abatement plans, and recovery plans published by the DoEE. As such, cumulative impacts to threatened and migratory species from planned impacts from the Crux project are not considered credible.

Based on the consideration of the potential interactions between aspects of the Crux project that may impact upon threatened and migratory species that are MNES, cumulative impacts to will be of an acceptable level. Refer to **Section 7** for additional information on the acceptable level of impact to threatened and migratory species that are MNES.

8.4.9.3 Conclusion

The project will not result in any material cumulative impacts to the marine environment at a local scale as there is no significant overlap with other existing facilities. No cumulative impacts to key values and sensitivities are expected. Therefore, the residual impact rankings detailed in the previous aspect assessments (**Sections 8.4.1** to **8.4.8** inclusive) remain unchanged.

Regional cumulative impacts may occur in terms of incremental increases in vessel movements and CO_2 emissions. However, these have been assessed as minor and do not change the residual impact rankings for any of the potential impacts assessed in this OPP.

The potential cumulative impacts to environmental receptors are low and will be largely restricted to the waters, sediment and benthic habitats and communities in the immediate vicinity of the Crux platform. Potential cumulative impacts, both aspect- and receptor-based, were all determined to be within the acceptable levels defined in **Section 7**.

8.4.10 Health Impacts

8.4.10.1 Project Context

This section assesses the potential public health impacts of the Crux project on local communities relevant to the socio-economic environment. The anticipated health impacts associated with the Crux project with potential to affect any onshore communities, in particular the onshore logistics bases of Broome and Darwin, are expected to be very minor with due consideration of:

- the remote offshore context for this project. The majority of construction and operation activities are well offshore, 620 km from Broome and approximately 700 km from Darwin.
- the logistical arrangements for transiting workers aims to minimise overnight stays in onshore locations, and seeking to utilise existing established supply chain logistics now in place for Prelude FLNG, and
- existing industrial areas will be utilised for bases in Broome and/or Darwin.

8.4.10.2 Description and Evaluation of Impacts and Risks

The project presents a number of potential hazards that may have occupational health consequences for workers if not managed appropriately. In particular, the potential for exposure to hazardous materials, equipment, air emissions and excessive noise levels

which could result in injury or fatality. These occupational health risks do not extend to onshore communities due to the significant distance of the Crux project from coastal communities. Similarly, the Crux project is distant from other facilities, such as Prelude or Montara, therefore interaction effects for considerations such as air emissions or noise amenity are not realistic, although there may be potential for noise from aircraft/helicopters in Broome in support of project personnel transfers. The risks to workers associated with the project and the appropriate workplace health and safety arrangements are addressed through Shell's Occupational, Health and Safety policies and procedures, and NOPSEMA/WorkSafe requirements (e.g. through Safety Case and occupational health and safety commitments). While fundamentally important to maintain positive health and wellbeing, occupational health and risk impacts are not within the scope of this OPP document for the evaluation of environmental impacts/risks.

Community Health Services

Onshore projects, in particular during construction, typically have some local impact on healthcare facilities and services. This is usually due to project drawing on the local healthcare system to meet worker needs for, among other things, health checks, medical examinations and vaccinations. Given the offshore nature of the Crux project, with relatively low personnel requirements compared to onshore gas facilities, this demand will be much less for the Crux project as onshore construction activities are limited.

Workers that cannot be adequately treated offshore will be brought to the nearest onshore health facility for treatment. Local healthcare services could also be called upon in the event of an emergency or non-routine event such as a serious offshore incident involving multiple workers requiring immediate medical treatment; however, the likelihood of this is low, and given the low personnel requirements for the project and the typical industry arrangements to be well equipped in emergency response arrangements for offshore operations, this is unlikely to present a significant demand on existing community services. In the event of a significant emergency, some additional external resources may need to be drawn on.

Given the offshore context, community interaction with the Crux project will be limited. The use of health facilities and services such as doctors, dentists, chemists and hospital beds by the onshore workforce in Broome or Darwin is likely to be minimal as only a small number may need to access local health facilities and services during their roster and while travelling to and from the facility. Offshore Fly-In Fly-Out workers are not expected to be in the local onshore communities for any length of time and are unlikely to seek elective healthcare services locally. The social receptors that could be affected by additional demands on community health services are the local onshore communities, tourists visiting the area and regional communities. In the event of a major non-routine event requiring major assistance, the Royal Flying Doctor Service, General Practitioners, paramedics and other local healthcare professionals will be called upon as required to respond to the situation at the time.

Should a non-routine event occur, access for Broome and/or Darwin residents to both regular and emergency health services could be reduced. The effects of the service reduction would be limited in duration but could be highly disruptive for local residents and service providers. Shell's Emergency Planning will therefore include early discussions with local health authorities on arrangements for triage, coordination of emergency response and maintenance of health services for local residents. Community health impacts associated with the Crux project are expected to be of minor magnitude for routine activities, and hence the significance has been assessed to be minor.

Workforce Influx Pressures

The Crux project will result in the increased presence of workers in Broome and/or Darwin, with a commensurate increase in the number of vessel/helicopter movements to/from the town, which will vary depending on the stage of project development.

There is potential for a 1–2-year peak period during peak construction. It is reasonably expected that the Broome community will experience some increased presence (including probably overnight stays) of Fly-In Fly-Out project workers during this peak construction phase. During steady state operations, there will be personnel transfers to Crux platform, which is expected to be preferentially by vessel via the Prelude FLNG facility. It is anticipated that there will be short-term intermittent increases associated with planned maintenance, for example during shutdowns (40 POB).

The addition of a project workforce has potential to contribute to existing pressures on public health capacity in the local communities. In the context of the Crux project, as an offshore project with minimal workforce requirements associated with the NNM operational philosophy, Shell is not anticipating significant impacts on this context. Shell is committed to building on the existing local supply chain logistics and arrangements that are now established with Prelude, in a manner that minimises disturbance to local communities and supports local content where practical. This includes, for example, the intent to replicate the arrangements for flights in/out of Broome to be scheduled in accordance with the Broome International Airport Fly Neighbourly Policy, which will also support the objective to minimise social amenity disturbance from intermittent noise.

8.4.10.3 Risk and Impact Summary and Key Management Controls

Table 8-42: Public Health Evaluation of Impacts and Risks

Project Component/ Activity	Environmental Value/Sensitivity				Evaluation – Planned		
	Physical Environment	Threatened Species and Ecological Communities	Ecosystems, Communities and Habitats	Socio-economic and Cultural Environment	Magnitude	Sensitivity	Residual Impact
Evaluation – Planned Impacts							
Planned impacts resulting from the Crux project, including: • effects on community health services, and • workforce influx pressures				X	Minor effect	Low	Minor
Key Management Controls							
An ongoing stakeholder engagement program will be undertaken as the project progresses through future phases of development planning and implementation. Emergency Planning will include early discussions with local health authorities on local community arrangements to provide appropriate support in the scenario of medical response. The Crux platform is designed to operate under a NNM concept, which will deliver benefits of minimal workforce requirements and commensurate minimal disturbance to onshore communities Scheduling of flights in accordance with the Broome International Airport Fly Neighbourly Policy. Shell will aim to replicate Prelude planned flight considerations (flight plans/times), which are designed to minimise local disturbance: • No flights on Sundays							

- Reduced number of flights on Saturday, and
- Flying route to avoid Roebuck Bay and local Aboriginal community (Mallingbar).

Shell is considering local content and progressing an AIP plan as part of the development of the Crux project.

8.4.10.4 Acceptability

Shell Australia's activities are governed in full alignment with the Shell General Business Principles. Key to these principles is that Shell employees share a set of core values – honesty, integrity and respect for people. Key principles include:

- local communities – Shell aims to be a good neighbour by continuously improving the ways in which we contribute directly or indirectly to the general wellbeing of the communities within which we work. We manage the social impacts of our business activities carefully and work with others to enhance the benefits to local communities, and to mitigate any negative impacts from our activities. In addition, Shell companies take a constructive interest in societal matters, directly or indirectly related to our business.
- communication and engagement – Shell recognises that regular dialogue and engagement with stakeholders is essential. In our interactions with local communities, we seek to listen and respond to them honestly and responsibly. Part of this commitment is ensuring those people and organisations that are impacted by our activities are engaged, and that their concerns are heard and responded to.

It is through this process of open engagement and dialogue, with strong emphasis on HSSE & SP governance through the Shell Control Framework, that public health impacts are demonstrably managed as core business to be acceptable and appropriate to the offshore context of the Crux project.

The residual impacts and risks are minor. Shell considers residual impacts of minor or lower to be acceptable if they meet legislative and Shell requirements. The discussion above demonstrates that these requirements have been met in relation to human health aspects of the Crux project.

Based on the points discussed above, Shell considered the impacts and risks from health impacts relevant to the Crux project to be acceptable.

Shell will continue to assess and manage community health impacts associated with the Crux project throughout the asset's life. There is no proposed environmental performance outcome proposed to manage the low level of inherent community health impact associated with the project.

9 Environmental Performance Framework

9.1 Introduction

This section of the OPP presents an Environmental Performance Framework for the Crux project. The purpose of this framework is to demonstrate Shell's delivery mechanism for the commitments made in this OPP and outline the monitoring that will be undertaken throughout project execution.

As presented in **Section 8**, EPOs have been developed in line with NOPSEMA's definition of an EPO as a "*measurable level of performance required for the management of environmental aspects of the project to ensure that the environmental impacts are risks will be of an acceptable level*" (NOPSEMA 2018a).

Given the intent of an OPP as an early stage, 'whole-of-project' approvals document, the EPOs defined for the Crux project are appropriately high-level, with a focus on the key environmental outcomes to be achieved commensurate to the impact/risk conclusions in **Section 8**. These will be proceeded by EPOs which are further refined for the purpose of developing activity-specific EPs, at which stage further definition of environmental risks, impacts and controls will be available.

The Environmental Performance Framework specific to the Crux project has been developed in line with Shell's HSSE & SP Policy (**Section 3**), principles of ESD and the relevant legislative requirements, codes, standards and guidelines available at this time (**Section 2**). Future activity-specific EPs will incorporate any contemporary changes to these requirements, codes, standards and guidelines, applicable at the time of the specific activity.

9.2 Environmental Acceptability

Through the impact and risk evaluation process presented in **Section 8**, the conclusions of acceptability are drawn with reference to the consideration of:

- all practicable measures have been identified commensurate with the risks and impacts
- internal context – the proposed controls and residual risk level are consistent with Shell policies, procedures and standards
- external context – consideration of the environment consequence and stakeholder expectations, and
- other requirements – the proposed controls and residual risk level are consistent with national and international standards, laws and policies.

The specific EPOs, and corresponding Key Management Controls, for each aspect are summarised in **Sections 8.4.1** to **8.4.10** inclusive, and are therefore not repeated in this section.

The key management controls will provide evidence of compliance and ensure EPOs are achieved and will be carried into the activity-specific EPs as defined in this early-stage OPP. Regular checks and performance reviews will be undertaken during the life of the project to ensure performance is maintained at each stage of the project.

Shell has considered the principles of ESD, as defined in Section 3A of the EPBC Act:

- decision-making processes should effectively integrate both long-term and short-term economic, environmental, social and equitable considerations

- if there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation
- the principles of inter-generational equity – that the present generation should ensure that the health, diversity and productivity of the environment is maintained or enhanced for the benefit of future generations
- the conservation of biological diversity and ecological integrity should be a fundamental consideration in decision-making, and
- improved valuation, pricing and incentive mechanisms should be promoted.

A summary of the Crux project, with regard to the Principles of ESD, is provided in **Table 9-1**.

Table 9-1: Summary of the Crux Project with Regard to the Principles of ESD

Principle of ESD	Project Alignment
Decision-making processes should effectively integrate both long-term and short-term economic, environmental, social and equitable considerations.	The evaluation presented in this OPP, as a whole-of-project life assessment, takes into account both short-term and long-term considerations and potential impacts and risks as relevant to the Crux offshore context. Specifically, alignment of the project with this principle is demonstrated with regard to: • Shell's HSSE & SP Management Framework, which mandates HSSE & SP principles and expectations for all assets throughout the project life-cycle • Provision of gas to support the continued operation of Prelude FLNG, is an important transitional fuel to meet regional and global demand for energy in a sustainable framework, with significant contribution to Government taxation revenue, creation of employment opportunities and economic growth.
If there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation (i.e. the precautionary principle).	An evaluation of all impacts and risks associated with the Crux project has been undertaken within this OPP (**Section 8**) and key management controls defined as relevant to the nature and scale of the potential impacts/risks. The assessment has acknowledged any specific areas where there may be some level of uncertainty (i.e. confidence), and this has been taken into account when defining the potential impacts and risks and residual risk rating. The assessment has been informed by a detailed marine baseline studies program and understanding of the marine environment (**Section 6**). The evaluation has also been informed by modelling, which has a number of levels of conservatism built in to take into account uncertainty in final project design.
The principle of inter-generational equity: that the present generation should ensure that the health, diversity and productivity of the environment is maintained or enhanced for the benefit of future generations.	The key management controls and EPOs, as presented in this OPP have been defined with consideration of this principle. The Crux project will ultimately provide source of gas for the continued operation of the Prelude FLNG facility, in an environmentally responsible manner to support intergenerational equity and stewardship.
The conservation of biological diversity and ecological integrity should be a fundamental consideration in decision-making.	The conservation of biological diversity and overall ecosystem integrity has been considered in the systematic evaluation of relevant impacts and risks (**Section 8**) to derive a conclusion of acceptability, and has been informed by a detailed understanding of the existing environment (**Section 6**) within the project area and wider area of influence. The key management controls and EPOs, as presented in **Section 8**, have also been defined with consideration of this principle.

Principle of ESD	Project Alignment
Improved valuation, pricing and incentive mechanisms should be promoted.	The key management controls, including the governing requirements embedded in Shell's HSSE & SP Control Framework, align with this principle, where practicable and relevant to this Crux project context.

9.3 HSE-MS Implementation and Review

9.3.1 Introduction

Shell manages all HSSE & SP aspects in accordance with the Shell Group Health, Security, Safety and Environment Policy (**Figure 3-1**). The Shell HSSE & SP-MS Manual is applicable to all Shell business groups and governs the effective management of these aspects and the implementation and review of environmental performance, as described in **Section 3.3** and further detailed in the following sections.

9.3.2 Contractor HSSE Management Process

Throughout the Crux project lifecycle contractors and sub-contractors will complete project related activities on behalf of Shell. Shell's HSSE & SP Control Framework (outlined in **Section 3**) contains the HSSE & SP requirements that apply to every Shell company, contractor and joint venture under Shell's operational control.

To ensure integrity, health and safety risks are effectively managed throughout the contract lifecycle, and for all contracted activities, Shell implements pre- and post-contract award processes in line with the Shell HSSE & SP Control Framework. Several key contractor HSSE & SP management processes are listed in **Table 9-2**.

A post contract award gap assessment may also be performed between Shell's HSSE & SP Control Framework and each contractor's plan for completeness.

Table 9-2: Key Shell Pre- and Post-Contract Award Processes

Pre-Contract Award Activities	Post-Contract Award Activities
• Appointing a competent Contract Owner and Contract Holder for each contract • Assess contract HSSE & SP risk and contract mode: Identifying the HSSE &SP risks associated with the contracted activities and defining how to manage the risks • During the bid evaluation, assessing whether the contractor has the capability and resources to manage the HSSE & SP risks, through HSSE & SP prequalification assessments (green-banding) • Before contract award, confirming that the contractor meets requirements. Focus on closing gaps in draft contract HSSE & SP Plan submitted by contractor • Defining the contractor HSSE key performance indicators • Defining the level of Company monitoring based on the capability of the contractor and the contract HSSE & SP risk	• Verifying that the contractor and its personnel have been informed of the HSSE & SP requirements of the contract • Verifying that the contractor manages the HSSE & SP requirements of the contract and review and approve the Contract HSSE & SP Plan when it is required • Monitoring and regularly assessing the HSSE & SP performance of the contractor • Regularly reviewing the management of risks in contracted activities

9.3.3 Competency Requirements and Assurance

It is the responsibility of each contractor to assure the competence of their personnel, and to ensure that their personnel have the appropriate level of competence required to safely and effectively carry out their work.

Competence Assurance Plans aligned with Shell training requirements will be developed for the Crux project. These Competence Assurance Plans will ensure contractor personnel records are maintained in a centralised manner and kept up-to-date with regard to personnel qualifications and experience.

9.3.4 Environmental Audits and Assurance

The Shell HSSE & SP MS Manual provides a structured and documented framework for the implementation, monitoring and reporting of HSSE compliance. Project specific Annual HSSE Plans stipulate the timing of environmental audits and reviews to be undertaken. This includes contractor HSSE audit, waste management audit/review, gap analyses against HSSE Control Framework Manuals, and compliance audits against EPs and this OPP.

To assure the functionality of the HSSE & SP MS as a whole, intermittent Shell Group audits are also undertaken across all Shell businesses. The results of these audits feed back into the process in the form of corrective actions that inform the improvement process. Corrective actions are monitored and reviewed through to completion. Assurance for the Crux platform will be executed as per an annual HSE assurance plan.

9.3.5 Management of Incidents and Non-Conformances

The Shell Australia HSSE Incident Reporting, Investigation and Follow up process governs the management of all HSSE incidents. For the purpose of this process, non-conformances are treated and referred to in the same manner as incidents. All employees and contracted staff are encouraged to submit incident reports such that all incidents may be successfully entered in the incident recording system.

Dedicated HSE Business Performance Reviews also require the number of incidents to be reported to Shell Group on a quarterly basis in accordance with the Shell Group (PMR standard.

9.3.6 Emergency Preparedness and Response

9.3.6.1 Spill Response

Oil Pollution Emergency Plan

An OPEP is an operational document which outlines the processes to be followed to effectively respond in the event of an unplanned release of hydrocarbons resulting from project activities. NOPSEMA (2018d) requires that an OPEP includes "*adequate arrangements to ensure that titleholders can implement oil pollution response control measures in a timely manner and for the duration of the activity.*"

Commensurate to this, an OPEP details the actions to be undertaken in response to an incident, the hierarchy for command, control and communication, and the emergency specialist response groups, statutory authorities and other relevant external bodies required for interface.

An integrated Crux – Prelude OPEP will be developed. The OPEP will incorporate a spill impact mitigation assessment which will assess the potential environmental benefit and detriment associated with each relevant spill scenario, and an ALARP assessment.

The OPEP will be tailored to the nature and scale of the hydrocarbon spill, providing situational awareness which is critical to an effective spill response. As per Regulation 14 (8A) of the OPGGS (E) Regulations, Shell will conduct a desktop and/or field-based test of OPEPs.

Operational and Scientific Monitoring Program

An OSMP will be developed as required by NOPSEMA to be deployed in the event of a hydrocarbon spill. The OSMP is crucial in determining the extent, severity and persistence of any impacts resulting from a hydrocarbon spill. The OSMP may also be used to determine the effectiveness of the spill response (OPEP), and inform future OPEPs and spill response, and enable an assessment of environmental performance.

The Shell OSMP will comprise a number of scientific and operational monitoring plans, as well as an implementation plan, which will serve to guide spill response and assess potential environmental impacts. It is expected that the existing OSMP framework, as established for Prelude, will be reviewed and extended as appropriate to accommodate Crux.

Shell has a number of existing alliances with service providers and businesses within the industry which may be leveraged in the event of a hydrocarbon spill. These will be reviewed and incorporated into the development of an OSMP.

9.3.7 Monitoring and Measurement of Emissions, Discharges and Environment Quality

Emissions and discharges from the Crux platform and ambient environment quality will be monitored on an ongoing basis.

Sections 5.7 and **8.4** provide a description of the emissions and discharges associated with the Crux platform and whole of life-cycle activities, and the relevant key controls to achieve ALARP. The monitoring frequency of key discharges and emissions are further summarised in **Table 9-3**. The specific parameters to be monitored and recorded will be further refined as the project progresses.

Table 9-3: Summary of Discharge and Emission Monitoring

Monitoring Program	Objectives	Indicative Frequency
Marine Discharges		
Crux platform monitoring Environment monitoring (water, quality, sediments and benthic habitats)	To understand impacts from the discharge of PFW from the Crux platform to inform if further action is required in order to meet the relevant EPO on an ongoing basis	Continuous monitoring, whilst available, of PFW discharge volume (online flow meter) and dispersed oil-in-water (online oil-in-water analyser) Chemical characterisation of PFW Additional monitoring as a result of trigger actions Periodic environment monitoring within the in-field development area.
Whole Effluent Toxicity testing	To characterise operational PFW discharges and to inform triggers appropriate to the relevant local environmental receptors (e.g. benthic communities)	Initially when a suitably representative PFW sample of normal operations could be taken, and then on a risk-based approach thereafter.
Atmospheric Emissions		
GHG emissions (e.g. from flaring, fuel gas and diesel combustion, and fugitive emissions)	To record and report emissions as required by the *National Greenhouse and Energy Reporting Act 2007* and the Safeguard Mechanism*	Ongoing to inform annual submission of NGER reports* during the operational stage of the project

Monitoring Program	Objectives	Indicative Frequency
Criteria pollutant emissions (e.g. from flaring, fuel gas and diesel combustion, and fugitive emissions)	To record and report emissions as required by the *National Pollutant Inventory**	Ongoing to inform annual submission of NGER reports* during the operational stage of the project

* Or in accordance with any relevant contemporary requirements at the time of activity.

The monitoring programs detailed in **Section 8.4** and summarised in **Table 9-3** for emissions and discharges, will form the basis of adaptive management frameworks developed for inclusion in activity-specific EPs. These frameworks will be consistent with a whole-of-project adaptive environmental management approach which will allow tailored management as the project progresses.

Adaptive management will allow adjustment in the relevant monitoring programs should more suitable monitoring approaches become available or sampling indicates contaminants are trending toward levels in exceedance of the relevant performance standards. The adaptive management framework will enable Shell to consistently manage risks and impacts to acceptable levels. The circular nature of the adaptive management framework will also enable further understanding and management of the environmental impacts related to project activities.

10 References and Acronyms

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10.2 List of Acronyms

Acronym	Definition
ABS	Australian Bureau of Statistics
ADB	Asian Development Bank
AFMA	Australian Fisheries Management Authority
AFZ	Australian Fishing Zone
AGRU	Acid Gas Removal Unit
AIMS	Australian Institute of Marine Science
AIP	Australian Industry Participation
ALARP	As Low as Reasonably Practicable
AMOSC	Australian Marine Oil Spill Centre
AMP	Australian Marine Park
AMSA	Australian Maritime Safety Association
ANSD	Australian National Shipwrecks Database
ANSI	American National Standards Institute
ANZECC & ARMCANZ	Australian and New Zealand Environment and Conservation Council and Agricultural and Resource Management Council of Australia and New Zealand
APPEA	Australian Petroleum Production and Exploration Association
ARP	Applied Research Program
BIA	Biologically Important Area
BoM	Bureau of Meteorology
Bonn Convention	Convention of the Conservation of Migratory Species of Wild Animals 1979
BOP	Blowout Preventer
BRUV	Baited Remote Underwater Video Station
BTEX	Benzene, Toluene, Ethylbenzene and Xylene
BWM	The International Convention for the Control and Management of Ships' Ballast Water and Sediments
CAMBA	Agreement Between the Government of Australia and the Government of the People's Republic of China for the Protection of Migratory Birds and Their Environment 1986
CAPEX	Capital Expenditure
CCS	Carbon Capture and Storage
CO_2	Carbon Dioxide
COLREGS	International Regulations for Preventing Collisions at Sea 1972
CSIRO	Commonwealth Scientific and Industrial Research Organisation
cP	Centipascals
DAC	Djarindjin Aboriginal Corporation
DAWR	Department of Agriculture and Water Resources
dB	Decibel
DBCA	Department of Biodiversity, Conservation and Attractions
DEC	Department of Environment and Conservation
DEH	Department of Environment and Heritage
DEWHA	Department of Environment, Water, Heritage and the Arts
DFES	Department of Fire and Emergency Services
DHA	Department of Home Affairs
DIIS	Department of Industry, Innovation and Science
DMIRS	Department of Mines, Industry Regulation and Safety
DMP	Department of Mines and Petroleum

DO	Dissolved Oxygen
DoE	Department of the Environment
DoEE	Department of the Environment and Energy
DoF	Department of Fisheries
DP	Dynamic Positioning
DPIRD	Department of Primary Industries and Regional Development
DPLH	Department of Planning, Lands and Heritage
DSEWPaC	Department of Sustainability, Environment, Water, Population and Communities
DWER	Department of Water and Environmental Regulation
EAA	East Asian-Australasian
EHS	Environment Health and Safety
EIS	Environmental Impact Statement
EPBC Act	*Environmental Protection, Biodiversity and Conservation Act 1999*
EPs	Environmental Plans
E&P Forum	Exploration and Production Forum
EPOs	Environmental Performance Outcomes
ESD	Ecologically Sustainable Development
ESHIA	Environment, Social, and Health Impact Assessment
FEED	Front End Engineering and Design
FID	Financial Investment Decision
FLNG	Floating Liquefied Natural Gas
FPSO	Floating Production Storage and Offloading
g	Grams
GHG	Greenhouse Gas
h	Hour
ha	Hectares
HEMP	Hazards and Effects Management Process
H_2S	Hydrogen Sulfide
HSE	Health Safety and Environment
HSSE	Health, Security, Safety, the Environment
HSSE & SP	Health, Security, Safety, the Environment and Social Performance
HSSE & SP-MS	Health, Security, Safety, the Environment and Social Performance Management System
Hz	Hertz
IOGP	International Association of Oil and Gas Producers
IFC	International Finance Corporation
IFO	Intermediate Fuel Oil
IMS	Invasive Marine Species
IMO	International Marine Organisation
ISQG	Interim Sediment Quality Guideline
IPIECA	International Petroleum Industry Environmental Conservation Association
ITF	Indonesian Throughflow
IUCN	International Union for Conservation of Nature
JAMBA	Agreement Between the Government of Australia and the Government of Japan for the Protection of Migratory Birds in Danger of Extinction and Their Environment 1974
KBAs	Key Biodiversity Areas
KDL	Key Decision Log

KEF	Key Ecological Features
kHz	kilohertz
kJ	Kilojoule
km	Kilometers
L	Litres
$L_{E,p}$	Sound Exposure Level
L_p	Sound Pressure Level
L_{pk}	Peak Pressure Level
LNG	Liquified Natural Gas
LP	Low Pressure
m	Meters
mm	Millimeters
MARPOL 73/78	International Convention for the Prevention of Pollution from Ships 1973
MEG	Monoethylene Glycol
mg	Milligrams
MNES	Matters of National Environmental Significance
MoU	Memorandum of Understanding
MPPE	Macro-Porous Polymer Extraction
µPa	Micropascals
MPR	Modular Platform Rig
NAGD	National Assessment Guidelines for Dredging
NAXA	North Australian Exercise Area
NEPC	National Environmental Protection Council
NEPMS	National Environmental Protection Measures
NGER	National Greenhouse and Energy Reporting
nm	Nautical Mile
NMR	North Marine Region
NNM	Not Normally Manned
NOAA	National Ocean and Atmospheric Administration
NOEC	No Observed Effect Concentration
NORM	Naturally Occurring Radioactive Material
NOPSEMA	National Offshore Petroleum Safety and Environmental Management Authority
NOPTA	National Offshore Petroleum Titles Administrator
NO_X	Oxides of Nitrogen
NPD	Naphthalene, Phenanthrene, Dibenzothiophene
NPI	National Pollutant Inventory
NRETAS	Department of Natural Resources, Environment, the Arts and Sport
NT	Northern Territory
NWMR	North-west Marine Region
NWS	North West Shelf
NWSTF	North West Slope Trawl Fishery
ODS	Ozone Depleting Substance
OPEP	Oil Pollution Emergency Plan
OPGGS	Offshore Petroleum and Greenhouse Gas Storage
OPGGS (E) Regulations	Offshore Petroleum and Greenhouse Gas Storage (Environment) Regulations, 2009
OPP	Offshore Petroleum Proposal
OSMP	Operational and Scientific Monitoring Program

PAH	Polycyclic Aromatic Hydrocarbon
PAR	Photosynthetically Active Radiation
PFW	Produced Formation Water
PIG	Pipeline Inspection Gauge
PLET	Pipeline End Termination
PLEM	Pipeline End Manifold
ppb	Parts Per Billion
ppm	Parts Per Million
POB	Persons on Board
POTS Act	*Protection of the Sea (Prevention of Pollution from Ships) Act 1983*
PSU	Practical Salinity Unit
PTTEP	Petroleum Authority of Thailand Exploration and Production
PTS	Permanent Threshold Shift
PQL	Practical Quantification Limit
PWSNT	Parks and Wildlife Service Northern Territory
RAM	Risk Assessment Matrix
Ramsar	International Convention on Wetlands of International Importance
ROKAMBA	Agreement Between the Government of Australia and the Government of the Republic for Korea for the Protection of Migratory Birds and Their Environment, 2002
RO	Reverse Osmosis
SEL	Sound Exposure Level
SBM	Synthetic Based Mud
SGG	Synthetic Greenhouse Gas
SGH	Seven Group Holdings
Shell	Shell Australia Proprietary Limited
SIMPOS	Simulataneous Operations
SOLAS convention	The International Convention for the Safety of Life at Sea 1974
SO_X	Sulphur Oxides
SPL	Sound Pressure Level
STCW Convention	International Convention on Standards of Training, Certification and Watchkeeping for Seafarers 1978
TEG	Triethylene Glycol
TKN	Total Kjeldahl Nitrogen
TLP	Tension Leg Platform
tpa	Tonnes Per Annum
TPH	Total Petroleum Hydrocarbons
TRH	Total Recoverable Hydrocarbons
TTS	Temporary Threshold Shift
TSS	Total Suspended Solids
µm	Micrometre
WA	Western Australia
WAFIC	Western Australian Fishing Industry Council
WAM	Western Australian Museum
WAMSI	Western Australian Marine Science Institution
WB	World Bank
WBM	Water Based Mud
WOB	Water Over Board

WOMP	Well Operations Management Plan
w/w	Weight per Weight
VOCs	Volatile Organic Compounds
VSP	Vertical Seismic Profiling

Appendix A: Water Quality Study (AECOM 2016)

Crux Field Baseline Water Quality Assessment

Shell Crux Baseline Environmental Surveys



Crux Field Baseline Water Quality Assessment

Shell Crux Baseline Environmental Surveys

Client: Shell Australia Pty Ltd

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Executive Summary

The Crux Field is located in Commonwealth waters in the Browse Basin (Timor Sea) approximately 110 km south-east of Cartier Island, 200 km off the Kimberley coast, 260 km from the Indonesian archipelago and East Timor and 600 km north-north-east of Broome, Western Australia. The field is on the Sahul Shelf in the Australian waters of the Territory of Ashmore and Cartier Islands Adjacent Area in permit AC/RL9. Water depths in the field range from 110 m to 170 m. The approximate field dimensions are 8 km long by 5 km wide (Shell 2014).

Shell Australia Proprietary Limited plans to pipe gas from the Crux Field, within the Browse Basin, to the Prelude Floating Liquefied Natural Gas Development, approximately 160 km south-west of the Crux Field.

The project is in the early Select Phase and as such a number of concepts are under consideration including:

- a Floating Production Storage and Offloading (FPSO) facility or a fixed platform in the Crux Field
- a pipeline from the Crux Field to the Prelude Field.

These proposed concepts, along with drilling, subsea and pipeline infrastructure will impact on the seabed environment throughout the project area during construction and ongoing operations.

This report outlines the outcomes from the water quality baseline survey undertaken in the Crux Field in April/May 2016. The survey included water sampling and analysis at 24 sites surrounding the proposed drill centres and FPSO locations, along the proposed pipeline route and at four reference sites.

The survey found water quality in the AC/RL9 area to be generally very good and can be classified as effectively unmodified which would be expected given the remote location of the Crux Field. This is reflected in the results presented whereby all but a very small number of toxicant concentrations were observed to be below the Guideline 99% species protection (where PQLs were sufficiently low). Findings of this study included:

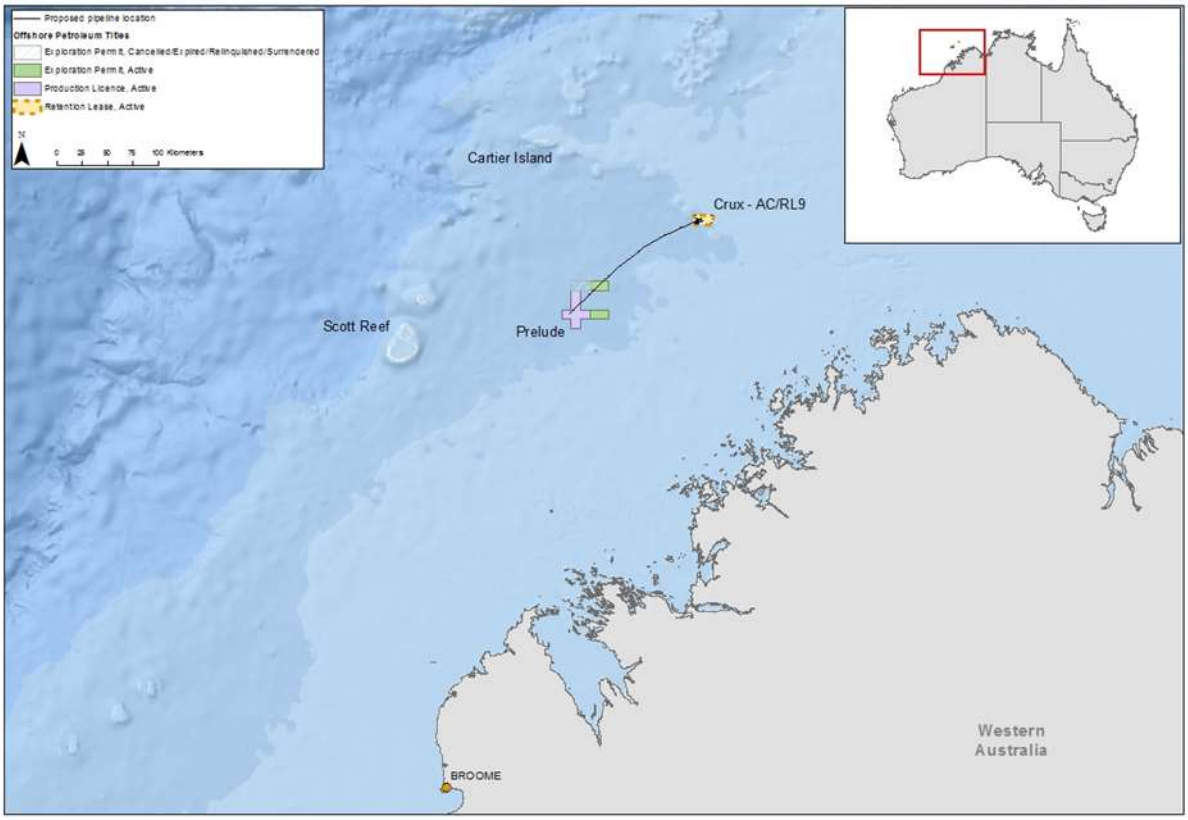
- Petroleum hydrocarbons below the detectable limit indicating no evidence of impact from petroleum development sites or natural seeps in the region.
- Metals concentrations were all within expected ranges with all but four results showing concentrations below the applicable Guideline 99% or 95% species protection levels and within levels expected for open ocean marine environments.
- Nutrient concentrations were very low across all sites. Combined with the analytical results for chlorophyll and phaeophytin, there is no evidence of any unexpected nutrient loads.
- Photosynthetic pigments in surface waters were very low. These concentrations may display seasonal variability, however the timing of this survey was such that it likely would have captured some of the higher concentrations that would be expected over the course of a year.
- Physical characteristics were within the expected ranges for this time of year when compared to the background data presented in previous desk top studies (Shell 2014, 2015).

The baseline data presented in this report may be used for future comparison to monitor environmental impact due to construction or routine operations and provides the initial data from which a set of site specific trigger levels may be developed as suggested by ANZECC & ARMCANZ guidelines.

1.0 Introduction

The Crux Field is located in Commonwealth waters in the Browse Basin (Timor Sea) approximately 110 km south-east of Cartier Island, 200 km off the Kimberley coast, 260 km from the Indonesian archipelago and East Timor and 600 km north-north-east of Broome, Western Australia (WA). The field is on the Sahul Shelf in the Australian waters of the Territory of Ashmore and Cartier Islands Adjacent Area in permit AC/RL9. Water depths in the field range from 110 m to 170 m. The approximate field dimensions are 8 km long by 5 km wide (Shell 2014).

Figure 1 Shell Crux Field retention lease AC/RL9 location



1.1 Objectives

This report presents the results of the baseline water quality survey completed between 30 April and 2 May 2016 at the AC/RL9 location and along the proposed pipeline route to the Prelude Field.

The objective of this survey was to collect data to describe the existing physical and chemical water quality characteristics at locations that may potentially be impacted by development of the field with a view to:

- characterise the pre-development water quality of the AC/RL9 site to inform the environmental permitting process
- provide a baseline dataset to which post impact (construction and operations) water quality measurements can be compared.

1.2 Survey overview

The survey was completed over three days in April/May 2016 on board the *MV Warrego* on completion of a metocean instrumentation deployment at the Crux Field and along the proposed pipeline route.

The survey comprised the collection of samples for physical and chemical analysis of water parameters, and the measurement of physicochemical profiles, at a total of 24 sites:

- 17 sites surrounding the proposed drill centres and Floating Production Storage and Offloading (FPSO) locations
- three sites along the pipeline route between AC/RL9 and the Prelude Field
- four reference sites (one at each corner of the AC/RL9 lease).

A detailed description of the survey is provided in Section 3.2.1 with sample site locations shown in Figure 3.

2.0 Background

2.1 Crux Field development

Shell Australia Proprietary Limited (Shell) plans to pipe gas from the Crux Field, within the Browse Basin, to the Prelude Floating Liquefied Natural Gas (FLNG) Development, approximately 160 km south-west of the Crux Field.

The project is in the early Select Phase and as such a number of concepts are under consideration including:

- an FPSO facility or a fixed platform in the Crux Field
- a pipeline from the Crux Field to the Prelude Field.

These proposed concepts, along with drilling, subsea and pipeline infrastructure will impact on the seabed environment throughout the project area during construction and ongoing operations.

2.2 Local environment

This study covers the Crux Field which is located on the North West Shelf, some 200 km off the Kimberly coast and the proposed pipeline route between the Crux and Prelude Fields. A description of the environment of the field is provided below.

2.2.1 Bathymetry, seabed features and associated habitats

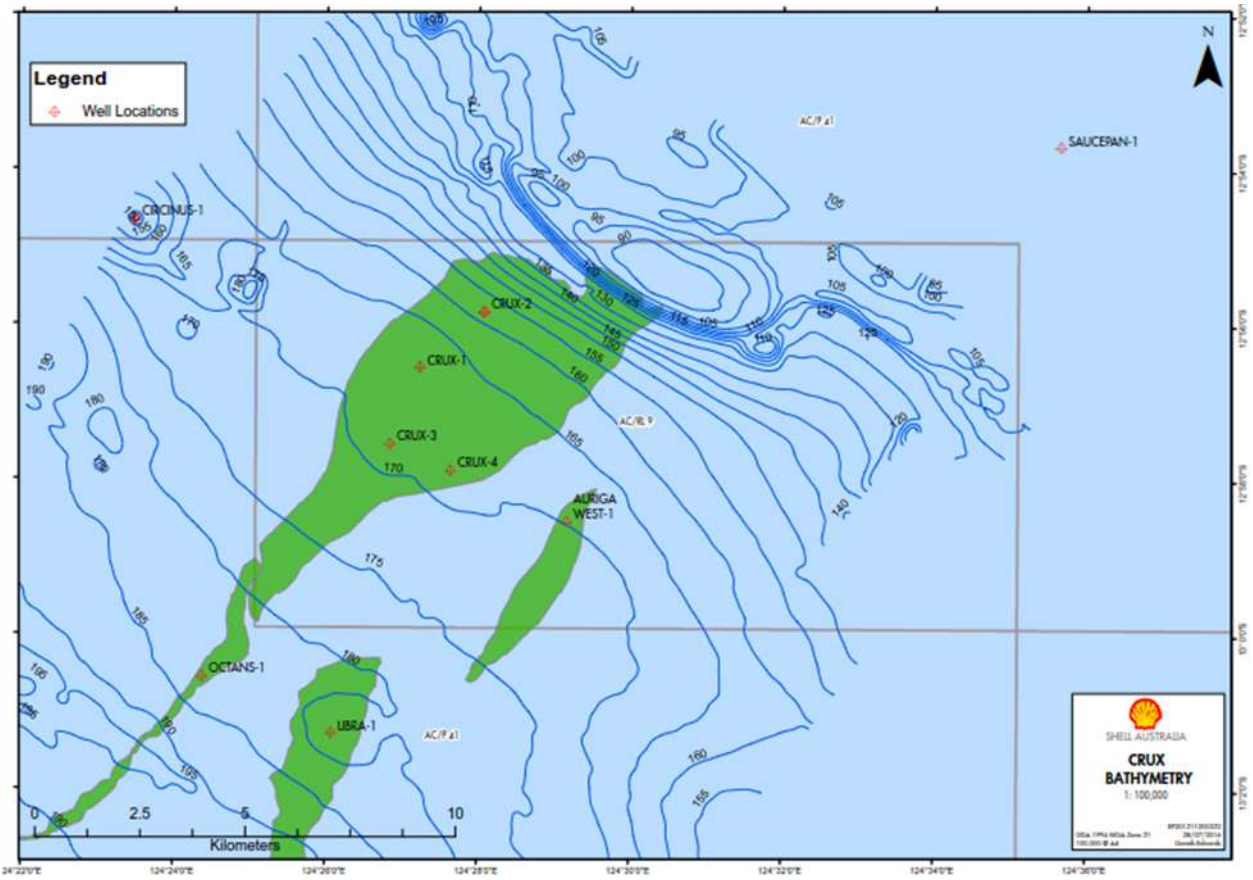
The seabed of the Crux Field is relatively uniform with depths varying from approximately 90 to 160 m observed during the survey. The shallower depths are found in the north-west section of the AC/RL9 lease. The seabed is typically composed of soft sediment

The AC/RL9 permit area bathymetry and seabed features have been described in Shell (2014), and are summarised below. Further bathymetry data will be required for the pipeline route and will be gained from hydrographic, geotechnical and habitat surveys.

- The project area is located on the Sahul Shelf; a broad shallow platform off the north-west coast of Australia.
- The seabed comprises fine clays, muds and sands. No reefs or areas of rocky substrate are known to occur within the nearby Prelude project area (Shell, 2009). Further investigation is required along the pipeline route and across the AC/RL9 permit area; however, the seafloor in those areas is believed to be fairly uniform comprising predominantly of soft sediment.
- Bathymetry of the AC/RL9 permit area is characterised by a shallow area towards the north-east corner of the lease area where depths of 90 to 100 m are typical. The depth falls to approximately 160 m in a south-westerly direction over approximately 2.5 km. The depth continues on a slight gradient until it reaches approximately 180 m depth in the south-west corner of the lease area (Figure 2).
- Single beam echo sounder bathymetry data captured during this survey reflects the above observations of bathymetry across the AC/RL permit area and shows a typically constant increase in depth along the proposed pipeline route.
- The major bathymetric feature along the pipeline route is a trench feature where the seabed drops from depths of approximately 210 m to a depth of approximately 270 m before returning to the regular depths around 250 m in the Prelude region. This feature is located closer to the Prelude field some 115 km south-west of the AC/RL lease.
- A number of shoals in the wider region present the most sensitive seabed habitats in the greater Browse Basin (Shell, 2014). The closest of these to the AC/RL9 lease area include:
    - Barracouta Shoals (approximately 90 km to the north-west)
    - Vulcan Shoals (approximately 18 km to the east)
    - Heywood Shoals approximately 13 km to the south-west)

The seabed of the Crux Field and proposed pipeline route will be described in more detail by a geophysical survey to be completed at a later date.

Figure 2 Bathymetry of the AC/RL9 lease area



2.2.2 Climate

The climate of the Browse Basin/Timor Sea region is monsoonal, and comprises two distinct seasons, winter (dry) from April to September and summer (wet) from October to March, with very rapid transition seasons, generally in April and September/October between the two main seasons (Shell, 2015a).

The location of the Crux Field is means that it is subjected to tropical cyclone activity with the highest chance of such storms occurring between November and April. Data suggest the peak cyclone frequency falls in January and March with the most intense cyclone activities observed in December and March – April (Shell, 2015a).

2.2.3 Tides and currents

Local tides and currents will impact the dispersion of any discharges to the marine environment and therefore the impact that these discharges may have. The Crux Field Development Metocean Reference Document (Shell, 2015a) details the key oceanographic systems at play in the region and suggests that currents at the Crux location are expected to be largely characterised by the tides.

Tides at the Crux site are predominantly semi-diurnal with successive tides generally being unequal and flowing along an approximate north-west – south-east axis (Shell, 2015a).

2.2.4 Physical water parameters

Existing data describing the physical water characteristics in the region have been summarised in various desktop study reports by Shell (2014, 2015a) with additional data expected to be collected in metocean surveys currently in progress. Existing information suggests:

- Sea surface temperatures generally range between 27 °C and 30 °C annually, in waters deeper than ~150 m the temperature is approximately 19 °C (Shell, 2014). Short term and long term variability could be expected at the Crux site (Shell, 2015a).
- Average monthly salinity profile data from the World Ocean Atlas for the Crux Filed location was presented in Shell (2015a). Salinity ranged from 34.5 – 35.1 PSU. Salinity profiles from CSIRO Marine and

Atmospheric Research in the region were also referenced showing salinity ranging from 33.3 – 34.8 PSU. It was also noted that short and long term variability would be expected to be observed.

2.3 Marine environmental effects

The Crux Field development will potentially comprise a number of installations and vessel operations that may impact marine water quality both during construction and once operational. Primarily, these impacts may result from routine discharges which may include:

- in situ overboard disposal of expended water-based mud (WBM) and associated drill cuttings from the Mobile Offshore Drilling Unit (MODU)
- macerated sewage and putrescible food scraps
- treated grey water from accommodation facilities and support vessels
- untreated deck drainage (deck wash and stormwater).
- treated oily water from FPSO and marine vessels
- treated drainage water discharges from platforms
- ballast water
- treated produced formation water (PFW) discharges from platforms / FPSO
- cooling water containing biofouling and corrosion control chemicals
- firewater and firefighting foam discharges (during system testing).

Seabed disturbance during installation may also impact water quality for short periods of time.

3.0 Crux Field Marine Water Quality Baseline Methodology

3.1 Objectives

The objective of the water quality baseline environmental survey was to gather data to inform the environmental planning and approvals process for the development of the Crux Field.

As well as providing data to understand the existing environment at the site of the proposed development, it can be used for future comparison to measure impacts of development activities in the field.

3.2 Water quality assessment

Water quality assessment consisted of water column vertical profiling, water sampling for nutrient and chemical analysis and phytoplankton sampling. A total of 24 sites were sampled across the Crux Field and along the proposed pipeline route to the Prelude location.

3.2.1 Sampling site locations

The sampling locations were selected to provide a spread of measurements around the sites of proposed infrastructure which includes wells, an FPSO/platform and a pipeline to the Prelude development some 160 km to the south-west. Sample sites were located as follows.

3.2.1.1 Sampling surrounding drill centres

Sample sites were located surrounding the three identified potential drill centres at:

- a central point (DC0) located approximately 1 km from the three drill centres on the western side
- two points along a transect north-west of DC1 and NE of DC2 at distances of 1000 and 2000 m
- two samples at distances of 1000 m and 2000 m along a transect extending south-west from DC0.

3.2.1.2 Sampling surrounding FPSO locations

The two potential FPSO locations were sampled at a number of sites:

- a point centrally located between the two potential FPSO positions (FPSO_0)
- two points located at a distance of 1000 m and 2000 m to the north-east of FPSO_0
- two points located at a distance of 1000 m and 2000 m to the south-west of FPSO_0
- two points located at a distance of 1000 m and 2000 m to the south-east of FPSO_0.

Sample sites are shown in Figure 3.

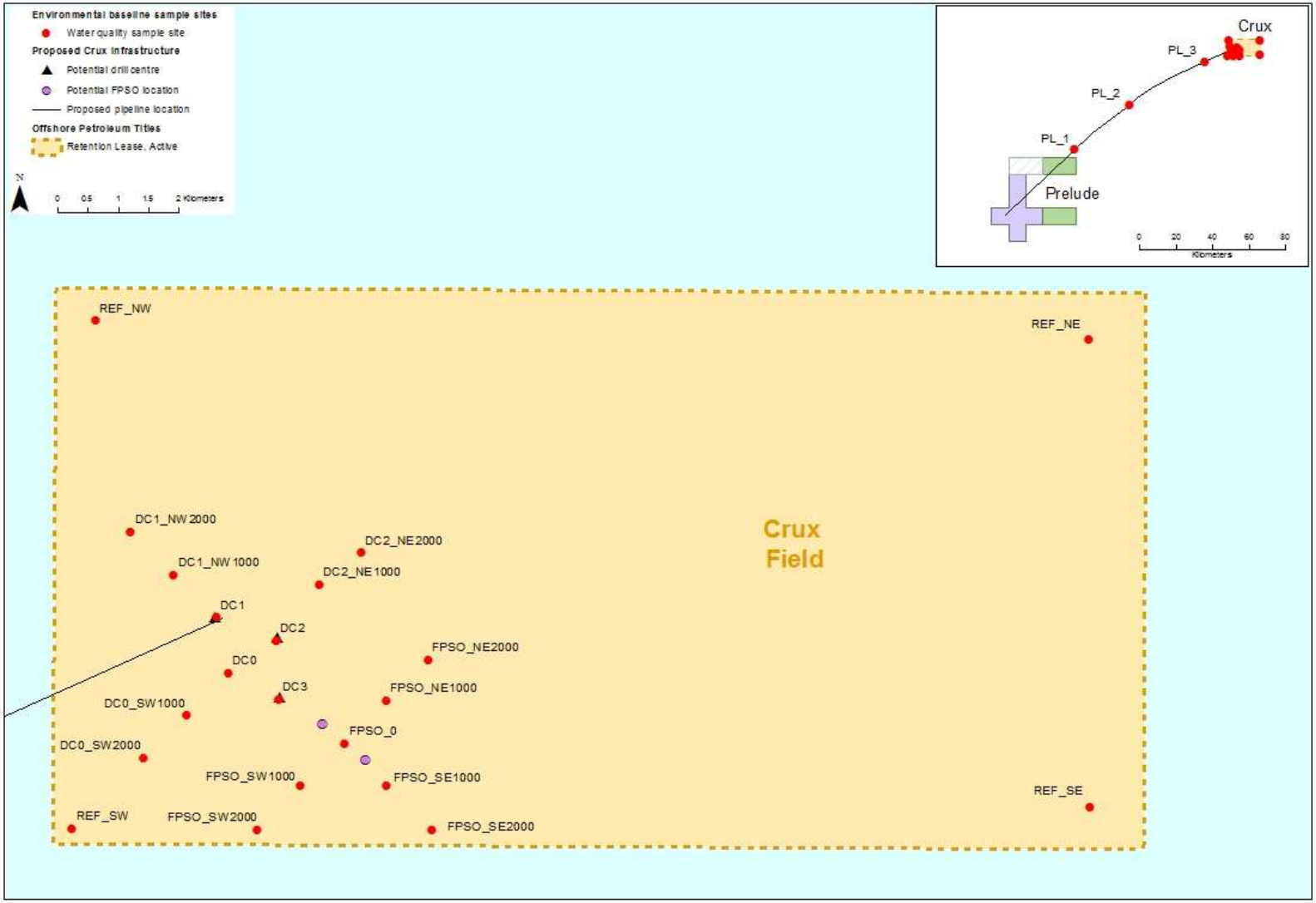
3.2.2 Vertical profiling

A Seabird SBE 19 plus V2 multi-parameter sonde was used to collect water quality data through vertical profiles of the water column at 24 sites (three along the pipeline route and 21 sites within the Crux Field). The sonde was set on internal logging mode and lowered to just above the seabed using the deck winch on the survey vessel, with each parameter measured every half second.

The sonde measured a suite of water quality parameters including depth (m), salinity (PSU), temperature (°C), turbidity (NTU) pH and dissolved oxygen (DO) (%).

The sonde was calibrated by RPS Metocean prior to the field survey, with the calibration certificate included in Appendix A. Water column profile data were used in calculating summary statistics for each site. Mean values were derived for each 10 m depth interval from the surface to the seabed between approximately 95 and 210 m water depth.

Figure 3 Water quality baseline sample sites



3.3 Sample collection

3.3.1 Sampling procedures

Water samples were collected using a Niskin sampler to collect a water sample just below the water surface (0.5 – 1 m depth).

The survey vessel was positioned such that sampling occurred on the upstream side of the vessel considering prevailing currents and wind direction to avoid any potential contamination from the vessel wash. All vessel discharge points were closed for the duration of sampling.

The Niskin bottle was deployed over the side of the vessel using the deck crane and lowered to a depth of approximately one metre below the water surface where it was triggered to collect a water sample.

The sampler was brought back on board the vessel and samples decanted directly into the sample containers using the pouring mechanism on the sampler.

A decontamination procedure for the water sampler was implemented after sampling each site. A solution of Decon 90 detergent and fresh water was mixed in a plastic bucket. Once a sample had been collected, the sampling equipment was thoroughly rinsed with the Decon 90 solution before a double freshwater rinse.

3.3.2 Nutrients and contaminants

Collection of water samples for nutrient and contaminant analysis was undertaken at each of the 24 sampling sites.

Surface water samples were collected and analysed to quantify the background concentrations of nutrients and potential hydrocarbon pollutants in the waters at the time of the survey. The samples were analysed for Total Phosphorous (TP), Total Nitrogen (TN), Total Kjeldahl Nitrogen (TKN), Total Recoverable Hydrocarbons (TRH) (C10-C36), Benzene, Toluene, Ethylbenzene, Xylenes (BTEX) and photosynthetic pigments (chlorophyll and phaeophytin).

TP and TN samples were collected in pre-cleaned 1 L polyethylene bottles. All nutrient samples were frozen for storage prior to analysis. Samples for analysis of TRH concentrations were collected in pre-cleaned 500 mL glass bottles and refrigerated in the dark until analysis. BTEX samples were collected in pairs of 40 mL glass vials.

All sample bottles were pre-washed and all samples were collected and stored in accordance with Australian/New Zealand Standard AS/NZS 5567.1 1998 (Standards Australia 1998). The samples were delivered to Analytical Reference Laboratory (ARL) for analysis within seven days of collection.

3.3.3 Phytoplankton

Chlorophyll concentrations in extracts of seawater filtrate were measured as an index of phytoplankton biomass. Five litres of fresh seawater was filtered through a glass fibre filter paper (GF/C) and the filter paper frozen for subsequent extraction and analysis of total chlorophyll, chlorophylls 'a', 'b' and 'c', and phaeophytin. The ratio of the three forms of chlorophyll (‘a’, ‘b’ and ‘c’) can be used as an indicator of the composition of the phytoplankton assemblages. Changes in the ratio of the pigments suggest changes in assemblage structure.

Photosynthetic pigments were extracted and measured by the Marine and Freshwater Research Laboratory (MAFRL) at Murdoch University according to the Standard Methods for Examination of Water and Wastewater.

3.3.4 Quality Assurance and Quality Control (QA/QC) samples

In addition to the primary water samples, a number of QA/QC samples were collected in accordance with Australian/New Zealand Standard AS/NZS 5567.1 1998 (Standards Australia 1998). These comprised:

- duplicate samples at three sites
- triplicate samples at two sites
- one field blank
- two rinsate blanks
- one trip blank.

Duplicate samples were collected from the same water sample as primary samples while triplicate samples were collected by deploying the Niskin sampler three separate times at the same site, one after the other. One of the three triplicate samples at each site was sent to a secondary laboratory for analysis.

Duplicate and triplicate samples were labelled so as to be identifiable to the sampler as replicates, but so that they were unrecognisable to the analysing laboratory as replicates.

3.4 Analysis of water samples

Sample analysis was undertaken by National Association of Testing Authorities (NATA) accredited laboratories for the analysis being undertaken. ARL analysed the primary contaminant and nutrient samples while ALS analysed the inter-laboratory duplicates. The Marine and Freshwater Resources Laboratory (MAFRL) conducted sample analysis for chlorophyll and phaeophytin.

Where possible, analysis was undertaken to a Practical Quantitation Limit (PQL) sufficiently low so as to allow assessment of results against the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (Australian and New Zealand Environment & Conservation Council and Agriculture & Resource Management Council of Australia and New Zealand [ANZECC & ARMCANZ] 2000; hereafter 'the Guidelines'. The PQLs applied are listed in Table 1.

The following analyses were undertaken:

- TRH (C_{6-9}, C_{10-14}, C_{15-28}, C_{29-36}, $C_{>36}$)
- BTEX
- total metals (aluminium, arsenic, barium, cadmium, cobalt, chromium, copper, iron, lead, mercury, nickel and zinc)
- nutrients (Total Nitrogen [TN], Total Kjeldahl Nitrogen [TKN] and Total Phosphorus [TP])
- photosynthetic pigments (chlorophyll and phaeophytin).

Table 1 Laboratory analysis and proposed PQL to be applied.

Analyte	Trigger Level^ (mg/L)	PQL (mg/L)
Hydrocarbons		
TRH	-	0.01
BTEX	0.5 (Benzene)	0.001 – 0.003
Total Metals:		
As	-	0.001
Al	-	0.01
Ba	-	0.001
Cd	0.0007	0.0001
Co	0.000005	0.001
Cr	0.0077	0.001
Cu	0.0003	0.001
Fe	-	0.01
Hg	0.0001	0.0001
Ni	0.007	0.001
Pb	0.0022	0.001
Zn	0.007	0.005
Nutrients		
TN, TKN, NOx-N	0.1# (TN), 0.004# (NOx-N)	0.2 (TN), 0.01 (NOx-N)

Analyte	Trigger Level^ (mg/L)	PQL (mg/L)
TP	0.01#	0.01
Photosynthetic pigments		
Chlorophyll a, b, c, phaeophytin	0.0009 (chl *a*) #	0.0001, 0.0002 (phaeophytin)

^: ANZECC & ARMCANZ (2000) 99% species protection trigger value for marine water.

#: ANZECC & ARMCANZ (2000) Default trigger values for physical and chemical stressors for tropical Australia for slightly disturbed ecosystems.

3.5 QA/QC

The primary objective of the data validation process is to ensure that the reported data can be used to achieve the project objectives. Analytical data were thoroughly checked by the laboratory prior to release. AECOM subsequently checked the analytical data against the data quality objectives of the project—comparing requested detection limits against PQLs, calculating Relative Percentage Differences (RPDs) and Relative Standard Deviations (RSDs) for field duplicates and replicates, respectively, and comparing RPDs and RSDs with Guideline recommendations.

Comparison of duplicates/triplicates through RPDs and RSDs may identify analytical results that appear to be unrealistically high (or low) and might prompt a request to the laboratory to reanalyse the samples as a further check of precision, or result in categorisation of those results as ‘estimates only’.

Laboratory QA/QC procedures included laboratory duplicates, method blanks, laboratory control samples and matrix spikes

4.0 Results and Discussion

This section presents the results and discussion of the physicochemical water profile data and water sample laboratory analysis.

A summary of the physicochemical water column profile data is provided in Appendix B. The laboratory analytical results are summarised in Appendix C with laboratory reports provided in Appendix D.

4.1 Physicochemical water column profiles

Water column profiles were collected at each of the sampling sites using a Seabird SBE 19 Plus V2 conductivity, temperature, depth (CTD) recorder. Measurements of temperature, salinity, DO, pH and turbidity were made every 0.5 seconds while lowering the recorder through the water column to the seabed.

Data were summarised and averaged in 10 m strata across the depth of the water column (Appendix B) and presented in depth profile plots for each parameter (Figure 4, Figure 5 and Figure 6). The following sections describe the profiles observed.

The Guidelines provide criteria levels for dissolved oxygen (> 90 % saturation), and pH values (8.2), and state that pH should not deviate more than ± 0.2 pH units among individual sampling sites. However, the Guidelines stress the need for site-specific information to enable the development of criteria that are more relevant to the system under study. The baseline data presented in this report may contribute to developing site specific criteria for future comparison.

4.1.1 Temperature

Temperature measurements were generally consistent across the sites with average surface temperatures (1 – 10 m) ranging from 30.8 to 31.3 °C. The temperature dropped consistently through the water column with no strong evidence of a thermocline.

4.1.2 Salinity

Salinity measurements were consistent across all sites. Average surface salinities (0 – 10 m) were observed between 34. 8 – 35.0 PSU with a halocline present at approximately 30 – 35 m. At this point a small drop in average salinity of approximately 0.4 PSU was observed indicating a surface layer of slightly more saline water overlying the otherwise consistent salinity of 34.5 – 34.6 PSU to the seabed.

4.1.3 Dissolved Oxygen

DO stratification in the water column was observed with a drop in DO evident at all sites, generally between 40 to 60 m but as shallow as 30 m at a small number of sites. The drop in DO was typically associated with similar occurrences in temperature and salinity which is expected (ANZECC & ARMCANZ 2000). Average surface DO (0–10 m) ranged from 87.3 – 100.4% saturation before rising slightly to a depth of approximately 30 m where DO saturation ranged from 98.2 – 100.9%. Below these surface layers, DO saturation decreased consistently through the water column.

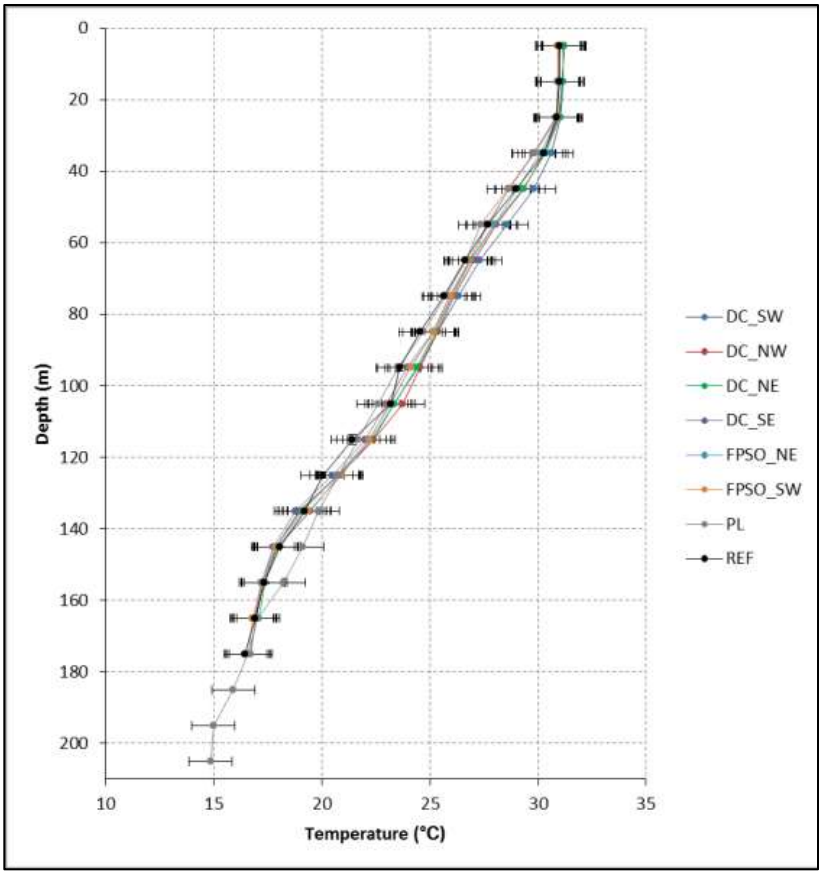
4.1.4 pH

pH levels were observed at consistent levels across all sites. Average pH was uniform in the well mixed surface layers to approximately 40 m depth where average pH was typically between 8 – 8.1. There was then a constant decrease through the water column to the seabed where pH values of 7.7 – 7.8 were observed at the deepest sites. These readings are consistent with expectations for offshore marine environments with the Guideline default trigger value for offshore marine waters set at 8.2.

4.1.5 Turbidity

Turbidity was consistently low throughout the water column (< 1 NTU), as expected for offshore marine environments. High seabed turbidity has been detected at the Prelude development site (Shell, 2015b); however there was no indication of significantly elevated turbidity close to the seabed at any of the sites in the Crux Field or along the pipeline.

Figure 4 Water column profiles for average temperature (top) and Salinity (bottom)



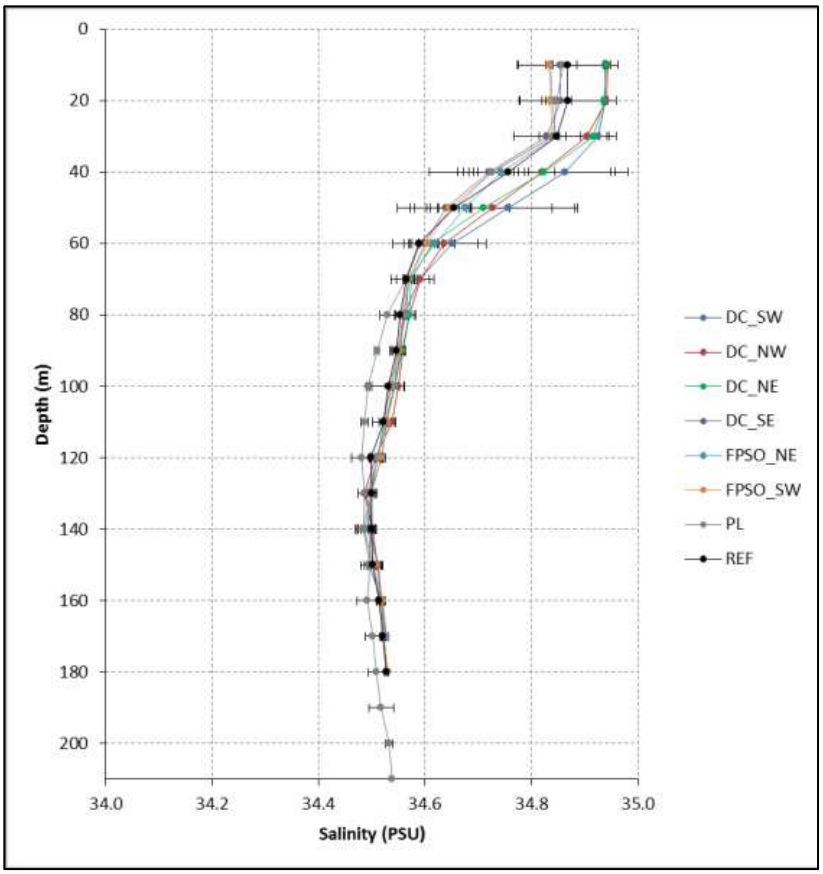
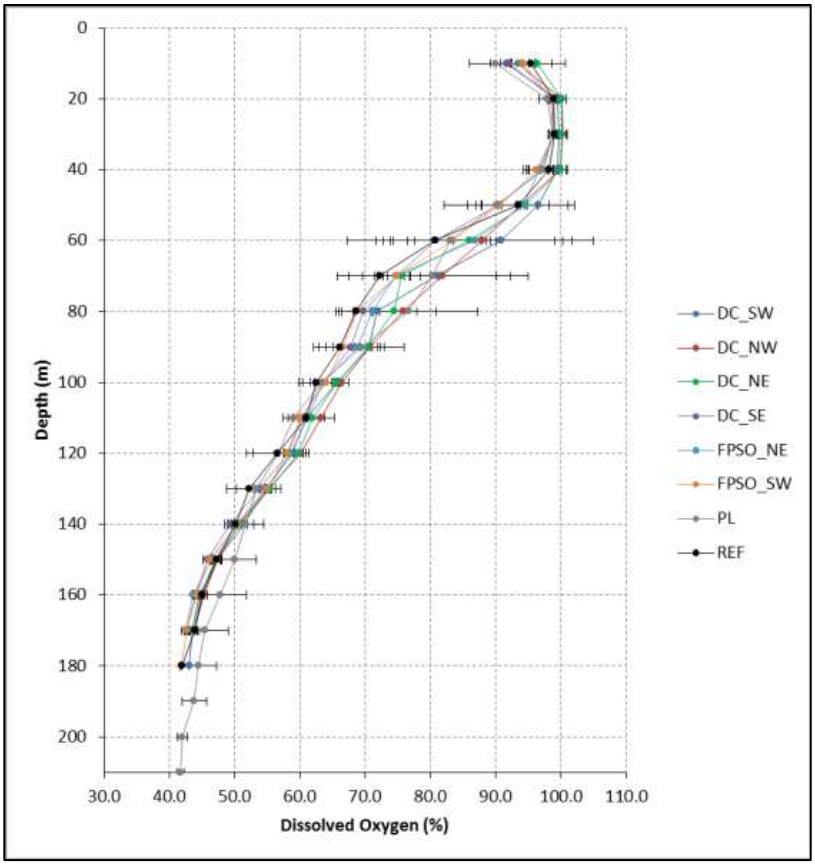


Figure 5 Water column profiles for average Dissolved Oxygen (top) and pH (bottom)



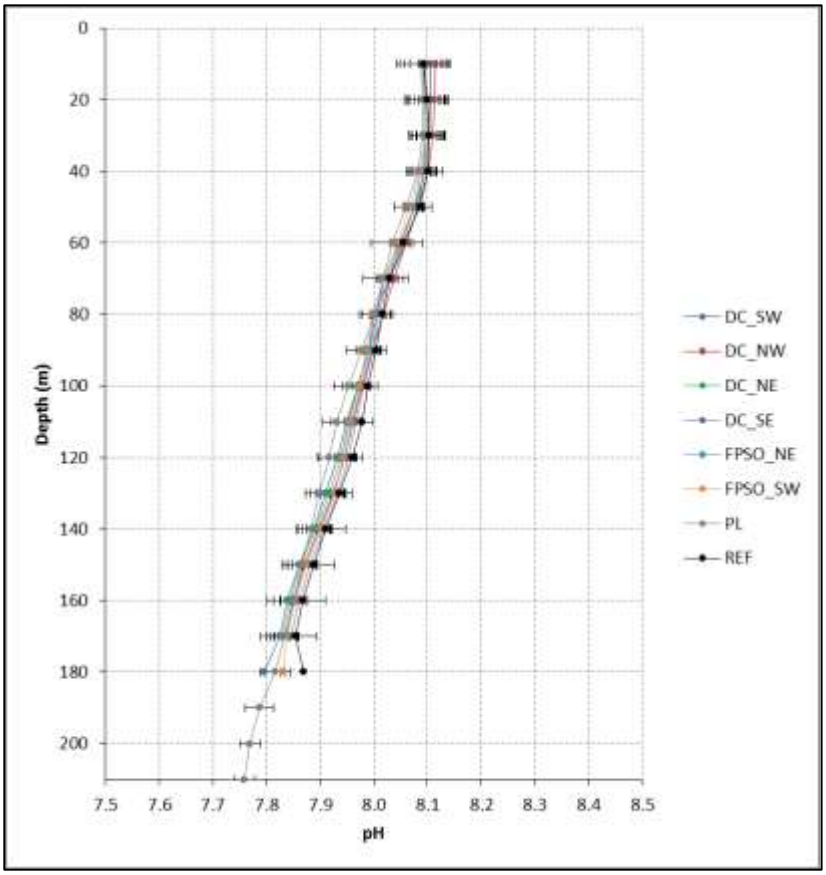
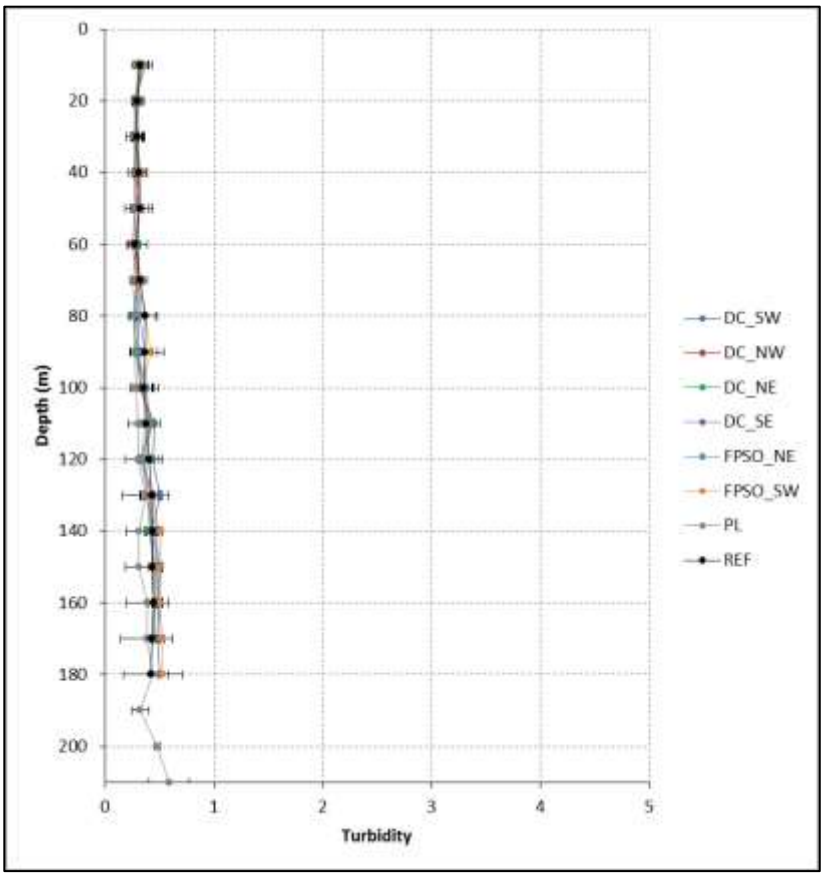


Figure 6 Water column profiles for average turbidity



4.2 Hydrocarbons

Water samples were analysed for TRH and BTEX. Analytical results are presented in Appendix C with laboratory reports provided in Appendix D.

TRH was not detectable above the PQL (0.01 mg/L) in any of the samples. This would be expected of a remote offshore ocean environment sufficiently distant from other existing development.

Similarly, BTEX were not detected above the applied PQLs of 0.001 mg/L (Benzene, Toluene and Ethylbenzene) and 0.003 mg/L (Xylenes). Low reliability trigger values for 99% species protection for BTEX in marine waters are suggested in the Guidelines. These are specified as 0.5 mg/L (Benzene), 0.18 mg/L (Toluene) and 0.005 mg/L (Ethylbenzene). Low reliability trigger levels for xylene isomers are suggested as 0.35 mg/L (o-xylene), 0.075 mg/L (m-xylene) and 0.2 mg/L (p-xylene).

4.3 Metals

Samples were analysed for total metals and results compared against the Guideline 99% species protection trigger values for marine waters. The metals tested for, and PQLs applied, are shown in Table 1 and the results are provided in the following sections. Analytical results are presented in Appendix C with laboratory reports provided in Appendix D.

With some exceptions, metals generally returned concentrations below the PQLs. Where this was not the case, concentrations were generally substantially below the Guideline 99% species protection trigger value for marine waters.

4.3.1 Arsenic

Arsenic concentrations were detected above the PQL of 0.001 mg/L at all sites however the concentrations were still very low with a range of 0.001 – 0.004 mg/L.

No Guideline 99% protection trigger exists for arsenic in marine waters however; low reliability guideline trigger levels of 0.0023 mg/L and 0.0045 mg/L are suggested for marine waters for As III and V species respectively. Analysis of samples for speciated arsenic was not undertaken as part of this program.

The low reliability trigger level for As III was exceeded at three sites (FPSO_NE2000, FPSO_SE2000 and REF_SW) where concentrations of 0.004, 0.003 and 0.003 mg/L for Total arsenic were recorded at each site respectively.

4.3.2 Aluminium

Aluminium concentrations were below the PQL of 0.01 mg/L in all samples. There is no Guideline trigger value for aluminium.

4.3.3 Zinc

Zinc was detected above the PQL of 0.005 mg/L at only one site (FPSO_NE2000) where a concentration of 0.021 mg/L was measured. At this concentration, it is above the Guideline 99% species protection trigger value of 0.007 mg/L however, it is unlikely to be representative of the zinc concentrations of the wider water body at the Crux Field. This may be indicative of an isolated occurrence of minor sample contamination from an undetermined source.

4.3.4 Cadmium

At all sites cadmium concentrations were below the PQL of 0.0001 mg/L and therefore below the Guideline 99% species protection trigger value of 0.0007 mg/L.

4.3.5 Cobalt

Cobalt was not detected at concentrations above the PQL of 0.001 mg/L at any of the sites sampled. It was not possible to apply a PQL sufficiently low to detect levels at the Guideline 99% species protection level trigger of 0.000005 mg/L, however, the PQL applied was sufficient to detect any exceedance of the Guideline 95% protection trigger level of 0.001 mg/L, of which none were observed.

4.3.6 Chromium

Chromium was detected above the PQL of 0.001 mg/L at one site (DC0_SW1000) where a concentration of 0.002 mg/L was measured. This is below the Guideline 99% species protection trigger level of 0.0077 mg/L.

4.3.7 Copper

Copper was detected at concentrations at or above the PQL of 0.001 mg/L at two sites (DC0_SW1000 – 0.001 mg/L and PL-1 – 0.002 mg/L).

It was not possible to apply a PQL sufficiently low to detect levels at the Guideline 99% species protection level trigger of 0.0003 mg/L, however, the PQL applied was sufficient to detect any exceedance of the 95% protection trigger level of 0.0013 mg/L.

Of the two sites where copper concentrations exceeded the PQL, one of these, PL-1 exceeded the 95% species protection trigger level by a small amount. This site is located along the proposed pipeline route some 100 km south-west of the Crux Field and, as a single sample, is an unreliable representation of copper concentrations across the Crux Field or the wider region. Rather, it may be indicative of an isolated occurrence of minor sample contamination from an undetermined source.

Further to this, copper concentrations were detected in the rinsate, field blank and trip blank samples. The source of this was identified by the analysing laboratory as the deionised water used for the blank and rinsate water. The laboratory confirmed that this would not have impacted the primary samples, which appears to be the case.

4.3.8 Iron

No Guideline trigger level is provided for iron in marine waters, in which it occurs naturally. Iron was detected above the PQL (0.01 mg/L) at 11 sites, at concentrations of 0.01 – 0.06 mg/L. At two of these sites (DC2 and FPSO_0) field duplicate samples were analysed and, in each instance, the primary sample had an iron concentration below PQL, while the duplicate sample showed a concentration above PQL (0.03 and 0.02 for DC2 and FPSO_0 respectively).

4.3.9 Lead

At all sites, lead concentrations were below the PQL of 0.001 mg/L and therefore below the Guideline 99 % species protection level of 0.0022 mg/L.

4.3.10 Nickel

Nickel concentrations exceeded the PQL of 0.001 mg/L at only one of the sites sampled (FPSO_NE2000) where a concentration of 0.001 mg/L was detected. This concentration is below the Guideline 99% species protection trigger level of 0.007 mg/L.

4.3.11 Mercury

Mercury was not detected above the PQL of 0.0001 mg/L at any of the sites sampled. The PQL is equal to the Guideline 99% species protection trigger level of 0.0001 mg/L so there were no exceedances of this trigger level.

4.3.12 Barium

Barium was not detected above the PQL of 0.01 mg/L at any of the sites sampled. While there is no Guideline water quality trigger level for barium, it is a common constituent in drilling muds and as such may become present in the water column should such materials be utilised during any future drilling.

While barium has been known to remain present in marine sediments post-drilling, it would not be expected to have any long lasting impact on water quality once drilling activities have ceased and suspended sediments have settled.

4.4 Nutrients and photosynthetic pigments

Concentrations of nutrients were analysed in all samples. Analytical results are presented in Appendix C with laboratory reports provided in Appendix D.

The Guidelines provide criteria levels for water contaminant concentrations. However, the guidelines stress the need for site-specific information to enable the development of criteria that are more relevant to the system under study.

In particular, the Guidelines note that the trigger values proposed for nutrient and chlorophyll concentrations in marine waters are not equally applicable to coastal and offshore waters. Location specific baseline information allows for more accurate assessment of these parameters due to the site-specific nature of ecosystem response to nutrient enrichment.

Therefore, the water quality parameters measured were assessed in terms of the recommendations in the Guidelines, but it is suggested that baseline data from this survey will form the basis for criteria levels for comparison in future impact assessments and monitoring.

4.4.1 Nitrogen

TN concentrations did not exceed the PQL of 0.2 mg/L at any of the sites sampled. While this PQL was not sufficiently low to detect the presence of nitrogen at the Guideline level of 0.1 mg/L, any exceedance that was undetected would not be substantially greater than 0.1 mg/L.

TKN is a measure of the total concentration of organic nitrogen and ammonia. TKN was not detected above the PQL of 0.2 mg/L. No default trigger level is provided by the Guidelines.

NOx-N was detected at or above the PQL of 0.01 mg/L at four sites (DC00, DC3, FPSO_NE1000 and FPSO_SE2000) where concentrations measured ranged from 0.01 – 0.05 mg/L. As for TN, the PQL was higher than the suggested guideline value (0.004 mg/L). As laboratories are typically unable to reliably analyse water samples to PQLs that are less than guideline values, any post-baseline comparisons of nitrogen levels will need to be between concentrations at potential impact sites and reference sites, rather than being compared back to baseline concentrations.

4.4.2 Total Phosphorus

TP concentrations did not exceed the PQL of 0.01 mg/L at any of the sites sampled. The PQL applied is equal to the Guideline default trigger value applicable to north-west WA offshore marine environments.

4.4.3 Photosynthetic pigments

Analytical results for photosynthetic pigments are presented in Appendix C with laboratory reports provided in Appendix D.

Of the four parameters analysed (Chlorophyll a, b, c and phaeophytin), only chlorophyll a was detected above the PQL of 0.0001 mg/L (0.0002 mg/L for phaeophytin). Concentrations of chlorophyll a above the PQL were detected at seven sites:

- five in the vicinity of the potential FPSO locations (FPSO_0, FPSO_NE1000 and NE2000, FPSO_SE1000 and SE2000)
- the two reference sites at the eastern end of the Crux Field (Ref_NE and REF_SE).

All detections of chlorophyll were very low, with concentrations of 0.0001 mg/L recorded at all of these sites with the exception of REF_SE where a concentration of 0.0002 mg/L was observed.

These results are below the Guideline trigger values for offshore marine waters of Northern Australia (0.0005 – 0.0009 mg/L). The lower of these two values is typical of clear coral dominated waters (e.g. Great Barrier Reef), while higher values are typical of turbid macrotidal systems (e.g. North West Shelf of WA) (ANZECC & ARMCANZ, 2000).

5.0 Conclusions

The following conclusions can be drawn from the 2016 water quality baseline survey:

- Water quality in the AC/RL9 area is generally very good and can be classified as effectively unmodified which would be expected given the remote location of the Crux Field. This is reflected in the results presented whereby all but a very small number of toxicant concentrations were observed to be below the Guideline 99% species protection (where PQLs were sufficiently low).
- Petroleum hydrocarbons were all below the detectable limit indicating no evidence of impact from petroleum development sites or natural seeps in the region. This would be expected due to the distance to neighbouring fields that have been developed.
- Metals concentrations were all within expected ranges with all but four results showing concentrations below the applicable Guideline 99% or 95% species protection levels (where the PQLs were sufficiently low). Where Guideline trigger values were not available, toxicant concentrations were observed within levels expected for open ocean marine environments.
- Nutrient concentrations were very low across all sites with all samples returning concentrations below the PQLs for both TP and TN and TKN. NOx-N concentrations were similarly low however measures above the PQL at four sites. Combined with the analytical results for chlorophyll and phaeophytin, there is no evidence of any unexpected nutrient loads.
- Photosynthetic pigments in surface waters were also very low and below the Guideline default trigger values applicable to north-west Western Australia. These concentrations may display seasonal variability, however the timing of this survey was such that it likely would have captured some of the higher concentrations that would be expected over the course of a year.
- Physical characteristics were within the expected ranges for this time of year when compared to the background data presented in previous desk top studies (Shell 2014, 2015). Baseline data collected as part of this survey are suitable for use in developing site-specific criteria against which future monitoring data could be assessed.

6.0 References

ANZECC & ARMCANZ 2000. Australian and New Zealand Guidelines for Fresh and Marine Water Quality, Australian and New Zealand Environment & Conservation Council and Agriculture & Resource Management Council of Australia & New Zealand, October 2000.

Shell 2009, Prelude Floating LNG Project Draft Environmental Impact Statement, Shell Development (Australia) Pty Ltd, October 2009

Shell 2014, AC/RL9 Environment Plan HSE_GEN_001004 (Revision 2), Shell Development (Australia) Pty Ltd.

Shell 2015a, Crux Field Development – Metocean Reference Document. Document Number TEC_CRU_005707. Shell Australia Pty Ltd.

Shell 2015b, Summary of studies into underwater visibility at Prelude field. Internal Report: 2000-010-S001-GE00-G00000-WA-5880, Michael Garvey, Shell Australia.

Standards Australia 1998, Water quality - Sampling Part 1: Guidance on the design of sampling programs, sampling techniques and the preservation and handling of samples (AS/NZS 5667.1:1998). Homebush, NSW.

Appendix A

Water quality sonde calibration certificates

Appendix A Water quality sonde calibration certificates

CTD Reference Checks

Instrument: CTD 19plus V2

Instrument Serial Number: 6243

Calibration Date: 12/04/2016

Sensor	Reference	Value	Residual	Pass/Fail	Expected Accuracy
Salinity (PSU)	29.83526	29.77190	0.06336	Pass	+/- 0.16
	32.90661	32.75784	0.14877	Pass	
Temperature (°C)	19.10000	19.09941	0.00059	Pass	+/- 0.0192
Depth (dB)	0.49033	0.41142	0.07892	Pass	+/- 0.12
Turbidity (NTU)	0.00000	0.30000	-0.30000	Pass	+/- 5% Linearity
	20.00000	18.80000	1.20000	Pass	
	100.00000	102.90000	-2.90000	Pass	
Dissolved Oxygen (ml/L)	9.01600	9.04900	-0.03300	Pass	+/- 2%
pH	4.00000	3.99500	0.00500	Pass	pH probe was calibrated with these values.
	7.00000	7.01100	-0.01100	Pass	
	10.00000	9.99500	0.00500	Pass	

Notes:

- Salinity tests were conducted using RPS MetOcean salinity baths, the reference values of the salinity baths have been generated from averaging 20 SBE37 salinity values.
- Temperature test was conducted against calibrated digital FLUKE thermometer, with CTD instrument submerged in freshwater.
- Depth test was conducted with instrument submerged to a known height.
- Turbidity tests were conducted against 3 known turbidty standards.
- Dissolved Oxygen was cross checked against a secondary dissolved oxygen sensor.
- pH tests were conducted by Imbros (SBE contractor) the values found were used to calibrate the sensor configuration.

Technician: M. MATSON Signed: Date: 20/04/16

QC Checker: G. WARK Signed: Date: 20-4-16

Sea-Bird Electronics, Inc.

13431 NE 20th Street, Bellevue, WA 98005-2010 USA

Phone: (+1) 425-643-9866 Fax (+1) 425-643-9954 Email: seabird@seabird.com

SENSOR SERIAL NUMBER: 1887
CALIBRATION DATE: 03-Jul-12

SBE 43 OXYGEN CALIBRATION DATA

COEFFICIENTS

Soc = 0.4325
Voffset = -0.4265
Tau20 = 4.72

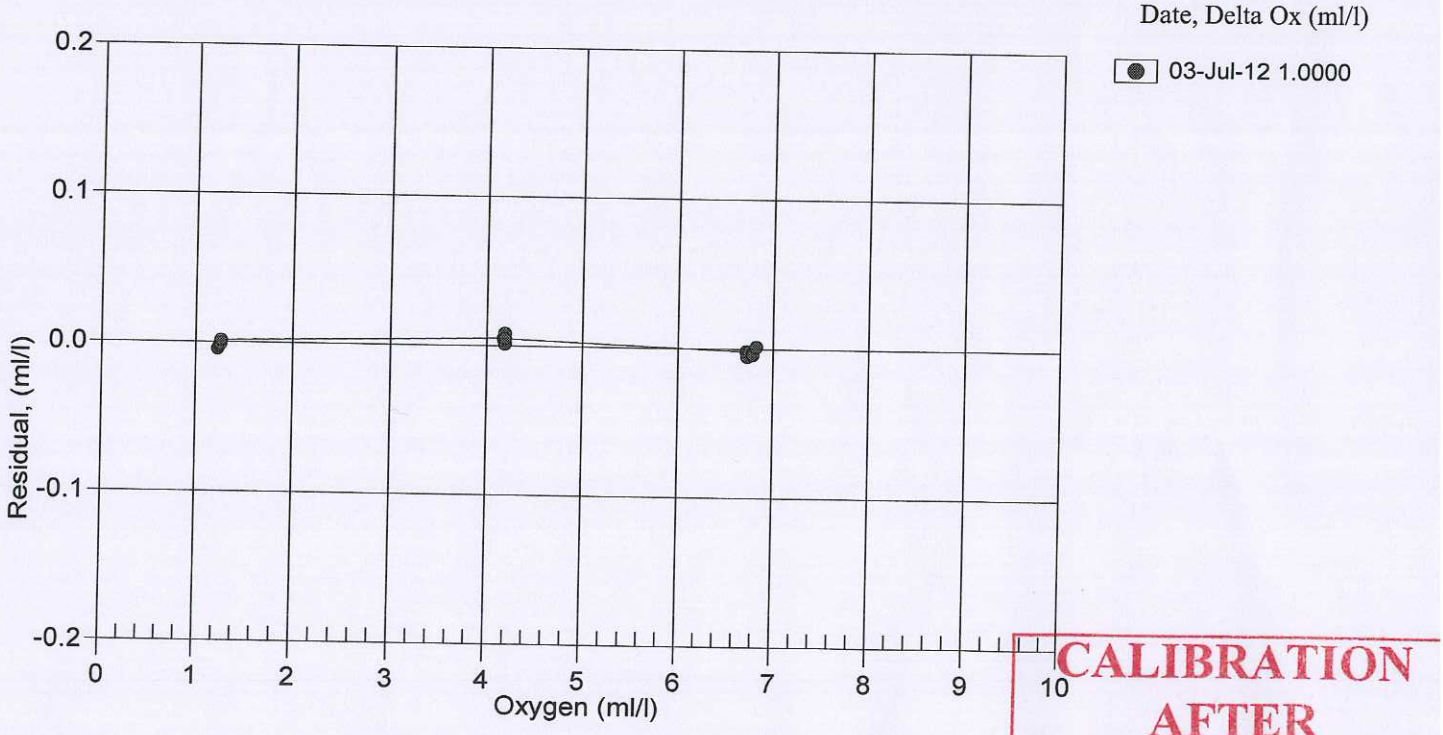
A = -2.2783e-003
B = 1.3259e-004
C = -2.7826e-006
E nominal = 0.036

NOMINAL DYNAMIC COEFFICIENTS

D1 = 1.92634e-4 H1 = -3.30000e-2
D2 = -4.64803e-2 H2 = 5.00000e+3
H3 = 1.45000e+3

BATH OX (ml/l)	BATH TEMP ITS-90	BATH SAL PSU	INSTRUMENT OUTPUT(VOLTS)	INSTRUMENT OXYGEN(ml/l)	RESIDUAL (ml/l)
1.23	2.00	0.16	0.720	1.22	-0.00
1.23	6.00	0.14	0.757	1.23	-0.00
1.24	12.00	0.13	0.812	1.24	-0.00
1.25	26.00	0.09	0.947	1.25	-0.00
1.26	20.00	0.11	0.889	1.25	-0.00
1.26	30.00	0.08	0.993	1.26	0.00
4.17	2.00	0.16	1.430	4.18	0.01
4.18	26.00	0.09	2.162	4.18	0.00
4.18	30.00	0.08	2.301	4.18	0.00
4.18	12.00	0.12	1.726	4.18	0.00
4.18	6.00	0.14	1.550	4.19	0.01
4.19	20.00	0.11	1.974	4.19	0.00
6.72	12.00	0.12	2.514	6.72	-0.00
6.72	20.00	0.11	2.906	6.72	-0.00
6.74	6.00	0.14	2.235	6.74	-0.00
6.78	30.00	0.08	3.463	6.78	-0.00
6.78	2.00	0.16	2.054	6.78	-0.00
6.82	26.00	0.08	3.257	6.82	0.00

Oxygen (ml/l) = Soc * (V + Voffset) * (1.0 + A * T + B * T^2 + C * T^3) * OxSol(T,S) * exp(E * P / K)
V = voltage output from SBE43, T = temperature [deg C], S = salinity [PSU], K = temperature [Kelvin]
OxSol(T,S) = oxygen saturation [ml/l], P = pressure [dbar], Residual = instrument oxygen - bath oxygen



CALIBRATION AFTER MODIFICATIONS

SEA-BIRD ELECTRONICS, INC.

1808 136th Place N.E., Bellevue, Washington, 98005 USA

Phone: (425) 643 - 9866 Fax (425) 643 - 9954 Email: seabird@seabird.com

SENSOR SERIAL NUMBER: 6243
CALIBRATION DATE: 20-Dec-08

SBE19plus CONDUCTIVITY CALIBRATION DATA
PSS 1978: C(35,15,0) = 4.2914 Siemens/meter

COEFFICIENTS:

```
g = -1.006465e+000
h =  1.539737e-001
i = -1.985717e-004
j =  3.753773e-005

CPcor = -9.5700e-008
CTcor =  3.2500e-006
```

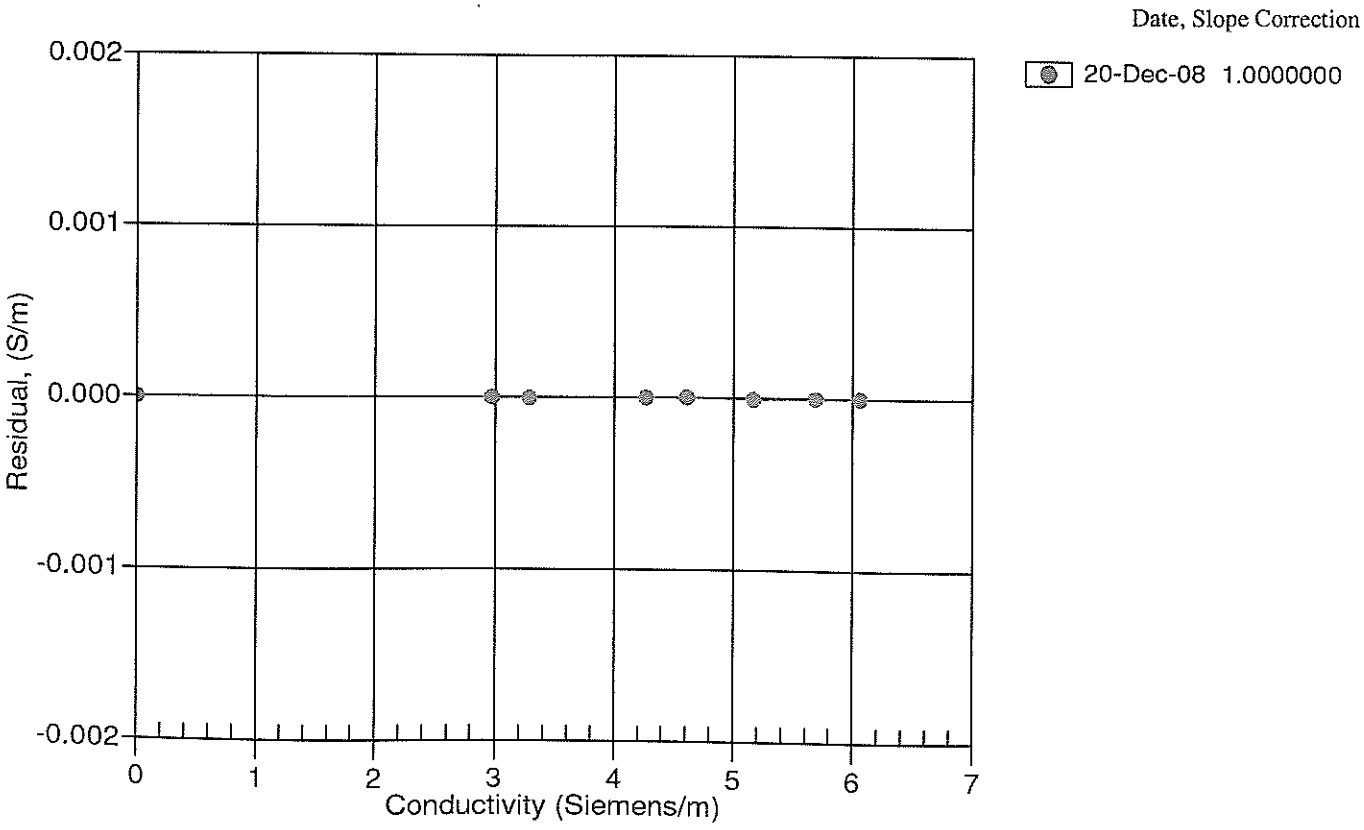
BATH TEMP (ITS-90)	BATH SAL (PSU)	BATH COND (Siemens/m)	INST FREQ (Hz)	INST COND (Siemens/m)	RESIDUAL (Siemens/m)
22.0000	0.0000	0.00000	2558.86	0.0000	0.00000
1.0000	34.7888	2.97384	5085.00	2.9738	0.00000
4.5000	34.7688	3.28068	5276.76	3.2807	-0.00000
15.0000	34.7253	4.26163	5847.09	4.2616	0.00000
18.5001	34.7150	4.60639	6034.51	4.6064	0.00001
24.0000	34.7029	5.16362	6325.43	5.1636	-0.00001
29.0000	34.6951	5.68470	6585.57	5.6847	-0.00000
32.5001	34.6889	6.05629	6764.82	6.0563	0.00000

f = INST FREQ / 1000.0

Conductivity = $(g + hf^2 + if^3 + jf^4) / (1 + \delta t + \varepsilon p)$ Siemens/meter

t = temperature[°C)]; p = pressure[decibars]; δ = CTcor; ε = CPcor;

Residual = instrument conductivity - bath conductivity



PO Box 518
620 Applegate St.
Philomath, OR 97370

(541) 929-5650
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www.wetlabs.com

NTU Characterization Sheet

Date: 17/04/2012 S/N: NTURT-263

Nephelometric Turbidity Unit (NTU) Scale Factor

Turbidity units expressed in NTU can be derived using the equation:

NTU = Scale Factor x (Output - Dark Counts)

	ASV1	ASV2	ASV4		Digital	
Dark Counts	0.058	0.027	0.011	V	50	counts
NTU Solution Value	4.64	2.32	1.16	V	3800	counts
Scale Factor (SF)	47	95	189	NTU/V	0.0579	NTU/count
Maximum Output	4.97	4.97	4.97	V	16380	counts
Resolution	0.0	0.0	0.0	mV	1.0	counts
Ambient temperature during calibration	22		°C			

Dark Counts: Signal output of the meter in clean water with black tape over detector.

SF: Scale factor is determined using the following equation: SF = xx ÷ (Output - Dark Counts), where xx is the value of a Formazin concentration. For example: 12.2 ÷ (2011 - 50) = 0.0062.

Maximum Output: Maximum signal output the meter is cabable of.

Resolution: standard deviation of 1 minute of collected data.

Imbros
1059 Cambridge Road, Cambridge, Tasmania Australia 7170
info@imbros.com.au
www.imbros.com.au
ABN 29 009 525 053
Ph: (03) 6216 1500
Fax: (03) 6216 1555

SENSOR SERIAL NUMBER: 180786
CALIBRATION DATE: 14-Apr-16

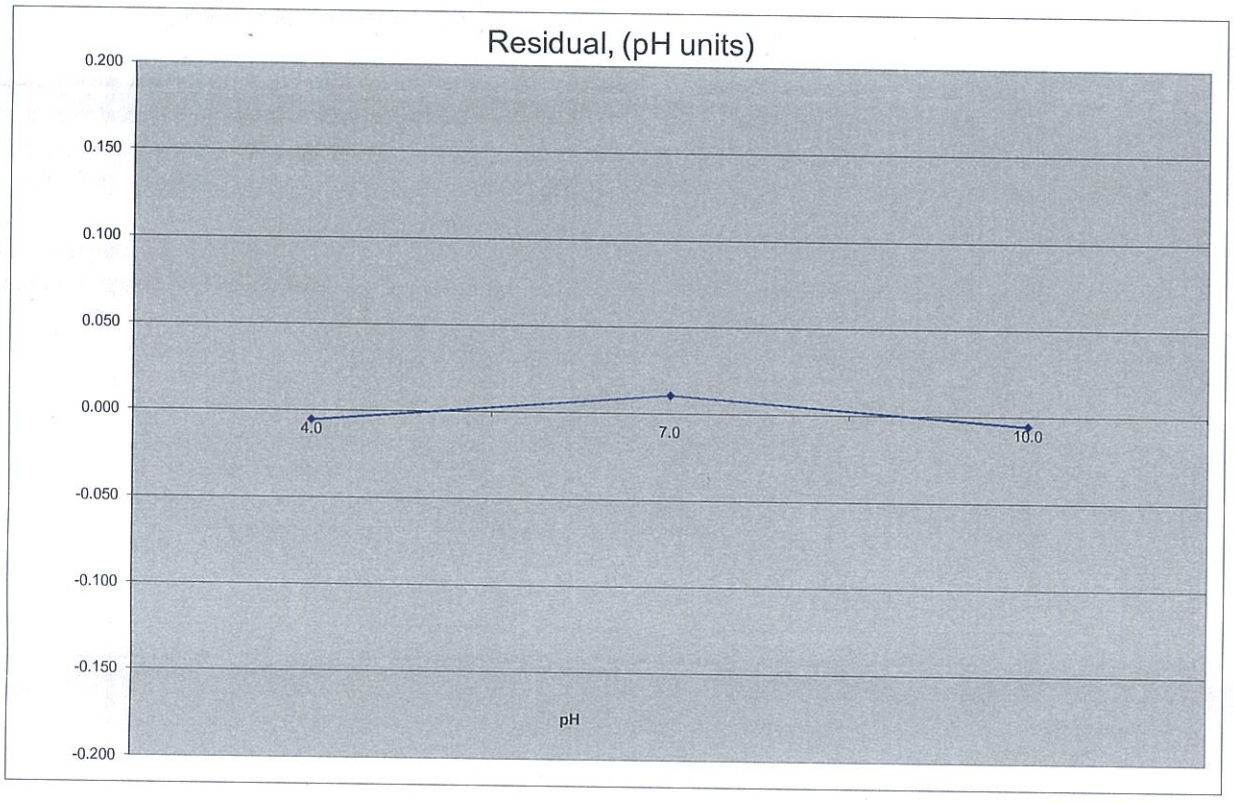
SBE18 pH CALIBRATION DATA

pH COEFFICENTS
pH slope = 4.5790
pHoffset = 2.5452

pH	Temperature (Deg C)	Vout	Instrument Output	Residual (pH units)
4.0	21.0	1.742	3.995	-0.005
7.0	21.0	2.548	7.011	0.011
10.0	21.0	3.346	9.995	-0.005

pH = 7.0 + (Vout - pHoffset) / (pHslope * K * 1.98416E-4)

Where:
Vout = pH sensor output in volts
K is the water temperature in degrees Kelvin
Risidual = instrument pH - buffer pH



SEA-BIRD ELECTRONICS, INC.

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SENSOR SERIAL NUMBER: 6243
CALIBRATION DATE: 20-Dec-08

SBE19plus TEMPERATURE CALIBRATION DATA
ITS-90 TEMPERATURE SCALE

ITS-90 COEFFICIENTS

a0 = 1.280611e-003
a1 = 2.605966e-004
a2 = -3.977704e-007
a3 = 1.545821e-007

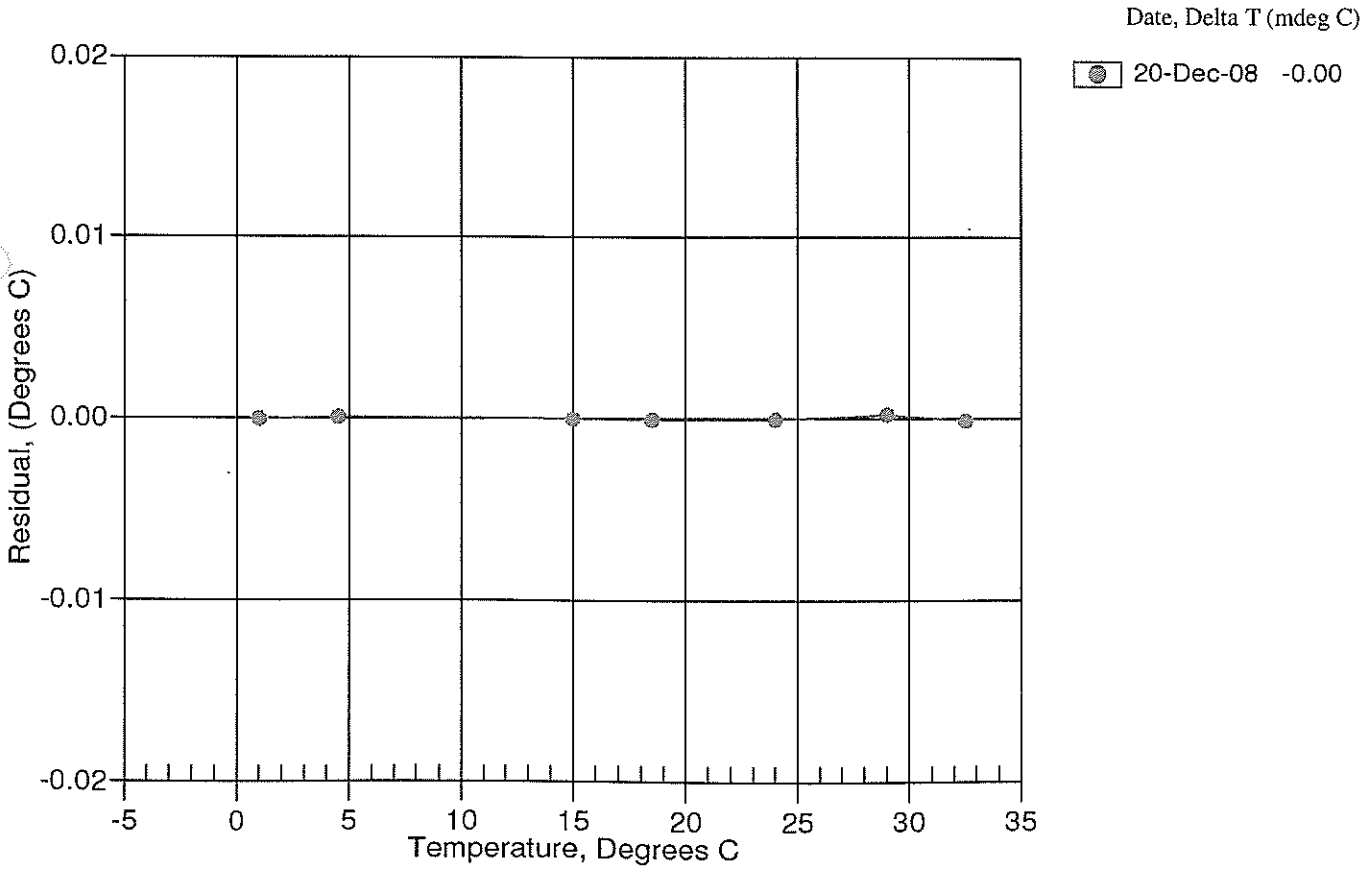
BATH TEMP (ITS-90)	INSTRUMENT OUTPUT(n)	INST TEMP (ITS-90)	RESIDUAL (ITS-90)
1.0000	649730.458	1.0000	-0.0000
4.5000	576602.881	4.5001	0.0001
15.0000	394676.898	15.0000	-0.0000
18.5001	345810.576	18.5000	-0.0001
24.0000	279538.525	23.9999	-0.0001
29.0000	229187.186	29.0002	0.0002
32.5001	198841.068	32.5000	-0.0001

MV = (n - 524288) / 1.6e+007

R = (MV * 2.900e+009 + 1.024e+008) / (2.048e+004 - MV * 2.0e+005)

Temperature ITS-90 = $1/\{a0 + a1[ln(R)] + a2[ln^2(R)] + a3[ln^3(R)]\} - 273.15$ (°C)

Residual = instrument temperature - bath temperature



SEA-BIRD ELECTRONICS, INC.
13431 NE 20th St. Bellevue, Washington 98005 USA
Phone: (425) 643-9866 Fax: (425) 643-9954 www.seabird.com

Pressure Test Certificate

Customer	Imbros
Job Number	69109
Date	6/20/2012
Technician	RH

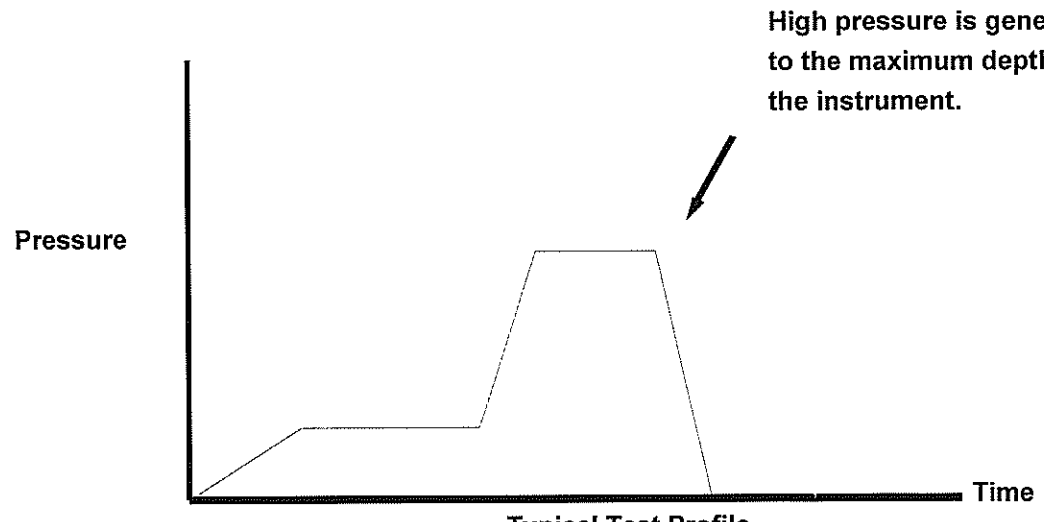
Serial Number	431887	
Low Pressure (PSI)	50	PSI
Time (Minutes)	15	Minutes
High Pressure (PSI)	750	PSI
Time (Minutes)	30	Minutes

Pass ☑

Fail ☐

Comments

Replaced spar, anode, getter, housing, connector and the main piston O-rings.



Typical Test Profile

Appendix B

Physicochemical water column profile data

Appendix B Physicochemical water column profile data

Table 2 Temperature (°C) / depth profiles at sites surrounding proposed Drill Centre locations

Depth	DC0	DC0_SW1000	DC0_SW2000	DC1	DC1_NW1000	DC1_NW2000	DC2	DC2_NE1000	DC2_NE2000	DC3
1 - 10 m	31.1	31.2	31.2	31.1	31.3	31.3	31.1	31.3	31.3	31.1
10 - 20 m	31.1	31.2	31.2	31.1	31.1	31.1	31.1	31.1	31.1	31.1
20 - 30 m	30.9	31.1	31.1	30.6	31.1	31.1	30.9	31.1	31.1	30.9
30 - 40 m	29.7	31.1	31.1	29.2	31.1	31.1	29.6	31.0	31.1	29.6
40 - 50 m	28.2	30.6	30.6	27.6	30.8	30.7	27.9	30.5	30.5	28.2
50 - 60 m	27.0	29.3	29.3	26.5	29.6	29.1	26.8	29.0	29.1	26.9
60 - 70 m	26.5	27.7	27.7	26.0	27.9	27.8	26.2	27.3	27.4	26.4
70 - 80 m	25.8	26.6	26.6	25.5	26.5	26.6	25.4	26.5	26.4	25.5
80 - 90 m	25.1	25.4	25.4	25.1	25.5	25.5	24.7	25.6	25.6	24.8
90 - 100 m	24.3	24.6	24.6	24.4	24.8	24.8	24.0	24.6	24.6	23.4
100 - 110 m	23.1	23.4	23.4	23.7	24.2	24.0	23.1	23.6	23.5	22.8
110 - 120 m	22.6	22.3	22.3	22.4	22.7	21.8	21.8	22.3	22.4	22.0
120 - 130 m	20.8	20.8	20.8	20.6	20.9	20.6	20.0	21.5	20.7	19.9
130 - 140 m	18.8	19.7	19.7	18.8	18.8	19.2	18.7	19.4	19.1	18.5
140 - 150 m	17.9	18.0	18.0	17.8	17.9	18.0	18.1	17.9	17.7	17.8
150 - 160 m	17.2	17.3	17.3	17.4	17.3	17.2	17.5	17.4	17.4	17.2
160 - 170 m	16.8	17.0	17.0	17.0	17.0	16.9	17.1	17.1	17.1	16.8
170 - 180 m		16.7	16.7	-	-	-	-	-	-	-
180 - 190 m	-	-	-	-	-	-	-	-	-	-
190 - 200 m	-	-	-	-	-	-	-	-	-	-
200 - 210 m	-	-	-	-	-	-	-	-	-	-

Table 3 Temperature (°C) / depth profiles at sites surrounding proposed FPSO Locations

Depth	FPSO_0	FPSO_SE1000	FPSO_SE2000	FPSO_NE1000	FPSO_NE2000	FPSO_SW1000	FPSO_SW2000
1 - 10 m	30.9	30.8	30.8	30.9	30.9	30.9	30.9
10 - 20 m	30.9	30.8	30.8	30.9	30.9	30.9	30.9
20 - 30 m	30.9	30.7	30.6	30.9	30.9	30.9	30.9
30 - 40 m	30.5	29.4	29.7	29.7	30.1	29.5	29.5
40 - 50 m	29.3	28.6	28.9	28.7	29.1	28.4	28.3
50 - 60 m	28.2	27.8	28.2	27.7	28.0	27.4	27.5
60 - 70 m	27.2	26.9	27.3	26.7	26.9	26.5	26.8
70 - 80 m	26.3	26.0	26.0	25.8	25.9	25.8	25.8
80 - 90 m	25.8	24.9	25.1	24.9	24.9	24.9	24.8
90 - 100 m	24.6	23.6	23.9	23.8	23.8	23.8	24.0
100 - 110 m	23.2	22.8	22.9	23.2	23.1	23.0	23.1
110 - 120 m	22.3	21.4	21.7	22.4	21.9	22.2	22.2
120 - 130 m	20.6	20.4	20.6	21.0	20.5	21.1	21.0
130 - 140 m	19.2	18.8	18.6	19.4	18.8	19.5	19.5
140 - 150 m	17.9	17.6	17.5	17.8	17.8	17.8	17.9
150 - 160 m	17.3	17.1	17.2	17.1	17.2	17.3	17.3
160 - 170 m	16.9	16.8	16.8	16.8	17.0	16.8	16.7
170 - 180 m	-	-	-	-	-	16.6	16.6
180 - 190 m	-	-	-	-	-	-	-
190 - 200 m	-	-	-	-	-	-	-
200 - 210 m	-	-	-	-	-	-	-

Table 4 Temperature (°C) / depth profiles at sites along the Pipeline and reference sites

Depth	PL-1	PL-2	PL-3	REF_NE	REF_SE	REF_NW	REF_SW
1 - 10 m	31.1	31.1	30.9	30.8	30.8	31.3	31.1
10 - 20 m	30.8	31.0	30.9	30.9	30.8	31.2	31.1
20 - 30 m	30.8	30.9	30.9	30.8	30.8	30.9	31.0
30 - 40 m	30.8	29.2	29.4	30.1	30.6	30.1	30.3
40 - 50 m	30.3	27.8	27.8	29.2	29.4	29.0	28.5
50 - 60 m	28.7	26.6	26.7	28.0	27.5	28.0	27.2
60 - 70 m	27.6	26.1	26.3	26.9	26.3	26.9	26.5
70 - 80 m	26.7	25.1	25.4	25.7	25.3	25.9	25.7
80 - 90 m	25.4	24.4	24.3	24.2	24.2	25.2	24.7
90 - 100 m	23.7	23.7	23.2	22.5	23.4	24.6	23.9
100 - 110 m	22.6	23.2	22.0	-	22.6	24.0	23.0
110 - 120 m	21.5	22.6	21.0	-	19.7	22.4	22.2
120 - 130 m	20.5	21.4	20.4	-	19.0	20.5	20.6
130 - 140 m	19.3	20.9	19.3	-	-	19.1	19.3
140 - 150 m	18.3	20.4	18.6	-	-	17.9	18.2
150 - 160 m	17.4	19.9	17.4	-	-	17.1	17.5
160 - 170 m	16.4	18.6	16.2	-	-	17.0	16.9
170 - 180 m	15.8	17.7	16.2	-	-	-	16.5
180 - 190 m	15.4	16.4	-	-	-	-	-
190 - 200 m	14.9	15.1	-	-	-	-	-
200 - 210 m	14.8	14.9	-	-	-	-	-

Table 5 Salinity (PSU) / depth profiles at sites surrounding proposed Drill Centre locations

Depth	DC0	DC0_SW1000	DC0_SW2000	DC1	DC1_NW1000	DC1_NW2000	DC2	DC2_NE1000	DC2_NE2000	DC3
1 - 10 m	34.94	34.94	34.94	34.94	34.94	34.95	34.94	34.94	34.94	34.94
10 - 20 m	34.94	34.94	34.94	34.94	34.94	34.94	34.94	34.94	34.94	34.93
20 - 30 m	34.90	34.94	34.94	34.83	34.94	34.94	34.89	34.94	34.94	34.87
30 - 40 m	34.73	34.93	34.93	34.68	34.93	34.94	34.71	34.93	34.93	34.71
40 - 50 m	34.61	34.83	34.83	34.58	34.88	34.84	34.59	34.82	34.82	34.60
50 - 60 m	34.58	34.69	34.69	34.58	34.71	34.67	34.57	34.65	34.65	34.57
60 - 70 m	34.57	34.60	34.60	34.58	34.60	34.62	34.56	34.59	34.59	34.56
70 - 80 m	34.56	34.56	34.56	34.57	34.58	34.57	34.56	34.58	34.58	34.55
80 - 90 m	34.56	34.55	34.55	34.56	34.56	34.55	34.56	34.55	34.56	34.54
90 - 100 m	34.53	34.55	34.55	34.56	34.56	34.55	34.54	34.55	34.55	34.53
100 - 110 m	34.53	34.52	34.52	34.53	34.55	34.54	34.52	34.52	34.53	34.53
110 - 120 m	34.52	34.52	34.52	34.51	34.51	34.49	34.49	34.52	34.51	34.51
120 - 130 m	34.48	34.50	34.50	34.47	34.49	34.50	34.50	34.51	34.50	34.49
130 - 140 m	34.50	34.50	34.50	34.51	34.50	34.50	34.51	34.48	34.47	34.51
140 - 150 m	34.51	34.49	34.49	34.51	34.51	34.51	34.51	34.51	34.52	34.52
150 - 160 m	34.51	34.52	34.52	34.52	34.52	34.51	34.51	34.52	34.52	34.51
160 - 170 m	34.52	34.52	34.52	34.53	34.53	34.53	34.52	34.52	34.53	34.53
170 - 180 m	-	34.53	34.53	-	-	-	-	-	-	-
180 - 190 m	-	-	-	-	-	-	-	-	-	-
190 - 200 m	-	-	-	-	-	-	-	-	-	-
200 - 210 m	-	-	-	-	-	-	-	-	-	-

Table 6 Salinity (PSU) / depth profiles at sites surrounding proposed FPSO Locations

Depth	FPSO_0	FPSO_SE1000	FPSO_SE2000	FPSO_NE1000	FPSO_NE2000	FPSO_SW1000	FPSO_SW2000
1 - 10 m	34.83	34.78	34.78	34.84	34.83	34.84	34.83
10 - 20 m	34.83	34.79	34.78	34.84	34.84	34.85	34.83
20 - 30 m	34.84	34.78	34.76	34.85	34.85	34.85	34.83
30 - 40 m	34.80	34.68	34.68	34.69	34.74	34.69	34.69
40 - 50 m	34.69	34.65	34.66	34.66	34.68	34.62	34.63
50 - 60 m	34.63	34.60	34.62	34.61	34.62	34.59	34.59
60 - 70 m	34.58	34.58	34.58	34.56	34.56	34.56	34.57
70 - 80 m	34.57	34.56	34.56	34.56	34.57	34.55	34.55
80 - 90 m	34.56	34.54	34.55	34.54	34.54	34.55	34.55
90 - 100 m	34.53	34.54	34.53	34.55	34.54	34.53	34.54
100 - 110 m	34.52	34.51	34.52	34.53	34.53	34.53	34.53
110 - 120 m	34.51	34.51	34.51	34.52	34.50	34.52	34.52
120 - 130 m	34.50	34.49	34.50	34.50	34.50	34.50	34.50
130 - 140 m	34.49	34.48	34.50	34.48	34.48	34.47	34.48
140 - 150 m	34.50	34.51	34.52	34.49	34.51	34.51	34.52
150 - 160 m	34.53	34.52	34.52	34.52	34.52	34.52	34.52
160 - 170 m	34.52	34.53	34.53	34.53	34.53	34.52	34.53
170 - 180 m	-	-	-	-	-	34.53	34.53
180 - 190 m	-	-	-	-	-	-	-
190 - 200 m	-	-	-	-	-	-	-
200 - 210 m	-	-	-	-	-	-	-

Table 7 Salinity (PSU) / depth profiles at sites along the Pipeline and reference sites

Depth	PL-1	PL-2	PL-3	REF_NE	REF_SE	REF_NW	REF_SW
1 - 10 m	34.86	34.88	34.83	34.79	34.79	34.96	34.94
10 - 20 m	34.86	34.86	34.82	34.79	34.79	34.96	34.93
20 - 30 m	34.86	34.84	34.81	34.78	34.77	34.90	34.93
30 - 40 m	34.86	34.67	34.65	34.75	34.75	34.74	34.78
40 - 50 m	34.78	34.60	34.58	34.67	34.67	34.67	34.61
50 - 60 m	34.64	34.56	34.56	34.59	34.56	34.63	34.58
60 - 70 m	34.59	34.55	34.55	34.57	34.55	34.59	34.56
70 - 80 m	34.54	34.53	34.52	34.54	34.55	34.57	34.56
80 - 90 m	34.51	34.51	34.51	34.53	34.55	34.56	34.55
90 - 100 m	34.49	34.50	34.50	34.49	34.54	34.55	34.55
100 - 110 m	34.48	34.49	34.49	-	34.50	34.54	34.53
110 - 120 m	34.49	34.46	34.50	-	34.49	34.49	34.52
120 - 130 m	34.49	34.48	34.50	-	34.51	34.50	34.49
130 - 140 m	34.49	34.49	34.47	-	-	34.50	34.50
140 - 150 m	34.51	34.50	34.49	-	-	34.49	34.51
150 - 160 m	34.51	34.50	34.47	-	-	34.52	34.51
160 - 170 m	34.51	34.49	34.51	-	-	34.53	34.52
170 - 180 m	34.53	34.49	34.51	-	-	-	34.53
180 - 190 m	34.53	34.50	-	-	-	-	-
190 - 200 m	34.54	34.53	-	-	-	-	-
200 - 210 m	34.54	34.54	-	-	-	-	-

Table 8 Dissolved Oxygen (% Saturation) / depth profiles at sites surrounding proposed Drill Centre locations

Depth	DC0	DC0_SW1000	DC0_SW2000	DC1	DC1_NW1000	DC1_NW2000	DC2	DC2_NE1000	DC2_NE2000	DC3
1 - 10 m	91.63	91.60	91.60	95.63	90.53	95.99	100.37	99.62	93.96	95.20
10 - 20 m	99.18	99.58	99.58	100.20	100.37	100.79	100.89	100.18	100.18	100.17
20 - 30 m	99.23	99.81	99.81	100.16	100.51	100.94	100.82	100.20	100.33	100.09
30 - 40 m	98.66	99.87	99.87	99.34	100.57	100.98	100.23	100.27	100.47	99.70
40 - 50 m	90.01	99.63	99.63	84.02	100.50	100.64	87.64	99.94	100.34	87.25
50 - 60 m	74.29	98.99	98.99	78.08	99.76	99.64	72.80	97.67	98.86	73.57
60 - 70 m	70.47	86.26	86.26	75.33	91.12	90.10	70.68	78.53	82.32	72.55
70 - 80 m	71.09	72.02	72.02	72.16	79.63	80.50	71.55	76.50	78.23	69.58
80 - 90 m	68.93	71.36	71.36	69.79	71.94	72.13	67.83	72.51	72.40	67.66
90 - 100 m	65.12	65.98	65.98	65.69	67.28	67.22	64.75	66.26	66.41	61.70
100 - 110 m	60.26	61.37	61.37	63.15	64.85	64.44	61.87	62.68	62.94	60.49
110 - 120 m	60.08	58.05	58.05	60.41	60.93	58.83	58.71	59.73	60.37	58.43
120 - 130 m	54.72	54.85	54.85	55.25	55.13	55.06	53.48	57.36	55.87	52.76
130 - 140 m	49.70	52.23	52.23	50.51	50.54	51.75	49.91	52.12	51.39	49.00
140 - 150 m	46.40	47.70	47.70	47.53	47.45	47.99	47.89	47.19	46.43	46.28
150 - 160 m	44.28	44.75	44.75	45.45	45.66	45.46	45.55	44.87	44.76	44.55
160 - 170 m	42.99	43.66	43.66	43.84	44.35	43.89	44.02	43.82	43.92	42.90
170 - 180 m	-	42.96	42.96	-	-	-	-	-	-	-
180 - 190 m	-	-	-	-	-	-	-	-	-	-
190 - 200 m	-	-	-	-	-	-	-	-	-	-
200 - 210 m	-	-	-	-	-	-	-	-	-	-

Table 9 Dissolved Oxygen (% Saturation) / depth profiles at sites surrounding proposed FPSO Locations

Depth	FPSO_0	FPSO_SE1000	FPSO_SE2000	FPSO_NE1000	FPSO_NE2000	FPSO_SW1000	FPSO_SW2000
1 - 10 m	93.47	87.34	92.87	95.28	92.47	96.18	92.94
10 - 20 m	98.30	98.44	98.38	98.57	98.54	98.63	98.82
20 - 30 m	98.67	98.19	98.31	98.72	98.79	98.88	98.94
30 - 40 m	98.11	93.57	94.36	95.08	96.63	95.24	95.37
40 - 50 m	94.87	90.42	89.66	94.15	93.82	89.02	88.01
50 - 60 m	89.95	82.34	83.93	83.32	87.15	79.37	80.85
60 - 70 m	76.11	75.66	79.67	73.70	74.15	72.48	75.93
70 - 80 m	71.27	67.80	68.79	70.97	70.92	67.17	67.52
80 - 90 m	71.37	65.62	65.06	67.12	67.54	64.55	63.36
90 - 100 m	65.99	61.67	63.04	62.26	62.56	62.67	63.30
100 - 110 m	60.97	59.79	59.73	61.03	61.17	59.15	59.72
110 - 120 m	58.53	56.32	57.21	59.07	58.17	57.82	57.58
120 - 130 m	54.42	53.15	53.34	55.45	54.12	55.34	55.13
130 - 140 m	50.27	48.80	48.25	51.02	49.53	50.52	50.30
140 - 150 m	46.38	45.21	44.82	46.49	46.05	46.05	46.26
150 - 160 m	43.70	43.53	43.89	43.43	43.62	44.10	44.43
160 - 170 m	42.61	42.36	42.29	42.18	42.62	42.66	42.43
170 - 180 m	-	-	-	-	-	41.76	41.67
180 - 190 m	-	-	-	-	-	-	-
190 - 200 m	-	-	-	-	-	-	-
200 - 210 m	-	-	-	-	-	-	-

Table 10 Dissolved Oxygen (% Saturation) / depth profiles at sites along the Pipeline and reference sites

Depth	PL-1	PL-2	PL-3	REF_NE	REF_SE	REF_NW	REF_SW
1 - 10 m	94.38	86.63	88.94	92.50	92.79	98.71	97.63
10 - 20 m	99.14	96.65	97.84	98.07	98.43	100.48	98.60
20 - 30 m	99.45	98.59	98.23	98.25	98.50	100.49	98.83
30 - 40 m	99.68	96.88	95.20	96.53	97.57	99.87	98.54
40 - 50 m	99.39	84.57	86.48	92.01	92.30	97.89	91.44
50 - 60 m	100.52	69.37	79.30	80.93	75.78	91.81	74.22
60 - 70 m	96.37	67.68	76.84	70.77	68.57	79.04	70.18
70 - 80 m	88.80	69.47	71.51	68.11	65.41	72.71	68.14
80 - 90 m	76.94	65.32	65.90	64.68	64.13	68.86	66.68
90 - 100 m	66.29	62.02	61.19	59.67	61.62	65.93	62.84
100 - 110 m	59.83	60.27	57.03	-	59.47	64.12	59.29
110 - 120 m	57.73	59.83	52.23	-	51.32	60.67	57.68
120 - 130 m	54.26	55.56	49.88	-	48.31	55.13	53.04
130 - 140 m	50.48	54.80	49.56	-	-	50.80	49.46
140 - 150 m	48.51	53.76	47.72	-	-	47.72	46.70
150 - 160 m	46.49	52.32	44.59	-	-	45.04	44.94
160 - 170 m	44.87	49.23	42.12	-	-	44.29	43.37
170 - 180 m	43.45	47.59	42.18	-	-	-	41.93
180 - 190 m	42.48	45.08	-	-	-	-	-
190 - 200 m	41.45	42.50	-	-	-	-	-
200 - 210 m	41.25	42.06	-	-	-	-	-

Table 11 pH / depth profiles at sites surrounding proposed Drill Centre locations

Depth	DC0	DC0_SW1000	DC0_SW2000	DC1	DC1_NW1000	DC1_NW2000	DC2	DC2_NE1000	DC2_NE2000	DC3
1 - 10 m	8.13	8.08	8.08	8.10	8.10	8.13	8.12	8.09	8.09	8.13
10 - 20 m	8.13	8.08	8.08	8.10	8.10	8.13	8.12	8.09	8.09	8.13
20 - 30 m	8.13	8.08	8.08	8.10	8.09	8.12	8.11	8.09	8.08	8.12
30 - 40 m	8.12	8.08	8.08	8.09	8.09	8.11	8.10	8.08	8.08	8.11
40 - 50 m	8.09	8.08	8.08	8.05	8.08	8.11	8.06	8.08	8.08	8.08
50 - 60 m	8.05	8.06	8.06	8.02	8.08	8.09	8.02	8.06	8.06	8.04
60 - 70 m	8.03	8.03	8.03	8.01	8.05	8.07	8.01	8.01	8.02	8.03
70 - 80 m	8.03	7.99	7.99	7.99	8.01	8.04	8.00	8.00	8.00	8.02
80 - 90 m	8.02	7.98	7.98	7.98	7.99	8.01	7.99	7.98	7.98	8.01
90 - 100 m	8.00	7.95	7.95	7.96	7.97	7.99	7.97	7.96	7.96	7.99
100 - 110 m	7.98	7.93	7.93	7.95	7.95	7.97	7.96	7.94	7.94	7.97
110 - 120 m	7.97	7.91	7.91	7.94	7.93	7.94	7.94	7.92	7.92	7.96
120 - 130 m	7.95	7.89	7.89	7.91	7.91	7.92	7.91	7.90	7.90	7.94
130 - 140 m	7.93	7.87	7.87	7.89	7.88	7.90	7.89	7.88	7.87	7.92
140 - 150 m	7.90	7.84	7.84	7.86	7.85	7.87	7.87	7.84	7.84	7.89
150 - 160 m	7.88	7.82	7.82	7.84	7.83	7.85	7.85	7.82	7.82	7.87
160 - 170 m	7.87	7.81	7.80	7.83	7.81	7.83	7.84	7.81	7.81	7.86
170 - 180 m	-	7.80	7.80	-	-	-	-	-	-	-
180 - 190 m	-	-	-	-	-	-	-	-	-	-
190 - 200 m	-	-	-	-	-	-	-	-	-	-
200 - 210 m	-	-	-	-	-	-	-	-	-	-

Table 12 pH / depth profiles at sites surrounding proposed FPSO Locations

Depth	FPSO_0	FPSO_SE1000	FPSO_SE2000	FPSO_NE1000	FPSO_NE2000	FPSO_SW1000	FPSO_SW2000
1 - 10 m	8.04	8.11	8.11	8.12	8.11	8.12	8.12
10 - 20 m	8.05	8.11	8.11	8.12	8.11	8.12	8.12
20 - 30 m	8.06	8.11	8.11	8.12	8.11	8.12	8.12
30 - 40 m	8.06	8.09	8.09	8.10	8.10	8.10	8.10
40 - 50 m	8.05	8.07	8.08	8.09	8.09	8.08	8.07
50 - 60 m	8.04	8.05	8.06	8.06	8.06	8.05	8.05
60 - 70 m	8.01	8.03	8.04	8.03	8.03	8.02	8.03
70 - 80 m	7.99	8.00	8.01	8.01	8.01	8.00	8.00
80 - 90 m	7.99	7.99	7.99	8.00	8.00	7.99	7.98
90 - 100 m	7.97	7.97	7.98	7.98	7.98	7.98	7.97
100 - 110 m	7.95	7.96	7.96	7.96	7.96	7.96	7.96
110 - 120 m	7.94	7.94	7.95	7.95	7.95	7.95	7.94
120 - 130 m	7.92	7.92	7.92	7.93	7.93	7.93	7.93
130 - 140 m	7.90	7.90	7.90	7.91	7.90	7.91	7.90
140 - 150 m	7.87	7.87	7.87	7.88	7.87	7.88	7.88
150 - 160 m	7.85	7.85	7.85	7.86	7.85	7.86	7.86
160 - 170 m	7.83	7.84	7.84	7.84	7.84	7.84	7.84
170 - 180 m	-	-	-	-	-	7.83	7.83
180 - 190 m	-	-	-	-	-	-	-
190 - 200 m	-	-	-	-	-	-	-
200 - 210 m	-	-	-	-	-	-	-

Table 13 pH / depth profiles at sites along the Pipeline and reference sites

Depth	PL-1	PL-2	PL-3	REF_NE	REF_SE	REF_NW	REF_SW
1 - 10 m	8.06	8.08	8.12	8.02	8.12	8.11	8.13
10 - 20 m	8.07	8.09	8.12	8.04	8.12	8.11	8.13
20 - 30 m	8.07	8.09	8.12	8.06	8.12	8.10	8.13
30 - 40 m	8.07	8.07	8.11	8.07	8.12	8.09	8.12
40 - 50 m	8.07	8.04	8.08	8.06	8.11	8.08	8.10
50 - 60 m	8.06	7.99	8.06	8.04	8.07	8.06	8.06
60 - 70 m	8.04	7.98	8.04	8.01	8.04	8.02	8.04
70 - 80 m	8.02	7.97	8.02	8.00	8.03	8.00	8.03
80 - 90 m	7.98	7.95	8.00	7.99	8.02	7.98	8.02
90 - 100 m	7.95	7.93	7.98	7.98	8.00	7.97	8.01
100 - 110 m	7.92	7.91	7.96	-	7.99	7.95	7.99
110 - 120 m	7.90	7.91	7.94	-	7.96	7.94	7.98
120 - 130 m	7.89	7.89	7.92	-	7.94	7.91	7.96
130 - 140 m	7.86	7.88	7.91	-	-	7.88	7.94
140 - 150 m	7.84	7.87	7.89	-	-	7.86	7.92
150 - 160 m	7.82	7.86	7.87	-	-	7.84	7.90
160 - 170 m	7.80	7.85	7.85	-	-	7.83	7.88
170 - 180 m	7.78	7.83	7.84	-	-	-	7.87
180 - 190 m	7.77	7.81	-	-	-	-	-
190 - 200 m	7.76	7.78	-	-	-	-	-
200 - 210 m	7.75	7.77	-	-	-	-	-

Table 14 Turbidity (NTU) / depth profiles at sites surrounding proposed Drill Centre locations

Depth	DC0	DC0_SW1000	DC0_SW2000	DC1	DC1_NW1000	DC1_NW2000	DC2	DC2_NE1000	DC2_NE2000	DC3
1 - 10 m	0.31	0.32	0.32	0.30	0.36	0.26	0.35	0.30	0.33	0.40
10 - 20 m	0.25	0.28	0.28	0.37	0.25	0.32	0.33	0.33	0.29	0.35
20 - 30 m	0.26	0.30	0.30	0.33	0.25	0.27	0.26	0.31	0.36	0.39
30 - 40 m	0.26	0.29	0.29	0.27	0.29	0.25	0.26	0.29	0.32	0.31
40 - 50 m	0.29	0.30	0.30	0.32	0.26	0.24	0.30	0.31	0.29	0.37
50 - 60 m	0.30	0.27	0.27	0.24	0.25	0.21	0.33	0.29	0.31	0.32
60 - 70 m	0.35	0.29	0.29	0.33	0.26	0.24	0.31	0.29	0.27	0.37
70 - 80 m	0.28	0.29	0.29	0.30	0.24	0.21	0.21	0.28	0.26	0.34
80 - 90 m	0.33	0.31	0.31	0.33	0.26	0.23	0.27	0.33	0.26	0.30
90 - 100 m	0.37	0.30	0.30	0.45	0.27	0.22	0.33	0.34	0.40	0.42
100 - 110 m	0.45	0.46	0.46	0.44	0.38	0.40	0.31	0.48	0.47	0.35
110 - 120 m	0.34	0.49	0.49	0.33	0.33	0.33	0.30	0.41	0.40	0.39
120 - 130 m	0.48	0.51	0.51	0.44	0.43	0.33	0.37	0.37	0.33	0.42
130 - 140 m	0.47	0.40	0.40	0.44	0.41	0.34	0.34	0.41	0.41	0.42
140 - 150 m	0.47	0.51	0.51	0.45	0.44	0.42	0.37	0.51	0.48	0.41
150 - 160 m	0.46	0.51	0.51	0.44	0.46	0.42	0.37	0.52	0.49	0.43
160 - 170 m	0.44	0.50	0.50	0.45	0.48	0.43	0.35	0.52	0.45	0.46
170 - 180 m	-	0.50	0.50	-	-	-	-	-	-	-
180 - 190 m	-	-	-	-	-	-	-	-	-	-
190 - 200 m	-	-	-	-	-	-	-	-	-	-
200 - 210 m	-	-	-	-	-	-	-	-	-	-

Table 15 Turbidity (NTU) / depth profiles at sites surrounding proposed FPSO Locations

Depth	FPSO_0	FPSO_SE1000	FPSO_SE2000	FPSO_NE1000	FPSO_NE2000	FPSO_SW1000	FPSO_SW2000
1 - 10 m	0.30	0.29	0.45	0.29	0.32	0.29	0.30
10 - 20 m	0.26	0.28	0.29	0.30	0.29	0.29	0.29
20 - 30 m	0.26	0.28	0.31	0.28	0.30	0.29	0.30
30 - 40 m	0.28	0.30	0.33	0.35	0.30	0.33	0.39
40 - 50 m	0.27	0.28	0.33	0.28	0.29	0.30	0.34
50 - 60 m	0.28	0.27	0.28	0.29	0.28	0.28	0.31
60 - 70 m	0.30	0.29	0.28	0.30	0.28	0.30	0.28
70 - 80 m	0.26	0.34	0.35	0.34	0.32	0.40	0.45
80 - 90 m	0.29	0.41	0.47	0.31	0.30	0.48	0.49
90 - 100 m	0.26	0.44	0.39	0.45	0.43	0.33	0.43
100 - 110 m	0.40	0.36	0.44	0.35	0.32	0.38	0.40
110 - 120 m	0.32	0.32	0.32	0.33	0.36	0.37	0.46
120 - 130 m	0.35	0.44	0.52	0.37	0.42	0.33	0.45
130 - 140 m	0.48	0.51	0.50	0.37	0.49	0.52	0.52
140 - 150 m	0.49	0.49	0.50	0.53	0.51	0.51	0.52
150 - 160 m	0.47	0.51	0.54	0.50	0.52	0.51	0.52
160 - 170 m	0.49	0.50	0.52	0.54	0.53	0.52	0.54
170 - 180 m	-	-	-	-	-	0.49	0.57
180 - 190 m	-	-	-	-	-	-	-
190 - 200 m	-	-	-	-	-	-	-
200 - 210 m	-	-	-	-	-	-	-

Table 16 Turbidity (NTU) / depth profiles at sites along the Pipeline and reference sites

Depth	PL-1	PL-2	PL-3	REF_NE	REF_SE	REF_NW	REF_SW
1 - 10 m	0.36	0.34	0.40	0.39	0.36	0.29	0.22
10 - 20 m	0.28	0.31	0.24	0.33	0.30	0.27	0.27
20 - 30 m	0.26	0.33	0.20	0.30	0.37	0.27	0.23
30 - 40 m	0.28	0.32	0.22	0.33	0.37	0.31	0.25
40 - 50 m	0.26	0.45	0.21	0.32	0.44	0.28	0.24
50 - 60 m	0.27	0.40	0.21	0.29	0.31	0.24	0.25
60 - 70 m	0.26	0.26	0.22	0.41	0.33	0.24	0.29
70 - 80 m	0.34	0.25	0.23	0.36	0.51	0.25	0.37
80 - 90 m	0.24	0.25	0.31	0.44	0.48	0.26	0.29
90 - 100 m	0.25	0.24	0.36	0.46	0.32	0.31	0.32
100 - 110 m	0.25	0.24	0.41	-	0.38	0.29	0.45
110 - 120 m	0.25	0.22	0.44	-	0.49	0.31	0.41
120 - 130 m	0.25	0.24	0.62	-	0.52	0.33	0.42
130 - 140 m	0.26	0.23	0.44	-	-	0.44	0.43
140 - 150 m	0.24	0.23	0.47	-	-	0.45	0.41
150 - 160 m	0.31	0.24	0.60	-	-	0.45	0.43
160 - 170 m	0.26	0.23	0.66	-	-	0.44	0.42
170 - 180 m	0.33	0.23	0.74	-	-	-	0.42
180 - 190 m	0.38	0.27	-	-	-	-	-
190 - 200 m	0.50	0.46	-	-	-	-	-
200 - 210 m	0.72	0.45	-	-	-	-	-

Appendix C

Water sample analytical results

Appendix C Water sample analytical results

Table 17 Laboratory analytical results for sample sites surrounding proposed Drill Centre locations

			Site	DC0	DC00	DC1	DC2	DC22	DC3	DC1_NW1000	DC1_NW2000	DC2_NE1000	DC2_NE2000	DC0_SW1000	DC0_SW10001	DC0_SW2000
Analyte	**Unit**	**Trigger[a]**	**PQL**													
Hydrocarbons																
TRH C6-C40 (sum)	µg/L	-	10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
BTEX																
Benzene	mg/L	0.5	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Toluene	mg/L	0.18[b]	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Ethylbenzene	mg/L	0.005[b]	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Xylenes (Total)	mg/L	0.625[b]	0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
Metals (Total)																
Arsenic - Total	mg/L	-	0.001	**0.002**	**0.002**	**0.002**	**0.001**	**0.002**	**0.002**	**0.002**	**0.002**	**0.002**	**0.002**	**0.002**	**0.002**	**0.002**
Aluminium - Total	mg/L	-	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Barium - Total	mg/L	-	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cadmium - Total	mg/L	0.0007	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Cobalt - Total	mg/L	0.001[c]	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Chromium - Total	mg/L	0.0077	0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	**0.002**	<0.001	<0.001
Copper - Total	mg/L	0.0013[c]	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	**0.001**	<0.001	<0.001
Iron - Total	mg/L	-	0.01	**0.06**	**0.01**	**0.04**	<0.01	**0.03**	**0.02**	<0.01	**0.02**	<0.01	**0.02**	<0.01	<0.01	<0.01
Mercury - Total	mg/L	0.0001	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Nickel - Total	mg/L	0.007	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Lead - Total	mg/L	0.0022	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Zinc - Total	mg/L	0.007	0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Nutrients																
Total Nitrogen	mg/L	0.1[d]	0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
TKN	mg/L	-	0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
NOx-N	mg/L	0.004[d]	0.01	<0.01	**0.01**	<0.01	<0.01	<0.01	**0.04**	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Total Phosphorus	mg/L	0.01[d]	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Photosynthetic pigments																
CHLORO 'a' 3020	µg/L	0.9[d]	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
CHLORO 'b' 3020	µg/L	-	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
CHLORO 'c' 3020	µg/L	-	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
CHLOROPHYLL'a' 3000	µg/L	0.9[d]	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
PHAEOPHYTIN'a' 3000	µg/L	-	0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2

Concentrations above PQL in **bold**

a - ANZECC / ARMCANZ 99% species protection level

b - ANZECC/ARMCANZZ low reliability trigger values

c - ANZECC / ARMCANZ 95% species protection level

d -ANZECC / ARMCANZ Default trigger level. Site specific trigger level to be developed using baseline data

Table 18 Laboratory analytical results for sample sites surrounding proposed FPSO locations

			Site	FPSO_0	FPSO_00	FPSO_NE1000	FPSO_NE2000	FPSO_SW1000	FPSO_SW2000	FPSO_SE1000	FPSO_SE2000
Analyte	**Unit**	**Trigger[a]**	**PQL**								
Hydrocarbons											
TRH C6-C40 (sum)	µg/L	-	10	<10	<10	<10	<10	<10	<10	<10	<10
BTEX											
Benzene	mg/L	0.5	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Toluene	mg/L	0.18[b]	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Ethylbenzene	mg/L	0.005[b]	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Xylenes (Total)	mg/L	0.625[b]	0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
Metals (Total)											
Arsenic - Total	mg/L	-	0.001	**0.002**	**0.002**	**0.002**	**0.004**	**0.002**	**0.002**	**0.003**	**0.002**
Aluminium - Total	mg/L	-	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Barium - Total	mg/L	-	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cadmium - Total	mg/L	0.0007	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Cobalt - Total	mg/L	0.001[c]	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Chromium - Total	mg/L	0.0077	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Copper - Total	mg/L	0.0013[c]	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Iron - Total	mg/L	-	0.01	<0.01	**0.02**	<0.01	**0.02**	**0.03**	**0.03**	<0.01	<0.01
Mercury - Total	mg/L	0.0001	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Nickel - Total	mg/L	0.007	0.001	<0.001	<0.001	<0.001	**0.001**	<0.001	<0.001	<0.001	<0.001
Lead - Total	mg/L	0.0022	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Zinc - Total	mg/L	0.007	0.005	<0.005	<0.005	<0.005	**0.021**	<0.005	<0.005	<0.005	<0.005
Nutrients											
Total Nitrogen	mg/L	0.1[d]	0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
TKN	mg/L	-	0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
NOx-N	mg/L	0.004[d]	0.01	<0.01	<0.01	**0.05**	<0.01	<0.01	<0.01	<0.01	**0.02**
Total Phosphorus	mg/L	0.01[d]	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Photosynthetic pigments											
CHLORO 'a' 3020	µg/L	0.9[d]	0.1	**0.1**	<0.1	**0.1**	**0.1**	<0.1	<0.1	**0.1**	**0.1**
CHLORO 'b' 3020	µg/L	-	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
CHLORO 'c' 3020	µg/L	-	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
CHLOROPHYLL'a' 3000	µg/L	0.9[d]	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	**0.1**
PHAEOPHYTIN'a' 3000	µg/L	-	0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2

Concentrations above PQL in **bold**

a - ANZECC / ARMCANZ 99% species protection level

b - ANZECC/ARMCANZZ low reliability trigger values

c - ANZECC / ARMCANZ 95% species protection level

d -ANZECC / ARMCANZ Default trigger level. Site specific trigger level to be developed using baseline data

Table 19 Laboratory analytical results for sample sites along the Pipeline, Reference Sites and QA/QC samples

			Site	PL_1	PL_2	PL_3	REF_NW	REF_NW2	REF_SW	REF_NE	REF_SE	Rin_1	Rin_2	FB_1	Trip Blank
Analyte	**Unit**	**Trigger[a]**	**PQL**												
Hydrocarbons															
TRH C6-C40 (sum)	µg/L	-	10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
BTEX															
Benzene	mg/L	0.5	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Toluene	mg/L	0.18[b]	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Ethylbenzene	mg/L	0.005[b]	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Xylenes (Total)	mg/L	0.625[b]	0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
Metals (Total)															
Arsenic - Total	mg/L	-	0.001	**0.002**	**0.002**	**0.002**	**0.002**	**0.002**	**0.003**	**0.002**	**0.002**	<0.001	<0.001	<0.001	<0.001
Aluminium - Total	mg/L	-	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	**0.03**	<0.01	<0.01
Barium - Total	mg/L	-	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cadmium - Total	mg/L	0.0007	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Cobalt - Total	mg/L	0.001[c]	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Chromium - Total	mg/L	0.0077	0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Copper - Total	mg/L	0.0013[c]	0.001	**0.002**	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	**0.003**	**0.003**	**0.002**	**0.003**
Iron - Total	mg/L	-	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Mercury - Total	mg/L	0.0001	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Nickel - Total	mg/L	0.007	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Lead - Total	mg/L	0.0022	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Zinc - Total	mg/L	0.007	0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Nutrients															
Total Nitrogen	mg/L	0.1[d]	0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	-	-	-	-
TKN	mg/L	-	0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	-	-	-	-
NOx-N	mg/L	0.004[d]	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	-	-	-
Total Phosphorus	mg/L	0.01[d]	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	-	-	-
Photosynthetic pigments															
CHLORO 'a' 3020	µg/L	0.9[d]	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	**0.1**	**0.2**				
CHLORO 'b' 3020	µg/L	-	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1				
CHLORO 'c' 3020	µg/L	-	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1				
CHLOROPHYLL'a' 3000	µg/L	0.9[d]	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	**0.1**	**0.1**				
PHAEOPHYTIN'a' 3000	µg/L	-	0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2				

Concentrations above PQL in **bold**

a - ANZECC / ARMCANZ 99% species protection level

b - ANZECC/ARMCANZZ low reliability trigger values

c - ANZECC / ARMCANZ 95% species protection level

d -ANZECC / ARMCANZ Default trigger level. Site specific trigger level to be developed using baseline data

Appendix D

Laboratory reports

Appendix D Laboratory reports

ARL
Analytical Reference Laboratory

LABORATORY REPORT

Job Number: 16-03180
Revision: 00
Date: 12 May 2016

ADDRESS: **AECOM Services Pty Ltd**
GPO Box B59
Perth WA 6849

ATTENTION: Peter Young

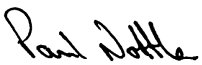
DATE RECEIVED: 4/05/2016

YOUR REFERENCE: 60478944

PURCHASE ORDER:

APPROVALS:


DouglasTodd
Laboratory Manager


Paul Nottle
Organics Manager


Sam Becker
Inorganics Manager

REPORT COMMENTS:

Samples are analysed on an as received basis unless otherwise noted.

METHOD REFERENCES:

ARL No. 009	Total Petroleum Hydrocarbons (TPH) in Water
ARL No. 007	Benzene, Toluene, Ethylbenzene and Xylenes in Water
ARL No. 29/402/403	Metals in Water by AAS/ICPOES/ICPMS
ARL No. 406	Mercury by Cold Vapour Atomic Absorption Spectrophotometry
ARL No. 330	Persulphate Method for Simultaneous Determination of TN & TP
ARL No. 308	Total Phosphorus in Water by Discrete Analyser
ARL No. 313/319	NOx in Water by Discrete Analyser

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LABORATORY REPORT

AECOM Services Pty Ltd

ARL Job No: 16-03180 *Revision: 00* *Date:* 12 May 2016

TPH Low Level 1 in Water Sample No: Sample Description:	LOR	UNITS	16-03180-1 DC0	16-03180-2 DC00	16-03180-3 DC1	16-03180-4 DC2	16-03180-5 DC22
TPH Low Level 1*	10	µg/L	<10	<10	<10	<10	<10

TPH Low Level 1 in Water Sample No: Sample Description:	LOR	UNITS	16-03180-6 DC3	16-03180-7 DC1_NW1000	16-03180-8 DC1_NM2000	16-03180-9 DC2_NE1000	16-03180-10 DC2_NE2000
TPH Low Level 1*	10	µg/L	<10	<10	<10	<10	<10

TPH Low Level 1 in Water Sample No: Sample Description:	LOR	UNITS	16-03180-11 DC0_SW1000	16-03180-12 DC0_SW10001	16-03180-13 DC0_SW2000	16-03180-14 FPSO_0	16-03180-15 FPSO_00
TPH Low Level 1*	10	µg/L	<10	<10	<10	<10	<10

TPH Low Level 1 in Water Sample No: Sample Description:	LOR	UNITS	16-03180-16 FPSO_NE1000	16-03180-17 FPSO_NE2000	16-03180-18 FPSO_SW1000	16-03180-19 FPSO_SW2000	16-03180-20 FPSO_SE1000
TPH Low Level 1*	10	µg/L	<10	<10	<10	<10	<10

TPH Low Level 1 in Water Sample No: Sample Description:	LOR	UNITS	16-03180-21 FPSO_SE2000	16-03180-22 PL_1	16-03180-23 PL_2	16-03180-24 PL_3	16-03180-25 REF_NW
TPH Low Level 1*	10	µg/L	<10	<10	<10	<10	<10

TPH Low Level 1 in Water Sample No: Sample Description:	LOR	UNITS	16-03180-26 REF_NW2	16-03180-27 REF_SW	16-03180-28 REF_NE	16-03180-29 REF_SE	16-03180-30 Rin_1
TPH Low Level 1*	10	µg/L	<10	<10	<10	<10	<10

TPH Low Level 1 in Water Sample No: Sample Description:	LOR	UNITS	16-03180-31 Rin_2	16-03180-32 FB_1	16-03180-33 Trip Blank
TPH Low Level 1*	10	µg/L	<10	<10	<10

BTEX in Water Sample No: Sample Description:	LOR	UNITS	16-03180-1 DC0	16-03180-2 DC00	16-03180-3 DC1	16-03180-4 DC2	16-03180-5 DC22
Benzene	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Toluene	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Ethylbenzene	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Xylenes (Total)	0.003	mg/L	<0.003	<0.003	<0.003	<0.003	<0.003

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BTEX in Water Sample No: Sample Description:	LOR	UNITS	16-03180-6 DC3	16-03180-7 DC1_NW1000	16-03180-8 DC1_NM2000	16-03180-9 DC2_NE1000	16-03180-10 DC2_NE2000
Benzene	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Toluene	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Ethylbenzene	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Xylenes (Total)	0.003	mg/L	<0.003	<0.003	<0.003	<0.003	<0.003

BTEX in Water Sample No: Sample Description:	LOR	UNITS	16-03180-11 DC0_SW1000	16-03180-12 DC0_SW10001	16-03180-13 DC0_SW2000	16-03180-14 FPSO_0	16-03180-15 FPSO_00
Benzene	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Toluene	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Ethylbenzene	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Xylenes (Total)	0.003	mg/L	<0.003	<0.003	<0.003	<0.003	<0.003

BTEX in Water Sample No: Sample Description:	LOR	UNITS	16-03180-16 FPSO_NE1000	16-03180-17 FPSO_NE2000	16-03180-18 FPSO_SW1000	16-03180-19 FPSO_SW2000	16-03180-20 FPSO_SE1000
Benzene	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Toluene	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Ethylbenzene	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Xylenes (Total)	0.003	mg/L	<0.003	<0.003	<0.003	<0.003	<0.003

BTEX in Water Sample No: Sample Description:	LOR	UNITS	16-03180-21 FPSO_SE2000	16-03180-22 PL_1	16-03180-23 PL_2	16-03180-24 PL_3	16-03180-25 REF_NW
Benzene	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Toluene	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Ethylbenzene	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Xylenes (Total)	0.003	mg/L	<0.003	<0.003	<0.003	<0.003	<0.003

BTEX in Water Sample No: Sample Description:	LOR	UNITS	16-03180-26 REF_NW2	16-03180-27 REF_SW	16-03180-28 REF_NE	16-03180-29 REF_SE	16-03180-30 Rin_1
Benzene	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Toluene	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Ethylbenzene	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Xylenes (Total)	0.003	mg/L	<0.003	<0.003	<0.003	<0.003	<0.003

BTEX in Water Sample No: Sample Description:	LOR	UNITS	16-03180-31 Rin_2	16-03180-32 FB_1	16-03180-33 Trip Blank
Benzene	0.001	mg/L	<0.001	<0.001	<0.001
Toluene	0.001	mg/L	<0.001	<0.001	<0.001
Ethylbenzene	0.001	mg/L	<0.001	<0.001	<0.001
Xylenes (Total)	0.003	mg/L	<0.003	<0.003	<0.003

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LABORATORY REPORT

AECOM Services Pty Ltd

ARL Job No: 16-03180 *Revision: 00* *Date:* 12 May 2016

Metals in Water Sample No: Sample Description:	LOR	UNITS	16-03180-1 DC0	16-03180-2 DC00	16-03180-3 DC1	16-03180-4 DC2	16-03180-5 DC22
Arsenic - Total	0.001	mg/L	0.002	0.002	0.002	0.001	0.002
Aluminium - Total	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01
Barium - Total	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01
Cadmium - Total	0.0001	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Cobalt - Total	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Chromium - Total	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	0.001
Copper - Total	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Iron - Total	0.01	mg/L	0.06	0.01	0.04	<0.01	0.03
Mercury - Total	0.0001	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Nickel - Total	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Lead - Total	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Zinc - Total	0.005	mg/L	<0.005	<0.005	<0.005	<0.005	<0.005

Metals in Water Sample No: Sample Description:	LOR	UNITS	16-03180-6 DC3	16-03180-7 DC1_NW1000	16-03180-8 DC1_NM2000	16-03180-9 DC2_NE1000	16-03180-10 DC2_NE2000
Arsenic - Total	0.001	mg/L	0.002	0.002	0.002	0.002	0.002
Aluminium - Total	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01
Barium - Total	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01
Cadmium - Total	0.0001	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Cobalt - Total	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Chromium - Total	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Copper - Total	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Iron - Total	0.01	mg/L	0.02	<0.01	0.02	<0.01	0.02
Mercury - Total	0.0001	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Nickel - Total	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Lead - Total	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Zinc - Total	0.005	mg/L	<0.005	<0.005	<0.005	<0.005	<0.005

Metals in Water Sample No: Sample Description:	LOR	UNITS	16-03180-11 DC0_SW1000	16-03180-12 DC0_SW10001	16-03180-13 DC0_SW2000	16-03180-14 FPSO_0	16-03180-15 FPSO_00
Arsenic - Total	0.001	mg/L	0.002	0.002	0.002	0.002	0.002
Aluminium - Total	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01
Barium - Total	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01
Cadmium - Total	0.0001	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Cobalt - Total	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Chromium - Total	0.001	mg/L	0.002	<0.001	<0.001	<0.001	<0.001
Copper - Total	0.001	mg/L	0.001	<0.001	<0.001	<0.001	<0.001
Iron - Total	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	0.02
Mercury - Total	0.0001	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Nickel - Total	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Lead - Total	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Zinc - Total	0.005	mg/L	<0.005	<0.005	<0.005	<0.005	<0.005

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Metals in Water Sample No: Sample Description:	LOR	UNITS	16-03180-16 FPSO_NE1000	16-03180-17 FPSO_NE2000	16-03180-18 FPSO_SW1000	16-03180-19 FPSO_SW2000	16-03180-20 FPSO_SE1000
Arsenic - Total	0.001	mg/L	0.002	0.004	0.002	0.002	0.003
Aluminium - Total	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01
Barium - Total	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01
Cadmium - Total	0.0001	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Cobalt - Total	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Chromium - Total	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Copper - Total	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Iron - Total	0.01	mg/L	<0.01	0.02	0.03	0.03	<0.01
Mercury - Total	0.0001	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Nickel - Total	0.001	mg/L	<0.001	0.001	<0.001	<0.001	<0.001
Lead - Total	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Zinc - Total	0.005	mg/L	<0.005	0.021	<0.005	<0.005	<0.005

Metals in Water Sample No: Sample Description:	LOR	UNITS	16-03180-21 FPSO_SE2000	16-03180-22 PL_1	16-03180-23 PL_2	16-03180-24 PL_3	16-03180-25 REF_NW
Arsenic - Total	0.001	mg/L	0.002	0.002	0.002	0.002	0.002
Aluminium - Total	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01
Barium - Total	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01
Cadmium - Total	0.0001	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Cobalt - Total	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Chromium - Total	0.001	mg/L	<0.001	<0.001	0.001	<0.001	<0.001
Copper - Total	0.001	mg/L	<0.001	0.002	<0.001	<0.001	<0.001
Iron - Total	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01
Mercury - Total	0.0001	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Nickel - Total	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Lead - Total	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Zinc - Total	0.005	mg/L	<0.005	<0.005	<0.005	<0.005	<0.005

Metals in Water Sample No: Sample Description:	LOR	UNITS	16-03180-26 REF_NW2	16-03180-27 REF_SW	16-03180-28 REF_NE	16-03180-29 REF_SE	16-03180-30 Rin_1
Arsenic - Total	0.001	mg/L	0.002	0.003	0.002	0.002	<0.001
Aluminium - Total	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01
Barium - Total	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01
Cadmium - Total	0.0001	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Cobalt - Total	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Chromium - Total	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Copper - Total	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	0.003
Iron - Total	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01
Mercury - Total	0.0001	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Nickel - Total	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Lead - Total	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Zinc - Total	0.005	mg/L	<0.005	<0.005	<0.005	<0.005	<0.005

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LABORATORY REPORT

AECOM Services Pty Ltd

ARL Job No: 16-03180 *Revision: 00* *Date:* 12 May 2016

Metals in Water Sample No: Sample Description:	LOR	UNITS	16-03180-31 Rin_2	16-03180-32 FB_1	16-03180-33 Trip Blank
Arsenic - Total	0.001	mg/L	<0.001	<0.001	<0.001
Aluminium - Total	0.01	mg/L	0.03	<0.01	<0.01
Barium - Total	0.01	mg/L	<0.01	<0.01	<0.01
Cadmium - Total	0.0001	mg/L	<0.0001	<0.0001	<0.0001
Cobalt - Total	0.001	mg/L	<0.001	<0.001	<0.001
Chromium - Total	0.001	mg/L	<0.001	<0.001	<0.001
Copper - Total	0.001	mg/L	0.003	0.002	0.003
Iron - Total	0.01	mg/L	<0.01	<0.01	<0.01
Mercury - Total	0.0001	mg/L	<0.0001	<0.0001	<0.0001
Nickel - Total	0.001	mg/L	<0.001	<0.001	<0.001
Lead - Total	0.001	mg/L	<0.001	<0.001	<0.001
Zinc - Total	0.005	mg/L	<0.005	<0.005	<0.005

Total Nitrogen in Water Sample No: Sample Description:	LOR	UNITS	16-03180-1 DC0	16-03180-2 DC00	16-03180-3 DC1	16-03180-4 DC2	16-03180-5 DC22
Total Nitrogen	0.2	mg/L	<0.2	<0.2	<0.2	<0.2	<0.2
TKN	0.2	mg/L	<0.2	<0.2	<0.2	<0.2	<0.2

Total Nitrogen in Water Sample No: Sample Description:	LOR	UNITS	16-03180-6 DC3	16-03180-7 DC1_NW1000	16-03180-8 DC1_NM2000	16-03180-9 DC2_NE1000	16-03180-10 DC2_NE2000
Total Nitrogen	0.2	mg/L	<0.2	<0.2	<0.2	<0.2	<0.2
TKN	0.2	mg/L	<0.2	<0.2	<0.2	<0.2	<0.2

Total Nitrogen in Water Sample No: Sample Description:	LOR	UNITS	16-03180-11 DC0_SW1000	16-03180-12 DC0_SW10001	16-03180-13 DC0_SW2000	16-03180-14 FPSO_0	16-03180-15 FPSO_00
Total Nitrogen	0.2	mg/L	<0.2	<0.2	<0.2	<0.2	<0.2
TKN	0.2	mg/L	<0.2	<0.2	<0.2	<0.2	<0.2

Total Nitrogen in Water Sample No: Sample Description:	LOR	UNITS	16-03180-16 FPSO_NE1000	16-03180-17 FPSO_NE2000	16-03180-18 FPSO_SW1000	16-03180-19 FPSO_SW2000	16-03180-20 FPSO_SE1000
Total Nitrogen	0.2	mg/L	<0.2	<0.2	<0.2	<0.2	<0.2
TKN	0.2	mg/L	<0.2	<0.2	<0.2	<0.2	<0.2

Total Nitrogen in Water Sample No: Sample Description:	LOR	UNITS	16-03180-21 FPSO_SE2000	16-03180-22 PL_1	16-03180-23 PL_2	16-03180-24 PL_3	16-03180-25 REF_NW
Total Nitrogen	0.2	mg/L	<0.2	<0.2	<0.2	<0.2	<0.2
TKN	0.2	mg/L	<0.2	<0.2	<0.2	<0.2	<0.2

Total Nitrogen in Water Sample No: Sample Description:	LOR	UNITS	16-03180-26 REF_NW2	16-03180-27 REF_SW	16-03180-28 REF_NE	16-03180-29 REF_SE
Total Nitrogen	0.2	mg/L	<0.2	<0.2	<0.2	<0.2

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Total Nitrogen in Water **Sample No:** **Sample Description:**	**LOR**	**UNITS**	**16-03180-26** **REF_NW2**	**16-03180-27** **REF_SW**	**16-03180-28** **REF_NE**	**16-03180-29** **REF_SE**
TKN	0.2	mg/L	<0.2	<0.2	<0.2	<0.2

Total Phosphorus in Water **Sample No:** **Sample Description:**	**LOR**	**UNITS**	**16-03180-1** **DC0**	**16-03180-2** **DC00**	**16-03180-3** **DC1**	**16-03180-4** **DC2**	**16-03180-5** **DC22**
Total Phosphorus	0.01	mg/L	<0.01	<0.01	<0.01	0.05	<0.01

Total Phosphorus in Water **Sample No:** **Sample Description:**	**LOR**	**UNITS**	**16-03180-6** **DC3**	**16-03180-7** **DC1_NW1000**	**16-03180-8** **DC1_NM2000**	**16-03180-9** **DC2_NE1000**	**16-03180-10** **DC2_NE2000**
Total Phosphorus	0.01	mg/L	<0.01	0.03	<0.01	<0.01	<0.01

Total Phosphorus in Water **Sample No:** **Sample Description:**	**LOR**	**UNITS**	**16-03180-11** **DC0_SW1000**	**16-03180-12** **DC0_SW10001**	**16-03180-13** **DC0_SW2000**	**16-03180-14** **FPSO_0**	**16-03180-15** **FPSO_00**
Total Phosphorus	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01

Total Phosphorus in Water **Sample No:** **Sample Description:**	**LOR**	**UNITS**	**16-03180-16** **FPSO_NE1000**	**16-03180-17** **FPSO_NE2000**	**16-03180-18** **FPSO_SW1000**	**16-03180-19** **FPSO_SW2000**	**16-03180-20** **FPSO_SE1000**
Total Phosphorus	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01

Total Phosphorus in Water **Sample No:** **Sample Description:**	**LOR**	**UNITS**	**16-03180-21** **FPSO_SE2000**	**16-03180-22** **PL_1**	**16-03180-23** **PL_2**	**16-03180-24** **PL_3**	**16-03180-25** **REF_NW**
Total Phosphorus	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01

Total Phosphorus in Water **Sample No:** **Sample Description:**	**LOR**	**UNITS**	**16-03180-26** **REF_NW2**	**16-03180-27** **REF_SW**	**16-03180-28** **REF_NE**	**16-03180-29** **REF_SE**
Total Phosphorus	0.01	mg/L	<0.01	<0.01	<0.01	<0.01

Ions by Discrete Analyser **Sample No:** **Sample Description:**	**LOR**	**UNITS**	**16-03180-1** **DC0**	**16-03180-2** **DC00**	**16-03180-3** **DC1**	**16-03180-4** **DC2**	**16-03180-5** **DC22**
NOx-N	0.01	mg/L	<0.01	0.01	<0.01	<0.01	<0.01

Analytical Reference Laboratory (WA) Pty. Ltd.
46-48 Banksia Road, Welshpool, Western Australia 6106 Telephone: 08 6253 4444 Facsimile: 08 6253 4440
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LABORATORY REPORT

AECOM Services Pty Ltd

ARL Job No: 16-03180 *Revision: 00* *Date:* 12 May 2016

Ions by Discrete Analyser Sample No: Sample Description:	LOR	UNITS	16-03180-6 DC3	16-03180-7 DC1_NW1000	16-03180-8 DC1_NM2000	16-03180-9 DC2_NE1000	16-03180-10 DC2_NE2000
NOx-N	0.01	mg/L	0.04	<0.01	<0.01	<0.01	<0.01

Ions by Discrete Analyser Sample No: Sample Description:	LOR	UNITS	16-03180-11 DC0_SW1000	16-03180-12 DC0_SW10001	16-03180-13 DC0_SW2000	16-03180-14 FPSO_0	16-03180-15 FPSO_00
NOx-N	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01

Ions by Discrete Analyser Sample No: Sample Description:	LOR	UNITS	16-03180-16 FPSO_NE1000	16-03180-17 FPSO_NE2000	16-03180-18 FPSO_SW1000	16-03180-19 FPSO_SW2000	16-03180-20 FPSO_SE1000
NOx-N	0.01	mg/L	0.05	<0.01	<0.01	<0.01	<0.01

Ions by Discrete Analyser Sample No: Sample Description:	LOR	UNITS	16-03180-21 FPSO_SE2000	16-03180-22 PL_1	16-03180-23 PL_2	16-03180-24 PL_3	16-03180-25 REF_NW
NOx-N	0.01	mg/L	0.02	<0.01	<0.01	<0.01	<0.01

Ions by Discrete Analyser Sample No: Sample Description:	LOR	UNITS	16-03180-26 REF_NW2	16-03180-27 REF_SW	16-03180-28 REF_NE	16-03180-29 REF_SE
NOx-N	0.01	mg/L	<0.01	<0.01	<0.01	<0.01

Result Definitions

LOR Limit of Reporting
[NT] Not Tested
[ND] Not Detected at indicated Limit of Reporting
[NR] Analysis Not Requested
(SS) Surrogate Standard Compound - Used for QC purposes. Acceptance Criteria is 60-120%.
* Denotes test not covered by NATA Accreditation

Analytical Reference Laboratory (WA) Pty. Ltd.
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www.arlwa.com.au ABN: 91 050 159 898

ALS Environmental

CERTIFICATE OF ANALYSIS

Work Order	: **EP1603971**	Page	: 1 of 5
Client	: **AECOM Australia Pty Ltd**	Laboratory	: Environmental Division Perth
Contact	: PETER YOUNG	Contact	: Loren Schiavon
Address	: LEVEL 6, 3 FORREST PLACE PERTH WA 6849	Address	: 10 Hod Way Malaga WA Australia 6090
Telephone	: 6432 2000	Telephone	: +61 2 8784 8503
Project	: 60478944 Shell Crux	Date Samples Received	: 04-May-2016 15:50
Order number	: ----	Date Analysis Commenced	: 06-May-2016
C-O-C number	: ----	Issue Date	: 13-May-2016 13:41
Sampler	: PETER YOUNG		
Site	: ----		
Quote number	: ----		
No. of samples received	: 3		
No. of samples analysed	: 3		

NATA Accredited Laboratory 825
Accredited for compliance with ISO/IEC 17025.

NATA
WORLD RECOGNISED ACCREDITATION

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted.

This Certificate of Analysis contains the following information:

- General Comments
- Analytical Results
- Surrogate Control Limits

Additional information pertinent to this report will be found in the following separate attachments: Quality Control Report, QA/QC Compliance Assessment to assist with Quality Review and Sample Receipt Notification.

Signatories

This document has been electronically signed by the authorized signatories below. Electronic signing is carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Canhuang Ke	Metals Instrument Chemist	Perth Inorganics, Malaga, WA
Celine Conceicao	Senior Spectroscopist	Sydney Inorganics, Smithfield, NSW
Jeremy Truong	Laboratory Supervisor	Perth Inorganics, Malaga, WA
Rassem Ayoubi	Senior Organic Chemist	Perth Organics, Malaga, WA
Sanjeshni Jyoti	Senior Chemist Volatiles	Sydney Organics, Smithfield, NSW

General Comments

The analytical procedures used by the Environmental Division have been developed from established internationally recognized procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are employed in the absence of documented standards or by client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insufficient sample for analysis.

Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

When sampling time information is not provided by the client, sampling dates are shown without a time component. In these instances, the time component has been assumed by the laboratory for processing purposes.

Where a result is required to meet compliance limits the associated uncertainty must be considered. Refer to the ALS Contact for details.

Key : CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting
ø = ALS is not NATA accredited for these tests.

- UT BTEXN/Metals conducted by ALS Sydney, NATA accreditation no. 825, site no 10911.

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)				Client sample ID	REF_NW3	DC23	Trip Blank	----	----
				Client sampling date / time	01-May-2016 13:28	01-May-2016 10:30	[01-May-2016]	----	----
Compound	CAS Number	LOR	Unit		EP1603971-001	EP1603971-002	EP1603971-003	--------	--------
					Result	Result	Result	----	----
EG093T: Total Metals in Saline Water by ORC-ICPMS									
Aluminium	7429-90-5	5	µg/L		<5	<5	----	----	----
Arsenic	7440-38-2	0.5	µg/L		**1.6**	**1.4**	----	----	----
Barium	7440-39-3	1	µg/L		**6**	**15**	----	----	----
Cadmium	7440-43-9	0.2	µg/L		<0.2	<0.2	----	----	----
Chromium	7440-47-3	0.5	µg/L		<0.5	<0.5	----	----	----
Cobalt	7440-48-4	0.2	µg/L		<0.2	<0.2	----	----	----
Copper	7440-50-8	1	µg/L		**2**	<1	----	----	----
Iron	7439-89-6	5	µg/L		<5	<5	----	----	----
Lead	7439-92-1	0.2	µg/L		<0.2	<0.2	----	----	----
Nickel	7440-02-0	0.5	µg/L		**1.1**	<0.5	----	----	----
Zinc	7440-66-6	5	µg/L		<5	<5	----	----	----
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser									
Nitrite + Nitrate as N	----	0.01	mg/L		<0.01	<0.01	----	----	----
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser									
Total Kjeldahl Nitrogen as N	----	0.1	mg/L		**0.2**	**0.1**	----	----	----
EK062G: Total Nitrogen as N (TKN + NOx) by Discrete Analyser									
^ **Total Nitrogen as N**	----	0.1	mg/L		**0.2**	**0.1**	----	----	----
EK067G: Total Phosphorus as P by Discrete Analyser									
Total Phosphorus as P	----	0.01	mg/L		<0.01	**0.01**	----	----	----
EP080/071: Total Petroleum Hydrocarbons									
C6 - C9 Fraction	----	20	µg/L		<20	<20	<20	----	----
C10 - C14 Fraction	----	50	µg/L		<50	<50	----	----	----
C15 - C28 Fraction	----	100	µg/L		<100	<100	----	----	----
C29 - C36 Fraction	----	50	µg/L		<50	<50	----	----	----
^ **C10 - C36 Fraction (sum)**	----	50	µg/L		<50	<50	----	----	----
EP080/071: Total Recoverable Hydrocarbons - NEPM 2013 Fractions									
C6 - C10 Fraction	C6_C10	20	µg/L		<20	<20	<20	----	----
^ **C6 - C10 Fraction minus BTEX (F1)**	C6_C10-BTEX	20	µg/L		<20	<20	<20	----	----
>C10 - C16 Fraction	----	100	µg/L		<100	<100	----	----	----
>C16 - C34 Fraction	----	100	µg/L		<100	<100	----	----	----
>C34 - C40 Fraction	----	100	µg/L		<100	<100	----	----	----
^ **>C10 - C40 Fraction (sum)**	----	100	µg/L		<100	<100	----	----	----

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)				Client sample ID	REF_NW3	DC23	Trip Blank	----	----
				Client sampling date / time	01-May-2016 13:28	01-May-2016 10:30	[01-May-2016]	----	----
Compound	CAS Number	LOR	Unit		EP1603971-001	EP1603971-002	EP1603971-003	--------	--------
					Result	Result	Result	----	----
EP080/071: Total Recoverable Hydrocarbons - NEPM 2013 Fractions - Continued									
^ **>C10 - C16 Fraction minus Naphthalene (F2)**	----	100	µg/L		<100	<100	----	----	----
EP125A: Monocyclic Aromatic Hydrocarbons									
Benzene	71-43-2	0.05	µg/L		<0.05	<0.05	<0.05	----	----
Toluene	108-88-3	0.5	µg/L		<0.5	<0.5	<0.5	----	----
Ethylbenzene	100-41-4	0.05	µg/L		<0.05	<0.05	<0.05	----	----
meta- & para-Xylene	108-38-3 106-42-3	0.05	µg/L		<0.05	<0.05	<0.05	----	----
Styrene	100-42-5	0.05	µg/L		<0.05	<0.05	<0.05	----	----
ortho-Xylene	95-47-6	0.05	µg/L		<0.05	<0.05	<0.05	----	----
1.3.5-Trimethylbenzene	108-67-8	0.05	µg/L		<0.05	<0.05	<0.05	----	----
1.2.4-Trimethylbenzene	95-63-6	0.05	µg/L		<0.05	<0.05	<0.05	----	----
Sum of Xylenes	1330-20-7	0.05	µg/L		<0.05	<0.05	<0.05	----	----
EP080S: TPH(V)/BTEX Surrogates									
1.2-Dichloroethane-D4	17060-07-0	2	%		**124**	**109**	**110**	----	----
Toluene-D8	2037-26-5	2	%		**120**	**101**	**100**	----	----
4-Bromofluorobenzene	460-00-4	2	%		**100**	**88.1**	**94.4**	----	----
EP125S: VOC Surrogates									
1.2-Dichloroethane-D4	17060-07-0	0.1	%		**101**	**115**	**112**	----	----
Toluene-D8	2037-26-5	0.1	%		**106**	**109**	**112**	----	----
4-Bromofluorobenzene	460-00-4	0.1	%		**104**	**110**	**109**	----	----

Surrogate Control Limits

Sub-Matrix: **WATER**		Recovery Limits (%)	
Compound	*CAS Number*	*Low*	*High*
EP080S: TPH(V)/BTEX Surrogates			
1.2-Dichloroethane-D4	17060-07-0	71	137
Toluene-D8	2037-26-5	79	131
4-Bromofluorobenzene	460-00-4	70	128
EP125S: VOC Surrogates			
1.2-Dichloroethane-D4	17060-07-0	73	129
Toluene-D8	2037-26-5	65	127
4-Bromofluorobenzene	460-00-4	68	124

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Murdoch UNIVERSITY

WATER QUALITY DATA

Contact: Peter Young
Customer: AECOM Australia Pty Ltd
Address: Level 6, 3 Forrest Place, Perth, WA, 6000

Date of Issue: 13/05/2016
Date Received: 04/05/2016
Our Reference: AEC16-1
Your Reference: 429060478944

METHOD SAMPLE CODE	Sampling Date	3020 CHLORO 'a' µg/L	3020 CHLORO 'b' µg/L	3020 CHLORO 'c' µg/L	3000 CHLOROPHYLL'a' µg/L	3000 PHAEOPHYTIN'a' µg/L
Reporting Limit		**<0.1**	**<0.1**	**<0.1**	**<0.1**	**<0.2**
File			**16051001**		**16051001**	
DC1	01/05/2016	<0.1	<0.1	<0.1	<0.1	<0.2
DC3	01/05/2016	<0.1	<0.1	<0.1	<0.1	<0.2
DC2	01/05/2016	<0.1	<0.1	<0.1	<0.1	<0.2
DC22	01/05/2016	<0.1	<0.1	<0.1	<0.1	<0.2
DC23	01/05/2016	<0.1	<0.1	<0.1	<0.1	<0.2
DC0	01/05/2016	<0.1	<0.1	<0.1	<0.1	<0.2
DC00	01/05/2016	<0.1	<0.1	<0.1	<0.1	<0.2
DC1_NW1000	01/05/2016	<0.1	<0.1	<0.1	<0.1	<0.2
DC1_NW2000	01/05/2016	<0.1	<0.1	<0.1	<0.1	<0.2
DC2_NE1000	01/05/2016	<0.1	<0.1	<0.1	<0.1	<0.2
DC2_NE2000	01/05/2016	<0.1	<0.1	<0.1	<0.1	<0.2
DC0_SW1000	01/05/2016	<0.1	<0.1	<0.1	<0.1	<0.2
DC0_SW1001	01/05/2016	<0.1	<0.1	<0.1	<0.1	<0.2
DC0_SW2000	01/05/2016	<0.1	<0.1	<0.1	<0.1	<0.2
FPSO_0	02/05/2016	0.1	<0.1	<0.1	<0.1	<0.2
FPSO_00	02/05/2016	<0.1	<0.1	<0.1	<0.1	<0.2
FPSO_NE1000	02/05/2016	0.1	<0.1	<0.1	<0.1	<0.2
FPSO_NE2000	02/05/2016	0.1	<0.1	<0.1	<0.1	<0.2
FPSO_SW1000	02/05/2016	<0.1	<0.1	<0.1	<0.1	<0.2
FPSO_SW2000	02/05/2016	<0.1	<0.1	<0.1	<0.1	<0.2

Signatory: Jamie Woodward
Date: 13/05/2016

All test items tested as received. Spare test items will be held for two months unless otherwise requested.

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Research Laboratory
Environmental Science
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Accreditation Number: 10603
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The results of the tests, calibrations and/or measurements included is this document are traceable to Australian/national standards.

Murdoch UNIVERSITY

WATER QUALITY DATA

Contact: Peter Young
Customer: AECOM Australia Pty Ltd
Address: Level 6, 3 Forrest Place, Perth, WA, 6000

Date of Issue: 13/05/2016
Date Received: 04/05/2016
Our Reference: AEC16-1
Your Reference: 429060478944

METHOD SAMPLE CODE	Sampling Date	3020 CHLORO 'a' µg/L	3020 CHLORO 'b' µg/L	3020 CHLORO 'c' µg/L	3000 CHLOROPHYLL'a' µg/L	3000 PHAEOPHYTIN'a' µg/L
Reporting Limit		**<0.1**	**<0.1**	**<0.1**	**<0.1**	**<0.2**
File			**16051001**		**16051001**	
FPSO_SE1000	02/05/2016	0.1	<0.1	<0.1	<0.1	<0.2
FPSO_SE2000	02/05/2016	0.1	<0.1	<0.1	0.1	<0.2
PL_1	30/04/2016	<0.1	<0.1	<0.1	<0.1	<0.2
PL_2	30/04/2016	<0.1	<0.1	<0.1	<0.1	<0.2
PL_3	30/04/2016	<0.1	<0.1	<0.1	<0.1	<0.2
REF_NW	01/05/2016	<0.1	<0.1	<0.1	<0.1	<0.2
REF_NW2	01/05/2016	<0.1	<0.1	<0.1	<0.1	<0.2
REF_NW3	01/05/2016	<0.1	<0.1	<0.1	<0.1	<0.2
REF_SW	01/05/2016	<0.1	<0.1	<0.1	<0.1	<0.2
REF_NE	01/05/2016	0.1	<0.1	<0.1	0.1	<0.2
REF_SE	01/05/2016	0.2	<0.1	<0.1	0.1	<0.2

Signatory: Jamie Woodward
Date: 13/05/2016

All test items tested as received. Spare test items will be held for two months unless otherwise requested.

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Appendix B: Sediment and Water Quality Study (AECOM 2017)

AECOM

Shell Crux Baseline Surveys
Shell Australia Pty Ltd
27-Apr-2017
Doc No. R1841/M&C4063

Commercial-in-Confidence

D R A F T

Crux Field Baseline Sediment and Water Quality Assessment

Shell Crux Baseline Environmental Surveys



D R A F T

Crux Field Baseline Sediment and Water Quality Assessment

Shell Crux Baseline Environmental Surveys

Client: Shell Australia Pty Ltd

ABN: 14009663576

Prepared by

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27-Apr-2017

Job No.: 604955921

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D R A F T

Quality Information

Document Crux Field Baseline Sediment and Water Quality Assessment

Ref 604955921/R1841/M&C4063

Date 27-Apr-2017

Prepared by Peter Young

Reviewed by Ian Baxter

Revision History

Rev	Revision Date	Details	Authorised	
			Name/Position	Signature
A	27-Apr-2017	For Review	Peter Young Principal Marine Environmental Scientist	

D R A F T

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Executive Summary

The Crux Field is located in Commonwealth waters in the Browse Basin (Timor Sea) approximately 110 km south-east of Cartier Island, 200 km off the Kimberley coast, 260 km from the Indonesian archipelago and East Timor and 600 km north-north-east of Broome, Western Australia. The field is on the Sahul Shelf in the waters of the Territory of Ashmore and Cartier Islands Adjacent Area in permit AC/RL9. Water depths in the field range from 110 m to 170 m. The approximate field dimensions are 8 km long by 5 km wide (Shell 2014).

Shell Australia Proprietary Limited plans to pipe gas from the Crux Field to the Prelude Floating Liquefied Natural Gas Development, approximately 160 km south-west of the Crux Field.

The project is in the early Select Phase and as such a number of concepts are under consideration including:

- a Floating Production Storage and Offloading (FPSO) facility or a fixed platform in the Crux Field
- a pipeline from the Crux Field to the Prelude Field.

These proposed concepts, along with drilling, subsea and pipeline infrastructure will impact on the seabed environment throughout the project area during construction and ongoing operations.

This report outlines the outcomes from the sediment and water quality baseline survey undertaken in the Crux Field in October/November 2016. The water quality component of the survey was a seasonal adjunct to a baseline survey conducted in April/May 2016. The survey comprised sediment sampling at 31 sites and water sampling at 10 sites around the proposed drill centres and FPSO locations, along the proposed pipeline route and at reference locations.

The survey found sediment and water quality in the AC/RL9 area to be generally very high and it can be considered unmodified from its natural condition, which would be expected given its remote location. This is reflected in the survey results, which show that all but a very small number of toxicant concentrations were below guideline criteria.

Findings of this study included the following in relation to sediment quality:

- Metals concentrations across the AC/RL 9 area were all well below guideline criteria. The only exceedance of a criterion was for nickel at one location at the Prelude end of the proposed pipeline route.
- Elevated barium concentrations were detected in some sites in the AC/RL9 area and are potentially associated to exploration drilling activities undertaken in the vicinity.
- Petroleum hydrocarbons were detected at very low concentrations (slightly above the laboratory practical quantitation limit [PQL]) at three sites, predominantly in the C16-C34 fraction. BTEX was not detected above the laboratory PQL in any of the samples, while naphthalene (at one site) was the only PAH detected above the PQL.
- Nitrogen was predominantly present as total kjeldahl nitrogen (TKN) with a small nitrate plus nitrite component at some sites, while phosphorus was present in higher concentrations.
- Particle size distribution composition varied, with sites across the Crux Field typically characterised by medium to fine sands with variable amounts of silt and clay between 5% and 42%, with the percentage of fines (particle size <4 – 62 µm) reducing with depth in a north easterly direction towards the shallowest part of the field. A higher percentage of fines was typical of the sites in deeper waters at the Prelude end of the proposed pipeline route.
- Benthic fauna communities were typically similar across the AC/RL9 block; however, there was some difference in community structure between this area and sites located along the proposed pipeline route.

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The key findings of the water sampling component of the survey include:

- A number of subtle changes in the physicochemical attributes were observed since the May survey that may be suggestive of seasonal variation.
- Water column profiles were typically similar to those observed in the May survey with a number of subtle differences reflecting temporal variation; these included marginally higher DO through the water column, marginally lower pH through the water column, and slightly lower salinity in the upper water column.
- All but a very small number of toxicant concentrations were observed to be below the ANZECC & ARMCANZ (2000) 99% species protection levels.
- Petroleum hydrocarbons were all below the quantifiable limit indicating no evidence of impact from petroleum development sites or natural seeps in the region.
- Metals concentrations were generally comparable to those reported for the May survey and, with the exception of zinc in all samples, and cobalt at one site, were within expected ranges, below the applicable ANZECC & ARMCANZ (2000) 99% or 95% species protection levels, and within levels expected for open ocean environments.
- Zinc concentrations were all above the ANZECC & ARMCANZ (2000) 99% species protection level. A wide-spread increase in a single metal concentration across a wide geographic area would not be expected to be a result of seasonal variation and, without an obvious source, the cause of these results is not immediately apparent.
- A very small increase in TP concentrations was observed; however combined with the analytical results for chlorophyll and phaeophytin, there is no evidence of any increase in nutrient loads.
- Photosynthetic pigments in surface waters were very low and showed very little seasonal variation between the two surveys.
- Physical characteristics were within the expected ranges for this time of year when compared to the background data presented in previous desk top studies (Shell 2014, 2015a).

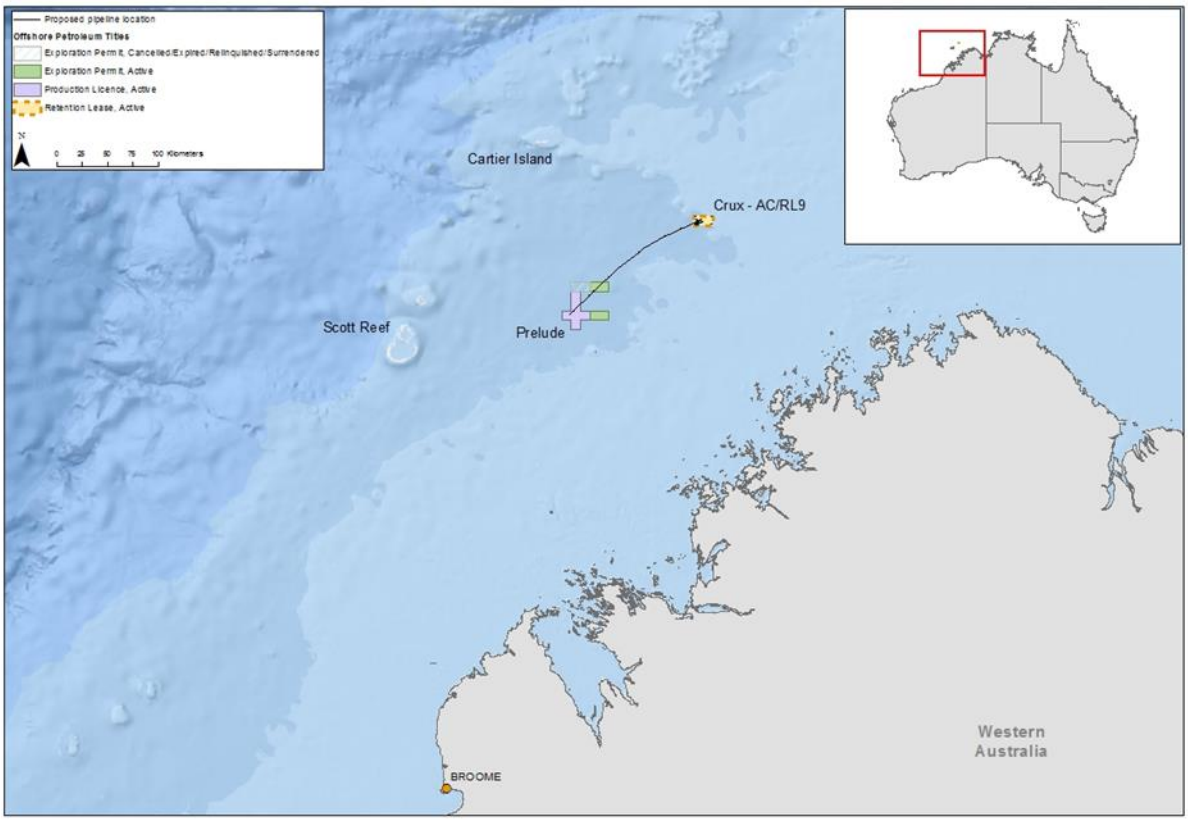
The baseline data presented in this report may be used for future comparison to monitor environmental impact due to construction or routine operations and provide the initial data from which a set of site specific-trigger levels may be developed as suggested by ANZECC & ARMCANZ (2000) guidelines.

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1.0 Introduction

The Crux Field is located in Commonwealth waters in the Browse Basin (Timor Sea) approximately 110 km south-east of Cartier Island, 200 km off the Kimberley coast, 260 km from the Indonesian archipelago and East Timor and 600 km north-north-east of Broome, Western Australia (WA). The field is on the Sahul Shelf in the waters of the Territory of Ashmore and Cartier Islands Adjacent Area in permit area AC/RL9 (Figure 1). Water depths in the permit area range from 90 m to 180 m. The approximate dimensions of the Crux Field within AC/RL9 are 8 km by 5 km (Shell 2014).

Figure 1 Shell Crux Field retention lease AC/RL9 location



1.1 Objective

This report presents the results of the baseline sediment and water quality survey completed between 31 October and 3 November 2016 within the AC/RL9 permit area and along the proposed pipeline route to the Prelude Field (hereafter referred to as 'this survey').

The objective of this survey was to collect data to describe the existing physical and chemical sediment and water quality characteristics at locations that may potentially be impacted by development of the field with a view to:

- characterise the pre-development sediment and water quality of the AC/RL9 permit area to inform the environmental permitting process
- provide a baseline dataset against which post-impact (construction and operations) sediment and water quality measurements can be compared.

The water quality component of the survey was a seasonal adjunct to a baseline survey conducted in April/May 2016 within AC/RL9 and along the proposed pipeline route. A subset of the April/May sites was sampled on this survey to ascertain the extent of seasonal influences on water quality.

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1.2 Survey overview

The survey was completed over three days in October/November 2016 on board the *MV Warrego* on completion of a metocean instrumentation servicing campaign (by RPS MetOcean) within AC/RL9 and along the proposed pipeline route.

The survey comprised:

- collection of sediment samples at 16 sites surrounding the proposed drill centres and Floating Production Storage and Offloading (FPSO) locations, nine sites along the potential pipeline route between AC/RL9 and the Prelude Field and four reference sites (one at each corner of the AC/RL9 lease)
- collection of water samples at six sites surrounding the proposed drill centres and FPSO locations, three sites along the potential pipeline route and one reference site
- measurement of physicochemical parameters through the water column, from seafloor to sea surface, at each of the water sampling sites.

A detailed description of the survey, including sample site locations, is provided in Section 3.0.

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2.0 Background

2.1 Crux Field development

Shell Australia Proprietary Limited (Shell) plans to pipe gas from the Crux Field, within the Browse Basin, to the Prelude Floating Liquefied Natural Gas (FLNG) Development, approximately 160 km south-west of the Crux Field.

The project is in the early Select Phase and as such a number of concepts are under consideration including:

- an FPSO facility or a fixed platform in the Crux Field
- a pipeline from the Crux Field to the Prelude Field.

These proposed concepts, along with drilling, subsea and pipeline infrastructure will impact on the seabed environment throughout the project area during construction and ongoing operations.

2.2 Local environment

This study covers the Crux Field which is located on the North West Shelf, some 200 km off the Kimberley coast, and the proposed pipeline route between the Crux and Prelude Fields. A description of the environment of the field is provided below.

2.2.1 Bathymetry, seabed features and associated habitats

The seabed of the Crux Field is relatively uniform with depths varying from approximately 95 to 175 m observed during the survey. The shallower depths are found in the north-west section of the AC/RL9 lease. The seabed is typically composed of soft sediment.

The AC/RL9 permit area bathymetry and seabed features have been described in Shell (2014), and are summarised below, with some additional descriptions. Further bathymetry data will be required for the pipeline route and will be gained from hydrographic, geotechnical and habitat surveys.

- The project area is located on the Sahul Shelf; a broad shallow platform off the north-west coast of Australia that comprises the eastern part of the North West Shelf region (Wilson 2013).
- The Crux Field lies within the Northwest Shelf Transition bioregion and the pipeline route extends into the Northern Shelf Province bioregion (Baker et al 2008). From a trophic systems perspective, the Crux Field is on the western boundary of the Western Joseph Bonaparte Gulf sub-region and the pipeline route extends into the Kimberley Slope sub-region, both of which are within the Indo-Pacific Throughflow Influence trophic system (Brewer et al 2007).
- Shell (2014) describes the seabed as comprising fine clays, muds and sands; this is consistent with the sediment characteristics presented by Baker et al (2008) for the Middle Shelf physiographic division of the Northwest Shelf Transition bioregion in which the Crux Field lies. No reefs or areas of rocky substrate are known to occur within the nearby Prelude project area (Shell 2009). The present survey found similar broad seabed characteristics within the AC/RL9 permit area, though the proportion of fines (clays and silts) was typically lower than in the Prelude Field. There was also considerable variability in sediment types between different parts of the AC/RL9 permit area.
- Bathymetry of the AC/RL9 permit area is characterised by a shallow area towards the north-east corner of the lease area where depths of 90 to 100 m are typical. The depth falls to approximately 160 m in a south-westerly direction over approximately 2.5 km. The depth continues on a slight gradient until it reaches approximately 180 m depth in the south-west corner of the lease area (Figure 2).
- Single beam echo sounder bathymetry data captured during this survey reflects the above observations of bathymetry across the AC/RL9 permit area and shows a typically constant increase in depth along the proposed pipeline route.
- The major bathymetric feature along the pipeline route is a trench feature where the seabed drops from depths of approximately 210 m to a depth of approximately 270 m before returning to

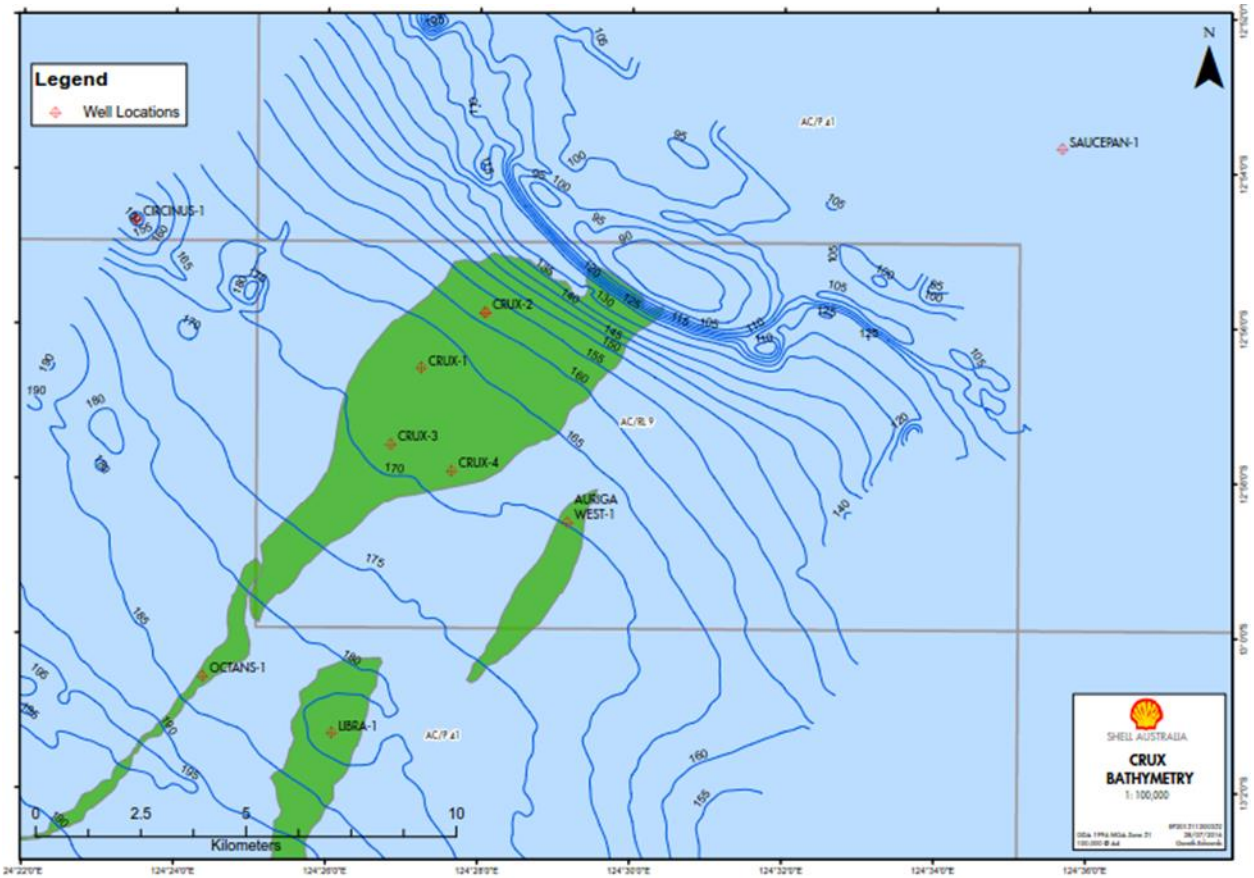
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the regular depths around 250 m in the Prelude region. This feature is located closer to the Prelude Field and is some 115 km south-west of the AC/RL9 lease.

- A number of shoals in the wider region present the most sensitive seabed habitats in the greater Browse Basin (Shell 2014). The closest of these to the AC/RL9 lease area include:
  - Barracouta Shoals (approximately 90 km to the north-west)
  - Vulcan Shoals (approximately 18 km to the east)
  - Heywood Shoals (approximately 13 km to the south-west)

The seabed of the Crux Field and proposed pipeline route will be described in more detail by a geophysical survey to be completed at a later date.

Figure 2 Bathymetry of the AC/RL9 lease area



2.2.2 Climate

The climate of the Browse Basin/Timor Sea region is monsoonal, and comprises two distinct seasons, winter (dry) from April to September and summer (wet) from October to March, with very rapid transition seasons, generally in April and September/October between the two main seasons (Shell 2015a).

The location of the Crux Field means that it is subjected to tropical cyclone activity, with the highest chance of such storms occurring between November and April. Data suggest the peak cyclone frequency falls in January and March, with the most intense cyclone activities observed in December and March/April (Shell 2015a).

2.2.3 Tides and currents

Local tides and currents will impact the dispersion of any discharges to the marine environment and therefore the impact that these discharges may have. The Crux Field Development Metocean

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Reference Document (Shell 2015a) details the key oceanographic systems at play in the region and suggests that currents at the Crux location are expected to be largely characterised by the tides.

Tides at the Crux site are predominantly semi-diurnal with successive tides generally being unequal and flowing along an approximate north-west – south-east axis (Shell 2015a).

2.2.4 Physical water parameters

Existing data describing the physical water characteristics in the region have been summarised in various desktop study reports by Shell (2014, 2015a) with additional data collected in metocean surveys currently in progress. Existing information suggests:

- Sea surface temperatures generally range between 27 °C and 30 °C annually, in waters deeper than ~150 m the temperature is approximately 19 °C (Shell 2014). Short term and long term variability is expected at the Crux site (Shell 2015a).
- Average monthly salinity profile data from the World Ocean Atlas for the Crux Filed location was presented in Shell (2015a). Salinity ranged from 34.5 – 35.1 PSU. Salinity profiles from CSIRO Marine and Atmospheric Research in the region were also referenced; these showed salinity ranging from 33.3 – 34.8 PSU. It was also noted that short and long term variability would be expected to be observed.

2.3 Marine environmental effects

The Crux Field development will potentially comprise a number of installations and vessel operations that may impact marine sediment and water quality during field development (including pipeline construction) and operations. Primarily, these impacts may result from routine discharges which could include:

- in situ overboard disposal of expended drilling mud and associated drill cuttings from drilling units
- macerated sewage and putrescible food scraps
- treated grey water from accommodation facilities and support vessels
- untreated deck drainage (deck wash and stormwater).
- treated oily water from the FPSO and marine vessels
- treated drainage water discharges
- ballast water
- treated produced formation water discharges
- cooling water containing biofouling and corrosion control chemicals
- firewater and firefighting foam discharges (during system testing).

Seabed disturbance during drilling, infrastructure placement and pipeline construction may also impact water quality for short periods of time due to sediment suspension.

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3.0 Sediment and Water Quality Survey Methodology

3.1 Objectives

The objectives of the sediment and water quality baseline survey were to gather data to:

- inform the environmental planning and approvals process for the development of the Crux Field
- use for comparison against data from future surveys, to measure impacts of field development and operations.

3.2 Sediment quality assessment

3.2.1 Sampling design and site locations

Figure 3 shows the sediment sample locations within the Crux Field and along the pipeline route. Site coordinates and water depths are provided in Appendix A.

Sample locations were fundamentally aligned along four transects radiating outward from the three potential drill centres; at distances of 500, 1000 and 2000 m along north-west – south-east and north-east – south-west axes. Where sites were located in close proximity, they were merged to avoid unnecessary duplication, resulting in a small variation to these distances. Transects of sample sites from two of the drill centres (DC1 and DC3 in Figure 3) were aligned along the prevailing tidal current axis (north-west – south-east) to provide a baseline sediment quality description where impacts from drill cuttings are most likely to be observed. The two transects from the remaining drill centre (DC2 in Figure 3) are aligned along a north-east – south-west axis; sampling at these sites allows characterisation of sediments that are perpendicular to the predominant tidal current direction.

Four reference sites to monitor the prevailing background conditions during future monitoring surveys were also sampled; one in each corner of the AC/RL9 lease area. These sites are considered sufficiently distant from future field development activities that any differences in sediment analytical results between surveys are likely indicate inter-annual variability in laboratory performance.

Along the proposed pipeline route between the Crux and Prelude fields, sediment samples were collected at 10-20 km intervals to provide an indication of the variability in sediment type that occurs along the route. The data also provide a baseline against which, if necessary, an assessment can be made of sediment contamination arising from pipeline installation.

3.2.2 Sample numbers

3.2.2.1 Samples for physicochemical analysis

Samples of seafloor sediments were collected for physicochemical analysis at 31 sites (Figure 3):

- 16 around potential future Crux Field drill centres and infrastructure
- four reference sites; one at each corner of the AC/RL9 lease area
- 11 sites along the proposed pipeline route.

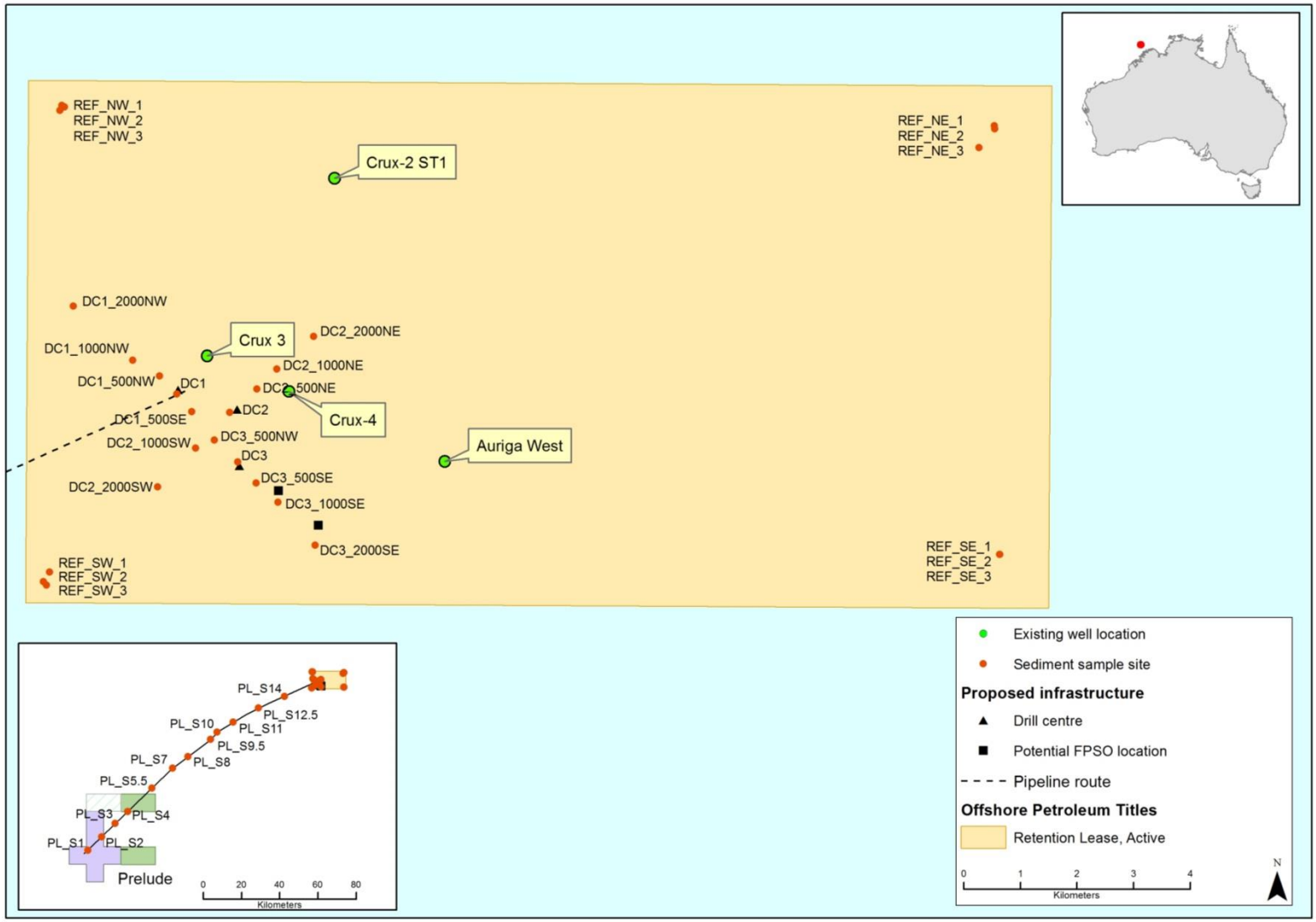
Additional samples were required for QA/QC purposes in accordance with AS/NZS 4482.1 2005:

- at least 5% field replication through collection of triplicate sediment samples (i.e. three separate grab deployments) at three sites (REF_NW, REF_NE and REF_SE)
- at least 10% field duplication by extracting two subsamples from the (homogenised) sediment collected at each of four sites (DC2_0, DC3_0, DC3_1000SE and DC3_2000SE).

The QA/QC samples were labelled so as to be identifiable to AECOM as replicates, but so that they would be unrecognisable to the analysing laboratory as replicates.

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Figure 3 Sediment sample sites



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Also for QA/QC purposes, the following water samples were associated with the sediment sampling process:

- One trip blank sample of deionised water provided by the primary analytical laboratory. This accompanied the field sample containers throughout the survey and were analysed on arrival back at the laboratory to assess whether contamination had occurred from the sample containers or during sample transportation.
- One field blank sample effected by exposing laboratory-supplied deionised water to the atmosphere during sample collection. This was used to identify and quantify any airborne contaminants present (e.g. exhaust emissions).
- Two rinsate blanks were collected, one on each of two of the sampling days, by pouring laboratory-supplied deionised water over the sampling equipment (polycarbonate core) after it had been decontaminated between sample sites and catching the rinse water in a glass jar for laboratory analysis.

Hence the total number of samples for chemical analysis was 45 (41 sediment samples and four water samples):

- 31 primary samples
- six triplicate samples (two additional samples at each of three sites)
- four duplicate samples (one additional sample at each of four sites)
- one trip blank (water)
- one field blank (water)
- two rinsate blanks (water).

3.2.2.2 Samples for benthic fauna analysis

Samples for analysis of benthic fauna were collected at all of the 31 primary sample locations. Triplicate samples were collected from all four of the reference sites; this involved taking three separate grab samples and sieving each individually to provide three samples for each reference site. Hence 39 samples were collected for benthic fauna analysis.

3.2.3 Sample collection, processing and handling

Sediment was collected from the seabed using a Day grab supplied and operated by RPS MetOcean and *Warrego* personnel. The grab weighed 230 kg (when empty) and the jaws had a gape of 64 cm x 40 cm; hence an area of seabed of 0.256 m^2 was sampled on each deployment.

The grab was lowered to the seabed and retrieved using the deck winch and A-frame on *Warrego* (Plate 1). On reaching the surface the grab was guided to its cradle, with crew ensuring the winch cable did not come into contact with the grab; this reduced the potential for grease from the cable to contaminate the sediment sample within the grab.

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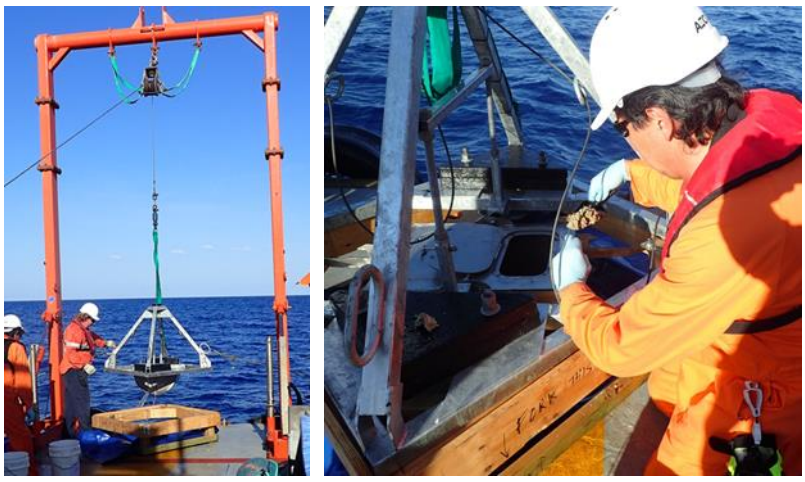


Plate 1 Day Grab operation (left) and sampling from the Day Grab inspection hatch (right)

Once the grab was secured in its cradle, one of the inspection hatches on the grab was opened and the following samples were removed (Plate 1):

- Samples to be analysed for metals, nutrients and particle size distribution (PSD) were collected by inserting a polycarbonate core into the sediments. Each sample was placed into a separate, labelled sterile plastic self-seal bag, which was in turn placed within a second labelled plastic self-seal bag for protection. Two of inter-laboratory triplicate samples were collected directly into plastic jars, as per the sampling requirements of the secondary analytical laboratory.
- Samples to be analysed for hydrocarbons and radionuclides were then collected, also through the inspection hatch. Each sample was collected by scraping a glass jar across the sediment surface. Once full, excess sediment was removed from the thread at the neck of the jar, a Teflon-lined cap was secured and the labelled jar was placed into a plastic self-seal bag.

The following precautions were implemented to reduce the potential for the introduction of contaminants into the samples:

- Sampling was undertaken in an area set aside for sample processing that had been thoroughly cleaned to remove potential contaminants such as hydrocarbon residues.
- Prior to opening the inspection hatches, *Warrego's* main engines were switched off to reduce the potential for airborne contaminants (i.e. within exhaust emissions) to enter the samples.
- Smoking was not permitted at any time in the vicinity of the sample collection and processing areas.
- Personnel involved in the removal of sediment samples from the grab wore nitrile gloves; new pairs of gloves were worn at each site.
- Care was taken to only sample sediments that were not in contact with the sides of the grab, thereby reducing the potential for the introduction of contaminants associated with the inside surfaces of the grab.

All sediment samples were frozen at the earliest opportunity. On completion of the survey the samples remained within the freezer aboard *Warrego* until demobilisation was completed in Exmouth. The samples were packed in insulated containers with freezer bricks and transported by refrigerated road freight to RPS MetOcean in Perth, then delivered by RPS MetOcean personnel to the analytical laboratories on 7 November.

Once the material for physicochemical analyses had been removed from each of the grab samples, approximately 0.0135 m^3 (e.g. 30 x 30 x 15 cm) of the remaining sediment was sieved through a 1 mm mesh to provide a sample for benthic fauna analysis. The material retained on the mesh was transferred to a calico bag and preserved in a 10% formalin solution. On completion of the survey the samples remained aboard *Warrego* until demobilisation was completed in Exmouth, then transported

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by refrigerated road freight to RPS MetOcean in Perth. RPS MetOcean personnel delivered the samples to The University of WA on 7 November.

3.2.4 Physicochemical analysis

3.2.4.1 Primary samples

Analysis of primary sediment samples was undertaken by ALS Environmental (ALS), a National Association of Testing Authorities (NATA) accredited laboratory for the analyses being undertaken:

- total metals (aluminium, arsenic, barium, cadmium, chromium, copper, iron, lead, mercury, nickel and zinc)
- total recoverable hydrocarbons (TRH)
- polycyclic aromatic hydrocarbons (PAH)
- oil and grease (O&G)
- benzene, toluene, ethylbenzene and xylene (BTEX)
- radionuclides (gross alpha and gross beta)
- nutrients (total nitrogen [TN], total Kjeldahl nitrogen [TKN] and total phosphorus [TP]).

Analyses were undertaken to Practical Quantitation Limits (PQLs) sufficiently low that assessment of results could be made against the sediment quality guidelines contained within the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (Australian and New Zealand Environment & Conservation Council and Agriculture & Resource Management Council of Australia and New Zealand [ANZECC & ARMCANZ] 2000), as revised by Simpson, Batley and Chariton (2013). Hereafter in this report, we refer to ‘Guideline trigger levels’ or ‘Interim Sediment Quality Guideline Low (ISQG-Low) values’, which refer to concentrations below which there exists only a low risk that adverse biological or ecological effects will occur (ANZECC & ARMCANZ 2000). Guideline trigger levels and PQLs are included in the tables of results in Section 4.1.1.

Sediment PSD was determined by Microanalysis Australia Pty Ltd using a combination of wet sieving and laser diffraction.

3.2.4.2 QA/QC samples

The duplicate sediment samples, and one of each of the triplicate sediment samples, were analysed by ALS for the analytes listed in Section 3.2.4.1. The third of the triplicate sediment samples was analysed by Analytical Reference Laboratory (ARL) for TRH, O&G and the metals and nutrients listed in Section 3.2.4.1. Analysis of the rinsate and blank samples is described in Section 3.3.4.2.

3.2.5 Benthic fauna analysis

Benthic fauna analysis was undertaken by suitably qualified and experienced biologists at the University of Western Australia. Benthic fauna were sorted and identified to the lowest possible taxa. Where possible, biota were identified to family (crustaceans and molluscs), subclass (polychaete worms), class (chordates and echinoderms) or phylum (sponges, cnidarians and sipunculid worms) level, using standard reference texts.

3.3 Water quality assessment

3.3.1 Site locations

The locations for assessment of water quality are shown in Figure 4; site coordinates and water depths are provided in Appendix F. The locations were selected to provide a spread of measurements around the sites of proposed infrastructure which includes wells, an FPSO and the pipeline to the Prelude development. Monitoring had been undertaken at each of the locations during the April/May 2016 survey.

Sample sites were located as follows:

- one site approximately equidistant to (and 1 km from) the three drill centres (DC0)

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- two sites approximately 3 km from DC0, one to the north-west (DC1_2000NW) and one to the north-east (DC2_2000NE)
- one site approximately 2 km to the south-west of DC0 (DC0_2000SW)
- one site approximately midway between the two potential FPSO locations (FPSO_0), which was approximately 2 km to the south-east of DC0
- one site approximately 2 km to the north-east of FPSO_0 (FPSO_NE2000)
- a reference site in the north-east corner of the AC/RL9 lease area (REF_NE)
- three sites along the proposed pipeline route between the Crux and Prelude fields (PL_1, PL_2 and PL_3).

3.3.2 Sample numbers

Samples of surface water were collected at each of the 10 sites. Additional samples were required for QA/QC purposes in accordance with AS/NZS 4482.1 2005:

- at least 5% field replication through collection of triplicate water samples (i.e. three separate deployments of the sampling device) at one site (DC0)
- at least 10% field duplication by extracting two subsamples from the water collected in a single deployment of the sampling device (site PL_3)
- one rinsate blank, effected by pouring laboratory-supplied deionised water into the Niskin sampler (after it had been decontaminated between sample sites) and decanting the water into appropriate sample bottles.

The duplicate and triplicate samples were labelled so as to be identifiable AECOM as replicates, but so that they would be unrecognisable to the analysing laboratory as replicates.

Hence the total number of samples for chemical analysis was 14:

- 10 primary samples
- two triplicate samples (two additional samples at one site)
- one duplicate sample (one additional sample at one site)
- one rinsate blank.

3.3.3 Methods

3.3.3.1 Sampling procedures

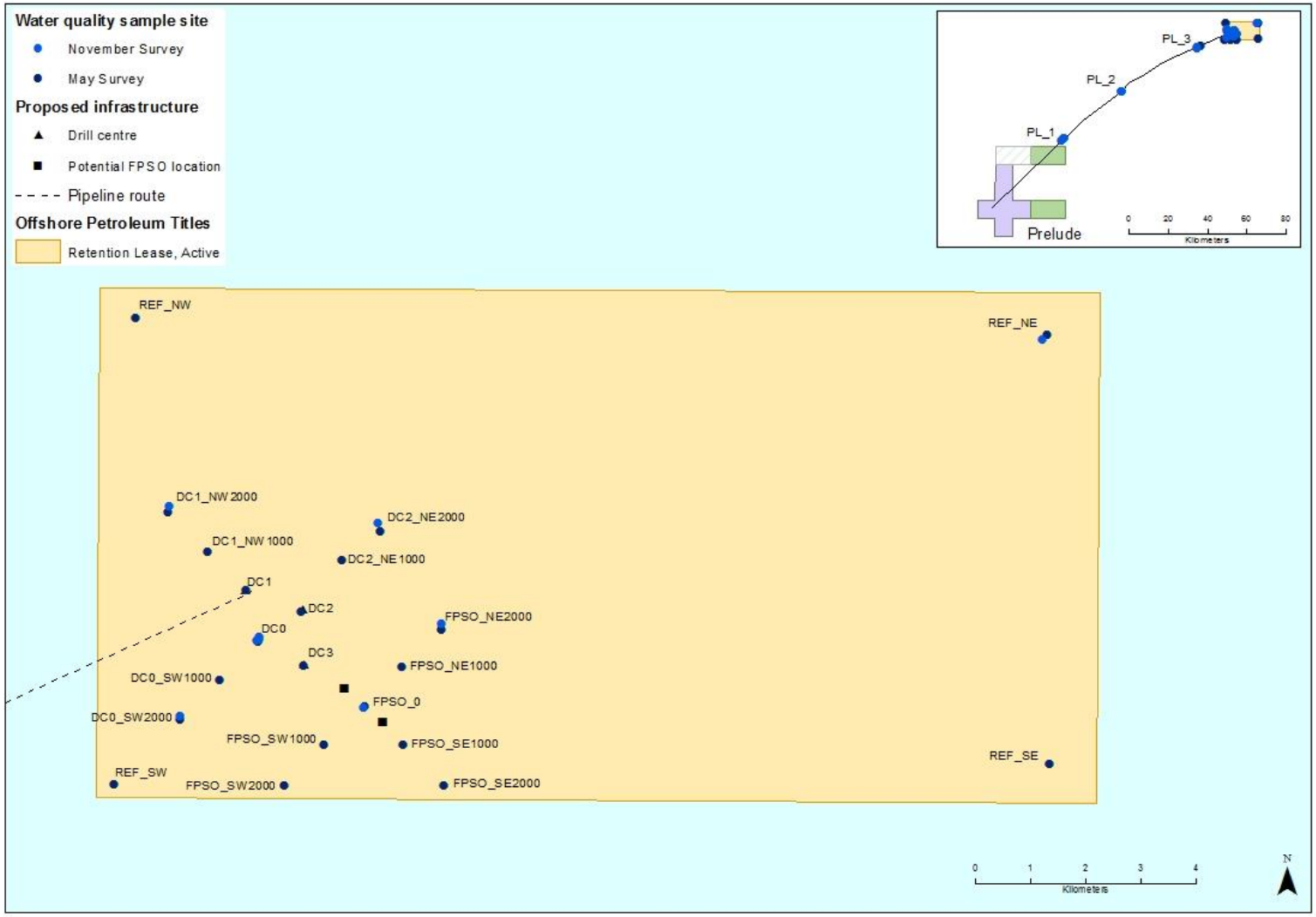
Warrego was positioned such that sampling occurred on the upstream side of the vessel (relative to prevailing currents and wind direction) to reduce the risk of contamination from the vessel wash. All vessel discharge points were closed for the duration of sampling.

Water samples were collected using a Niskin bottle deployed over the side of the vessel using the deck crane and lowered to a depth of approximately one metre below the water surface, where it was triggered to collect a sample. The sampler was brought back on board the vessel and samples were decanted directly into sample containers using the pouring mechanism on the sampler.

A decontamination procedure for the water sampler was implemented after sampling each site. A solution of Decon 90 detergent and seawater was mixed in a plastic bucket. Once a sample had been collected, the sampling equipment was thoroughly rinsed with the Decon 90 solution, then seawater.

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Figure 4 Water quality baseline sample sites



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3.3.3.2 Nutrients and contaminants

Water samples for analysis by the primary laboratory were decanted from the Niskin sampler into the following:

- 500 mL amber glass bottles for TPH analysis
- pairs of 40 mL glass vials for BTEX analysis
- 120 mL polyethylene bottles for metals analysis
- 500 mL polyethylene bottles for nutrient analysis.

Water samples for analysis by the secondary laboratory (trip and field blanks, rinsates and one of the triplicate samples) were decanted into the following:

- 100 mL amber glass bottles for TPH and TRH analysis
- pairs of 40 mL amber glass vials for BTEXN (BTEX plus naphthalene) analysis
- 60 mL polyethylene bottles for metals and nutrients analyses.

All water samples were refrigerated at the earliest opportunity after collection. At the completion of the survey, the samples were packed in insulated containers with freezer bricks and taken to Perth as accompanied baggage. On arrival in Perth (5 November) the samples were hand delivered to the analytical laboratories; this was achieved within three days (at most) of sample collection to meet holding time requirements (the shortest of which was seven days, for TPH).

3.3.3.3 Phytoplankton

Chlorophyll concentrations in extracts of seawater filtrate were measured as an index of phytoplankton biomass. At each site, five litres of seawater was filtered through a glass fibre filter paper (GF/C) and the filter paper frozen for subsequent pigment extraction and analysis. The filter papers were frozen at the earliest opportunity after collection, packed with the water samples and taken to Perth as accompanied baggage, then held in a freezer in Perth prior to delivery to Murdoch University on 7 November.

3.3.3.4 Vertical profiling

A Seabird SBE 19 plus V2 multi-parameter sonde was used to measure physicochemical data through vertical profiles of the water column at all 10 sampling sites. The sonde was calibrated by RPS MetOcean prior to the field survey; the calibration certificate is included as Appendix E.

The sonde was set on internal logging mode and lowered to just above the seabed using the deck winch on the survey vessel, with each parameter measured every 0.5 seconds while lowering the recorder through the water column to the seabed. The sonde measured a suite of water quality parameters - depth (m), salinity (PSU), temperature (°C), turbidity (NTU), pH and % dissolved oxygen (DO).

3.3.4 Analysis of water samples

3.3.4.1 Primary samples

Primary water sample analysis was undertaken by ARL for:

- hydrocarbons (TPH and BTEX)
- total metals (aluminium, arsenic, barium, cadmium, chromium, cobalt, copper, iron, lead, mercury, nickel and zinc)
- nutrients (TN, TKN, nitrite + nitrate [NO_x] and TP).

Where possible, analysis was undertaken to a PQL sufficiently low so as to allow assessment of results against the ANZECC & ARMCANZ (2000) guidelines. Guideline criteria levels and PQLs are included in the tables of results in Appendix G.

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3.3.4.2 QA/QC samples

ALS undertook the following analyses on the blank, rinsate and inter-laboratory duplicate water samples:

- hydrocarbons (TPH, TRH, BTEX)
- nutrients (TN, TKN, NO_x and TP).

3.3.4.3 Phytoplankton

Photosynthetic pigments were extracted from the filter papers by the Marine and Freshwater Research Laboratory (MAFRL) at Murdoch University according to the Standard Methods for Examination of Water and Wastewater. Analysis was undertaken for total chlorophyll, chlorophylls 'a', 'b' and 'c', and phaeophytin. The ratio of the three forms of chlorophyll (‘a’, ‘b’ and ‘c’) can be used as an indicator of the composition of the phytoplankton assemblages. Changes in the ratio of the pigments suggest changes in assemblage structure.

3.4 Data QA/QC

The primary objective of the data validation process is to ensure that the reported data can be used to achieve the project objectives. Analytical data were thoroughly checked by the laboratory prior to release. AECOM subsequently checked the analytical data against the data quality objectives of the project—comparing requested detection limits against PQLs, calculating Relative Percentage Differences (RPDs) and Relative Standard Deviations (RSDs) for field duplicates and triplicates, respectively, and comparing RPDs and RSDs with guideline recommendations.

Comparison of duplicates/triplicates through RPDs and RSDs can identify analytical results that appear to be unrealistically high (or low) and might prompt a request to the laboratory to reanalyse the samples as a further check of precision, or result in categorisation of those results as ‘estimates only’.

Laboratory QA/QC procedures included laboratory duplicates, method blanks, laboratory control samples and matrix spikes

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4.0 Results and Discussion

4.1 Sediment quality assessment

Field log sheets showing site details (coordinates, water depth, sediment description, etc.) and photos of most sediment samples are presented in Appendix A. Laboratory analytical result summaries and laboratory reports and for the sediment samples are presented in Appendix B (chemical analysis), Appendix C (physical analysis), and Appendix D (benthic fauna analysis).

4.1.1 Sediment physicochemistry

4.1.1.1 Metals in sediments

Metal concentrations in sediment samples were all below the ANZECC Guideline trigger values at all sites with the exception of nickel at site PL-S2 which, at a concentration of 21.9 mg/kg, was marginally above the ISQG-Low value of 21 mg/kg. No obvious spatial trends were observed in metal concentrations.

The concentrations of metals in the sediment samples are provided in Table 1 and summarised in the following sections. Summary statistics showing the mean concentrations of metals in the Crux Field (reference and non-reference sites) and along the proposed pipeline route are presented in Table 2.

4.1.1.1.1 Aluminium

Aluminium was detected at concentrations above the laboratory PQL of 50 mg/kg in all samples analysed ranging from 720 to 5870 mg/kg with a mean value of 2875.6 mg/kg and a standard deviation of 1032.6 mg/kg. The three sites at the Prelude end of the proposed pipeline route had the highest concentration of aluminium with the lowest concentrations shown in the reference sites at the eastern edge of the Crux Field. Aluminium concentrations in the remaining two reference sites were consistent with those observed at other samples taken from within the Crux Field. There is no Guideline trigger level for aluminium.

4.1.1.1.2 Arsenic

Arsenic was detected at concentrations above the laboratory PQL of 1 mg/kg at all sites with concentrations detected ranging from 1.17 to 13.8 mg/kg, all below the ISQG-Low value of 20 mg/kg. Concentrations of arsenic along the proposed pipeline route were generally higher than those observed around the Crux Field where concentrations all fell within the range of concentrations detected in samples collected at reference sites.

4.1.1.1.3 Barium

Barium was detected at concentrations above the laboratory PQL of 0.1 mg/kg at all sites with concentrations ranging from 6.7 to 56.2 mg/kg with an average concentration of 18.1 mg/kg and a standard deviation of 12.7 mg/kg. The highest concentrations were detected at the proposed drill centre sites (DC1 and DC2) while the concentration at DC3 was higher than that detected at reference sites, though it was only marginally higher than other samples taken from around the Crux Field. Barium concentrations were typically patchy and showed signs of a decreasing trend with distance from the proposed drill centres. This may be explained by the drilling of four exploration wells in the Crux Field in 2015 using water based muds (WBM) (Shell, 2014), two of which (Crux-3 and Crux-4, Figure 2) are in the vicinity of the sediment sampling sites sampled during this survey. Barium concentrations are indicative of the presence of WBM residues from drilling activities and that no remedial actions are necessary as barium is considered to have limited bioavailability when associated with drilling muds (Swan, Neff & Young 1994).

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Table 1 Metals concentrations in sediments

Analyte	Aluminium	Arsenic	Barium	Cadmium	Chromium	Cobalt	Copper	Iron	Lead	Mercury	Nickel	Zinc
	mg/kg											
LOR	50	1	0.1	0.1	1	0.5	1	50	1	0.01	1	1
ISQG-High	NA	70	NA	10	370	NA	270	NA	220	1	52	410
ISQG-Low	NA	20	NA	1.5	80	NA	65	NA	50	0.15	21	200
DC1_0	3530	3.7	56.2	0.3	21.1	2.4	5.9	5110	2.8	0.03	10.2	20.7
DC1_500NW	3670	3.9	25.4	0.3	20.7	2.6	6	5150	2.6	0.03	11.1	20.9
DC1_1000NW	2550	4.0	24.5	0.3	19.1	2.1	4.6	4150	2.6	0.03	8.5	18
DC1_2000NW	2540	3.9	9.3	0.3	19.4	1.9	4.3	4380	2.5	0.03	7.9	18
DC1_500SE	3540	2.7	25.9	0.3	19.4	2.4	6	4670	2.5	0.03	9.8	19.4
DC2_0	3440	4.5	53	0.3	22.5	2.4	5.5	5520	2.9	0.04	10.1	21.9
DC2_0[a]	3260	4.0	47.8	0.3	19.8	2.2	5.2	5200	2.9	0.04	9.1	19.6
DC2_500NE	3060	4.6	45.1	0.3	21.5	2.2	5.1	4940	2.7	0.04	9.2	19.8
DC2_1000NE	2750	3.9	14.4	0.2	19.7	2.3	5	4420	2.5	0.04	9.1	19.7
DC2_2000NE	2580	4.0	9.4	0.3	20.2	2.7	4.2	4740	2.8	0.04	8.8	22
DC2_1000SW	3230	3.7	19.9	0.3	20.8	2.3	5.5	4790	2.8	0.04	9.6	20.1
DC2_2000SW	3140	3.0	15.8	0.3	19.5	2.2	5.2	4720	2.5	0.04	9	19.5
DC3_0	2880	3.3	9.9	0.3	20.1	2	4.7	4690	2.4	0.04	8.5	19.1
DC3_0[a]	3330	3.8	28.3	0.3	20.3	2.2	5.2	5520	3	0.04	9.3	19.7
DC3_500SE	3440	3.4	15.7	0.3	21.6	2.4	5.6	5030	2.6	0.04	9.6	21.3
DC3_1000SE	2530	4.6	11.2	0.3	20.6	2.2	4.5	4870	2.6	0.04	8.6	19.6
DC3_1000SE[a]	2640	5.0	11.1	0.3	20.4	2	4.3	5330	3	0.04	8.2	25.4
DC3_2000SE	3660	3.5	22.9	0.3	22.4	2.6	5.9	5170	2.6	0.04	10.3	21.5

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Analyte	Aluminium	Arsenic	Barium	Cadmium	Chromium	Cobalt	Copper	Iron	Lead	Mercury	Nickel	Zinc
	mg/kg											
LOR	50	1	0.1	0.1	1	0.5	1	50	1	0.01	1	1
ISQG-High	NA	70	NA	10	370	NA	270	NA	220	1	52	410
ISQG-Low	NA	20	NA	1.5	80	NA	65	NA	50	0.15	21	200
DC3_2000SE[a]	3680	2.7	27.4	0.3	18.3	2.4	5.8	4900	2.5	0.04	9.6	19.4
DC3_500NW	3040	4.1	25	0.3	20.9	2.2	5.4	4820	2.7	0.04	9.4	20.3
REF_NW	2680	4.2	12.5	0.3	21.3	2	4.6	4710	2.8	0.04	8.8	19.3
REF_NW[a]	2340	2.1	16.4	0.2	13.3	1.7	4.5	3280	1.9	0.02	7.1	13.8
REF_NW[b]	2500	<5	10	0.5	15	2	17	4400	5	0.02	7	15
REF_SW	2230	6.1	8	0.3	20.1	2.7	3.5	5730	3.8	0.05	9.7	20.8
REF_NE	740	1.5	6.7	0.3	15.1	0.8	1.2	1740	<1.0	<0.01	2.9	7.3
REF_NE[a]	720	1.6	9.8	0.2	13.8	0.6	1.5	1780	1.2	0.01	2.9	6
REF_NE[b]	820	<5	7	0.4	12	<1	15	2500	4	<0.02	3	6
REF_SE	1940	1.3	12.7	0.2	13.9	1.5	3.5	2890	1.5	0.02	6.4	13.8
REF_SE[a]	1700	1.3	11.8	0.2	11.2	1.2	2.9	2680	1.6	0.02	5.2	11.6
REF_SE[b]	1780	1.2	12.9	0.2	11.1	1.3	3.1	2630	1.6	0.02	5.6	11.7
PL_S1	4680	2.7	13.3	0.2	22	4	11.6	5370	2.1	0.02	16	27.7
PL_S2	5390	7.7	10	0.3	41.3	6.1	7.7	8990	3.5	0.02	21.9	47.2
PL_S3	5870	8.7	21	0.2	43.3	6.3	7.7	16200	5.5	0.05	18.5	45.2
PL_S4	2830	2.2	28	0.3	15.9	3.4	5.9	5700	2.8	0.03	10.3	25.2
PL_S5.5	2670	11.4	10	0.5	29.8	3.7	3.6	7750	3.8	0.02	11.9	24.7
PL_S7	2240	11.3	8	0.6	31	3.6	2.4	6660	2.8	0.01	13.7	24.8
PL_S8	2870	13.4	9.4	0.5	38	4.1	5.6	8860	3.7	0.02	16.5	28.3

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Analyte	Aluminium	Arsenic	Barium	Cadmium	Chromium	Cobalt	Copper	Iron	Lead	Mercury	Nickel	Zinc
	mg/kg											
LOR	50	1	0.1	0.1	1	0.5	1	50	1	0.01	1	1
ISQG-High	NA	70	NA	10	370	NA	270	NA	220	1	52	410
ISQG-Low	NA	20	NA	1.5	80	NA	65	NA	50	0.15	21	200
PL_S9.5	2170	6.8	7.6	0.3	18.1	3.1	12.8	5040	3.3	0.02	8.8	24.4
PL_S11	2710	13.8	7.3	0.4	36.8	5	4.1	6800	5.4	0.02	16.1	25.9
PL_S12.5	2740	2.6	10.4	0.3	19.2	2.5	4.3	5460	1.9	0.02	8.3	21
PL_S14	3790	5.8	9.9	0.3	29.2	2.8	4.6	7120	3	0.03	11.3	26.4

a duplicate sample

b inter-laboratory duplicate sample

Concentrations above ISQG-Low value are highlighted yellow.

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4.1.1.1.4 Cadmium

Cadmium was detected in concentrations above the laboratory PQL of 0.1 mg/kg at all sites with concentrations ranging from 0.2 to 0.6 mg/kg with a mean of 0.3 mg/kg and a standard deviation of 0.1 mg/kg. All concentrations were well below the ISQG-Low value of 1.5 mg/kg. Cadmium concentrations were typically even across the Crux Field with marginally higher concentrations detected along the proposed pipeline route at sites PL_S5.5, PL_S7, PL_S8, though these concentrations were similar to that returned from the analysis of the inter-laboratory duplicate sample from reference site REF_NW.

4.1.1.1.5 Chromium

Chromium was detected in concentrations above the laboratory PQL of 1 mg/kg at all sites with concentrations ranging from 11.1 to 43.3 mg/kg with a mean of 21.5 mg/kg and a standard deviation of 7.5 mg/kg. All concentrations are well below the ISQG-Low level of 80 mg/kg. Chromium concentrations across the Crux Field were typically consistent, with slightly lower concentrations detected at reference sites at the eastern end of the field. The highest concentrations were detected along the proposed pipeline route although the highest concentrations (41.3 and 43.3 mg/kg detected at sites PL_S2 and PL_S3 respectively) are still just over half of the ISQG-Low value.

4.1.1.1.6 Cobalt

Cobalt was detected above the Laboratory PQL of 0.5 mg/kg at all sites with concentrations ranging from 0.6 to 6.3 mg/kg with a mean of 2.5 mg/kg and a standard deviation of 1.2 mg/kg. There is no Guideline trigger level for cobalt however; the concentrations detected across the Crux Field were all within the range of concentrations detected at reference sites. Concentrations of cobalt at sites along the proposed pipeline route were generally higher than those across the Crux Field.

4.1.1.1.7 Copper

Copper was detected in concentrations above the laboratory PQL of 1 mg/kg at all sites with concentrations ranging from 1.2 to 17 mg/kg and a mean of 5.6 mg/kg and standard deviation of 3.2 mg/kg. At these levels copper concentrations are well below the ISQG-Low value of 65 mg/kg at all sites. Concentrations at sites across the Crux Field ranged from 4.2 – 6.0 mg/kg, slightly higher than concentrations detected at the reference sites (1.2 – 4.5 mg/kg). Concentrations at sites along the proposed pipeline route were typically similar to those across the Crux Field with the exception of PL_S1 and PL_S9.5 where notably elevated concentrations of 11.6 and 12.9 mg/kg, respectively, were present. Even at these levels, the concentrations are still well below the ISQG-Low value.

4.1.1.1.8 Iron

Iron was detected in concentrations above the laboratory PQL of 50 mg/kg at all sites with concentrations ranging from 1740 to 16200 mg/kg and a mean of 5229.5 mg/kg and standard deviation of 2357.3 mg/kg. There is no ISQG-Low value for iron however, concentrations of iron detected in samples across the Crux Field all fell within the range of concentrations detected at the reference sites while a number of samples along the proposed pipeline route showed concentrations above this range. The sample collected from site PL_S3 was almost double that of any other site.

4.1.1.1.9 Lead

Lead was detected in concentrations above the laboratory PQL of 1.0 mg/kg at all sites with the exception of one of the reference sites (REF_NE). Concentrations ranged from 1.2 to 5.5 mg/kg with a mean of 2.8 mg/kg and a standard deviation of 1.0 mg/kg. These concentrations are all well below the ISQG-Low value of 50 mg/kg. Concentrations at two sites fell outside of the rage of concentrations detected at reference sites with PL_S3 and PL_S11 returning concentrations of 5.5 and 5.4 mg/kg respectively. A lead concentration of 3.8 mg/kg, equal to that of REF_SW (the highest of the reference sites), was detected at a third site along the proposed pipeline (PL_5.5).

4.1.1.1.10 Mercury

Mercury was detected in concentrations above the laboratory PQL of 0.01 mg/kg at all sites with the exception of one of the reference sites (REF_NE). Concentrations ranged from 0.01 to 0.05 mg/kg with a mean of 0.03 mg/kg and a standard deviation of 0.01 mg/kg. Mercury concentrations were all well below the ISQG-Low value of 0.15 mg/kg and within the range of concentrations detected at the reference sites. Mercury concentrations across the Crux Field were marginally higher than those

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detected at sites along the proposed pipeline route with the exception of site PL_S3 which returned the highest concentration of mercury (0.05 mg/kg), the same as reference site REF_SW and still well below the ISQG-Low value.

4.1.1.1.11 Nickel

Nickel was detected at concentrations above the laboratory PQL of 1 mg/kg at all sites with concentrations ranging from 2.9 to 21.9 mg/kg with a mean of 9.7 mg/kg and a standard deviation of 3.9 mg/kg. The ISQG-Low value of 21 mg/kg was exceeded at one location (PL_S2) where a concentration of 21.9 mg/kg was detected. This site is at the Prelude end of the proposed pipeline route, distant from the Crux Field. Nickel concentrations across the Crux Field were generally within the range of concentrations at the reference sites while a number of sites along the proposed pipeline route showed elevated concentrations of nickel when compared to the reference sites.

4.1.1.1.12 Zinc

Zinc was detected at concentrations above the laboratory PQL of 1 mg/kg at all sites with concentrations ranging from 6.0 to 47.2 mg/kg with a mean of 18.1 mg/kg and a standard deviation of 7.9 mg/kg. These concentrations are all well below the ISQG-Low value of 200 mg/kg. The highest concentrations were recorded at sites PL_S2 and PL_S3, with other concentrations along the proposed pipeline route generally marginally higher than concentrations at the reference sites and sites across the Crux Field.

4.1.1.1.13 Differences between locations

A summary of the metals concentrations grouped by location (Crux Field, proposed pipeline route and reference sites) is presented in Table 2. Initial data analysis indicated that average metals concentrations were typically lower at the reference sites than at the other sites. Further analysis revealed that the average concentrations of metals at the reference sites were being skewed by the lower concentrations measured in the samples collected at REF_NE. This site is located in a shallower part of the field where sediment grain sizes are coarser. This difference in physical characteristics at the site may compromise its suitability as a reference site for future monitoring programs. The primary concern of reference site selection is to choose sites that are similar in nature to the potential impact sites so as to enable an assessment to be made of whether changes in concentrations between surveys are attributable to natural variation in the region, to inter-annual variability in laboratory performance, or to anthropogenic influences. If a reference site differs greatly in its physical characteristics from the potential impact sites, it is difficult to make such an assessment. Hence it is suggested that REF_NE can be excluded as a reference site in future surveys.

Table 2 Summary of metals in sediment at sites grouped as reference and non-reference sites

Metal	Unit	Trigger value[a]	Maximum concentration recorded	Average by location			
				Crux Field	Proposed pipeline route	Reference (All)	Reference (ex. REF_NE)
Aluminium	mg/kg	N/A	5870	3124	3450	1745	2167
Arsenic		20	13.8	3.8	7.9	1.9	2.7
Barium		N/A	56.2	24.9	12.3	10.8	12.0
Cadmium		1.5	0.6	0.3	0.4	0.3	0.3
Chromium		80	43.3	20.4	29.5	14.7	15.1
Cobalt		N/A	6.3	2.3	4.1	1.4	1.8
Copper		65	17	5.2	6.4	3.6	4.2
Iron		N/A	16200	4906	7631	1310	3760
Lead		50	5.5	2.7	3.4	1.7	2.2
Mercury		0.2	0.05	0.038	0.024	0.020	0.027
Nickel		21	21.9	9.3	13.9	5.9	7.1
Zinc		200	47.2	20.3	29.2	12.5	15.1

a = ANZECC 2000 ISQG-Low value

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4.1.1.2 Hydrocarbons in sediments

The concentrations of hydrocarbons in the sediment samples (where detected above the laboratory PQL) are summarised in Table 3. TRH and TPH were detected at three sites; however, BTEX and PAHs were not detected above the laboratory PQL in any of the sediment samples collected, with the exception of DC3_1000SE where naphthalene was detected at a concentration of 5 µg/kg, equal to the laboratory PQL.

While ANZECC/ARMCANZ (2000) listed ISQG values for a number of PAHs individually, the subsequent update to the ISQG values by Simpson et al (2013) suggest a more appropriate measure of PAHs is through the use of a guideline value for the sum of PAHs (where the sum refers to the unsubstituted PAHs listed in ANZECC/ARMCANZ [2000]). The rationale suggested by Simpson et al. (2013) is that for the majority of assessments, the concentration of total PAHs represents contributions from a large number of individual PAHs, with each being a small percentage of the total. While it is recognised that the toxicities of the individual PAHs differ significantly, it is considered unlikely that an individual PAH will, by itself, dominate the total PAHs concentration. Simpson et al (2013) also provide an updated sediment quality guideline value (SQGV) for TPH.

Based on their research, Simpson et al. (2013) SQGVs of 280 mg/kg and 10 mg/kg (10,000 µg/kg) for the sum of TPHs and sum of PAHs, respectively, as an update to the ANZECC/ARMCANZ ISQG values.

When comparing the survey results to these SQGVs, the naphthalene concentration detected is well below the SQGV of 10,000 µg/kg for sum of PAHs and the ANZECC & ARMCANZ (2000) ISQG-Low value of 160 µg/kg for naphthalene.

Table 3 TRH and TPH concentrations in sediments (where detected)

TRH					
Fraction	**C6 - C10**	**>C10 - C16**	**>C16 - C34**	**>C34 - C40**	**>C10 - C40 (sum)**
	mg/kg				
LOR	**3**	**3**	**3**	**5**	**3**
REF_NW	<3	<3	<3	<5	<3
REF_NW[a]	<3	<3	**25**	<5	**25**
REF_NW[b]	<0.2	<0.2	<0.4	<0.4	<0.4
PL_S3	<3	**4**	**19**	<5	**23**
PL_S5.5	<3	<3	**12**	<5	**12**
TPH					
	C6 – C9	**C10 – C14**	**C15 – C28**	**C29 – C36**	**C10 – C36 (sum)**
	mg/kg				
LOR	**-**	**3**	**3**	**5**	**3**
REF_NW	-	<3	<3	<5	<3
REF_NW[a]	-	<3	**15**	**12**	**27**
REF_NW[b]	-	-	-	-	-
PL_S3	-	<3	**14**	**7**	**21**
PL_S5.5	-	<3	**7**	**7**	**14**

a duplicate sample

b inter-laboratory duplicate sample

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It can be seen that the highest concentration of hydrocarbons was detected in one sample from REF_NW; however, TRH/TPHs were not detected above the laboratory PQL in either of the two duplicate samples also analysed from this site (including one carried out by a second laboratory). TPH/TRH concentrations at the two sites along the proposed pipeline route where they were detected (PL_S3 and PL_S5.5) were well below the SQGV for the sum of TPHs of 280 mg/kg suggested by Simpson et al (2013).

Oil and grease was detected above the PQL of 100 mg/kg at all sites with concentrations ranging from 510 – 2200 mg/kg with the average concentration being 1142.8 mg/kg. A number of sites across the Crux Field and along the proposed pipeline route were higher than the concentrations measured at the reference sites; however no apparent spatial trends were evident and higher the concentrations were spread across the Crux Field and along the proposed pipeline route.

4.1.1.3 Radionuclides

Sediment samples were analysed for gross alpha and gross beta radionuclides. Gross alpha were more commonly detected than gross beta with concentrations above the PQL of 500 Bq/kg at 20 sites ranging from 560 – 1860 Bq/kg compared to gross beta which was detected above the PQL at just one site (PL_S11) where a concentration of 640 Bq/kg was measured.

No ANZECC & ARMCANZ (2000) guidelines exist for radionuclides, as such the low screening level of 35,000 Bq/kg (for sum of gross alpha and gross beta) specified in the National Assessment Guidelines for Dredging 2009 (NAGD) (Commonwealth of Australia 2009) were applied. The sum of gross alpha and gross beta at PL_S11 (2500 Bq/kg) was the highest of any but was well below the screening level.

4.1.1.4 Nutrients in sediments

Sediment samples were analysed for nutrients (TN, NOx, TKN and TP) at all sites. While there are no Guideline trigger values for nutrients in sediments, assessing the concentrations of these nutrients at this time will provide a baseline against which project-related anthropogenic concentrations can be assessed in the future.

Nutrient concentrations are presented in Appendix B.

4.1.1.4.1 Nitrogen

Sediment samples were analysed for NOx, TKN and TN (TKN + NOx). NOx concentrations were very low where detected (concentrations exceeded the laboratory PQL of 0.1 mg/kg at 23 sites) with concentrations ranging from 0.1 to 1.8 mg/kg. TKN ranged from 210 to 1040 mg/kg which also reflected the concentration of TN given the very low concentrations of NOx detected.

No spatial pattern was evident in the concentration of nitrogen. TKN and TN concentrations were generally higher across the Crux Field and some sites along the proposed pipeline route than at the reference sites however, this was not the case for all sites. The highest NOx concentrations were obtained from sample sites located across the Crux Field and, with the exception of four sites (DC2_2000NE, DC3_0, DC3_1000SE and DC3_2000SE), NOx concentrations fell within the range of concentrations found at the reference sites.

4.1.1.4.2 Phosphorus

Phosphorus was detected above the laboratory PQL of 2 mg/kg at all sites, with concentrations ranging from 816 to 10200 mg/kg. The highest concentrations were detected along the proposed pipeline route with samples from PL_S2, PL_S5.5 and PL_S9.5 approaching or exceeding 1000 mg/kg. Phosphorus concentrations at the remaining sites fell within the range of concentrations at the reference sites.

4.1.1.5 Sediment PSD

Sediment particle size distribution was assessed at each site with PSD data shown in Figure 5. Sediment PSD composition varied with sites across the Crux Field typically characterised by medium to fine sands with variable amounts of silt and clay (between 5% and 42%) with the percentage of fines (defined as the silt and clay particle fraction <4 – 62 µm) reducing with depth in a north easterly

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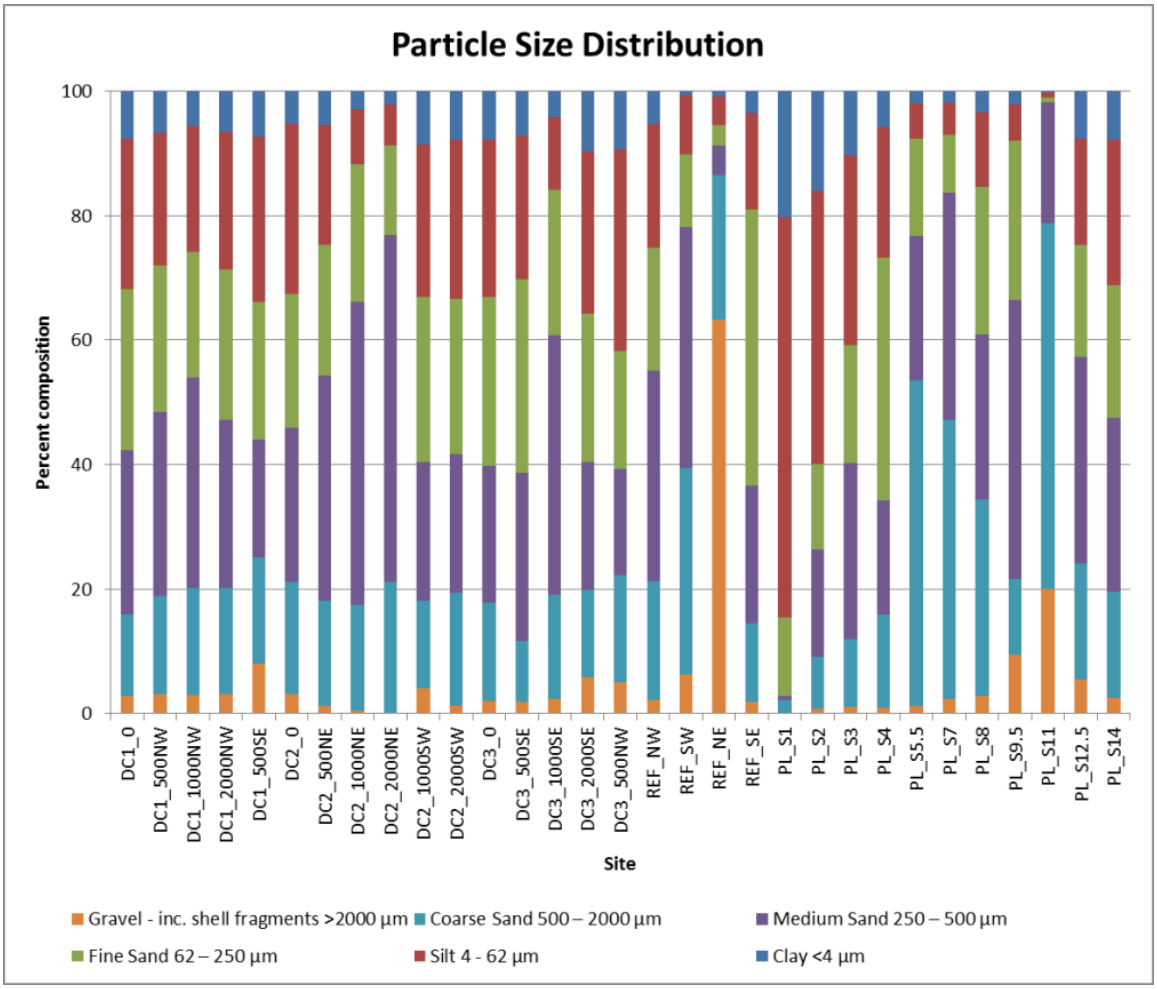
direction towards the shallowest part of the field around site REF_NE where a high gravel content (63.3%) occurred.

A number of sites along the proposed pipeline route had notably higher coarse sand fraction. The fines fraction, ranged from 0.94% (PL_S11) to 84.5% (PL_S1) with the highest fines content found at the Prelude end of the proposed pipeline route where sites PL_S1, PL_S2 and PL_S3 had fines content of 84.5%, 60% and 40.7% respectively.

The presence of a high percentage of fines is of interest due to the potential for metals to bind at greater densities to smaller, silt and clay particles with higher available surface area than to sand particles (Simpson and Batley 2016), often resulting in a higher concentration of metals present in the sediment. This was observed in a number of cases where sites with comparatively low fines content at the Prelude end of the pipeline showed the highest concentrations of a number of metals in sediment samples.

A number of metals showed a weak positive correlation between metal concertation and percent fines, suggesting that the presence of fines may not be the only factor contributing the distribution of metals in sediments of the region.

Figure 5 Sediment PSD



4.1.2 Sediment benthic fauna

A total of 39 sediment samples were analysed for benthic fauna. From these samples, 457 individuals were processed, belonging to 153 morphospecies. All samples except two contained at least one species with an average of 11.7 ± 2.51 (mean ± 1 standard error) individuals belong to 6.9 ± 1.11 morphospecies per sample.

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There were 11 major taxa (phyla or sub-phyla) represented in the samples (Table 4). The most common sub-phylum (30% of individuals and 36% of morphospecies) was the Annelida, (Polychaeta), followed by Arthropoda (Crustacea) with 15% of individuals and 24% of morphospecies and Mollusca (24% of individuals and 12% of morphospecies).

Analysis was undertaken with samples grouped by direction from the central drill centre (DC) sites with the samples collected along the proposed pipeline route grouped separately (PL).There was no consistent difference between samples grouped by location (DC, SE, SW, NE, NW and PL). One-way permutational ANOVA, run in the PERMANOVA add-on to the PRIMER-E package, showed no difference in species richness (S) or abundance (N), but a significant difference in assemblage structure between locations (Table 5). Post-hoc tests between locations revealed this difference in assemblage structure to be a result of differences between assemblages at DC and PL sites, with all other locations showing no difference between each other, or with DC or PL. This lack of difference is almost certainly due to the small sample sizes at the reference sites (SE, SW, NE and NW).

Further analysis of DC sites and the SE, SW, NE and NW references sites showed no difference in species richness, abundance or assemblage structure between the five locations (Table 6), even though DC sites appeared to have more species and individuals than the reference sites (Figure 6 and Figure 7).

Table 4 Benthic fauna abundance

Phylum	# individuals	% total	#morphospecies	% total
Porifera	50	10.94	8	5.23
Nemertea	8	1.75	2	1.31
Annelida (Echiura)	2	0.44	2	1.31
Annelida (Sipunculida)	31	6.78	10	6.53
Annelida (Polychaeta)	137	30.0	55	35.95
Mollusca	108	23.62	18	11.76
Bryozoa	5	1.09	3	1.96
Nematoda	16	3.50	4	2.61
Arthropoda (Crustacea)	70	15.3	37	24.2
Echinodermata	29	6.35	13	8.50
Chordata	1	0.21	1	0.65
Total	**457**		**153**	

Table 5 Results of permutational analyses of variance testing the effect of one fixed factor (Location) with six levels (DC, SE, SW, NE, NW and PL) on species richness, abundance and assemblage structure.

Variable	Mean Square	Pseudo-F	P(perm)	Unique permutations
Species richness	21.56	0.3236	0.9027	8158
Abundance	116.1	0.4378	0.823	9569
Assemblage structure	3095.9	1.3148	**0.0188**	9784

Table 6 Results of permutational analyses of variance testing the effect of one fixed factor (Location) with five levels (DC, SE, SW, NE, NW) on species richness, abundance and assemblage structure.

Variable	Mean Square	Pseudo-F	P(perm)	Unique permutations
Species richness	22.121	0.4282	0.8358	4130

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Variable	Mean Square	Pseudo-F	P(perm)	Unique permutations
Abundance	144.3	0.4770	0.7247	7812
Assemblage structure	3355.6	1.0363	0.3578	9828

Figure 6 Mean number of species per sample from five locations in the AC/RL9 lease area.

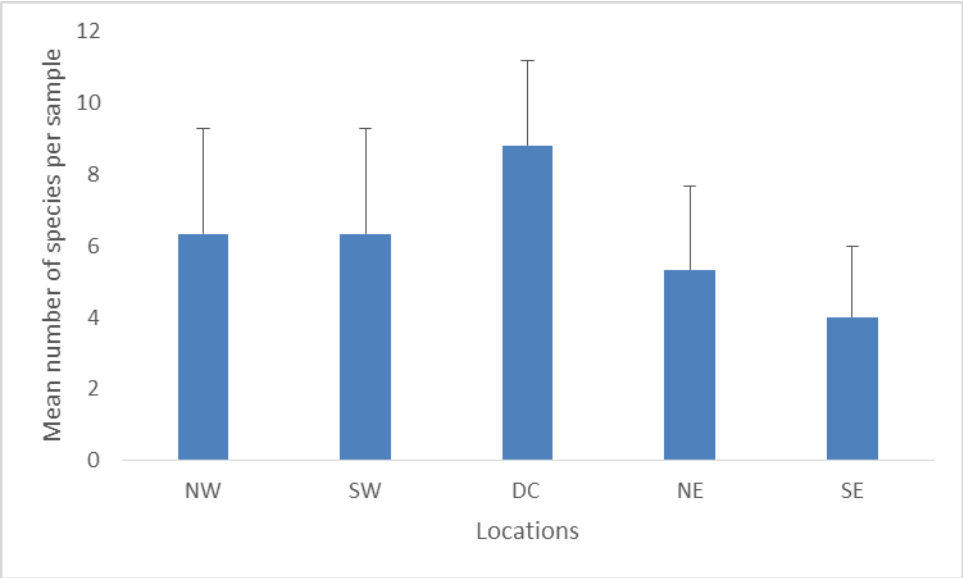
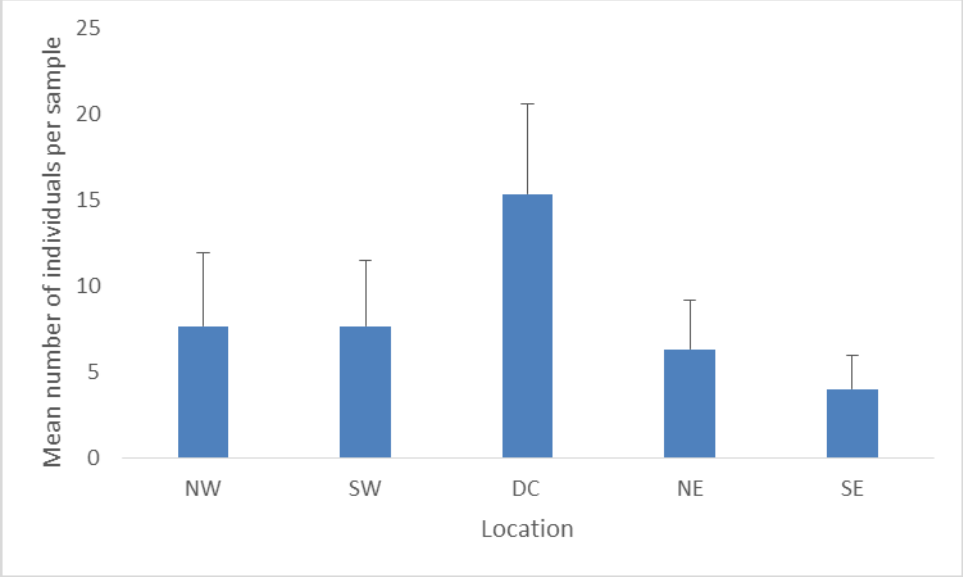


Figure 7 Mean number of individuals per sample from five locations in the AC/RL9 lease area.



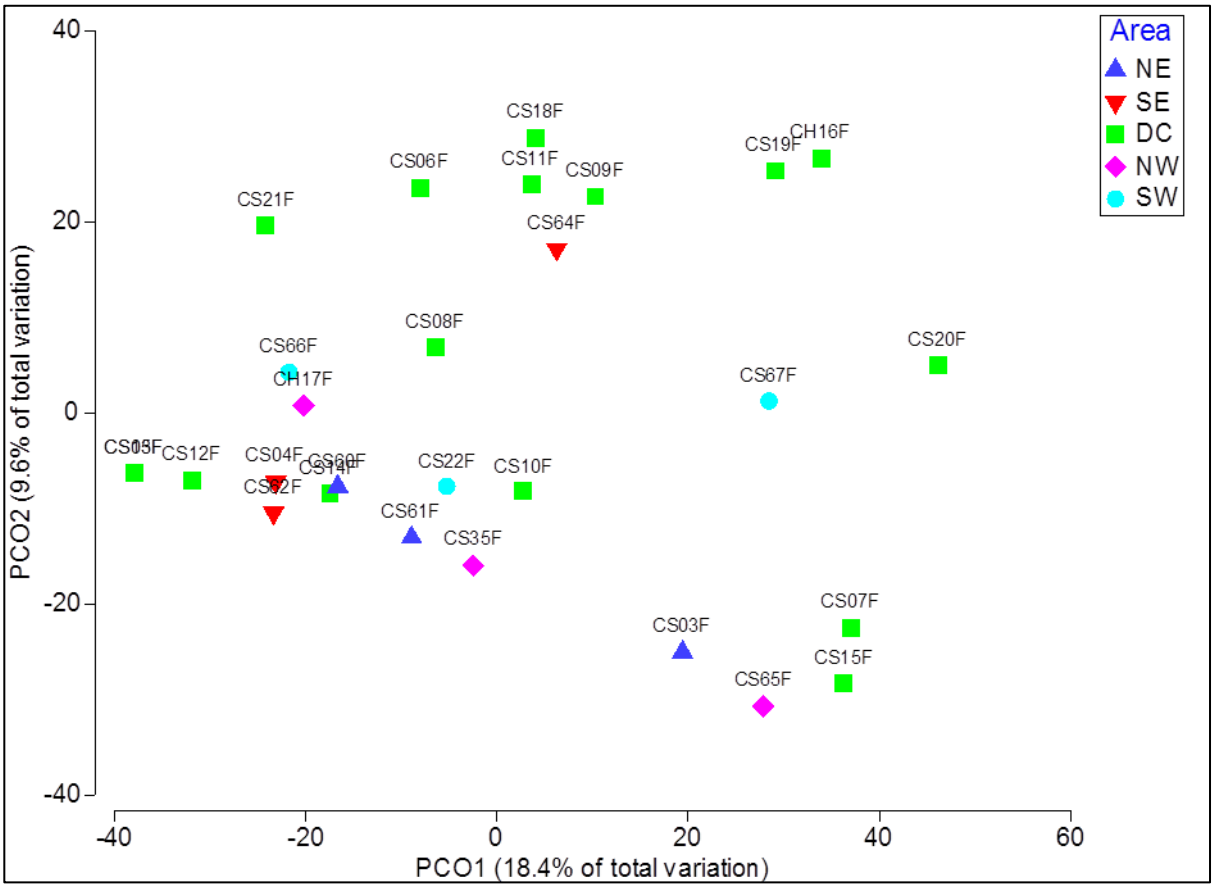
Principal coordinate analysis shows a complete overlap of locations, although it should be noted that the two axes displayed account for only 28% of the variance among samples (Figure 8). Data were square root transformed prior to analysis. Each point in Figure 8represents one sample, labelled with its sample code with location identified by the colour and shape of the symbol.

The water depth at the site and %fines in the sample differed between DC sites and all the reference sites. Distance-based Linear Modelling showed that depth and %fines explained only 7% of the variation in assemblage structure and that models containing either or both of these variables had

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higher akaike information criterion (AIC) values (228.16 – 229.25) than the null model (AIC = 227.45), suggesting neither variable was useful in explaining assemblage structure.

Figure 8 Analysis of principle coordinates based on a Bray-Curtis similarity matrix of assemblage data of the benthic fauna from sediment samples.



In summary, the statistical analysis of the data show there are no distinct groupings of sites, patterns of distribution or variation with physical seabed attributes (water depth, % fines). Similarly, a qualitative analysis of the infauna data indicates that:

There is a high degree of variability in species richness, abundance, diversity and composition between the replicate samples at each reference site. Such variability is not unexpected in soft sediment habitats, where patchiness in distribution of benthic fauna is typically apparent on spatial scales of metres, to tens of metres, to hundreds of metres. This indicates that a high intensity of fauna sampling would be required to generate sufficiently high statistical power in the event that monitoring of impacts on the basis of changes in community characteristics was to be required as a part of project approvals.

- High abundances of individual morphospecies can occur at single sites but be poorly represented or absent at most other sites, for example:
  - Demospongia sponge species at sites DC1_500NW and DC1_1000NW. There was no clear correlation between the presence of sponges and sediment type; many of the samples collected within the Crux Field had similar PSD, but few or no sponges were contained within them.
  - One polychaete species at sites DC2_1000SW. Samples with almost identical PSDs (from other sites within Crux Field) contained either few or none of these species. There was also no clear correlation between total polychaete abundances and sediment type.
  - One species of polychaete (Polynoidae), one species of gastropod (Crepidula sp.) and a gammarid crustacean species at site DC3_500SE. The sediment sample from this site did not have any distinctive physico-chemical characteristics relative to those of sediments at

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nearby sites, yet overall benthic fauna abundances and diversities at the nearby sites were substantially lower.

- Along the proposed pipeline route, there were some sites at which benthic fauna characteristics may have been related to seabed characteristics:
  - The highest proportion of fines (84% silt and clay) in any of the samples collected during the survey was at site PL_S1 (at the Prelude Field end of the route); the benthic fauna within the sample comprised only two individuals of a single species of sipunculid worm.
  - At the south-western end of the route (sites PL_S1 to PL_S5.5) there was a general increase in fauna abundance with decreasing fines content.
  - The highest fauna abundance along the route was at site PL_S5.5, where a single species of bivalve mollusc accounted for 85% of the fauna in the sample. This was the site with the highest proportion of coarse sand of all sites sampled. However, at site PL_S7 the sediment PSD was similar to that at PL_S5.5, yet fauna abundance was substantially lower.
  - The lowest fauna abundance along the route (a single bivalve) was recorded in the sample from site PL_S11, in which the proportion of fines (1%) was the lowest, and the proportion of coarse sand (60%) the highest, of any of the samples collected during the survey.
- Across all sites, with some exceptions, species richness was typically highest in sediments with 25-35% fines content. As the predominant morphospecies at these sites were burrowing species (worms and bivalve molluscs), this may be indicative of an 'optimal' sediment structure for these fauna. Where the fines content was much greater (e.g. site PL_S11) it is possible that the greater density of sediments may preclude many burrowing species. Where the fines content is low (<10%), burrowing species may have difficulty in maintaining competent burrows, especially in coarse sand habitats.

4.2 Physicochemical water column profiles

A summary of the physicochemical water column profile data is provided in Appendix F; data from the April/May survey are included for comparative purposes. Data have been averaged in 10 m strata across the depth of the water column at all sites; these are presented below in depth profile plots for each parameter (Figure 9). Depth profile plots comparing each parameter at each site individually for both surveys are also presented in Appendix F.

The ANZECC & ARMCANZ (2000) guidelines provide criteria levels for DO (> 90% saturation) and pH values (8.2), and state that pH should not deviate more than ± 0.2 pH units among individual sampling sites. However, the guidelines stress the need for site-specific information to enable the development of criteria that are more relevant to the system under study. The baseline data presented in this report may contribute to developing site specific criteria for future comparison.

4.2.1 Temperature

Temperature measurements were generally consistent across the sites with average surface temperatures (1 – 10 m) generally slightly lower (ranging from 30.1 to 30.9 °C) compared to the May survey, when the average surface water temperature ranged from 30.8 to 31.3 °C. Temperatures in the lower water column (below approximately 50 – 60 m depth) recorded during the second survey were slightly cooler than those recorded at the same sites during the May survey. As was the case at the time of the May survey, the temperature dropped consistently through the water column with no strong evidence of a distinct thermocline.

4.2.2 Salinity

Salinity measurements were consistent across all sites. Average surface salinities (0 – 10 m) were observed between 34. 4 – 34.8 PSU compared with a range of 34.8 – 35.0 PSU observed at the same sites during the May survey. In contrast to the salinity profiles observed at the time of the May survey (when a halocline was evident at approximately 30 – 35 m), surface salinities in October were lower in the surface waters and increased slowly to about mid-way through the water column before falling slightly again with depth through the water column to the sea bed.

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4.2.3 Dissolved Oxygen

DO concentrations were lower at the time of the October survey than in May, but generally followed the same trend, with higher DO in the upper water column which decreased consistently with depth to the seabed. Average surface DO (0–10 m) ranged from 102.4 – 109.4% compared to a range of 91.6 – 96.0% saturation at the time of the May survey. DO did not typically increase in the shallow surface water (<20 m) as it did during the May survey; however, beyond this depth DO generally decreased consistently through the water column in a manner similar to that observed in the May survey.

4.2.4 pH

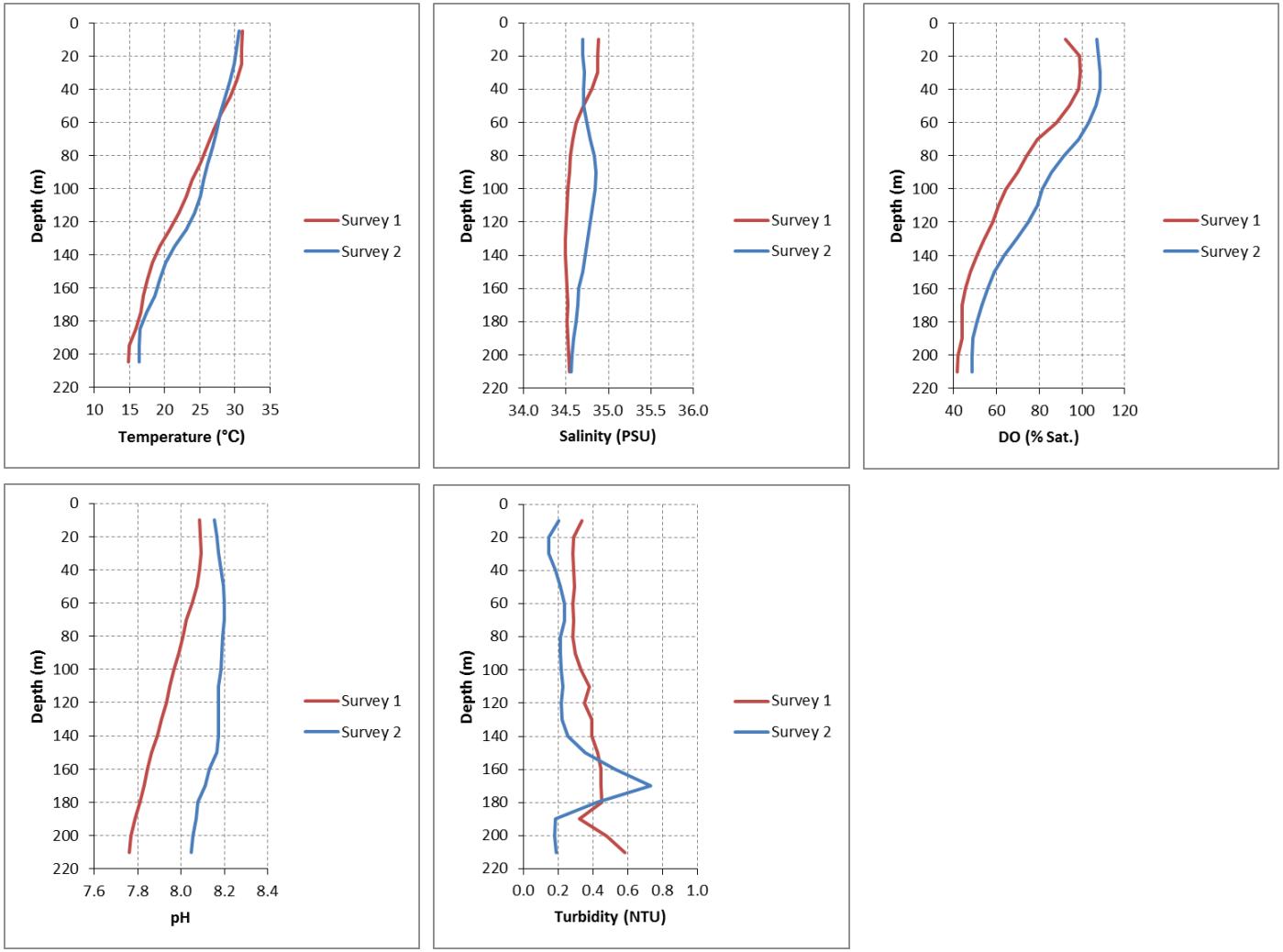
pH levels were generally marginally higher than those recoded during the May survey; however, they were consistent across all sites with the exception of DC_SW2000, which had a slightly lower pH (approximately 0.2) throughout the water column compared to other sites measured on the October survey. pH in surface waters to 40 – 60 m increased slightly before stabilising at a pH of approximately 8.2. At 150 m depth, average pH was recorded at approximately 8.15 – 8.17 before dropping slightly through the remaining water column to the seabed, where an average pH of approximately 8 was recorded. These readings are consistent with expectations for offshore marine environments with the Guideline default trigger value for offshore marine waters set at 8.2.

4.2.5 Turbidity

Consistent with the results obtained during the May survey, turbidity was low throughout the water column (< 1 NTU), as expected for offshore marine environments. High seabed turbidity has been detected at the Prelude development site (Shell, 2015b); however there was no indication of significantly elevated turbidity close to the seabed at any of the sites in the Crux Field or along the proposed pipeline route during the May survey. This was in contrast to the October survey during which elevated turbidity was observed at a number of the sites across the Crux Field. This elevated turbidity was observed up to approximately 20 m above the seabed.

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Figure 9 Water column profiles for average temperature, average salinity, average DO, average pH and average turbidity



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4.3 Water chemistry

Laboratory analytical results for the water samples are presented in Appendix G with laboratory reports provided in Appendix H. The majority of analyte concentrations were below laboratory PQLs; those that exceeded the PQLs are presented in Table 7.

Table 7 Analytes with concentrations exceeding PQL

	Aluminium	Barium	Chromium	Cobalt	Iron	Nickel	Zinc	Total Phosphorus
PQL	**0.01**	**0.01**	**0.001**	**0.001**	**0.01**	**0.001**	**0.005**	**0.005**
Trigger	**-**	**-**	**0.0077[a]**	**0.001[b]**	**-**	**0.007[a]**	**0.007[a]**	**0.01[c]**
REF_NE	<0.01	**0.02**	<0.001	**0.002**	**0.2**	<0.001	**0.046**	**0.012**
DCO_SW2000	<0.01	**0.01**	<0.001	**0.001**	**0.1**	<0.001	**0.035**	**0.011**
DCO	<0.01	**0.01**	<0.001	**0.001**	**0.06**	**0.001**	**0.029**	**0.012**
DCO	<0.01	**0.01**	**0.002**	**0.001**	**0.05**	**0.001**	**0.029**	**0.011**
FPSO_0	<0.01	**0.02**	<0.001	**0.001**	**0.04**	**0.001**	**0.026**	**0.011**
FPSO_NE2000	**0.06**	**0.01**	<0.001	**0.001**	**0.04**	<0.001	**0.026**	**0.01**
DC2_NE2000	<0.01	<0.01	<0.001	**0.001**	**0.09**	**0.001**	**0.011**	**0.011**
DC1_NW2000	<0.01	**0.02**	<0.001	**0.001**	**0.04**	**0.001**	**0.01**	**0.011**
PL_3	<0.01	<0.01	<0.001	**0.001**	**0.03**	**0.001**	**0.02**	**0.01**
PL_3	<0.01	<0.01	<0.001	**0.001**	**0.03**	**0.001**	**0.02**	**0.01**
PL_2	**0.01**	<0.01	<0.001	**0.001**	**0.02**	**0.001**	**0.015**	**0.011**
PL_1	**0.02**	<0.01	<0.001	**0.001**	**0.02**	**0.001**	**0.014**	**0.01**

a = ANZECC/ARMCANZ 99% species protection level
b = ANZECC/ARMCANZ 95% species protection level
c = ANZECC / ARMCANZ Default trigger level. Site specific trigger level to be developed using baseline data
Bold = concentration above PQL
Yellow = exceeded trigger level

4.3.1 Hydrocarbons

As was the case for results of the May survey, TRH was not detectable above the PQL (0.01 mg/L) in any of the samples. This would be expected of a remote offshore ocean environment distant from existing developments.

Similarly, BTEX were again not detected above the applied PQLs of 0.001 mg/L (Benzene, Toluene and Ethylbenzene) and 0.003 mg/L (Xylenes). Low reliability trigger levels for 99% species protection for BTEX in marine waters are suggested in the ANZECC & ARMCANZ (2000) guidelines. These are specified as 0.5 mg/L (Benzene), 0.18 mg/L (Toluene) and 0.005 mg/L (Ethylbenzene). Low reliability trigger levels for xylene isomers are suggested as 0.35 mg/L (o-xylene), 0.075 mg/L (m-xylene) and 0.2 mg/L (p-xylene).

4.3.2 Metals

Samples were analysed for total metals and the results were compared against the ANZECC & ARMCANZ (2000) 99% species protection trigger values for marine waters. In May 2016, metals concentrations were generally below the PQLs, with some exceptions. Where this was not the case, concentrations were generally substantially below the guideline 99% species protection trigger levels for marine waters. The results from this survey showed similarly low concentrations of metals in water samples and, while there were a number of metal concentrations above the laboratory PQLs, these were (with the exception of zinc) generally very close to the PQLs and below the ANZECC/ARMCANZ 99% species protection levels.

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4.3.2.1 Aluminium

Aluminium concentrations above the PQL of 0.01 mg/L were detected at four sites, ranging from 0.01 – 0.07 mg/L. There is no Guideline trigger level for aluminium. During the May survey, aluminium was not detected above the PQL at any sites.

4.3.2.2 Arsenic

Arsenic was not detected above the laboratory PQL of 0.001 mg/L at any site during the October survey. This is consistent with the May survey where all sites returned concentrations slightly above the PQL (with a range of 0.001 – 0.004 mg/L).

No ANZECC & ARMCANZ (2000) 99% protection trigger level exists for arsenic in marine waters however; low reliability guideline trigger levels of 0.0023 mg/L and 0.0045 mg/L are suggested for marine waters for As III and V species respectively. Given the evidently low concentrations of arsenic,, analysis of samples for speciated arsenic was not warranted as part of this program.

4.3.2.3 Barium

Barium was detected above the PQL of 0.01 mg/L at seven sites, with concentrations ranging from 0.01 – 0.02 mg/L. While there is no Guideline trigger level for comparison, these very low concentrations are consistent with the results from the May survey, where barium was not detected at any sites.

4.3.2.4 Cadmium

In line with the results of the May survey, cadmium concentrations were again below the PQL of 0.0001 mg/L at all sites and therefore below the ANZECC & ARMCANZ (2000) 99% species protection trigger level of 0.0007 mg/L.

4.3.2.5 Chromium

Chromium was detected above the PQL of 0.001 mg/L at one site (DC0) where a concentration of 0.002 mg/L was measured. This is below the ANZECC & ARMCANZ (2000) 99% species protection trigger level of 0.0077 mg/L. These results are in line with those from the May survey, in which chromium was only reported at one site (DC0_SW1000) at a concentration of 0.002 mg/L.

4.3.2.6 Cobalt

Cobalt was detected in all samples at a concertation equal to the laboratory PQL of 0.001 mg/kg except at the reference site REF_NE where a concentration of 0.002 mg/L was detected. During the May survey, cobalt was not detected at concentrations above the PQL at any of the sites sampled. It was not possible to apply a PQL sufficiently low to detect levels at the ANZECC & ARMCANZ (2000) 99% species protection level trigger of 0.000005 mg/L; however, the PQL applied was sufficient to detect any exceedance of the Guideline 95% protection trigger level of 0.001 mg/L, which was exceeded only at the REF_NE site.

4.3.2.7 Copper

Copper was not detected above the PQL of 0.001 mg/L at any site during the October survey.

It was not possible to apply a PQL sufficiently low to detect levels at the ANZECC & ARMCANZ (2000) 99% species protection level trigger of 0.0003 mg/L, however, the PQL applied was sufficient to detect any exceedance of the Guideline 95% protection trigger level of 0.0013 mg/L. Two sites exceeded this level during the May survey, by a very small amount however, both of these sites (DC0_SW1000 and PL-1) returned concentrations below the PQL during the October survey.

4.3.2.8 Iron

No ANZECC & ARMCANZ (2000) trigger level is provided for iron in marine waters, in which it occurs naturally. Iron was detected above the PQL (0.01 mg/L) at all sites, at concentrations of 0.01 – 0.09 mg/L. Concentrations were typically in line with those detected during the May survey.

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4.3.2.9 Lead

As was the case during the May survey, lead concentrations were below the PQL of 0.001 mg/L and therefore below the ANZECC & ARMCANZ (2000) 99% species protection level of 0.0022 mg/L during this survey.

4.3.2.10 Mercury

Mercury was not detected above the PQL of 0.0001 mg/L at any of the sites sampled during this survey. The PQL is equal to the ANZECC & ARMCANZ (2000) 99% species protection trigger level of 0.0001 mg/L so there were no exceedances of this trigger level. This was also the case during the May survey.

4.3.2.11 Nickel

Nickel concentrations were equal to the PQL of 0.001 mg/L at seven sites during this survey compared to only one site during the May survey. During this survey nickel was not detected above the PQL at the site where nickel was detected during the May survey (FPSO_NE2000, 0.001 mg/L). At 0.001 mg/L, the maximum concentration detected is below the ANZECC & ARMCANZ (2000) 99% species protection trigger level of 0.007 mg/L.

4.3.2.12 Zinc

Zinc was detected above the PQL of 0.005 mg/L at all sites sampled during this survey, with concentrations detected ranging from 0.01 – 0.046 mg/L. This is in contrast to the May survey, when the PQL was exceeded at only one site (FPSO_NE2000), where a concentration of 0.021 mg/L was measured. At these concentrations, zinc is above the ANZECC & ARMCANZ (2000) 99% species protection trigger value of 0.007 mg/L.

Zinc was not detected in either of the two inter laboratory duplicates; however, it was detected at a concentration of 0.006 mg/L in a rinsate sample. This suggests that the elevated zinc levels may be due to laboratory processes and/or (to a limited extent) sample contamination during collection. Hence the reported concentrations may not be representative of the actual concentrations within the water samples collected during the survey. This would render the data unsuitable for use in determining site-specific trigger levels for zinc in the study area.

4.3.3 Nutrients and photosynthetic pigments

The ANZECC & ARMCANZ (2000) guidelines provide criteria levels for water contaminant concentrations. However, the guidelines stress the need for site-specific information to enable the development of criteria that are more relevant to the system under study. In particular, the guidelines note that the trigger levels proposed for nutrient and chlorophyll concentrations in marine waters are not equally applicable to coastal and offshore waters. Location-specific baseline information allows for more accurate assessment of these parameters due to the site-specific nature of ecosystem responses to nutrient enrichment.

Therefore, the water quality parameters measured were assessed in terms of the recommendations in the guidelines, but it is suggested that baseline data from this survey and the May survey will form the basis for criteria levels for comparison in future impact assessments and monitoring.

4.3.3.1 Nitrogen

TN concentrations did not exceed the PQL of 0.2 mg/L at any of the sites sampled during the May survey. This PQL was not sufficiently low to detect the presence of nitrogen at the ANZECC & ARMCANZ (2000) trigger level of 0.1 mg/L. The PQL was lowered for the October survey and no detections above the lower PQL of 0.1 mg/L were measured.

NOx was not detected above the laboratory PQL of 0.002 mg/L. This is consistent with the May survey, in which NOx was not detected above the higher PQL of 0.01 mg/L applied to that analysis. The PQL was lowered to 0.002 mg/L for this survey; which is closer to the suggested guideline value of 0.001 mg/L (suggested to be typical of clear offshore waters).

4.3.3.2 Phosphorus

In contrast to the May survey when TP concentrations did not exceed the PQL of 0.01 mg/L at any of the sites sampled, results from this survey returned concentrations of TP which exceeded a lower PQL

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of 0.005 mg/L. Concentrations of TP measured during the October survey ranged from 0.01 – 0.012 mg/L. The ANZECC & ARMCANZ (2000) default trigger level applicable to offshore marine environments is 0.01 mg/L; hence all sites either equalled, or marginally exceeded, this Guideline level.

4.3.3.3 Photosynthetic pigments

For the four parameters analysed (Chlorophyll a, b, c and phaeophytin), no sites registered a result above the laboratory PQL of 0.0001 mg/L (0.0002 mg/L for phaeophytin). This is marginally different to the May survey results, where concentrations of chlorophyll a were measured above the PQL at seven sites, three of which were re-sampled during the October survey (FPSO_0, FPSO_NE2000 and REF_NE).

In May, all detections of total chlorophyll were very low. The measured concentration of total chlorophyll at all sites re-sampled on this survey was 0.0001 mg/L.

These results are below the ANZECC & ARMCANZ (2000) trigger levels for offshore marine waters of Northern Australia (0.0005 – 0.0009 mg/L). The lower of these two values is typical of clear coral dominated waters (e.g. Great Barrier Reef), while higher values are typical of turbid macrotidal systems (e.g. North West Shelf of WA) (ANZECC & ARMCANZ 2000).

4.4 Data QA/QC

4.4.1 Sediment samples

Field triplicate and duplicate samples were taken at three and four sites respectively. The calculated RPD and RSD values for metals from the field QA/QC samples exceeded the guideline of ±50% for a number of analytes.

Exceedances of RPD/RSD in a number of these samples were at very low levels and where both primary and duplicate samples were < 10 times the PQL. At these concentrations, the RPD is not considered to be significant due to the very low concentrations detected.

A small number of RPDs fell outside of these criteria:

- Barium at DC3_0
- NOx at DC3_0, DC3_1000SE and DC3_2000SE

The RSD for Copper at REF_NE and REF_NW also fell outside of these criteria.

Barium at site DC3_0 may have fallen outside of these limits if drilling muds containing barium have been used in the area. This may result in a heterogeneous sediment sample composition resulting in this breach of the RPD target. This is conceivable given that a well was drilled at this location and elevated Barium concentrations were found at a number of surrounding sites compared to Reference sites and sites further afield.

NOx were analysed to a low level PQL of 0.1 mg/kg. At the very low levels detected in the duplicate samples (1.1 – 1.8 mg/L) and the relatively small component of TN that this NOx makes up (with TKN shown to be the dominant nitrogen component in all samples), these exceedances in RPD are not seen to invalidate the overall assessment of nitrogen in sediment samples.

The RSD for copper fell outside of the guideline criteria due to the result for from the secondary laboratory being notably higher than the two samples from the primary laboratory (which met the RPD criteria). These samples were referred back to the laboratory and re-analysed. The revised results showed concentrations in line with the primary sample and the revised RSD. The result for REF_NW fell within the criteria and, while the RSD for the revised result for REF_NE remained outside the ±50% guideline, all results were less than 10 times the LOR and so is deemed satisfactory.

Laboratory QA/QC data were all within the acceptable laboratory levels for duplicates, method blanks, laboratory control samples and matrix spikes.

4.4.2 Water samples

One duplicate and one triplicate water sample were taken during the October survey. In all cases, the RPDs and RSDs were within the guideline criteria of ±50%.

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Laboratory QA/QC data were all within the acceptable laboratory levels for duplicates, method blanks, laboratory control samples and matrix spikes.

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5.0 Summary and Conclusions

5.1 Summary

The outcomes from the October 2016 sediment quality assessment are as follows:

- Metals concentrations across the AC/RL 9 area were all well below the Guideline ISQG-Low levels. The only exceedance of an ISQG-Low level was at site PL_S2, at the Prelude end of the proposed pipeline route.
- Petroleum hydrocarbons were detected at very low concentrations (slightly above the laboratory PQL) at three sites, predominantly in the C16-C34 fraction. One of these sites was a reference site at which the duplicate and triplicate samples did not register any TPH above the PQL. The concentrations detected were well below the SQGV level for TPH.
- BTEX was not detected above the laboratory PQL in any of the samples, while naphthalene was the only PAH detected above the PQL - at one site where the concentration was equal to the PQL and well below the Guideline level.
- Oil and grease were detected at all sites with no apparent spatial trends in the distribution of concentrations.
- Radionuclides were detected at 20 sites with gross alpha more prevalent than gross beta. Concentrations were well below the screening level applied.
- Nitrogen was predominantly present as TKN with a small NOx component at some sites, while phosphorus was present in higher concentrations.
- PSD composition varied, with sites across the Crux Field typically characterised by medium to fine sands with variable amounts of silt and clay between 5% and 42%, with the percentage of fines (particle size <4 – 62 µm) reducing with depth in a north easterly direction towards the shallowest part of the field. A higher percentage of fines was typical of the sites in deeper waters at the Prelude end of the proposed pipeline route.
- Species richness within benthic fauna communities was typically higher in sediments with 25-35% fines content than those with very high (>80%) or very low (<10%) fines. However, there were many exceptions within the AC/RL9 block and along the proposed pipeline route.
- At the sites where benthic fauna abundance within the samples was greatest, this was typically attributable to a high abundance of a single morphospecies. These species were typically absent, or present at much lower abundances, in samples from neighbouring sites and from sites with similar seabed characteristics.

The key outcomes from the November 2016 water quality assessment, where a number of subtle changes in the physicochemical attributes were observed since the May survey that may be suggestive of seasonal variation, were as follows:

- Water column profiles were typically similar to those observed in the May survey with a number of subtle differences reflecting temporal variation these include:
  - marginally higher DO through the water column
  - marginally lower pH through the water column
  - slightly lower salinity in the upper water column which increased to be higher than the May survey in the mid water column before falling consistently to similar concentrations at the seabed
- All but a very small number of toxicant concentrations were observed to be below the ANZECC & ARMCANZ (2000) 99% species protection levels (where PQLs were sufficiently low).
- Petroleum hydrocarbons were all below the quantifiable limit indicating no evidence of impact from petroleum development sites or natural seeps in the region.

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- Metals concentrations were generally comparable to those reported for the May survey and, with the exception of zinc, were all within expected ranges with all but one result (cobalt at REF_NE) showing concentrations below the applicable ANZECC & ARMCANZ (2000) guidelines 99% or 95% species protection levels. Where guideline trigger values were not available, toxicant concentrations were observed within levels expected for open ocean marine environments.
- Zinc concentrations were above the Guideline level of 0.007 mg/L in all samples. Zinc was not detected in either of the two inter laboratory duplicates; however, it was detected at a concentration of 0.006 mg/L in a rinsate sample. This suggests that the elevated zinc levels may be due to laboratory processes and/or (to a limited extent) sample contamination during collection. Hence the reported concentrations may not be representative of the actual concentrations within the water samples collected during the survey. This would render the data unsuitable for use in determining site-specific trigger levels for zinc in the study area
- Nutrient concentrations were very low across all sites with all samples returning concentrations below the PQLs for both TN and NOx consistent with the results at the same set of sites sampled during the May survey. Samples were tested for TP to a lower PQL in October (PQL = 0.005 mg/L) compared to the May survey (PQL = 0.01 mg/L) with concentrations all slightly above the previously applied 0.01 mg/L PQL. This suggests a very small increase in TP concentrations during the October survey. Combined with the analytical results for chlorophyll and phaeophytin, there is no evidence of any increase in nutrient loads even with the small observed increase in TP.
- Photosynthetic pigments in surface waters were below the laboratory PQL at all sites. This is consistent with the May survey where chlorophyll concentrations equalled the PQL of 0.1 mg/L at three of the sites that were resampled in October. These results suggest very little seasonal variation in photosynthetic pigments in the surface waters between the two surveys.
- Physical characteristics were within the expected ranges for this time of year when compared to the background data presented in previous desk top studies (Shell 2014, 2015a).

5.2 Conclusion

No evidence was found to suggest that the marine environment across the Crux Field or along the proposed pipeline route has been impacted adversely to date from natural or anthropogenic sources.

The results of the October survey supports the assertion that water quality in the AC/RL9 area can be classified as effectively unmodified, which would be expected given the remote location of the Crux Field and the distance to neighbouring fields that have been developed.

Little seasonal variation was observed in the limited number of sites sampled in both the May survey and this survey. Notable differences were all in the physical parameters rather than chemical characteristics of the waterbody. Baseline data relating to the physical water characteristics collected as part of this survey are suitable for use in developing site-specific criteria against which future monitoring data could be assessed. With the exception of the zinc data from this survey, the baseline dataset could also be used to develop site-specific criteria

Similarly, there is generally little evidence of substantial widespread impacts upon sediment quality from anthropogenic sources; however it is possible that the higher concentrations of metals at the Prelude end of the proposed pipeline route may be due to a combination of the higher proportion of finer particles and the activities associated with the Prelude development. Some increased levels of barium in the vicinity of exploration wells drilled in 2015 appear to be evident , but this is expected of drilling activities and would be anticipated to attenuate naturally over time. Detections of hydrocarbons in sediment samples were dispersed across a wide area suggesting that it is unlikely that these results are due to large scale or wide spread anthropogenic sources.

average concentrations of metals at the reference sites were being skewed by the lower concentrations measured in the samples collected at REF_NE. This site is located in a shallower part of the field where sediment grain sizes are coarser. This difference in physical characteristics at the site may compromise its suitability as a reference site for future monitoring programs. Hence it is suggested that REF_NE can be excluded as a reference site in future surveys.

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The water and sediment quality data collected during the baseline surveys provide a snapshot of the marine environment at these locations and will allow future comparisons to identify any impacts due to the development and/or operation of the Crux Field.

The high degree of variability in benthic community characteristics between the replicate samples at each reference site, and between sites with similar physical sediment characteristics (e.g. PSD, water depth) is indicative of the patchiness in benthic fauna distribution typically found in soft sediment habitats. This precludes the effective use of benthic fauna monitoring to detect impacts from field activities.

Any future comparisons that are made to this baseline data should be done considering the surrounding field activities (development and operations), natural medium to long-term climatic cycles and temporal variation associated with these systems.

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6.0 References

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Appendix A

Field Log - Sediments

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Appendix A Field Log - Sediments

Table 8 Sediment sample field sampling data sheets

Level 6, 3 Forrest Place, Perth WA 6000
T: 61 8 6208 0000; F: 61 8 6208 0999

Field Sediment Sampling Data Sheet

Project Number	**60495521**	**Site Name**	**Crux Field**	**Weather Conditions AM:**		**Time**	**Height**	**Time**	**Height**
Project Name	**Shell Crux Sediment Baseline Survey**	**Site Location**	**Crux Field**		**High Tide**				
Project Manager	**Peter Young**	**Client Name**	**Shell**	**Weather Conditions PM:**	**Low Tide**				
Sampled By	**IAN BAXTER**	**Sample Method**	**Day Grab**						

		Geo Ref. Sys. GDA94			**Sample**		**Sediment**		**Sediment Description**				
Site ID	**Time**	**Latitude**	**Longitude**	**Water Depth**	**Depth (bgl)**	**Colour**	**1°**	**2°**	**Biota**	**Shell Presence**	**Organic Content**	**Odour**	**Other Comments** (e.g foreign material, veneers, strata, biota)
CS01 (PL_S1)	31/10/16 1630	13º 45.995' S	123º 20.473' E	250 m	25 cm	GBr	Cl	Si	Few	Minor	x	x	
CS02 (PL_S2)	1745	13º 42.203' S	123º 24.523' E	252 m	20 cm	LBr	Cl	FS	Few	Minor	x	x	
CS03 (REF_NE)	1/11/16 0630	12º 55.510' S	124º 34.367' E	96 m	5 cm	Br	Gr	Si	Few	Lots	x	x	Triplicate
CS60 (REF_NE)	700	12º 55.328' S	124º 34.521' E	96 m	10 cm	Br	FS	Gr	Few	Lots	x	x	Triplicate
CS61 (REF_NE)	730	12º 55.301' S	124º 34.517' E	96 m	10 cm	Br	FS	Gr	Few	Lots	x	x	Triplicate
CS04 (REF_SE)	800	12º 59.404' S	124º 34.593' E	122 m	15 cm	Br	MS	Si	Few	Moderate	x	x	
CS62 (REF_SE)	830	12º 59.404' S	124º 34.593' E	122 m	15 cm	Br	MS	Si	Few	Moderate	x	x	Prawn
CS64 (REF_SE)	855	12º 59.404' S	124º 34.593' E	122 m	15 cm	Br	MS	Si	Few	Moderate	x	x	
CS05 (DC3_2000SE)	1000	12º 59.352' S	124º 27.902' E	168 m	20 cm	Br	MS	Si	Few	Lots	x	x	Duplicate
CS50 (DC3_2000SE)	1000	12º 59.352' S	124º 27.902' E	168 m	20 cm	Br	MS	Si	Few	Lots	x	x	Duplicate
CS06 (DC3_1000SE)	1030	12º 58.945' S	124º 27.536' E	168 m	25 cm	Br	MS	Si	Few	Lots	x	x	Duplicate
CS51 (DC3_1000SE)	1030	12º 58.945' S	124º 27.536' E	168 m	25 cm	Br	MS	Si	Few	Lots	x	x	Duplicate
CS07 (DC3_500SE)	1115	12º 58.762' S	124º 27.323' E	168 m	15 cm	Br	FS	Si	Many	Minor	x	x	Two large glass sponges, two hermit crabs
CS08 (DC3_0)	1145	12º 58.561' S	124º 27.142' E	168 m	15 cm	Br	FS	Si	Few	Moderate	x	x	Duplicate
CS52 (DC3_0)	1145	12º 58.561' S	124º 27.142' E	168 m	15 cm	Br	FS	Si	Few	Moderate	x	x	Duplicate

Sediment Constituents				
Si = Silt	Cl = Clay	FS = Fine Sand	MS = Medium Sand	CS = Coarse Sand
		Gr = Gravel	Co = Cobbles	

Sediment Colour							
M = Mottled	L= Light	D = Dark	Br = Brown	Bl = Black	Re = Red	Or = Orange	G = Grey

Level 6, 3 Forrest Place, Perth WA 6000
T: 61 8 6208 0000; F: 61 8 6208 0999

Field Sediment Sampling Data Sheet

						Time	Height	Time	Height
Project Number	60495521	Site Name	Crux Field	Weather Conditions AM:					
Project Name	Shell Crux Sediment Baseline Survey	Site Location	Crux Field		High Tide				
Project Manager	Peter Young	Client Name	Shell	Weather Conditions PM:	Low Tide				
Sampled By	IAN BAXTER	Sample Method	Day Grab						

		Geo Ref. Sys. GDA94			Sample		Sediment		Sediment Description				
Site ID	Time	Latitude	Longitude	Water Depth	Depth (bgl)	Colour	1°	2°	Biota	Shell Presence	Organic Content	Odour	Other Comments (e.g foreign material, veneers, strata, biota)
CS09 (DC3_500NW)	1/11/16 1330	12º 58.353' S	124º 26.913' E	167 m	25 cm	Br	FS	Si	Minor	Moderate	x	x	
CS10 (DC2_0)	1400	12º 58.087' S	124º 27.061' E	166 m	25 cm	Br	FS	Si	Minor	Moderate	x	x	Duplicate
CS53 (DC2_0)	1400	12º 58.087' S	124º 27.061' E	166 m	25 cm	Br	FS	Si	Minor	Moderate	x	x	Duplicate
CS11 (DC2_500NE)	1430	12º 57.863' S	124º 27.324' E	165 m	25 cm	Br	FS	Si	Minor	Moderate	x	x	
CS12 (DC2_1000NE)	1515	12º 57.670' S	124º 27.518' E	164 m	20 cm	Br	FS	Si	Minor	Moderate	x	x	
CS13 (DC2_2000NE)	1600	12º 57.355' S	124º 27.876' E	162 m	20 cm	Br	FS	-	V. Few	Few	x	x	
CS14 (DC1_0)	1630	12º 57.912' S	124º 26.542' E	164 m	15 cm	Br	FS	MS	Minor	Moderate	x	x	
CS15 (DC1_500NW)	1645	12º 57.743' S	124º 26.371' E	164 m	10 cm	Br	FS	Si	Moderate	Moderate	x	x	Glass sponge, sea star, brittle star
CS16 (DC1_1000NW)	1715	12º 57.594' S	124º 26.110' E	164 m	10 cm	Br	FS	Si	Few	Moderate	x	x	
CS17 (REF_NW)	2/11/16 0900	12º 55.203' S	124º 25.385' E	160 m	15 cm	LBr	FS	Si	Few	Moderate	x	x	Triplicate
CS35 (REF_NW)	900	12º 55.157' S	124º 25.401' E	160 m	15 cm	LBr	FS	Si	Few	Moderate	x	x	Triplicate
CS65 (REF_NW)	900	12º 55.173' S	124º 25.430' E	160 m	10 cm	LBr	FS	Si	Few	Moderate	x	x	Triplicate
CS18 (DC1_2000NW)	1030	12º 57.079' S	124º 25.525' E	167 m	15 cm	Br	FS	Si	Few	Moderate	x	x	
CS19 (DC1_500SE)	1115	12º 58.080' S	124º 26.689' E	166 m	20 cm	Br	FS	Si	Few	Lots	x	x	
CS20 (DC2_1000SW)	1145	12º 58.429' S	124º 26.729' E	168 m	15 cm	Br	FS	Si	Few	Moderate	x	x	

Sediment Constituents				
Si = Silt	Cl = Clay	FS = Fine Sand	MS = Medium Sand	CS = Coarse Sand
		Gr = Gravel	Co = Cobbles	

Sediment Colour							
M = Mottled	L= Light	D = Dark	Br = Brown	Bl = Black	Re = Red	Or = Orange	G = Grey

AECOM
Level 6, 3 Forrest Place, Perth WA 6000
T: 61 8 6208 0000; F: 61 8 6208 0999

Field Sediment Sampling Data Sheet

Project Number	**60495521**	**Site Name**	**Crux Field**	**Weather Conditions AM:**		**Time**	**Height**	**Time**	**Height**
Project Name	**Shell Crux Sediment Baseline Survey**	**Site Location**	**Crux Field**		**High Tide**				
Project Manager	**Peter Young**	**Client Name**	**Shell**	**Weather Conditions PM:**	**Low Tide**				
Sampled By	**IAN BAXTER**	**Sample Method**	**Day Grab**						

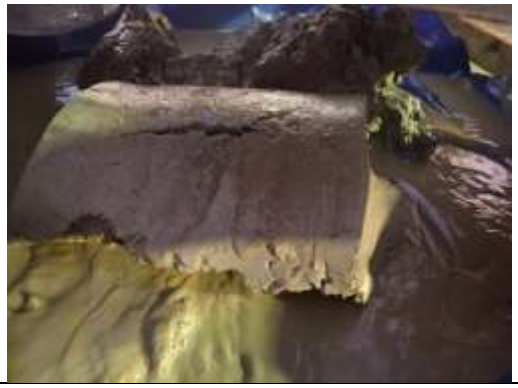
		Geo Ref. Sys. GDA94			**Sample**		**Sediment**		**Sediment Description**				
Site ID	**Time**	**Latitude**	**Longitude**	**Water Depth**	**Depth (bgl)**	**Colour**	**1°**	**2°**	**Biota**	**Shell Presence**	**Organic Content**	**Odour**	**Other Comments** (e.g foreign material, veneers, strata, biota)
CS21 (DC2_2000SW)	2/11/16 1215	12º 58.802' S	124º 26.360' E	170 m	15 cm	Br	FS	Si	Few	Moderate	x	x	
CS22 (REF_SW)	1330	12º 59.625' S	124º 25.308' E	175 m	15 cm	LBr	FS	-	Few	Moderate	x	x	Triplicate
CS66 (REF_SW)	1330	12º 59.718' S	124º 25.249' E	175 m	10 cm	LBr	FS	Si	Few	Moderate	x	x	Triplicate (fauna only)
CS67 (REF_SW)	1330	12º 59.750' S	124º 25.278' E	175 m	10 cm	LBr	FS	Si	Few	Moderate	x	x	Triplicate (fauna only)
CS23 (PL_S14)	3/11/16 0700	13º 02.147' S	124º 17.377' E	178 m	20 cm	LBr	FS	Si	Minor	Minor	x	x	
CS24 (PL_S12.5)	800	13º 05.499' S	124º 09.814' E	191 m	20 cm	LBr	FS	Cl	Moderate	Minor	x	x	
CS25 (PL_S11)	900	13º 09.498' S	124º 02.568' E	202 m	25 cm	G	CS	MS	Minor	Lots	x	x	
CS26 (PL_S9.5)	1115	13º 14.433' S	123º 55.996' E	201 m	25 cm	G	MS	FS	Few	Moderate	x	x	
CS27 (PL_S8)	1315	13º 19.386' S	123º 49.464' E	208 m	20 cm	G	FS	Si	Minor	Moderate	x	x	
CS28 (PL_S7)	1400	13º 22.613' S	123º 45.059' E	206 m	10 cm	LBr	FS	Si	Minor	Moderate	x	x	
CS29 (PL_S5.5)	1530	13º 28.290' S	123º 39.025' E	201 m	15 cm	LBr	FS	Si	Minor	Moderate	x	x	
CS30 (PL_S4)	1645	13º 34.924' S	123º 32.020' E	232 m	10 cm	LBr	Si	CS	Minor	Moderate	x	x	
CS31 (PL_S3)	1730	13º 38.320' S	123º 28.387' E	261 m	25 cm	GBr	Cl	Si	Few	Minor	x	x	

Sediment Constituents				
Si = Silt	Cl = Clay	FS = Fine Sand	MS = Medium Sand	CS = Coarse Sand
		Gr = Gravel	Co = Cobbles	

Sediment Colour							
M = Mottled	L= Light	D = Dark	Br = Brown	Bl = Black	Re = Red	Or = Orange	G = Grey

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Table 9 Sediment sample photographic record

Sample ID	Site name	Image
CS01	PL_S1	
CS02	PL_S2	
CS03	REF_NE	
CS04	REF_SE	

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Sample ID	Site name	Image
CS51	DC3_1000SE	
CS07	DC3_500SE	
CS08	DC3_0	
CS09	DC3_500NW	

D R A F T

Sample ID	Site name	Image
CS10	DC2_0	
CS11	DC2_500NE	
CS12	DC2_1000NE	
CS13	DC2_2000NE	

D R A F T

Sample ID	Site name	Image
CS14	DC1_0	
CS15	DC1_500NW	
CS16	DC1_1000NW	
CS17	REF_NW	

D R A F T

Sample ID	Site name	Image
CS35	REF_NW	
CS65	REF_NW	
CS18	DC1_2000NW	
CS19	DC1_500SE	

D R A F T

Sample ID	Site name	Image
CS20	DC2_1000SW	
CS21	DC2_2000SW	
CS22	REF_SW	
CS66	REF_SW	

D R A F T

Sample ID	Site name	Image
CS67	REF_SW	
CS23	PL_S14	
CS24	PL_S12.5	
CS25	PL_S11	

D R A F T

Sample ID	Site name	Image
CS26	PL_S9.5	
CS27	PL_S8	
CS28	PL_S7	
CS31	PL_S3	

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Appendix B

Laboratory reports – Sediment Chemistry

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Appendix B Analysis results and Laboratory reports – Sediment Chemistry

Table 10 Sediment sample chemical analysis results for sites around the proposed drill centres

		Site		DC1_0	DC1_500NW	DC1_1000NW	DC1_2000NW	DC1_500SE	DC2_0	DC2_0	DC2_500NE	DC2_1000NE	DC2_2000NE	DC2_1000SW	DC2_2000SW	DC3_0	DC3_0	DC3_2000SE	DC3_1000SE	DC3_500SE	DC3_500NW	DC3_2000SE	DC3_1000SE
Analyte	**Units**	**PQL**	**Trigger[a]**																				
Metals																							
Aluminium	mg/kg	50	-	**3530**	**3670**	**2550**	**2540**	**3540**	**3260**	**3440**	**3060**	**2750**	**2580**	**3230**	**3140**	**3330**	**2880**	**3660**	**2530**	**3440**	**3040**	**3680**	**2640**
Arsenic	mg/kg	1	20	**3.65**	**3.94**	**4.04**	**3.85**	**2.73**	**3.99**	**4.48**	**4.55**	**3.86**	**4.03**	**3.66**	**3.02**	**3.81**	**3.31**	**3.49**	**4.59**	**3.43**	**4.1**	**2.65**	**5.04**
Barium	mg/kg	0.1	-	**56.2**	**25.4**	**24.5**	**9.3**	**25.9**	**47.8**	**53**	**45.1**	**14.4**	**9.4**	**19.9**	**15.8**	**28.3**	**9.9**	**22.9**	**11.2**	**15.7**	**25**	**27.4**	**11.1**
Iron	mg/kg	50	-	**5110**	**5150**	**4150**	**4380**	**4670**	**5200**	**5520**	**4940**	**4420**	**4740**	**4790**	**4720**	**5520**	**4690**	**5170**	**4870**	**5030**	**4820**	**4900**	**5330**
Cadmium	mg/kg	0.1	1.5	**0.3**	**0.3**	**0.3**	**0.3**	**0.3**	**0.3**	**0.3**	**0.3**	**0.2**	**0.3**	**0.3**	**0.3**	**0.3**	**0.3**	**0.3**	**0.3**	**0.3**	**0.3**	**0.3**	**0.3**
Chromium	mg/kg	1	80	**21.1**	**20.7**	**19.1**	**19.4**	**19.4**	**19.8**	**22.5**	**21.5**	**19.7**	**20.2**	**20.8**	**19.5**	**20.3**	**20.1**	**22.4**	**20.6**	**21.6**	**20.9**	**18.3**	**20.4**
Cobalt	mg/kg	0.5	-	**2.4**	**2.6**	**2.1**	**1.9**	**2.4**	**2.2**	**2.4**	**2.2**	**2.3**	**2.7**	**2.3**	**2.2**	**2.2**	**2**	**2.6**	**2.2**	**2.4**	**2.2**	**2.4**	**2**
Copper	mg/kg	1	65	**5.9**	**6**	**4.6**	**4.3**	**6**	**5.2**	**5.5**	**5.1**	**5**	**4.2**	**5.5**	**5.2**	**5.2**	**4.7**	**5.9**	**4.5**	**5.6**	**5.4**	**5.8**	**4.3**
Lead	mg/kg	1	50	**2.8**	**2.6**	**2.6**	**2.5**	**2.5**	**2.9**	**2.9**	**2.7**	**2.5**	**2.8**	**2.8**	**2.5**	**3**	**2.4**	**2.6**	**2.6**	**2.6**	**2.7**	**2.5**	**3**
Mercury	mg/kg	0.01	0.15	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**	**0.04**	**0.04**	**0.04**	**0.04**	**0.04**	**0.04**	**0.04**	**0.04**	**0.04**	**0.04**	**0.04**	**0.04**	**0.04**	**0.04**	**0.04**
Nickel	mg/kg	1	21	**10.2**	**11.1**	**8.5**	**7.9**	**9.8**	**9.1**	**10.1**	**9.2**	**9.1**	**8.8**	**9.6**	**9**	**9.3**	**8.5**	**10.3**	**8.6**	**9.6**	**9.4**	**9.6**	**8.2**
Zinc	mg/kg	1	200	**20.7**	**20.9**	**18**	**18**	**19.4**	**19.6**	**21.9**	**19.8**	**19.7**	**22**	**20.1**	**19.5**	**19.7**	**19.1**	**21.5**	**19.6**	**21.3**	**20.3**	**19.4**	**25.4**
Nutrients																							
Total Nitrogen as N	mg/kg	20	-	**600**	**530**	**540**	**420**	**670**	**720**	**660**	**470**	**490**	**550**	**590**	**570**	**560**	**510**	**630**	**440**	**510**	**510**	**680**	**460**
Nitrite + Nitrate	mg/kg	0.1	-	<0.1	**0.6**	<0.1	<0.1	**0.3**	**0.2**	**0.6**	**0.8**	**0.6**	**1.6**	**0.2**	**0.3**	**1.8**	<0.1	**1.3**	<0.1	**0.4**	**0.8**	<0.1	**1.1**
Total Kjeldahl Nitrogen as N	mg/kg	20	-	**600**	**530**	**540**	**420**	**670**	**720**	**660**	**470**	**490**	**550**	**590**	**570**	**560**	**510**	**630**	**440**	**510**	**510**	**680**	**460**
Total Phosphorus as P	mg/kg	2	-	**5620**	**4890**	**5030**	**6640**	**4970**	**5360**	**5160**	**5000**	**6340**	**4000**	**4160**	**4090**	**4470**	**4000**	**3800**	**4070**	**4100**	**4610**	**4200**	**5690**
Hydrocarbons																							
C6 - C9 Fraction	mg/kg	3	-	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3
C10 - C14 Fraction	mg/kg	3	-	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3
C15 - C28 Fraction	mg/kg	3	-	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3
C29 - C36 Fraction	mg/kg	5	-	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
C10 - C36 Fraction (sum)	mg/kg	3	-	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3
TRH																							
>C10 - C16 Fraction	mg/kg	3	-	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3
>C16 - C34 Fraction	mg/kg	3	-	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3
>C34 - C40 Fraction	mg/kg	5	-	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
>C10 - C40 Fraction (sum)	mg/kg	3	-	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3
BTEX																							
Benzene	mg/kg	0.2	-	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Toluene	mg/kg	0.2	-	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Ethylbenzene	mg/kg	0.2	-	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
meta- & para-Xylene	mg/kg	0.2	-	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
ortho-Xylene	mg/kg	0.2	-	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Total Xylenes	mg/kg	0.5	-	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Sum of BTEX	mg/kg	0.2	-	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Naphthalene	mg/kg	0.2	-	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
PAH																							
Naphthalene	µg/kg	5	-	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	**5**	<5
2-Methylnaphthalene	µg/kg	5	-	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Acenaphthylene	µg/kg	4	-	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4
Acenaphthene	µg/kg	4	-	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4
Fluorene	µg/kg	4	-	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4
Phenanthrene	µg/kg	4	-	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4
Anthracene	µg/kg	4	-	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4
Fluoranthene	µg/kg	4	-	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4
Pyrene	µg/kg	4	-	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4
Benz(a)anthracene	µg/kg	4	-	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4
Chrysene	µg/kg	4	-	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4
Benzo(b+j)fluoranthene	µg/kg	4	-	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4
Benzo(k)fluoranthene	µg/kg	4	-	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4
Benzo(e)pyrene	µg/kg	4	-	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4
Benzo(a)pyrene	µg/kg	4	-	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4
Perylene	µg/kg	4	-	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4
Benzo(g.h.i)perylene	µg/kg	4	-	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4
Dibenz(a.h)anthracene	µg/kg	4	-	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4
Indeno(1.2.3.cd)pyrene	µg/kg	4	-	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4
Coronene	µg/kg	5	-	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Sum of PAHs	µg/kg	4	-	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	**5**	<4
Radionuclides																							
Gross alpha	Bq/kg DW	500	-	**1580**	**1150**	**1390**	<500	<500	<500	<500	**650**	**560**	**650**	<500	**780**	<500	<500	<500	<500	**590**	<500	**640**	**840**
Gross beta	Bq/kg DW	500	-	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500
Oil and Grease																							
Oil and Grease	mg/kg	100	-	**1900**	**1100**	**1300**	**510**	**2200**	**1200**	**1000**	**1300**	**1900**	**2200**	**930**	**930**	**960**	**1800**	**910**	**990**	**1500**	**1000**	**960**	**1000**

Concetrations above the PQL shown in **bold**
a - ANZECC / ARMCANZ ISQG Low trigger value
Trigger value exceedance

Table 11 Sediment sample chemical analysis results for reference sites and sites along the proposed pipeline route

			Site	PL_S1	PL_S2	PL_S3	PL_S4	PL_S5.5	PL_S7	PL_S8	PL_S9.5	PL_S11	PL_S12.5	PL_S14	REF_NE	REF_NE	REF_SE	REF_NW	REF_NW	REF_SE	REF_SE	REF_SW
Analyte	**Units**	**PQL**	**Trigger[a]**																			
Metals																						
Aluminium	mg/kg	50	-	**4680**	**5390**	**5870**	**2830**	**2670**	**2240**	**2870**	**2170**	**2710**	**2740**	**3790**	**740**	**720**	**1940**	**2340**	**2680**	**1700**	**1780**	**2230**
Arsenic	mg/kg	1	20	**2.72**	**7.71**	**8.68**	**2.16**	**11.4**	**11.3**	**13.4**	**6.81**	**13.8**	**2.58**	**5.82**	**1.54**	**1.56**	**1.32**	**2.1**	**4.24**	**1.28**	**1.17**	**6.05**
Barium	mg/kg	0.1	-	**13.3**	**10**	**21**	**28**	**10**	**8**	**9.4**	**7.6**	**7.3**	**10.4**	**9.9**	**6.7**	**9.8**	**12.7**	**16.4**	**12.5**	**11.8**	**12.9**	**8**
Iron	mg/kg	50	-	**5370**	**8990**	**16200**	**5700**	**7750**	**6660**	**8860**	**5040**	**6800**	**5460**	**7120**	**1740**	**1780**	**2890**	**3280**	**4710**	**2680**	**2630**	**5730**
Cadmium	mg/kg	0.1	1.5	**0.2**	**0.3**	**0.2**	**0.3**	**0.5**	**0.6**	**0.5**	**0.3**	**0.4**	**0.3**	**0.3**	**0.3**	**0.2**	**0.2**	**0.2**	**0.3**	**0.2**	**0.2**	**0.3**
Chromium	mg/kg	1	80	**22**	**41.3**	**43.3**	**15.9**	**29.8**	**31**	**38**	**18.1**	**36.8**	**19.2**	**29.2**	**15.1**	**13.8**	**13.9**	**13.3**	**21.3**	**11.2**	**11.1**	**20.1**
Cobalt	mg/kg	0.5	-	**4**	**6.1**	**6.3**	**3.4**	**3.7**	**3.6**	**4.1**	**3.1**	**5**	**2.5**	**2.8**	**0.8**	**0.6**	**1.5**	**1.7**	**2**	**1.2**	**1.3**	**2.7**
Copper	mg/kg	1	65	**11.6**	**7.7**	**7.7**	**5.9**	**3.6**	**2.4**	**5.6**	**12.8**	**4.1**	**4.3**	**4.6**	**1.2**	**1.5**	**3.5**	**4.5**	**4.6**	**2.9**	**3.1**	**3.5**
Lead	mg/kg	1	50	**2.1**	**3.5**	**5.5**	**2.8**	**3.8**	**2.8**	**3.7**	**3.3**	**5.4**	**1.9**	**3**	<1.0	**1.2**	**1.5**	**1.9**	**2.8**	**1.6**	**1.6**	**3.8**
Mercury	mg/kg	0.01	0.15	**0.02**	**0.02**	**0.05**	**0.03**	**0.02**	**0.01**	**0.02**	**0.02**	**0.02**	**0.02**	**0.03**	<0.01	**0.01**	**0.02**	**0.02**	**0.04**	**0.02**	**0.02**	**0.05**
Nickel	mg/kg	1	21	**16**	**21.9**	**18.5**	**10.3**	**11.9**	**13.7**	**16.5**	**8.8**	**16.1**	**8.3**	**11.3**	**2.9**	**2.9**	**6.4**	**7.1**	**8.8**	**5.2**	**5.6**	**9.7**
Zinc	mg/kg	1	200	**27.7**	**47.2**	**45.2**	**25.2**	**24.7**	**24.8**	**28.3**	**24.4**	**25.9**	**21**	**26.4**	**7.3**	**6**	**13.8**	**13.8**	**19.3**	**11.6**	**11.7**	**20.8**
Nutrients																						
Total Nitrogen as N	mg/kg	20	-	**1040**	**680**	**740**	**710**	**340**	**230**	**320**	**280**	**210**	**530**	**550**	**270**	**230**	**430**	**480**	**520**	**420**	**410**	**390**
Nitrite + Nitrate	mg/kg	0.1	-	**0.1**	<0.1	**0.1**	<0.1	**0.2**	**0.3**	<0.1	**0.4**	<0.1	**0.4**	<0.1	**0.1**	<0.1	**0.1**	**0.1**	**0.1**	**0.2**	**0.4**	**0.9**
Total Kjeldahl Nitrogen as N	mg/kg	20	-	**1040**	**680**	**740**	**710**	**340**	**230**	**320**	**280**	**210**	**530**	**550**	**270**	**230**	**430**	**480**	**520**	**420**	**410**	**390**
Total Phosphorus as P	mg/kg	2	-	**1480**	**9820**	**6200**	**1860**	**9970**	**5660**	**3700**	**10200**	**3820**	**4730**	**4360**	**816**	**907**	**1810**	**3480**	**3650**	**1510**	**1630**	**6680**
Hydrocarbons																						
C6 - C9 Fraction	mg/kg	3	-	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3
C10 - C14 Fraction	mg/kg	3	-	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3
C15 - C28 Fraction	mg/kg	3	-	<3	<3	**14**	<3	**7**	<3	<3	<3	<3	<3	<3	<3	<3	<3	**15**	<3	<3	<3	<3
C29 - C36 Fraction	mg/kg	5	-	<5	<5	**7**	<5	**7**	<5	<5	<5	<5	<5	<5	<5	<5	<5	**12**	<5	<5	<5	<5
C10 - C36 Fraction (sum)	mg/kg	3	-	<3	<3	**21**	<3	**14**	<3	<3	<3	<3	<3	<3	<3	<3	<3	**27**	<3	<3	<3	<3
TRH																						
>C10 - C16 Fraction	mg/kg	3	-	<3	<3	**4**	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3
>C16 - C34 Fraction	mg/kg	3	-	<3	<3	**19**	<3	**12**	<3	<3	<3	<3	<3	<3	<3	<3	<3	**25**	<3	<3	<3	<3
>C34 - C40 Fraction	mg/kg	5	-	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
>C10 - C40 Fraction (sum)	mg/kg	3	-	<3	<3	**23**	<3	**12**	<3	<3	<3	<3	<3	<3	<3	<3	<3	**25**	<3	<3	<3	<3
BTEX																						
Benzene	mg/kg	0.2	-	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Toluene	mg/kg	0.2	-	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Ethylbenzene	mg/kg	0.2	-	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
meta- & para-Xylene	mg/kg	0.2	-	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
ortho-Xylene	mg/kg	0.2	-	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Total Xylenes	mg/kg	0.5	-	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Sum of BTEX	mg/kg	0.2	-	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Naphthalene	mg/kg	0.2	-	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
PAH																						
Naphthalene	µg/kg	5	-	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
2-Methylnaphthalene	µg/kg	5	-	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Acenaphthylene	µg/kg	4	-	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4
Acenaphthene	µg/kg	4	-	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4
Fluorene	µg/kg	4	-	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4
Phenanthrene	µg/kg	4	-	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4
Anthracene	µg/kg	4	-	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4
Fluoranthene	µg/kg	4	-	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4
Pyrene	µg/kg	4	-	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4
Benz(a)anthracene	µg/kg	4	-	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4
Chrysene	µg/kg	4	-	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4
Benzo(b+j)fluoranthene	µg/kg	4	-	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4
Benzo(k)fluoranthene	µg/kg	4	-	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4
Benzo(e)pyrene	µg/kg	4	-	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4
Benzo(a)pyrene	µg/kg	4	-	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4
Perylene	µg/kg	4	-	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4
Benzo(g.h.i)perylene	µg/kg	4	-	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4
Dibenz(a.h)anthracene	µg/kg	4	-	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4
Indeno(1.2.3.cd)pyrene	µg/kg	4	-	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4
Coronene	µg/kg	5	-	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Sum of PAHs	µg/kg	4	-	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4
Radionuclides																						
Gross alpha	Bq/kg DW	500	-	<500	**1050**	**840**	**720**	**840**	<500	<500	**590**	**1860**	**750**	**780**	<500	<500	<500	<500	**900**	<500	<500	**590**
Gross beta	Bq/kg DW	500	-	<500	<500	<500	<500	<500	<500	<500	<500	**640**	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500
Oil and Grease																						
Oil and Grease	mg/kg	100	-	**1700**	**860**	**1100**	**1000**	**680**	**580**	**980**	**760**	**610**	**1800**	**1300**	**670**	**870**	**1200**	**920**	**700**	**1300**	**1100**	**850**

Concetrations above the PQL shown in **bold**
a - ANZECC / ARMCANZ ISQG Low trigger value
Trigger value exceedance

ALS Environmental

CERTIFICATE OF ANALYSIS

Work Order	: **EP1610856**	Page	: 1 of 27
Client	: **AECOM SERVICES PTY LTD**	Laboratory	: Environmental Division Perth
Contact	: PETER YOUNG	Contact	: ShukHui Li
Address	: Supplier ID number - 1179447 LEVEL 6 3 FORREST PLACE PERTH WA, AUSTRALIA 6000	Address	: 10 Hod Way Malaga WA Australia 6090
Telephone	: +61 08 9326 0100	Telephone	: 08 9209 7655
Project	: 60495521 Shell Crux Sediment Baseline Survey	Date Samples Received	: 14-Nov-2016 10:45
Order number	: 60495521/1.4	Date Analysis Commenced	: 15-Nov-2016
C-O-C number	: ----	Issue Date	: 30-Nov-2016 12:42
Sampler	: IAN BAXTER		
Site	: ----		
Quote number	: ----		
No. of samples received	: 39		
No. of samples analysed	: 39		

Accreditation No. 825
Accredited for compliance with
ISO/IEC 17025 - Testing

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted. This document shall not be reproduced, except in full.

This Certificate of Analysis contains the following information:

- General Comments
- Analytical Results
- Surrogate Control Limits

Additional information pertinent to this report will be found in the following separate attachments: Quality Control Report, QA/QC Compliance Assessment to assist with Quality Review and Sample Receipt Notification.

Signatories

This document has been electronically signed by the authorized signatories below. Electronic signing is carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Efua Wilson	Metals Chemist	Perth Inorganics, Malaga, WA
Indra Astuty	Instrument Chemist	Perth Inorganics, Malaga, WA
Jeremy Truong	Laboratory Manager	Perth Inorganics, Malaga, WA
Rassem Ayoubi	Senior Organic Chemist	Perth Organics, Malaga, WA

General Comments

The analytical procedures used by the Environmental Division have been developed from established internationally recognized procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are employed in the absence of documented standards or by client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insufficient sample for analysis.

Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

When sampling time information is not provided by the client, sampling dates are shown without a time component. In these instances, the time component has been assumed by the laboratory for processing purposes.

Where a result is required to meet compliance limits the associated uncertainty must be considered. Refer to the ALS Contact for details.

Key : CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting
ø = ALS is not NATA accredited for these tests.
~ = Indicates an estimated value.

- EP132-SD: 4-Terphenyl-d14 surrogate recovery for samples "CS24" & "CS27" fall outside ALS Dynamic Control Limits. However they are within USEPA Based Acceptance Limits. No further action required.
- Oil and Grease Analysis (CM067) is conducted by ALS Scoresby NATA accreditation no. 992, site no. 989.. NATA accreditation does not cover performance of this method.

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Client sample ID	CS01	CS02	CS03	CS04	CS05
			Client sampling date / time	[31-Oct-2016]	[31-Oct-2016]	[01-Nov-2016]	[01-Nov-2016]	[01-Nov-2016]
Compound	CAS Number	LOR	Unit	EP1610856-001	EP1610856-002	EP1610856-003	EP1610856-004	EP1610856-005
				Result	Result	Result	Result	Result
EA055: Moisture Content								
Moisture Content (dried @ 103°C)	----	1	%	42.0	35.9	28.6	42.7	42.6
EG005-SD: Total Metals in Sediments by ICP-AES								
Aluminium	7429-90-5	50	mg/kg	4680	5390	740	1940	3660
Iron	7439-89-6	50	mg/kg	5370	8990	1740	2890	5170
EG020-SD: Total Metals in Sediments by ICPMS								
Arsenic	7440-38-2	1	mg/kg	2.72	7.71	1.54	1.32	3.49
Cadmium	7440-43-9	0.1	mg/kg	0.2	0.3	0.3	0.2	0.3
Chromium	7440-47-3	1	mg/kg	22.0	41.3	15.1	13.9	22.4
Copper	7440-50-8	1	mg/kg	11.6	7.7	1.2	3.5	5.9
Cobalt	7440-48-4	0.5	mg/kg	4.0	6.1	0.8	1.5	2.6
Lead	7439-92-1	1	mg/kg	2.1	3.5	<1.0	1.5	2.6
Nickel	7440-02-0	1	mg/kg	16.0	21.9	2.9	6.4	10.3
Zinc	7440-66-6	1	mg/kg	27.7	47.2	7.3	13.8	21.5
EG020T: Total Metals by ICP-MS								
Barium	7440-39-3	0.1	mg/kg	13.3	10.0	6.7	12.7	22.9
EG035T: Total Recoverable Mercury by FIMS								
Mercury	7439-97-6	0.01	mg/kg	0.02	0.02	<0.01	0.02	0.04
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser								
Nitrite + Nitrate as N (Sol.)	----	0.1	mg/kg	0.1	<0.1	0.1	0.1	1.3
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser								
Total Kjeldahl Nitrogen as N	----	20	mg/kg	1040	680	270	430	630
EK062: Total Nitrogen as N (TKN + NOx)								
^ Total Nitrogen as N	----	20	mg/kg	1040	680	270	430	630
EK067G: Total Phosphorus as P by Discrete Analyser								
Total Phosphorus as P	----	2	mg/kg	1480	9820	816	1810	3800
EP080/071: Total Recoverable Hydrocarbons - NEPM 2013 Fractions								
>C10 - C16 Fraction	----	3	mg/kg	<3	<3	<3	<3	<3
>C16 - C34 Fraction	----	3	mg/kg	<3	<3	<3	<3	<3
>C34 - C40 Fraction	----	5	mg/kg	<5	<5	<5	<5	<5
>C10 - C40 Fraction (sum)	----	3	mg/kg	<3	<3	<3	<3	<3
>C10 - C16 Fraction minus Naphthalene (F2)	----	3	mg/kg	<3	<3	<3	<3	<3
EP080-SD / EP071-SD: Total Petroleum Hydrocarbons								
C6 - C9 Fraction	----	3	mg/kg	<3	<3	<3	<3	<3

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)				Client sample ID	CS01	CS02	CS03	CS04	CS05
				Client sampling date / time	[31-Oct-2016]	[31-Oct-2016]	[01-Nov-2016]	[01-Nov-2016]	[01-Nov-2016]
Compound	CAS Number	LOR	Unit		EP1610856-001	EP1610856-002	EP1610856-003	EP1610856-004	EP1610856-005
					Result	Result	Result	Result	Result
EP080-SD / EP071-SD: Total Petroleum Hydrocarbons - Continued									
C10 - C14 Fraction	----	3	mg/kg		<3	<3	<3	<3	<3
C15 - C28 Fraction	----	3	mg/kg		<3	<3	<3	<3	<3
C29 - C36 Fraction	----	5	mg/kg		<5	<5	<5	<5	<5
^ C10 - C36 Fraction (sum)	----	3	mg/kg		<3	<3	<3	<3	<3
EP080-SD / EP071-SD: Total Recoverable Hydrocarbons									
C6 - C10 Fraction	C6_C10	3	mg/kg		<3	<3	<3	<3	<3
C6 - C10 Fraction minus BTEX (F1)	C6_C10-BTEX	3	mg/kg		<3.0	<3.0	<3.0	<3.0	<3.0
EP080-SD: BTEXN									
Benzene	71-43-2	0.2	mg/kg		<0.2	<0.2	<0.2	<0.2	<0.2
Toluene	108-88-3	0.2	mg/kg		<0.2	<0.2	<0.2	<0.2	<0.2
Ethylbenzene	100-41-4	0.2	mg/kg		<0.2	<0.2	<0.2	<0.2	<0.2
meta- & para-Xylene	108-38-3 106-42-3	0.2	mg/kg		<0.2	<0.2	<0.2	<0.2	<0.2
ortho-Xylene	95-47-6	0.2	mg/kg		<0.2	<0.2	<0.2	<0.2	<0.2
^ Total Xylenes	1330-20-7	0.5	mg/kg		<0.5	<0.5	<0.5	<0.5	<0.5
^ Sum of BTEX	----	0.2	mg/kg		<0.2	<0.2	<0.2	<0.2	<0.2
Naphthalene	91-20-3	0.2	mg/kg		<0.2	<0.2	<0.2	<0.2	<0.2
EP132B: Polynuclear Aromatic Hydrocarbons									
Naphthalene	91-20-3	5	µg/kg		<5	<5	<5	<5	<5
2-Methylnaphthalene	91-57-6	5	µg/kg		<5	<5	<5	<5	<5
Acenaphthylene	208-96-8	4	µg/kg		<4	<4	<4	<4	<4
Acenaphthene	83-32-9	4	µg/kg		<4	<4	<4	<4	<4
Fluorene	86-73-7	4	µg/kg		<4	<4	<4	<4	<4
Phenanthrene	85-01-8	4	µg/kg		<4	<4	<4	<4	<4
Anthracene	120-12-7	4	µg/kg		<4	<4	<4	<4	<4
Fluoranthene	206-44-0	4	µg/kg		<4	<4	<4	<4	<4
Pyrene	129-00-0	4	µg/kg		<4	<4	<4	<4	<4
Benz(a)anthracene	56-55-3	4	µg/kg		<4	<4	<4	<4	<4
Chrysene	218-01-9	4	µg/kg		<4	<4	<4	<4	<4
Benzo(b+j)fluoranthene	205-99-2 205-82-3	4	µg/kg		<4	<4	<4	<4	<4
Benzo(k)fluoranthene	207-08-9	4	µg/kg		<4	<4	<4	<4	<4
Benzo(e)pyrene	192-97-2	4	µg/kg		<4	<4	<4	<4	<4
Benzo(a)pyrene	50-32-8	4	µg/kg		<4	<4	<4	<4	<4
Perylene	198-55-0	4	µg/kg		<4	<4	<4	<4	<4

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)				Client sample ID	CS01	CS02	CS03	CS04	CS05
				Client sampling date / time	[31-Oct-2016]	[31-Oct-2016]	[01-Nov-2016]	[01-Nov-2016]	[01-Nov-2016]
Compound	CAS Number	LOR	Unit		EP1610856-001	EP1610856-002	EP1610856-003	EP1610856-004	EP1610856-005
					Result	Result	Result	Result	Result
EP132B: Polynuclear Aromatic Hydrocarbons - Continued									
Benzo(g.h.i)perylene	191-24-2	4	µg/kg		<4	<4	<4	<4	<4
Dibenz(a.h)anthracene	53-70-3	4	µg/kg		<4	<4	<4	<4	<4
Indeno(1.2.3.cd)pyrene	193-39-5	4	µg/kg		<4	<4	<4	<4	<4
Coronene	191-07-1	5	µg/kg		<5	<5	<5	<5	<5
^ **Sum of PAHs**	----	4	µg/kg		<4	<4	<4	<4	<4
EP080-SD: TPH(V)/BTEX Surrogates									
1.2-Dichloroethane-D4	17060-07-0	0.2	%		**101**	**95.4**	**96.5**	**88.7**	**88.8**
Toluene-D8	2037-26-5	0.2	%		**91.4**	**87.7**	**87.1**	**80.4**	**79.3**
4-Bromofluorobenzene	460-00-4	0.2	%		**94.9**	**89.6**	**89.2**	**82.9**	**83.0**
EP132T: Base/Neutral Extractable Surrogates									
2-Fluorobiphenyl	321-60-8	10	%		**72.5**	**72.2**	**80.4**	**74.2**	**80.8**
Anthracene-d10	1719-06-8	10	%		**81.5**	**81.6**	**77.2**	**88.2**	**88.2**
4-Terphenyl-d14	1718-51-0	10	%		**82.5**	**85.1**	**80.9**	**91.6**	**91.9**

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Client sample ID	CS06	CS07	CS08	CS09	CS10
			Client sampling date / time	[01-Nov-2016]	[01-Nov-2016]	[01-Nov-2016]	[01-Nov-2016]	[01-Nov-2016]
Compound	CAS Number	LOR	Unit	EP1610856-006	EP1610856-007	EP1610856-008	EP1610856-009	EP1610856-010
				Result	Result	Result	Result	Result
EA055: Moisture Content								
Moisture Content (dried @ 103°C)	----	1	%	42.4	42.2	38.8	40.6	42.9
EG005-SD: Total Metals in Sediments by ICP-AES								
Aluminium	7429-90-5	50	mg/kg	2530	3440	2880	3040	3440
Iron	7439-89-6	50	mg/kg	4870	5030	4690	4820	5520
EG020-SD: Total Metals in Sediments by ICPMS								
Arsenic	7440-38-2	1	mg/kg	4.59	3.43	3.31	4.10	4.48
Cadmium	7440-43-9	0.1	mg/kg	0.3	0.3	0.3	0.3	0.3
Chromium	7440-47-3	1	mg/kg	20.6	21.6	20.1	20.9	22.5
Copper	7440-50-8	1	mg/kg	4.5	5.6	4.7	5.4	5.5
Cobalt	7440-48-4	0.5	mg/kg	2.2	2.4	2.0	2.2	2.4
Lead	7439-92-1	1	mg/kg	2.6	2.6	2.4	2.7	2.9
Nickel	7440-02-0	1	mg/kg	8.6	9.6	8.5	9.4	10.1
Zinc	7440-66-6	1	mg/kg	19.6	21.3	19.1	20.3	21.9
EG020T: Total Metals by ICP-MS								
Barium	7440-39-3	0.1	mg/kg	11.2	15.7	9.9	25.0	53.0
EG035T: Total Recoverable Mercury by FIMS								
Mercury	7439-97-6	0.01	mg/kg	0.04	0.04	0.04	0.04	0.04
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser								
Nitrite + Nitrate as N (Sol.)	----	0.1	mg/kg	<0.1	0.4	<0.1	0.8	0.6
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser								
Total Kjeldahl Nitrogen as N	----	20	mg/kg	440	510	510	510	660
EK062: Total Nitrogen as N (TKN + NOx)								
^ Total Nitrogen as N	----	20	mg/kg	440	510	510	510	660
EK067G: Total Phosphorus as P by Discrete Analyser								
Total Phosphorus as P	----	2	mg/kg	4070	4100	4000	4610	5160
EP080/071: Total Recoverable Hydrocarbons - NEPM 2013 Fractions								
>C10 - C16 Fraction	----	3	mg/kg	<3	<3	<3	<3	<3
>C16 - C34 Fraction	----	3	mg/kg	<3	<3	<3	<3	<3
>C34 - C40 Fraction	----	5	mg/kg	<5	<5	<5	<5	<5
>C10 - C40 Fraction (sum)	----	3	mg/kg	<3	<3	<3	<3	<3
>C10 - C16 Fraction minus Naphthalene (F2)	----	3	mg/kg	<3	<3	<3	<3	<3
EP080-SD / EP071-SD: Total Petroleum Hydrocarbons								
C6 - C9 Fraction	----	3	mg/kg	<3	<3	<3	<3	<3

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)				Client sample ID	CS06	CS07	CS08	CS09	CS10
				Client sampling date / time	[01-Nov-2016]	[01-Nov-2016]	[01-Nov-2016]	[01-Nov-2016]	[01-Nov-2016]
Compound	CAS Number	LOR	Unit		EP1610856-006	EP1610856-007	EP1610856-008	EP1610856-009	EP1610856-010
					Result	Result	Result	Result	Result
EP080-SD / EP071-SD: Total Petroleum Hydrocarbons - Continued									
C10 - C14 Fraction	----	3	mg/kg		<3	<3	<3	<3	<3
C15 - C28 Fraction	----	3	mg/kg		<3	<3	<3	<3	<3
C29 - C36 Fraction	----	5	mg/kg		<5	<5	<5	<5	<5
^ C10 - C36 Fraction (sum)	----	3	mg/kg		<3	<3	<3	<3	<3
EP080-SD / EP071-SD: Total Recoverable Hydrocarbons									
C6 - C10 Fraction	C6_C10	3	mg/kg		<3	<3	<3	<3	<3
C6 - C10 Fraction minus BTEX (F1)	C6_C10-BTEX	3	mg/kg		<3.0	<3.0	<3.0	<3.0	<3.0
EP080-SD: BTEXN									
Benzene	71-43-2	0.2	mg/kg		<0.2	<0.2	<0.2	<0.2	<0.2
Toluene	108-88-3	0.2	mg/kg		<0.2	<0.2	<0.2	<0.2	<0.2
Ethylbenzene	100-41-4	0.2	mg/kg		<0.2	<0.2	<0.2	<0.2	<0.2
meta- & para-Xylene	108-38-3 106-42-3	0.2	mg/kg		<0.2	<0.2	<0.2	<0.2	<0.2
ortho-Xylene	95-47-6	0.2	mg/kg		<0.2	<0.2	<0.2	<0.2	<0.2
^ Total Xylenes	1330-20-7	0.5	mg/kg		<0.5	<0.5	<0.5	<0.5	<0.5
^ Sum of BTEX	----	0.2	mg/kg		<0.2	<0.2	<0.2	<0.2	<0.2
Naphthalene	91-20-3	0.2	mg/kg		<0.2	<0.2	<0.2	<0.2	<0.2
EP132B: Polynuclear Aromatic Hydrocarbons									
Naphthalene	91-20-3	5	µg/kg		<5	<5	<5	<5	<5
2-Methylnaphthalene	91-57-6	5	µg/kg		<5	<5	<5	<5	<5
Acenaphthylene	208-96-8	4	µg/kg		<4	<4	<4	<4	<4
Acenaphthene	83-32-9	4	µg/kg		<4	<4	<4	<4	<4
Fluorene	86-73-7	4	µg/kg		<4	<4	<4	<4	<4
Phenanthrene	85-01-8	4	µg/kg		<4	<4	<4	<4	<4
Anthracene	120-12-7	4	µg/kg		<4	<4	<4	<4	<4
Fluoranthene	206-44-0	4	µg/kg		<4	<4	<4	<4	<4
Pyrene	129-00-0	4	µg/kg		<4	<4	<4	<4	<4
Benz(a)anthracene	56-55-3	4	µg/kg		<4	<4	<4	<4	<4
Chrysene	218-01-9	4	µg/kg		<4	<4	<4	<4	<4
Benzo(b+j)fluoranthene	205-99-2 205-82-3	4	µg/kg		<4	<4	<4	<4	<4
Benzo(k)fluoranthene	207-08-9	4	µg/kg		<4	<4	<4	<4	<4
Benzo(e)pyrene	192-97-2	4	µg/kg		<4	<4	<4	<4	<4
Benzo(a)pyrene	50-32-8	4	µg/kg		<4	<4	<4	<4	<4
Perylene	198-55-0	4	µg/kg		<4	<4	<4	<4	<4

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)				Client sample ID	CS06	CS07	CS08	CS09	CS10
				Client sampling date / time	[01-Nov-2016]	[01-Nov-2016]	[01-Nov-2016]	[01-Nov-2016]	[01-Nov-2016]
Compound	CAS Number	LOR	Unit		EP1610856-006	EP1610856-007	EP1610856-008	EP1610856-009	EP1610856-010
					Result	Result	Result	Result	Result
EP132B: Polynuclear Aromatic Hydrocarbons - Continued									
Benzo(g.h.i)perylene	191-24-2	4	µg/kg		<4	<4	<4	<4	<4
Dibenz(a.h)anthracene	53-70-3	4	µg/kg		<4	<4	<4	<4	<4
Indeno(1.2.3.cd)pyrene	193-39-5	4	µg/kg		<4	<4	<4	<4	<4
Coronene	191-07-1	5	µg/kg		<5	<5	<5	<5	<5
^ Sum of PAHs	----	4	µg/kg		<4	<4	<4	<4	<4
EP080-SD: TPH(V)/BTEX Surrogates									
1.2-Dichloroethane-D4	17060-07-0	0.2	%		86.2	87.2	86.3	90.7	85.5
Toluene-D8	2037-26-5	0.2	%		81.6	83.5	83.4	84.6	84.5
4-Bromofluorobenzene	460-00-4	0.2	%		81.1	82.2	81.0	83.9	79.8
EP132T: Base/Neutral Extractable Surrogates									
2-Fluorobiphenyl	321-60-8	10	%		74.2	88.0	72.7	77.0	73.8
Anthracene-d10	1719-06-8	10	%		74.6	95.0	83.1	96.6	77.0
4-Terphenyl-d14	1718-51-0	10	%		82.3	102	93.2	103	73.8

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Client sample ID	CS11	CS12	CS13	CS14	CS15
			Client sampling date / time	[01-Nov-2016]	[01-Nov-2016]	[01-Nov-2016]	[01-Nov-2016]	[01-Nov-2016]
Compound	CAS Number	LOR	Unit	EP1610856-011	EP1610856-012	EP1610856-013	EP1610856-014	EP1610856-015
				Result	Result	Result	Result	Result
EA055: Moisture Content								
Moisture Content (dried @ 103°C)	----	1	%	39.9	43.6	40.2	40.9	44.4
EG005-SD: Total Metals in Sediments by ICP-AES								
Aluminium	7429-90-5	50	mg/kg	3060	2750	2580	3530	3670
Iron	7439-89-6	50	mg/kg	4940	4420	4740	5110	5150
EG020-SD: Total Metals in Sediments by ICPMS								
Arsenic	7440-38-2	1	mg/kg	4.55	3.86	4.03	3.65	3.94
Cadmium	7440-43-9	0.1	mg/kg	0.3	0.2	0.3	0.3	0.3
Chromium	7440-47-3	1	mg/kg	21.5	19.7	20.2	21.1	20.7
Copper	7440-50-8	1	mg/kg	5.1	5.0	4.2	5.9	6.0
Cobalt	7440-48-4	0.5	mg/kg	2.2	2.3	2.7	2.4	2.6
Lead	7439-92-1	1	mg/kg	2.7	2.5	2.8	2.8	2.6
Nickel	7440-02-0	1	mg/kg	9.2	9.1	8.8	10.2	11.1
Zinc	7440-66-6	1	mg/kg	19.8	19.7	22.0	20.7	20.9
EG020T: Total Metals by ICP-MS								
Barium	7440-39-3	0.1	mg/kg	45.1	14.4	9.4	56.2	25.4
EG035T: Total Recoverable Mercury by FIMS								
Mercury	7439-97-6	0.01	mg/kg	0.04	0.04	0.04	0.03	0.03
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser								
Nitrite + Nitrate as N (Sol.)	----	0.1	mg/kg	0.8	0.6	1.6	<0.1	0.6
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser								
Total Kjeldahl Nitrogen as N	----	20	mg/kg	470	490	550	600	530
EK062: Total Nitrogen as N (TKN + NOx)								
^ Total Nitrogen as N	----	20	mg/kg	470	490	550	600	530
EK067G: Total Phosphorus as P by Discrete Analyser								
Total Phosphorus as P	----	2	mg/kg	5000	6340	4000	5620	4890
EP080/071: Total Recoverable Hydrocarbons - NEPM 2013 Fractions								
>C10 - C16 Fraction	----	3	mg/kg	<3	<3	<3	<3	<3
>C16 - C34 Fraction	----	3	mg/kg	<3	<3	<3	<3	<3
>C34 - C40 Fraction	----	5	mg/kg	<5	<5	<5	<5	<5
>C10 - C40 Fraction (sum)	----	3	mg/kg	<3	<3	<3	<3	<3
>C10 - C16 Fraction minus Naphthalene (F2)	----	3	mg/kg	<3	<3	<3	<3	<3
EP080-SD / EP071-SD: Total Petroleum Hydrocarbons								
C6 - C9 Fraction	----	3	mg/kg	<3	<3	<3	<3	<3

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)				Client sample ID	CS11	CS12	CS13	CS14	CS15
				Client sampling date / time	[01-Nov-2016]	[01-Nov-2016]	[01-Nov-2016]	[01-Nov-2016]	[01-Nov-2016]
Compound	CAS Number	LOR	Unit		EP1610856-011	EP1610856-012	EP1610856-013	EP1610856-014	EP1610856-015
					Result	Result	Result	Result	Result
EP080-SD / EP071-SD: Total Petroleum Hydrocarbons - Continued									
C10 - C14 Fraction	----	3	mg/kg		<3	<3	<3	<3	<3
C15 - C28 Fraction	----	3	mg/kg		<3	<3	<3	<3	<3
C29 - C36 Fraction	----	5	mg/kg		<5	<5	<5	<5	<5
^ C10 - C36 Fraction (sum)	----	3	mg/kg		<3	<3	<3	<3	<3
EP080-SD / EP071-SD: Total Recoverable Hydrocarbons									
C6 - C10 Fraction	C6_C10	3	mg/kg		<3	<3	<3	<3	<3
C6 - C10 Fraction minus BTEX (F1)	C6_C10-BTEX	3	mg/kg		<3.0	<3.0	<3.0	<3.0	<3.0
EP080-SD: BTEXN									
Benzene	71-43-2	0.2	mg/kg		<0.2	<0.2	<0.2	<0.2	<0.2
Toluene	108-88-3	0.2	mg/kg		<0.2	<0.2	<0.2	<0.2	<0.2
Ethylbenzene	100-41-4	0.2	mg/kg		<0.2	<0.2	<0.2	<0.2	<0.2
meta- & para-Xylene	108-38-3 106-42-3	0.2	mg/kg		<0.2	<0.2	<0.2	<0.2	<0.2
ortho-Xylene	95-47-6	0.2	mg/kg		<0.2	<0.2	<0.2	<0.2	<0.2
^ Total Xylenes	1330-20-7	0.5	mg/kg		<0.5	<0.5	<0.5	<0.5	<0.5
^ Sum of BTEX	----	0.2	mg/kg		<0.2	<0.2	<0.2	<0.2	<0.2
Naphthalene	91-20-3	0.2	mg/kg		<0.2	<0.2	<0.2	<0.2	<0.2
EP132B: Polynuclear Aromatic Hydrocarbons									
Naphthalene	91-20-3	5	µg/kg		<5	<5	<5	<5	<5
2-Methylnaphthalene	91-57-6	5	µg/kg		<5	<5	<5	<5	<5
Acenaphthylene	208-96-8	4	µg/kg		<4	<4	<4	<4	<4
Acenaphthene	83-32-9	4	µg/kg		<4	<4	<4	<4	<4
Fluorene	86-73-7	4	µg/kg		<4	<4	<4	<4	<4
Phenanthrene	85-01-8	4	µg/kg		<4	<4	<4	<4	<4
Anthracene	120-12-7	4	µg/kg		<4	<4	<4	<4	<4
Fluoranthene	206-44-0	4	µg/kg		<4	<4	<4	<4	<4
Pyrene	129-00-0	4	µg/kg		<4	<4	<4	<4	<4
Benz(a)anthracene	56-55-3	4	µg/kg		<4	<4	<4	<4	<4
Chrysene	218-01-9	4	µg/kg		<4	<4	<4	<4	<4
Benzo(b+j)fluoranthene	205-99-2 205-82-3	4	µg/kg		<4	<4	<4	<4	<4
Benzo(k)fluoranthene	207-08-9	4	µg/kg		<4	<4	<4	<4	<4
Benzo(e)pyrene	192-97-2	4	µg/kg		<4	<4	<4	<4	<4
Benzo(a)pyrene	50-32-8	4	µg/kg		<4	<4	<4	<4	<4
Perylene	198-55-0	4	µg/kg		<4	<4	<4	<4	<4

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)				Client sample ID	CS11	CS12	CS13	CS14	CS15
				Client sampling date / time	[01-Nov-2016]	[01-Nov-2016]	[01-Nov-2016]	[01-Nov-2016]	[01-Nov-2016]
Compound	CAS Number	LOR	Unit		EP1610856-011	EP1610856-012	EP1610856-013	EP1610856-014	EP1610856-015
					Result	Result	Result	Result	Result
EP132B: Polynuclear Aromatic Hydrocarbons - Continued									
Benzo(g.h.i)perylene	191-24-2	4	µg/kg		<4	<4	<4	<4	<4
Dibenz(a.h)anthracene	53-70-3	4	µg/kg		<4	<4	<4	<4	<4
Indeno(1.2.3.cd)pyrene	193-39-5	4	µg/kg		<4	<4	<4	<4	<4
Coronene	191-07-1	5	µg/kg		<5	<5	<5	<5	<5
^ **Sum of PAHs**	----	4	µg/kg		<4	<4	<4	<4	<4
EP080-SD: TPH(V)/BTEX Surrogates									
1.2-Dichloroethane-D4	17060-07-0	0.2	%		**86.2**	**83.1**	**92.4**	**85.5**	**83.8**
Toluene-D8	2037-26-5	0.2	%		**85.9**	**78.3**	**84.0**	**81.9**	**84.1**
4-Bromofluorobenzene	460-00-4	0.2	%		**81.4**	**76.8**	**85.9**	**78.2**	**79.9**
EP132T: Base/Neutral Extractable Surrogates									
2-Fluorobiphenyl	321-60-8	10	%		**94.0**	**97.1**	**104**	**103**	**96.4**
Anthracene-d10	1719-06-8	10	%		**110**	**107**	**114**	**110**	**102**
4-Terphenyl-d14	1718-51-0	10	%		**113**	**116**	**120**	**116**	**107**

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Client sample ID	CS16	CS17	CS18	CS19	CS20
			Client sampling date / time	[01-Nov-2016]	[02-Nov-2016]	[02-Nov-2016]	[02-Nov-2016]	[02-Nov-2016]
Compound	CAS Number	LOR	Unit	EP1610856-016	EP1610856-017	EP1610856-018	EP1610856-019	EP1610856-020
				Result	Result	Result	Result	Result
EA055: Moisture Content								
Moisture Content (dried @ 103°C)	----	1	%	40.1	39.7	37.4	41.4	42.3
EG005-SD: Total Metals in Sediments by ICP-AES								
Aluminium	7429-90-5	50	mg/kg	2550	2680	2540	3540	3230
Iron	7439-89-6	50	mg/kg	4150	4710	4380	4670	4790
EG020-SD: Total Metals in Sediments by ICPMS								
Arsenic	7440-38-2	1	mg/kg	4.04	4.24	3.85	2.73	3.66
Cadmium	7440-43-9	0.1	mg/kg	0.3	0.3	0.3	0.3	0.3
Chromium	7440-47-3	1	mg/kg	19.1	21.3	19.4	19.4	20.8
Copper	7440-50-8	1	mg/kg	4.6	4.6	4.3	6.0	5.5
Cobalt	7440-48-4	0.5	mg/kg	2.1	2.0	1.9	2.4	2.3
Lead	7439-92-1	1	mg/kg	2.6	2.8	2.5	2.5	2.8
Nickel	7440-02-0	1	mg/kg	8.5	8.8	7.9	9.8	9.6
Zinc	7440-66-6	1	mg/kg	18.0	19.3	18.0	19.4	20.1
EG020T: Total Metals by ICP-MS								
Barium	7440-39-3	0.1	mg/kg	24.5	12.5	9.3	25.9	19.9
EG035T: Total Recoverable Mercury by FIMS								
Mercury	7439-97-6	0.01	mg/kg	0.03	0.04	0.03	0.03	0.04
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser								
Nitrite + Nitrate as N (Sol.)	----	0.1	mg/kg	<0.1	0.1	<0.1	0.3	0.2
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser								
Total Kjeldahl Nitrogen as N	----	20	mg/kg	540	520	420	670	590
EK062: Total Nitrogen as N (TKN + NOx)								
^ Total Nitrogen as N	----	20	mg/kg	540	520	420	670	590
EK067G: Total Phosphorus as P by Discrete Analyser								
Total Phosphorus as P	----	2	mg/kg	5030	3650	6640	4970	4160
EP080/071: Total Recoverable Hydrocarbons - NEPM 2013 Fractions								
>C10 - C16 Fraction	----	3	mg/kg	<3	<3	<3	<3	<3
>C16 - C34 Fraction	----	3	mg/kg	<3	<3	<3	<3	<3
>C34 - C40 Fraction	----	5	mg/kg	<5	<5	<5	<5	<5
>C10 - C40 Fraction (sum)	----	3	mg/kg	<3	<3	<3	<3	<3
>C10 - C16 Fraction minus Naphthalene (F2)	----	3	mg/kg	<3	<3	<3	<3	<3
EP080-SD / EP071-SD: Total Petroleum Hydrocarbons								
C6 - C9 Fraction	----	3	mg/kg	<3	<3	<3	<3	<3

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)				Client sample ID	CS16	CS17	CS18	CS19	CS20
				Client sampling date / time	[01-Nov-2016]	[02-Nov-2016]	[02-Nov-2016]	[02-Nov-2016]	[02-Nov-2016]
Compound	CAS Number	LOR	Unit		EP1610856-016	EP1610856-017	EP1610856-018	EP1610856-019	EP1610856-020
					Result	Result	Result	Result	Result
EP080-SD / EP071-SD: Total Petroleum Hydrocarbons - Continued									
C10 - C14 Fraction	----	3	mg/kg		<3	<3	<3	<3	<3
C15 - C28 Fraction	----	3	mg/kg		<3	<3	<3	<3	<3
C29 - C36 Fraction	----	5	mg/kg		<5	<5	<5	<5	<5
^ C10 - C36 Fraction (sum)	----	3	mg/kg		<3	<3	<3	<3	<3
EP080-SD / EP071-SD: Total Recoverable Hydrocarbons									
C6 - C10 Fraction	C6_C10	3	mg/kg		<3	<3	<3	<3	<3
C6 - C10 Fraction minus BTEX (F1)	C6_C10-BTEX	3	mg/kg		<3.0	<3.0	<3.0	<3.0	<3.0
EP080-SD: BTEXN									
Benzene	71-43-2	0.2	mg/kg		<0.2	<0.2	<0.2	<0.2	<0.2
Toluene	108-88-3	0.2	mg/kg		<0.2	<0.2	<0.2	<0.2	<0.2
Ethylbenzene	100-41-4	0.2	mg/kg		<0.2	<0.2	<0.2	<0.2	<0.2
meta- & para-Xylene	108-38-3 106-42-3	0.2	mg/kg		<0.2	<0.2	<0.2	<0.2	<0.2
ortho-Xylene	95-47-6	0.2	mg/kg		<0.2	<0.2	<0.2	<0.2	<0.2
^ Total Xylenes	1330-20-7	0.5	mg/kg		<0.5	<0.5	<0.5	<0.5	<0.5
^ Sum of BTEX	----	0.2	mg/kg		<0.2	<0.2	<0.2	<0.2	<0.2
Naphthalene	91-20-3	0.2	mg/kg		<0.2	<0.2	<0.2	<0.2	<0.2
EP132B: Polynuclear Aromatic Hydrocarbons									
Naphthalene	91-20-3	5	µg/kg		<5	<5	<5	<5	<5
2-Methylnaphthalene	91-57-6	5	µg/kg		<5	<5	<5	<5	<5
Acenaphthylene	208-96-8	4	µg/kg		<4	<4	<4	<4	<4
Acenaphthene	83-32-9	4	µg/kg		<4	<4	<4	<4	<4
Fluorene	86-73-7	4	µg/kg		<4	<4	<4	<4	<4
Phenanthrene	85-01-8	4	µg/kg		<4	<4	<4	<4	<4
Anthracene	120-12-7	4	µg/kg		<4	<4	<4	<4	<4
Fluoranthene	206-44-0	4	µg/kg		<4	<4	<4	<4	<4
Pyrene	129-00-0	4	µg/kg		<4	<4	<4	<4	<4
Benz(a)anthracene	56-55-3	4	µg/kg		<4	<4	<4	<4	<4
Chrysene	218-01-9	4	µg/kg		<4	<4	<4	<4	<4
Benzo(b+j)fluoranthene	205-99-2 205-82-3	4	µg/kg		<4	<4	<4	<4	<4
Benzo(k)fluoranthene	207-08-9	4	µg/kg		<4	<4	<4	<4	<4
Benzo(e)pyrene	192-97-2	4	µg/kg		<4	<4	<4	<4	<4
Benzo(a)pyrene	50-32-8	4	µg/kg		<4	<4	<4	<4	<4
Perylene	198-55-0	4	µg/kg		<4	<4	<4	<4	<4

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)				Client sample ID	CS16	CS17	CS18	CS19	CS20
				Client sampling date / time	[01-Nov-2016]	[02-Nov-2016]	[02-Nov-2016]	[02-Nov-2016]	[02-Nov-2016]
Compound	CAS Number	LOR	Unit		EP1610856-016	EP1610856-017	EP1610856-018	EP1610856-019	EP1610856-020
					Result	Result	Result	Result	Result
EP132B: Polynuclear Aromatic Hydrocarbons - Continued									
Benzo(g.h.i)perylene	191-24-2	4	µg/kg		<4	<4	<4	<4	<4
Dibenz(a.h)anthracene	53-70-3	4	µg/kg		<4	<4	<4	<4	<4
Indeno(1.2.3.cd)pyrene	193-39-5	4	µg/kg		<4	<4	<4	<4	<4
Coronene	191-07-1	5	µg/kg		<5	<5	<5	<5	<5
^ Sum of PAHs	----	4	µg/kg		<4	<4	<4	<4	<4
EP080-SD: TPH(V)/BTEX Surrogates									
1.2-Dichloroethane-D4	17060-07-0	0.2	%		84.3	74.9	86.2	81.0	81.6
Toluene-D8	2037-26-5	0.2	%		79.8	81.0	82.6	82.4	82.0
4-Bromofluorobenzene	460-00-4	0.2	%		88.2	84.6	82.2	79.0	79.3
EP132T: Base/Neutral Extractable Surrogates									
2-Fluorobiphenyl	321-60-8	10	%		86.2	75.9	114	106	104
Anthracene-d10	1719-06-8	10	%		98.6	71.7	118	112	115
4-Terphenyl-d14	1718-51-0	10	%		99.3	75.4	126	118	117

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Client sample ID	CS21	CS22	CS23	CS24	CS25
			Client sampling date / time	[02-Nov-2016]	[02-Nov-2016]	[03-Nov-2016]	[03-Nov-2016]	[03-Nov-2016]
Compound	CAS Number	LOR	Unit	EP1610856-021	EP1610856-022	EP1610856-023	EP1610856-024	EP1610856-025
				Result	Result	Result	Result	Result
EA055: Moisture Content								
Moisture Content (dried @ 103°C)	----	1	%	40.4	37.5	44.2	39.9	16.4
EG005-SD: Total Metals in Sediments by ICP-AES								
Aluminium	7429-90-5	50	mg/kg	3140	2230	3790	2740	2710
Iron	7439-89-6	50	mg/kg	4720	5730	7120	5460	6800
EG020-SD: Total Metals in Sediments by ICPMS								
Arsenic	7440-38-2	1	mg/kg	3.02	6.05	5.82	2.58	13.8
Cadmium	7440-43-9	0.1	mg/kg	0.3	0.3	0.3	0.3	0.4
Chromium	7440-47-3	1	mg/kg	19.5	20.1	29.2	19.2	36.8
Copper	7440-50-8	1	mg/kg	5.2	3.5	4.6	4.3	4.1
Cobalt	7440-48-4	0.5	mg/kg	2.2	2.7	2.8	2.5	5.0
Lead	7439-92-1	1	mg/kg	2.5	3.8	3.0	1.9	5.4
Nickel	7440-02-0	1	mg/kg	9.0	9.7	11.3	8.3	16.1
Zinc	7440-66-6	1	mg/kg	19.5	20.8	26.4	21.0	25.9
EG020T: Total Metals by ICP-MS								
Barium	7440-39-3	0.1	mg/kg	15.8	8.0	9.9	10.4	7.3
EG035T: Total Recoverable Mercury by FIMS								
Mercury	7439-97-6	0.01	mg/kg	0.04	0.05	0.03	0.02	0.02
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser								
Nitrite + Nitrate as N (Sol.)	----	0.1	mg/kg	0.3	0.9	<0.1	0.4	<0.1
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser								
Total Kjeldahl Nitrogen as N	----	20	mg/kg	570	390	550	530	210
EK062: Total Nitrogen as N (TKN + NOx)								
^ Total Nitrogen as N	----	20	mg/kg	570	390	550	530	210
EK067G: Total Phosphorus as P by Discrete Analyser								
Total Phosphorus as P	----	2	mg/kg	4090	6680	4360	4730	3820
EP080/071: Total Recoverable Hydrocarbons - NEPM 2013 Fractions								
>C10 - C16 Fraction	----	3	mg/kg	<3	<3	<3	<3	<3
>C16 - C34 Fraction	----	3	mg/kg	<3	<3	<3	<3	<3
>C34 - C40 Fraction	----	5	mg/kg	<5	<5	<5	<5	<5
>C10 - C40 Fraction (sum)	----	3	mg/kg	<3	<3	<3	<3	<3
>C10 - C16 Fraction minus Naphthalene (F2)	----	3	mg/kg	<3	<3	<3	<3	<3
EP080-SD / EP071-SD: Total Petroleum Hydrocarbons								
C6 - C9 Fraction	----	3	mg/kg	<3	<3	<3	<3	<3

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)				Client sample ID	CS21	CS22	CS23	CS24	CS25
				Client sampling date / time	[02-Nov-2016]	[02-Nov-2016]	[03-Nov-2016]	[03-Nov-2016]	[03-Nov-2016]
Compound	CAS Number	LOR	Unit		EP1610856-021	EP1610856-022	EP1610856-023	EP1610856-024	EP1610856-025
					Result	Result	Result	Result	Result
EP080-SD / EP071-SD: Total Petroleum Hydrocarbons - Continued									
C10 - C14 Fraction	----	3	mg/kg		<3	<3	<3	<3	<3
C15 - C28 Fraction	----	3	mg/kg		<3	<3	<3	<3	<3
C29 - C36 Fraction	----	5	mg/kg		<5	<5	<5	<5	<5
^ C10 - C36 Fraction (sum)	----	3	mg/kg		<3	<3	<3	<3	<3
EP080-SD / EP071-SD: Total Recoverable Hydrocarbons									
C6 - C10 Fraction	C6_C10	3	mg/kg		<3	<3	<3	<3	<3
C6 - C10 Fraction minus BTEX (F1)	C6_C10-BTEX	3	mg/kg		<3.0	<3.0	<3.0	<3.0	<3.0
EP080-SD: BTEXN									
Benzene	71-43-2	0.2	mg/kg		<0.2	<0.2	<0.2	<0.2	<0.2
Toluene	108-88-3	0.2	mg/kg		<0.2	<0.2	<0.2	<0.2	<0.2
Ethylbenzene	100-41-4	0.2	mg/kg		<0.2	<0.2	<0.2	<0.2	<0.2
meta- & para-Xylene	108-38-3 106-42-3	0.2	mg/kg		<0.2	<0.2	<0.2	<0.2	<0.2
ortho-Xylene	95-47-6	0.2	mg/kg		<0.2	<0.2	<0.2	<0.2	<0.2
^ Total Xylenes	1330-20-7	0.5	mg/kg		<0.5	<0.5	<0.5	<0.5	<0.5
^ Sum of BTEX	----	0.2	mg/kg		<0.2	<0.2	<0.2	<0.2	<0.2
Naphthalene	91-20-3	0.2	mg/kg		<0.2	<0.2	<0.2	<0.2	<0.2
EP132B: Polynuclear Aromatic Hydrocarbons									
Naphthalene	91-20-3	5	µg/kg		<5	<5	<5	<5	<5
2-Methylnaphthalene	91-57-6	5	µg/kg		<5	<5	<5	<5	<5
Acenaphthylene	208-96-8	4	µg/kg		<4	<4	<4	<4	<4
Acenaphthene	83-32-9	4	µg/kg		<4	<4	<4	<4	<4
Fluorene	86-73-7	4	µg/kg		<4	<4	<4	<4	<4
Phenanthrene	85-01-8	4	µg/kg		<4	<4	<4	<4	<4
Anthracene	120-12-7	4	µg/kg		<4	<4	<4	<4	<4
Fluoranthene	206-44-0	4	µg/kg		<4	<4	<4	<4	<4
Pyrene	129-00-0	4	µg/kg		<4	<4	<4	<4	<4
Benz(a)anthracene	56-55-3	4	µg/kg		<4	<4	<4	<4	<4
Chrysene	218-01-9	4	µg/kg		<4	<4	<4	<4	<4
Benzo(b+j)fluoranthene	205-99-2 205-82-3	4	µg/kg		<4	<4	<4	<4	<4
Benzo(k)fluoranthene	207-08-9	4	µg/kg		<4	<4	<4	<4	<4
Benzo(e)pyrene	192-97-2	4	µg/kg		<4	<4	<4	<4	<4
Benzo(a)pyrene	50-32-8	4	µg/kg		<4	<4	<4	<4	<4
Perylene	198-55-0	4	µg/kg		<4	<4	<4	<4	<4

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)				Client sample ID	CS21	CS22	CS23	CS24	CS25
				Client sampling date / time	[02-Nov-2016]	[02-Nov-2016]	[03-Nov-2016]	[03-Nov-2016]	[03-Nov-2016]
Compound	CAS Number	LOR	Unit		EP1610856-021	EP1610856-022	EP1610856-023	EP1610856-024	EP1610856-025
					Result	Result	Result	Result	Result
EP132B: Polynuclear Aromatic Hydrocarbons - Continued									
Benzo(g.h.i)perylene	191-24-2	4	µg/kg		<4	<4	<4	<4	<4
Dibenz(a.h)anthracene	53-70-3	4	µg/kg		<4	<4	<4	<4	<4
Indeno(1.2.3.cd)pyrene	193-39-5	4	µg/kg		<4	<4	<4	<4	<4
Coronene	191-07-1	5	µg/kg		<5	<5	<5	<5	<5
^ **Sum of PAHs**	----	4	µg/kg		<4	<4	<4	<4	<4
EP080-SD: TPH(V)/BTEX Surrogates									
1.2-Dichloroethane-D4	17060-07-0	0.2	%		**82.9**	**83.6**	**81.6**	**83.0**	**90.6**
Toluene-D8	2037-26-5	0.2	%		**80.1**	**82.3**	**83.4**	**83.7**	**88.0**
4-Bromofluorobenzene	460-00-4	0.2	%		**79.4**	**79.5**	**79.0**	**80.4**	**87.0**
EP132T: Base/Neutral Extractable Surrogates									
2-Fluorobiphenyl	321-60-8	10	%		**72.1**	**79.4**	**102**	**114**	**94.4**
Anthracene-d10	1719-06-8	10	%		**75.6**	**90.1**	**115**	**116**	**112**
4-Terphenyl-d14	1718-51-0	10	%		**89.9**	**99.2**	**127**	**134**	**130**

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Client sample ID	CS26	CS27	CS28	CS29	CS30
			Client sampling date / time	[03-Nov-2016]	[03-Nov-2016]	[03-Nov-2016]	[03-Nov-2016]	[03-Nov-2016]
Compound	CAS Number	LOR	Unit	EP1610856-026	EP1610856-027	EP1610856-028	EP1610856-029	EP1610856-030
				Result	Result	Result	Result	Result
EA055: Moisture Content								
Moisture Content (dried @ 103°C)	----	1	%	33.5	38.2	32.7	37.8	49.5
EG005-SD: Total Metals in Sediments by ICP-AES								
Aluminium	7429-90-5	50	mg/kg	2170	2870	2240	2670	2830
Iron	7439-89-6	50	mg/kg	5040	8860	6660	7750	5700
EG020-SD: Total Metals in Sediments by ICPMS								
Arsenic	7440-38-2	1	mg/kg	6.81	13.4	11.3	11.4	2.16
Cadmium	7440-43-9	0.1	mg/kg	0.3	0.5	0.6	0.5	0.3
Chromium	7440-47-3	1	mg/kg	18.1	38.0	31.0	29.8	15.9
Copper	7440-50-8	1	mg/kg	12.8	5.6	2.4	3.6	5.9
Cobalt	7440-48-4	0.5	mg/kg	3.1	4.1	3.6	3.7	3.4
Lead	7439-92-1	1	mg/kg	3.3	3.7	2.8	3.8	2.8
Nickel	7440-02-0	1	mg/kg	8.8	16.5	13.7	11.9	10.3
Zinc	7440-66-6	1	mg/kg	24.4	28.3	24.8	24.7	25.2
EG020T: Total Metals by ICP-MS								
Barium	7440-39-3	0.1	mg/kg	7.6	9.4	8.0	10.0	28.0
EG035T: Total Recoverable Mercury by FIMS								
Mercury	7439-97-6	0.01	mg/kg	0.02	0.02	0.01	0.02	0.03
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser								
Nitrite + Nitrate as N (Sol.)	----	0.1	mg/kg	0.4	<0.1	0.3	0.2	<0.1
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser								
Total Kjeldahl Nitrogen as N	----	20	mg/kg	280	320	230	340	710
EK062: Total Nitrogen as N (TKN + NOx)								
^ Total Nitrogen as N	----	20	mg/kg	280	320	230	340	710
EK067G: Total Phosphorus as P by Discrete Analyser								
Total Phosphorus as P	----	2	mg/kg	10200	3700	5660	9970	1860
EP080/071: Total Recoverable Hydrocarbons - NEPM 2013 Fractions								
>C10 - C16 Fraction	----	3	mg/kg	<3	<3	<3	<3	<3
>C16 - C34 Fraction	----	3	mg/kg	<3	<3	<3	12	<3
>C34 - C40 Fraction	----	5	mg/kg	<5	<5	<5	<5	<5
>C10 - C40 Fraction (sum)	----	3	mg/kg	<3	<3	<3	12	<3
>C10 - C16 Fraction minus Naphthalene (F2)	----	3	mg/kg	<3	<3	<3	<3	<3
EP080-SD / EP071-SD: Total Petroleum Hydrocarbons								
C6 - C9 Fraction	----	3	mg/kg	<3	<3	<3	<3	<3

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)				Client sample ID	CS26	CS27	CS28	CS29	CS30
				Client sampling date / time	[03-Nov-2016]	[03-Nov-2016]	[03-Nov-2016]	[03-Nov-2016]	[03-Nov-2016]
Compound	CAS Number	LOR	Unit		EP1610856-026	EP1610856-027	EP1610856-028	EP1610856-029	EP1610856-030
					Result	Result	Result	Result	Result
EP080-SD / EP071-SD: Total Petroleum Hydrocarbons - Continued									
C10 - C14 Fraction	----	3	mg/kg		<3	<3	<3	<3	<3
C15 - C28 Fraction	----	3	mg/kg		<3	<3	<3	**7**	<3
C29 - C36 Fraction	----	5	mg/kg		<5	<5	<5	**7**	<5
^ C10 - C36 Fraction (sum)	----	3	mg/kg		<3	<3	<3	**14**	<3
EP080-SD / EP071-SD: Total Recoverable Hydrocarbons									
C6 - C10 Fraction	C6_C10	3	mg/kg		<3	<3	<3	<3	<3
C6 - C10 Fraction minus BTEX (F1)	C6_C10-BTEX	3	mg/kg		<3.0	<3.0	<3.0	<3.0	<3.0
EP080-SD: BTEXN									
Benzene	71-43-2	0.2	mg/kg		<0.2	<0.2	<0.2	<0.2	<0.2
Toluene	108-88-3	0.2	mg/kg		<0.2	<0.2	<0.2	<0.2	<0.2
Ethylbenzene	100-41-4	0.2	mg/kg		<0.2	<0.2	<0.2	<0.2	<0.2
meta- & para-Xylene	108-38-3 106-42-3	0.2	mg/kg		<0.2	<0.2	<0.2	<0.2	<0.2
ortho-Xylene	95-47-6	0.2	mg/kg		<0.2	<0.2	<0.2	<0.2	<0.2
^ Total Xylenes	1330-20-7	0.5	mg/kg		<0.5	<0.5	<0.5	<0.5	<0.5
^ Sum of BTEX	----	0.2	mg/kg		<0.2	<0.2	<0.2	<0.2	<0.2
Naphthalene	91-20-3	0.2	mg/kg		<0.2	<0.2	<0.2	<0.2	<0.2
EP132B: Polynuclear Aromatic Hydrocarbons									
Naphthalene	91-20-3	5	µg/kg		<5	<5	<5	<5	<5
2-Methylnaphthalene	91-57-6	5	µg/kg		<5	<5	<5	<5	<5
Acenaphthylene	208-96-8	4	µg/kg		<4	<4	<4	<4	<4
Acenaphthene	83-32-9	4	µg/kg		<4	<4	<4	<4	<4
Fluorene	86-73-7	4	µg/kg		<4	<4	<4	<4	<4
Phenanthrene	85-01-8	4	µg/kg		<4	<4	<4	<4	<4
Anthracene	120-12-7	4	µg/kg		<4	<4	<4	<4	<4
Fluoranthene	206-44-0	4	µg/kg		<4	<4	<4	<4	<4
Pyrene	129-00-0	4	µg/kg		<4	<4	<4	<4	<4
Benz(a)anthracene	56-55-3	4	µg/kg		<4	<4	<4	<4	<4
Chrysene	218-01-9	4	µg/kg		<4	<4	<4	<4	<4
Benzo(b+j)fluoranthene	205-99-2 205-82-3	4	µg/kg		<4	<4	<4	<4	<4
Benzo(k)fluoranthene	207-08-9	4	µg/kg		<4	<4	<4	<4	<4
Benzo(e)pyrene	192-97-2	4	µg/kg		<4	<4	<4	<4	<4
Benzo(a)pyrene	50-32-8	4	µg/kg		<4	<4	<4	<4	<4
Perylene	198-55-0	4	µg/kg		<4	<4	<4	<4	<4

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)				Client sample ID	CS26	CS27	CS28	CS29	CS30
				Client sampling date / time	[03-Nov-2016]	[03-Nov-2016]	[03-Nov-2016]	[03-Nov-2016]	[03-Nov-2016]
Compound	CAS Number	LOR	Unit		EP1610856-026	EP1610856-027	EP1610856-028	EP1610856-029	EP1610856-030
					Result	Result	Result	Result	Result
EP132B: Polynuclear Aromatic Hydrocarbons - Continued									
Benzo(g.h.i)perylene	191-24-2	4	µg/kg		<4	<4	<4	<4	<4
Dibenz(a.h)anthracene	53-70-3	4	µg/kg		<4	<4	<4	<4	<4
Indeno(1.2.3.cd)pyrene	193-39-5	4	µg/kg		<4	<4	<4	<4	<4
Coronene	191-07-1	5	µg/kg		<5	<5	<5	<5	<5
^ Sum of PAHs	----	4	µg/kg		<4	<4	<4	<4	<4
EP080-SD: TPH(V)/BTEX Surrogates									
1.2-Dichloroethane-D4	17060-07-0	0.2	%		82.0	84.2	84.5	80.6	75.9
Toluene-D8	2037-26-5	0.2	%		81.4	86.7	86.1	81.0	78.5
4-Bromofluorobenzene	460-00-4	0.2	%		79.2	82.0	81.8	80.0	74.0
EP132T: Base/Neutral Extractable Surrogates									
2-Fluorobiphenyl	321-60-8	10	%		87.6	87.4	80.9	73.4	72.9
Anthracene-d10	1719-06-8	10	%		87.2	101	96.1	123	88.1
4-Terphenyl-d14	1718-51-0	10	%		129	109	127	135	99.8

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Client sample ID	CS31	CS35	CS50	CS51	CS52
			Client sampling date / time	[03-Nov-2016]	[02-Nov-2016]	[01-Nov-2016]	[01-Nov-2016]	[01-Nov-2016]
Compound	CAS Number	LOR	Unit	EP1610856-031	EP1610856-032	EP1610856-033	EP1610856-034	EP1610856-035
				Result	Result	Result	Result	Result
EA055: Moisture Content								
Moisture Content (dried @ 103°C)	----	1	%	44.8	39.8	46.9	40.5	41.8
EG005-SD: Total Metals in Sediments by ICP-AES								
Aluminium	7429-90-5	50	mg/kg	5870	2340	3680	2640	3330
Iron	7439-89-6	50	mg/kg	16200	3280	4900	5330	5520
EG020-SD: Total Metals in Sediments by ICPMS								
Arsenic	7440-38-2	1	mg/kg	8.68	2.10	2.65	5.04	3.81
Cadmium	7440-43-9	0.1	mg/kg	0.2	0.2	0.3	0.3	0.3
Chromium	7440-47-3	1	mg/kg	43.3	13.3	18.3	20.4	20.3
Copper	7440-50-8	1	mg/kg	7.7	4.5	5.8	4.3	5.2
Cobalt	7440-48-4	0.5	mg/kg	6.3	1.7	2.4	2.0	2.2
Lead	7439-92-1	1	mg/kg	5.5	1.9	2.5	3.0	3.0
Nickel	7440-02-0	1	mg/kg	18.5	7.1	9.6	8.2	9.3
Zinc	7440-66-6	1	mg/kg	45.2	13.8	19.4	25.4	19.7
EG020T: Total Metals by ICP-MS								
Barium	7440-39-3	0.1	mg/kg	21.0	16.4	27.4	11.1	28.3
EG035T: Total Recoverable Mercury by FIMS								
Mercury	7439-97-6	0.01	mg/kg	0.05	0.02	0.04	0.04	0.04
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser								
Nitrite + Nitrate as N (Sol.)	----	0.1	mg/kg	0.1	0.1	<0.1	1.1	1.8
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser								
Total Kjeldahl Nitrogen as N	----	20	mg/kg	740	480	680	460	560
EK062: Total Nitrogen as N (TKN + NOx)								
^ Total Nitrogen as N	----	20	mg/kg	740	480	680	460	560
EK067G: Total Phosphorus as P by Discrete Analyser								
Total Phosphorus as P	----	2	mg/kg	6200	3480	4200	5690	4470
EP080/071: Total Recoverable Hydrocarbons - NEPM 2013 Fractions								
>C10 - C16 Fraction	----	3	mg/kg	4	<3	<3	<3	<3
>C16 - C34 Fraction	----	3	mg/kg	19	25	<3	<3	<3
>C34 - C40 Fraction	----	5	mg/kg	<5	<5	<5	<5	<5
>C10 - C40 Fraction (sum)	----	3	mg/kg	23	25	<3	<3	<3
>C10 - C16 Fraction minus Naphthalene (F2)	----	3	mg/kg	4	<3	<3	<3	<3
EP080-SD / EP071-SD: Total Petroleum Hydrocarbons								
C6 - C9 Fraction	----	3	mg/kg	<3	<3	<3	<3	<3

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)				Client sample ID	CS31	CS35	CS50	CS51	CS52
				Client sampling date / time	[03-Nov-2016]	[02-Nov-2016]	[01-Nov-2016]	[01-Nov-2016]	[01-Nov-2016]
Compound	CAS Number	LOR	Unit		EP1610856-031	EP1610856-032	EP1610856-033	EP1610856-034	EP1610856-035
					Result	Result	Result	Result	Result
EP080-SD / EP071-SD: Total Petroleum Hydrocarbons - Continued									
C10 - C14 Fraction	----	3	mg/kg		<3	<3	<3	<3	<3
C15 - C28 Fraction	----	3	mg/kg		**14**	**15**	<3	<3	<3
C29 - C36 Fraction	----	5	mg/kg		**7**	**12**	<5	<5	<5
^ C10 - C36 Fraction (sum)	----	3	mg/kg		**21**	**27**	<3	<3	<3
EP080-SD / EP071-SD: Total Recoverable Hydrocarbons									
C6 - C10 Fraction	C6_C10	3	mg/kg		<3	<3	<3	<3	<3
C6 - C10 Fraction minus BTEX (F1)	C6_C10-BTEX	3	mg/kg		<3.0	<3.0	<3.0	<3.0	<3.0
EP080-SD: BTEXN									
Benzene	71-43-2	0.2	mg/kg		<0.2	<0.2	<0.2	<0.2	<0.2
Toluene	108-88-3	0.2	mg/kg		<0.2	<0.2	<0.2	<0.2	<0.2
Ethylbenzene	100-41-4	0.2	mg/kg		<0.2	<0.2	<0.2	<0.2	<0.2
meta- & para-Xylene	108-38-3 106-42-3	0.2	mg/kg		<0.2	<0.2	<0.2	<0.2	<0.2
ortho-Xylene	95-47-6	0.2	mg/kg		<0.2	<0.2	<0.2	<0.2	<0.2
^ Total Xylenes	1330-20-7	0.5	mg/kg		<0.5	<0.5	<0.5	<0.5	<0.5
^ Sum of BTEX	----	0.2	mg/kg		<0.2	<0.2	<0.2	<0.2	<0.2
Naphthalene	91-20-3	0.2	mg/kg		<0.2	<0.2	<0.2	<0.2	<0.2
EP132B: Polynuclear Aromatic Hydrocarbons									
Naphthalene	91-20-3	5	µg/kg		<5	<5	**5**	<5	<5
2-Methylnaphthalene	91-57-6	5	µg/kg		<5	<5	<5	<5	<5
Acenaphthylene	208-96-8	4	µg/kg		<4	<4	<4	<4	<4
Acenaphthene	83-32-9	4	µg/kg		<4	<4	<4	<4	<4
Fluorene	86-73-7	4	µg/kg		<4	<4	<4	<4	<4
Phenanthrene	85-01-8	4	µg/kg		<4	<4	<4	<4	<4
Anthracene	120-12-7	4	µg/kg		<4	<4	<4	<4	<4
Fluoranthene	206-44-0	4	µg/kg		<4	<4	<4	<4	<4
Pyrene	129-00-0	4	µg/kg		<4	<4	<4	<4	<4
Benz(a)anthracene	56-55-3	4	µg/kg		<4	<4	<4	<4	<4
Chrysene	218-01-9	4	µg/kg		<4	<4	<4	<4	<4
Benzo(b+j)fluoranthene	205-99-2 205-82-3	4	µg/kg		<4	<4	<4	<4	<4
Benzo(k)fluoranthene	207-08-9	4	µg/kg		<4	<4	<4	<4	<4
Benzo(e)pyrene	192-97-2	4	µg/kg		<4	<4	<4	<4	<4
Benzo(a)pyrene	50-32-8	4	µg/kg		<4	<4	<4	<4	<4
Perylene	198-55-0	4	µg/kg		<4	<4	<4	<4	<4

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)				Client sample ID	CS31	CS35	CS50	CS51	CS52
				Client sampling date / time	[03-Nov-2016]	[02-Nov-2016]	[01-Nov-2016]	[01-Nov-2016]	[01-Nov-2016]
Compound	CAS Number	LOR	Unit		EP1610856-031	EP1610856-032	EP1610856-033	EP1610856-034	EP1610856-035
					Result	Result	Result	Result	Result
EP132B: Polynuclear Aromatic Hydrocarbons - Continued									
Benzo(g.h.i)perylene	191-24-2	4	µg/kg		<4	<4	<4	<4	<4
Dibenz(a.h)anthracene	53-70-3	4	µg/kg		<4	<4	<4	<4	<4
Indeno(1.2.3.cd)pyrene	193-39-5	4	µg/kg		<4	<4	<4	<4	<4
Coronene	191-07-1	5	µg/kg		<5	<5	<5	<5	<5
^ Sum of PAHs	----	4	µg/kg		<4	<4	5	<4	<4
EP080-SD: TPH(V)/BTEX Surrogates									
1.2-Dichloroethane-D4	17060-07-0	0.2	%		81.0	83.0	87.6	104	82.9
Toluene-D8	2037-26-5	0.2	%		84.8	83.0	84.7	118	85.6
4-Bromofluorobenzene	460-00-4	0.2	%		79.8	79.1	80.3	115	81.7
EP132T: Base/Neutral Extractable Surrogates									
2-Fluorobiphenyl	321-60-8	10	%		74.2	90.1	84.0	76.2	72.7
Anthracene-d10	1719-06-8	10	%		93.7	113	101	87.0	79.7
4-Terphenyl-d14	1718-51-0	10	%		110	125	104	91.0	86.1

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Client sample ID	CS53	CS60	CS62	CS64	----
			Client sampling date / time	[01-Nov-2016]	[01-Nov-2016]	[01-Nov-2016]	[01-Nov-2016]	----
Compound	CAS Number	LOR	Unit	EP1610856-036	EP1610856-037	EP1610856-038	EP1610856-039	--------
				Result	Result	Result	Result	----
EA055: Moisture Content								
Moisture Content (dried @ 103°C)	----	1	%	42.1	28.6	40.3	39.5	----
EG005-SD: Total Metals in Sediments by ICP-AES								
Aluminium	7429-90-5	50	mg/kg	3260	720	1700	1780	----
Iron	7439-89-6	50	mg/kg	5200	1780	2680	2630	----
EG020-SD: Total Metals in Sediments by ICPMS								
Arsenic	7440-38-2	1	mg/kg	3.99	1.56	1.28	1.17	----
Cadmium	7440-43-9	0.1	mg/kg	0.3	0.2	0.2	0.2	----
Chromium	7440-47-3	1	mg/kg	19.8	13.8	11.2	11.1	----
Copper	7440-50-8	1	mg/kg	5.2	1.5	2.9	3.1	----
Cobalt	7440-48-4	0.5	mg/kg	2.2	0.6	1.2	1.3	----
Lead	7439-92-1	1	mg/kg	2.9	1.2	1.6	1.6	----
Nickel	7440-02-0	1	mg/kg	9.1	2.9	5.2	5.6	----
Zinc	7440-66-6	1	mg/kg	19.6	6.0	11.6	11.7	----
EG020T: Total Metals by ICP-MS								
Barium	7440-39-3	0.1	mg/kg	47.8	9.8	11.8	12.9	----
EG035T: Total Recoverable Mercury by FIMS								
Mercury	7439-97-6	0.01	mg/kg	0.04	0.01	0.02	0.02	----
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser								
Nitrite + Nitrate as N (Sol.)	----	0.1	mg/kg	0.2	<0.1	0.2	0.4	----
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser								
Total Kjeldahl Nitrogen as N	----	20	mg/kg	720	230	420	410	----
EK062: Total Nitrogen as N (TKN + NOx)								
^ Total Nitrogen as N	----	20	mg/kg	720	230	420	410	----
EK067G: Total Phosphorus as P by Discrete Analyser								
Total Phosphorus as P	----	2	mg/kg	5360	907	1510	1630	----
EP080/071: Total Recoverable Hydrocarbons - NEPM 2013 Fractions								
>C10 - C16 Fraction	----	3	mg/kg	<3	<3	<3	<3	----
>C16 - C34 Fraction	----	3	mg/kg	<3	<3	<3	<3	----
>C34 - C40 Fraction	----	5	mg/kg	<5	<5	<5	<5	----
>C10 - C40 Fraction (sum)	----	3	mg/kg	<3	<3	<3	<3	----
>C10 - C16 Fraction minus Naphthalene (F2)	----	3	mg/kg	<3	<3	<3	<3	----
EP080-SD / EP071-SD: Total Petroleum Hydrocarbons								
C6 - C9 Fraction	----	3	mg/kg	<3	<3	<3	<3	----

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Client sample ID	CS53	CS60	CS62	CS64	----
			Client sampling date / time	[01-Nov-2016]	[01-Nov-2016]	[01-Nov-2016]	[01-Nov-2016]	----
Compound	CAS Number	LOR	Unit	EP1610856-036	EP1610856-037	EP1610856-038	EP1610856-039	--------
				Result	Result	Result	Result	----
EP080-SD / EP071-SD: Total Petroleum Hydrocarbons - Continued								
C10 - C14 Fraction	----	3	mg/kg	<3	<3	<3	<3	----
C15 - C28 Fraction	----	3	mg/kg	<3	<3	<3	<3	----
C29 - C36 Fraction	----	5	mg/kg	<5	<5	<5	<5	----
^ **C10 - C36 Fraction (sum)**	----	3	mg/kg	<3	<3	<3	<3	----
EP080-SD / EP071-SD: Total Recoverable Hydrocarbons								
C6 - C10 Fraction	C6_C10	3	mg/kg	<3	<3	<3	<3	----
C6 - C10 Fraction minus BTEX (F1)	C6_C10-BTEX	3	mg/kg	<3.0	<3.0	<3.0	<3.0	----
EP080-SD: BTEXN								
Benzene	71-43-2	0.2	mg/kg	<0.2	<0.2	<0.2	<0.2	----
Toluene	108-88-3	0.2	mg/kg	<0.2	<0.2	<0.2	<0.2	----
Ethylbenzene	100-41-4	0.2	mg/kg	<0.2	<0.2	<0.2	<0.2	----
meta- & para-Xylene	108-38-3 106-42-3	0.2	mg/kg	<0.2	<0.2	<0.2	<0.2	----
ortho-Xylene	95-47-6	0.2	mg/kg	<0.2	<0.2	<0.2	<0.2	----
^ **Total Xylenes**	1330-20-7	0.5	mg/kg	<0.5	<0.5	<0.5	<0.5	----
^ **Sum of BTEX**	----	0.2	mg/kg	<0.2	<0.2	<0.2	<0.2	----
Naphthalene	91-20-3	0.2	mg/kg	<0.2	<0.2	<0.2	<0.2	----
EP132B: Polynuclear Aromatic Hydrocarbons								
Naphthalene	91-20-3	5	µg/kg	<5	<5	<5	<5	----
2-Methylnaphthalene	91-57-6	5	µg/kg	<5	<5	<5	<5	----
Acenaphthylene	208-96-8	4	µg/kg	<4	<4	<4	<4	----
Acenaphthene	83-32-9	4	µg/kg	<4	<4	<4	<4	----
Fluorene	86-73-7	4	µg/kg	<4	<4	<4	<4	----
Phenanthrene	85-01-8	4	µg/kg	<4	<4	<4	<4	----
Anthracene	120-12-7	4	µg/kg	<4	<4	<4	<4	----
Fluoranthene	206-44-0	4	µg/kg	<4	<4	<4	<4	----
Pyrene	129-00-0	4	µg/kg	<4	<4	<4	<4	----
Benz(a)anthracene	56-55-3	4	µg/kg	<4	<4	<4	<4	----
Chrysene	218-01-9	4	µg/kg	<4	<4	<4	<4	----
Benzo(b+j)fluoranthene	205-99-2 205-82-3	4	µg/kg	<4	<4	<4	<4	----
Benzo(k)fluoranthene	207-08-9	4	µg/kg	<4	<4	<4	<4	----
Benzo(e)pyrene	192-97-2	4	µg/kg	<4	<4	<4	<4	----
Benzo(a)pyrene	50-32-8	4	µg/kg	<4	<4	<4	<4	----
Perylene	198-55-0	4	µg/kg	<4	<4	<4	<4	----

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)				Client sample ID	CS53	CS60	CS62	CS64	----
				Client sampling date / time	[01-Nov-2016]	[01-Nov-2016]	[01-Nov-2016]	[01-Nov-2016]	----
Compound	CAS Number	LOR	Unit		EP1610856-036	EP1610856-037	EP1610856-038	EP1610856-039	--------
					Result	Result	Result	Result	----
EP132B: Polynuclear Aromatic Hydrocarbons - Continued									
Benzo(g.h.i)perylene	191-24-2	4	µg/kg		<4	<4	<4	<4	----
Dibenz(a.h)anthracene	53-70-3	4	µg/kg		<4	<4	<4	<4	----
Indeno(1.2.3.cd)pyrene	193-39-5	4	µg/kg		<4	<4	<4	<4	----
Coronene	191-07-1	5	µg/kg		<5	<5	<5	<5	----
^ **Sum of PAHs**	----	4	µg/kg		<4	<4	<4	<4	----
EP080-SD: TPH(V)/BTEX Surrogates									
1.2-Dichloroethane-D4	17060-07-0	0.2	%		**89.4**	**92.7**	**88.1**	**110**	----
Toluene-D8	2037-26-5	0.2	%		**81.5**	**79.9**	**79.0**	**108**	----
4-Bromofluorobenzene	460-00-4	0.2	%		**80.1**	**87.4**	**81.9**	**117**	----
EP132T: Base/Neutral Extractable Surrogates									
2-Fluorobiphenyl	321-60-8	10	%		**100**	**101**	**107**	**115**	----
Anthracene-d10	1719-06-8	10	%		**110**	**102**	**117**	**122**	----
4-Terphenyl-d14	1718-51-0	10	%		**116**	**108**	**124**	**120**	----

Surrogate Control Limits

Sub-Matrix: **SOIL**

Compound	CAS Number	Recovery Limits (%) Low	High
EP080-SD: TPH(V)/BTEX Surrogates			
1.2-Dichloroethane-D4	17060-07-0	70	130
Toluene-D8	2037-26-5	70	130
4-Bromofluorobenzene	460-00-4	70	130
EP132T: Base/Neutral Extractable Surrogates			
2-Fluorobiphenyl	321-60-8	70	130
Anthracene-d10	1719-06-8	70	130
4-Terphenyl-d14	1718-51-0	70	130

ALS Environmental

CERTIFICATE OF ANALYSIS

Work Order	: **EP1611495**	Page	: 1 of 10
Client	: **AECOM SERVICES PTY LTD**	Laboratory	: Environmental Division Perth
Contact	: PETER YOUNG	Contact	: ShukHui Li
Address	: Supplier ID number - 1179447 LEVEL 6 3 FORREST PLACE PERTH WA, AUSTRALIA 6000	Address	: 10 Hod Way Malaga WA Australia 6090
Telephone	: +61 08 9326 0100	Telephone	: 08 9209 7655
Project	: 60495521 Shell Crux Sediment Baseline Survey	Date Samples Received	: 14-Nov-2016 10:45
Order number	: 60495521/1.4	Date Analysis Commenced	: 08-Dec-2016
C-O-C number	: ----	Issue Date	: 08-Dec-2016 11:25
Sampler	: IAN BAXTER		
Site	: ----		
Quote number	: ----		
No. of samples received	: 39		
No. of samples analysed	: 39		

Accreditation No. 825
Accredited for compliance with
ISO/IEC 17025 - Testing

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted. This document shall not be reproduced, except in full.

This Certificate of Analysis contains the following information:

- General Comments
- Analytical Results

Additional information pertinent to this report will be found in the following separate attachments: Quality Control Report, QA/QC Compliance Assessment to assist with Quality Review and Sample Receipt Notification.

Signatories

This document has been electronically signed by the authorized signatories below. Electronic signing is carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Tom Maloney	Nutrients Section Supervisor	Brisbane External Subcontracting, Stafford, QLD

General Comments

The analytical procedures used by the Environmental Division have been developed from established internationally recognized procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are employed in the absence of documented standards or by client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insufficient sample for analysis.

Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

When sampling time information is not provided by the client, sampling dates are shown without a time component. In these instances, the time component has been assumed by the laboratory for processing purposes.

Where a result is required to meet compliance limits the associated uncertainty must be considered. Refer to the ALS Contact for details.

Key : CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting
ø = ALS is not NATA accredited for these tests.
~ = Indicates an estimated value.

- Radiological work undertaken by ALS Laboratory Group (Ceska Lipa) under CAI accreditation No. L1163. Report No. $$. NATA and CAI accreditations' are both recognised under ILAC.

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)				Client sample ID	CS01	CS02	CS03	CS04	CS05
				Client sampling date / time	[30-Nov-2016]	[30-Nov-2016]	[30-Nov-2016]	[30-Nov-2016]	[30-Nov-2016]
Compound	CAS Number	LOR	Unit		EP1611495-001	EP1611495-002	EP1611495-003	EP1611495-004	EP1611495-005
					Result	Result	Result	Result	Result
Radionucleides / Activity									
Gross alpha	----	500	Bq/kg DW		<500	**1050**	<500	<500	<500
Gross beta	----	500	Bq/kg DW		<500	<500	<500	<500	<500

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)				Client sample ID	CS06	CS07	CS08	CS09	CS10
				Client sampling date / time	[30-Nov-2016]	[30-Nov-2016]	[30-Nov-2016]	[30-Nov-2016]	[30-Nov-2016]
Compound	CAS Number	LOR	Unit		EP1611495-006	EP1611495-007	EP1611495-008	EP1611495-009	EP1611495-010
					Result	Result	Result	Result	Result
Radionucleides / Activity									
Gross alpha	----	500	Bq/kg DW		<500	**590**	<500	<500	<500
Gross beta	----	500	Bq/kg DW		<500	<500	<500	<500	<500

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)				Client sample ID	CS11	CS12	CS13	CS14	CS15
				Client sampling date / time	[30-Nov-2016]	[30-Nov-2016]	[30-Nov-2016]	[30-Nov-2016]	[30-Nov-2016]
Compound	CAS Number	LOR	Unit		EP1611495-011	EP1611495-012	EP1611495-013	EP1611495-014	EP1611495-015
					Result	Result	Result	Result	Result
Radionucleides / Activity									
Gross alpha	----	500	Bq/kg DW		**650**	**560**	**650**	**1580**	**1150**
Gross beta	----	500	Bq/kg DW		<500	<500	<500	<500	<500

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)				Client sample ID	CS16	CS17	CS18	CS19	CS20
				Client sampling date / time	[30-Nov-2016]	[30-Nov-2016]	[30-Nov-2016]	[30-Nov-2016]	[30-Nov-2016]
Compound	CAS Number	LOR	Unit		EP1611495-016	EP1611495-017	EP1611495-018	EP1611495-019	EP1611495-020
					Result	Result	Result	Result	Result
Radionucleides / Activity									
Gross alpha	----	500	Bq/kg DW		**1390**	**900**	<500	<500	<500
Gross beta	----	500	Bq/kg DW		<500	<500	<500	<500	<500

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)				Client sample ID	CS21	CS22	CS23	CS24	CS25
				Client sampling date / time	[30-Nov-2016]	[30-Nov-2016]	[30-Nov-2016]	[30-Nov-2016]	[30-Nov-2016]
Compound	CAS Number	LOR	Unit		EP1611495-021	EP1611495-022	EP1611495-023	EP1611495-024	EP1611495-025
					Result	Result	Result	Result	Result
Radionucleides / Activity									
Gross alpha	----	500	Bq/kg DW		**780**	**590**	**780**	**750**	**1860**
Gross beta	----	500	Bq/kg DW		<500	<500	<500	<500	**640**

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)				Client sample ID	CS26	CS27	CS28	CS29	CS30
				Client sampling date / time	[30-Nov-2016]	[30-Nov-2016]	[30-Nov-2016]	[30-Nov-2016]	[30-Nov-2016]
Compound	CAS Number	LOR	Unit		EP1611495-026	EP1611495-027	EP1611495-028	EP1611495-029	EP1611495-030
					Result	Result	Result	Result	Result
Radionucleides / Activity									
Gross alpha	----	500	Bq/kg DW		**590**	<500	<500	**840**	**720**
Gross beta	----	500	Bq/kg DW		<500	<500	<500	<500	<500

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)				Client sample ID	CS31	CS35	CS50	CS51	CS52
				Client sampling date / time	[30-Nov-2016]	[30-Nov-2016]	[30-Nov-2016]	[30-Nov-2016]	[30-Nov-2016]
Compound	CAS Number	LOR	Unit		EP1611495-031	EP1611495-032	EP1611495-033	EP1611495-034	EP1611495-035
					Result	Result	Result	Result	Result
Radionucleides / Activity									
Gross alpha	----	500	Bq/kg DW		**840**	<500	**640**	**840**	<500
Gross beta	----	500	Bq/kg DW		<500	<500	<500	<500	<500

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)				Client sample ID	CS53	CS60	CS62	CS64	----
				Client sampling date / time	[30-Nov-2016]	[30-Nov-2016]	[30-Nov-2016]	[30-Nov-2016]	----
Compound	CAS Number	LOR	Unit		EP1611495-036	EP1611495-037	EP1611495-038	EP1611495-039	--------
					Result	Result	Result	Result	----
Radionucleides / Activity									
Gross alpha	----	500	Bq/kg DW		<500	<500	<500	<500	----
Gross beta	----	500	Bq/kg DW		<500	<500	<500	<500	----

ALS Water

NATA Accredited Laboratory No. 992
Accredited for compliance with ISO/IEC 17025 - Testing

CERTIFICATE OF ANALYSIS

Batch No:	**16-51949**	*Page*	Page 1 of 6
Final Report	592785	*Laboratory*	Scoresby Laboratory
		Address	Caribbean Business Park, 22 Dalmore Drive, Scoresby, VIC 3179
Client:	**Australian Laboratory Services Pty Ltd**	*Phone*	03 8756 8000
		Fax	03 9763 1862
Contact:	**Jeremy Truong**	Contact:	Ximena Iglesias Client Manager Ximena.Iglesias@alsglobal.com
Address:	10 Hod Way MALAGA WA 6090		
Client Program Ref:	**EP1610856**	Date Sampled:	31-Oct-2016
ALS Program Ref:	**ALSWA**	Date Samples Received:	15-Nov-2016
PO No:	**461156**	*Date Issued:*	**23-Nov-2016**

The sample(s) referred to in this report were analysed by the following method(s) under NATA Accreditation No. 992.
The hash (#) below indicates methods not covered by NATA accreditation in the performance of this service .

Analysis	*Method*	*Laboratory*	*Analysis*	*Method*	*Laboratory*	*Analysis*	*Method*	*Laboratory*
Oil & Grease (Soil)	# EP020SC	Scoresby						

Where a result is required to meet compliance limits the associated uncertainty must be considered. Refer to the ALS Contact for details.

Signatories
These results have been electronically signed by the authorised signatories indicated below. Electronic signing has been carried out in compliance with procedures specified in 21 CFR Part 11

Name	*Title*	*Name*	*Title*
Joseph De Alwis	**Analyst**		

LOR = Limit of reporting. When a reported LOR is higher than the standard LOR, this may be due to high moisture content, insufficient sample or matrix interference.
CAS Number = Chemistry Abstract Services Number. The analytical procedures in this report (including in house methods) are developed from internationally recognised procedures such as those published by USEPA, APHA and NEPM.

				Sample No.	4990866	4990867	4990868	4990869	4990870	4990871
				Client Sample ID	001	002	003	004	005	006
				Sample Date	31/10/16	31/10/16	31/10/16	31/10/16	31/10/16	31/10/16
				Sample Type	SOIL	SOIL	SOIL	SOIL	SOIL	SOIL
Analysis	**Analyte**	**CAS #**	**LOR**							
Oil & Grease (Soil)	Oil and Grease	Oil_Grease	<100	mg/kg	1700	860	670	1200	910	990

LOR = Limit of reporting. When a reported LOR is higher than the standard LOR, this may be due to high moisture content, insufficient sample or matrix interference.
CAS Number = Chemistry Abstract Services Number. The analytical procedures in this report (including in house methods) are developed from internationally recognised procedures such as those published by USEPA, APHA and NEPM.

				Sample No.	4990872	4990873	4990874	4990875	4990876	4990877
				Client Sample ID	007	008	009	010	011	012
				Sample Date	31/10/16	31/10/16	31/10/16	31/10/16	31/10/16	31/10/16
				Sample Type	SOIL	SOIL	SOIL	SOIL	SOIL	SOIL
Analysis	**Analyte**	**CAS #**	**LOR**							
Oil & Grease (Soil)	Oil and Grease	Oil_Grease	<100	mg/kg	1500	1800	1000	1000	1300	1900

Samples not collected by ALS and are tested as received.

A blank space indicates no test performed. Soil results expressed in mg/kg dry weight unless specified otherwise. Microbiological testing was commenced on the day of receival and within 24 hours of sampling unless otherwise stated. MM524: Plate count results <10 per mL and >300 per mL are deemed as approximate. MM526: Plate count results <2,500 per mL and >250,000 per mL are deemed as approximate. Calculated results are based on raw data.

Batch No: 16-51949
Report Number: 592785
Client: Australian Laboratory Services Pty Ltd
Client Program Ref: EP1610856

LOR = Limit of reporting. When a reported LOR is higher than the standard LOR, this may be due to high moisture content, insufficient sample or matrix interference.
CAS Number = Chemistry Abstract Services Number. The analytical procedures in this report (including in house methods) are developed from internationally recognised procedures such as those published by USEPA, APHA and NEPM.

				Sample No.	4990878	4990879	4990880	4990881	4990882	4990883
				Client Sample ID	013	014	015	016	017	018
				Sample Date	31/10/16	31/10/16	31/10/16	31/10/16	31/10/16	31/10/16
				Sample Type	SOIL	SOIL	SOIL	SOIL	SOIL	SOIL
Analysis	**Analyte**	**CAS #**	**LOR**							
Oil & Grease (Soil)	Oil and Grease	Oil_Grease	<100	mg/kg	2200	1900	1100	1300	700	510

LOR = Limit of reporting. When a reported LOR is higher than the standard LOR, this may be due to high moisture content, insufficient sample or matrix interference.
CAS Number = Chemistry Abstract Services Number. The analytical procedures in this report (including in house methods) are developed from internationally recognised procedures such as those published by USEPA, APHA and NEPM.

				Sample No.	4990884	4990885	4990886	4990887	4990888	4990889
				Client Sample ID	019	020	021	022	023	024
				Sample Date	31/10/16	31/10/16	31/10/16	31/10/16	31/10/16	31/10/16
				Sample Type	SOIL	SOIL	SOIL	SOIL	SOIL	SOIL
Analysis	**Analyte**	**CAS #**	**LOR**							
Oil & Grease (Soil)	Oil and Grease	Oil_Grease	<100	mg/kg	2200	930	930	850	1300	1800

Samples not collected by ALS and are tested as received.

A blank space indicates no test performed. Soil results expressed in mg/kg dry weight unless specified otherwise. Microbiological testing was commenced on the day of receival and within 24 hours of sampling unless otherwise stated. MM524: Plate count results <10 per mL and >300 per mL are deemed as approximate. MM526: Plate count results <2,500 per mL and >250,000 per mL are deemed as approximate. Calculated results are based on raw data.

LOR = Limit of reporting. When a reported LOR is higher than the standard LOR, this may be due to high moisture content, insufficient sample or matrix interference.
CAS Number = Chemistry Abstract Services Number. The analytical procedures in this report (including in house methods) are developed from internationally recognised procedures such as those published by USEPA, APHA and NEPM.

				Sample No.	4990890	4990891	4990892	4990893	4990894	4990895
				Client Sample ID	025	026	027	028	029	030
				Sample Date	31/10/16	31/10/16	31/10/16	31/10/16	31/10/16	31/10/16
				Sample Type	SOIL	SOIL	SOIL	SOIL	SOIL	SOIL
Analysis	**Analyte**	**CAS #**	**LOR**							
Oil & Grease (Soil)	Oil and Grease	Oil_Grease	<100	mg/kg	610	760	980	580	680	1000

LOR = Limit of reporting. When a reported LOR is higher than the standard LOR, this may be due to high moisture content, insufficient sample or matrix interference.
CAS Number = Chemistry Abstract Services Number. The analytical procedures in this report (including in house methods) are developed from internationally recognised procedures such as those published by USEPA, APHA and NEPM.

				Sample No.	4990896	4990897	4990898	4990899	4990900	4990901
				Client Sample ID	031	032	033	034	035	036
				Sample Date	31/10/16	31/10/16	31/10/16	31/10/16	31/10/16	31/10/16
				Sample Type	SOIL	SOIL	SOIL	SOIL	SOIL	SOIL
Analysis	**Analyte**	**CAS #**	**LOR**							
Oil & Grease (Soil)	Oil and Grease	Oil_Grease	<100	mg/kg	1100	920	960	1000	960	1200

Samples not collected by ALS and are tested as received.

A blank space indicates no test performed. Soil results expressed in mg/kg dry weight unless specified otherwise. Microbiological testing was commenced on the day of receival and within 24 hours of sampling unless otherwise stated. MM524: Plate count results <10 per mL and >300 per mL are deemed as approximate. MM526: Plate count results <2,500 per mL and >250,000 per mL are deemed as approximate. Calculated results are based on raw data.

LOR = Limit of reporting. When a reported LOR is higher than the standard LOR, this may be due to high moisture content, insufficient sample or matrix interference.
CAS Number = Chemistry Abstract Services Number. The analytical procedures in this report (including in house methods) are developed from internationally recognised procedures such as those published by USEPA, APHA and NEPM.

				Sample No.	4990902	4990903	4990904
				Client Sample ID	037	038	039
				Sample Date	31/10/16	31/10/16	31/10/16
				Sample Type	SOIL	SOIL	SOIL
Analysis	**Analyte**	**CAS #**	**LOR**				
Oil & Grease (Soil)	Oil and Grease	Oil_Grease	<100	mg/kg	870	1300	1100

Samples not collected by ALS and are tested as received.

A blank space indicates no test performed. Soil results expressed in mg/kg dry weight unless specified otherwise. Microbiological testing was commenced on the day of receival and within 24 hours of sampling unless otherwise stated. MM524: Plate count results <10 per mL and >300 per mL are deemed as approximate. MM526: Plate count results <2,500 per mL and >250,000 per mL are deemed as approximate. Calculated results are based on raw data.

QUALITY CONTROL - BLANKS

QC Blanks are an 'analyte free' matrix in which all applicable reagents have been added in the same proportion as in standard samples and are an internal monitor for laboratory contamination.

					Value
Lab Sample ID	**Client Sample ID**	**Analysis**	**Analyte**		
4999019	QC - Blank	Oil & Grease (Soil)	Oil and Grease	mg/kg	<100

QUALITY CONTROL - DUPLICATES

QC Data for duplicates is calculated on raw 'unrounded' values. Laboratory duplicates are randomly selected samples tested by the laboratory to maintain method precision and provide information on sample homogeniety.
RPD = Relative Percentage Difference for duplicate determinations. RPD's that fall outside the general acceptance criteria will be attributed to non-homogeneity of samples or results of low magnitudes.

					Sample Value	Duplicate Value	% RPD
Lab Sample ID	**Client Sample ID**	**Analysis**	**Analyte**				
4999022	003	Oil & Grease (Soil)	Oil and Grease	mg/kg	670	640	4.8

Samples not collected by ALS and are tested as received.

A blank space indicates no test performed. Soil results expressed in mg/kg dry weight unless specified otherwise. Microbiological testing was commenced on the day of receival and within 24 hours of sampling unless otherwise stated. MM524: Plate count results <10 per mL and >300 per mL are deemed as approximate. MM526: Plate count results <2,500 per mL and >250,000 per mL are deemed as approximate. Calculated results are based on raw data.

ARL GROUP

LABORATORY REPORT

Job Number: 16-08651
Revision: 02
Date: 24 April 2017

ADDRESS: **AECOM Services Pty Ltd**
GPO Box B59
Perth WA 6849

ATTENTION: Peter Young

DATE RECEIVED: 5/11/2016

YOUR REFERENCE: N/A

PURCHASE ORDER:

APPROVALS:

Douglas Todd	Fiona Reid	Min How	Paul Nottle	Sam Becker
Laboratory Manager	Inorganics Supervisor	Chemist - Organics	Organics Manager	Inorganics Manager

REPORT COMMENTS:

This report is issued by Analytical Reference Laboratory (WA) Pty Ltd
Samples are analysed on an as received basis unless otherwise noted.
Gross Alpha and Beta analysis subcontracted to SGS, NATA Accred No. 2562, Report Number 9893

METHOD REFERENCES:

Methods prefixed with "ARL" are covered under NATA Accreditation Number: 2377
Methods prefixed with "PM" are covered under NATA Accreditation Number: 2561

ARL No. 192	Total Recoverable Hydrocarbons (C_6-C_{10}) in Soil
ARL No. 193	Total Recoverable Hydrocarbons (>C_{10}-C_{40}) in Soil
ARL No. 058	Oil and Grease in Soil by Gravimetric Analysis
ARL No. 401/403	Metals in Soil and Sediment by ICPOES/MS
ARL No. 406	Mercury by Cold Vapour Atomic Absorption Spectrophotometry
ARL No. 118	Total Phosphorus and TKN in Soil and Biosolids
ARL No. 314	NOx in Soil and Sediment by Discrete Analyser
ARL No. 009	Total Petroleum Hydrocarbons (TPH) in Water
ARL No. 007	Benzene, Toluene, Ethylbenzene and Xylenes in Water
ARL No. 331	Persulphate Method Determination of Low Level Total Nitrogen
ARL No. 049	Low Level Total and Filtered Reactive Phosphorus In Water
ARL No. 033	NOx in Water
ARL No. 29/402/403	Metals in Water by AAS/ICPOES/ICPMS
Subcontracting	See Report Comments section for more information.

NATA
WORLD RECOGNISED ACCREDITATION
Accredited for compliance with ISO/IEC 17025 - Testing

LABORATORY REPORT

AECOM Services Pty Ltd

ARL Job No: 16-08651 *Revision: 02* *Date:* 24 April 2017

TRH (C_6-C_{40}) in Soil Sample No: Sample Description: Sample Date:	**LOR**	**UNITS**	**16-08651-14 CS61 1/11/16**	**16-08651-15 CS65 2/11/16**
$TRHC_{6-10}$	0.2	mg/kg	<0.2	<0.2
$TRHC_{>10-16}$	0.2	mg/kg	<0.2	<0.2
$TRHC_{>16-34}$	0.4	mg/kg	<0.4	<0.4
$TRHC_{>34-40}$	0.4	mg/kg	<0.4	<0.4
$TRHC_{>10-40}$ (sum)	1.2	mg/kg	<1.2	<1.2

Oil & Grease in Soil Sample No: Sample Description: Sample Date:	**LOR**	**UNITS**	**16-08651-14 CS61 1/11/16**	**16-08651-15 CS65 2/11/16**
Oil and Grease	500	mg/kg	<500	<500

8 Heavy Metals in Soil Sample No: Sample Description: Sample Date:	**LOR**	**UNITS**	**16-08651-14 CS61 1/11/16**	**16-08651-15 CS65 2/11/16**
Arsenic	5	mg/kg	<5	<5
Cadmium	0.1	mg/kg	0.3	0.4
Chromium	1	mg/kg	12	15
Copper	1	mg/kg	4	7
Mercury	0.02	mg/kg	<0.02	0.02
Nickel	1	mg/kg	3	7
Lead	1	mg/kg	1	2
Zinc	1	mg/kg	6	15

Metals in Soil and Sediment Sample No: Sample Description: Sample Date:	**LOR**	**UNITS**	**16-08651-14 CS61 1/11/16**	**16-08651-15 CS65 2/11/16**
Aluminium	1	mg/kg	820	2,500
Barium	1	mg/kg	7	10
Cobalt	1	mg/kg	<1	2
Iron	1	mg/kg	2,500	4,400

Nutrients in Soil Sample No: Sample Description: Sample Date:	**LOR**	**UNITS**	**16-08651-14 CS61 1/11/16**	**16-08651-15 CS65 2/11/16**
Total Nitrogen	10	mg/kg	200	270
NOx-N	1	mg/kg	<1	<1
Total Phosphorus	1	mg/kg	1,700	3,000

DRAFT

Appendix C

Laboratory report - Particle Size Distribution

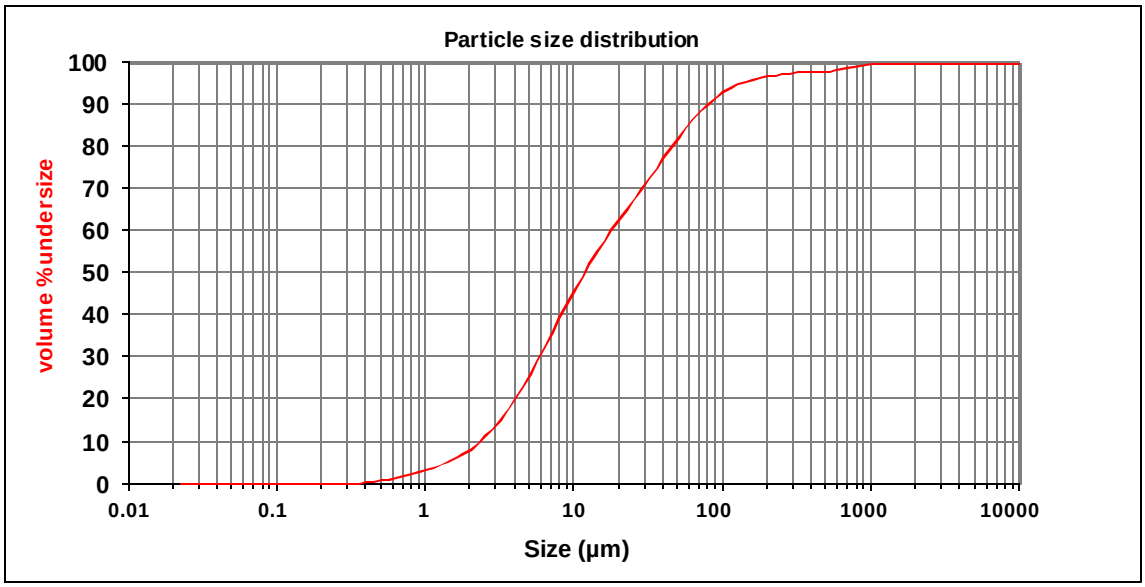
Revision A – 27-Apr-2017
Prepared for – Shell Australia Pty Ltd – ABN: 14009663576

37 Kensington Street
East Perth
WA 6004

Client:	AECOM Australia Pty Ltd
Sample Name :	CS01P
Batch No :	16_1453
Lab ID No :	16_1453_01

Analysis :	Size distribution by laser diffraction following ISO13320-1:2009 and wet sieving	**Result units:**	Volume
Dispersant:	Water	**Analysis model:**	General purpose
Additives:	10 millilitres sodium hexametaphosphate	**Total sample wt (g):**	10.5065
Sonication:	5 min sonication		

Span:	6.50	**Vol. Weighted mean D[4,3]:**	43.21 µm	**d(0.1)**	2.30 µm
		Surface weighted mean D[3,2]	5.19 µm	**d(0.5)**	11.62 µm
				d(0.9)	77.81 µm



Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %
0.020	0.00	0.142	0.00	1.002	3.34	7.096	36.02	50.238	82.20	355.66	97.82
0.022	0.00	0.159	0.00	1.125	3.91	7.962	39.42	56.368	84.50	399.05	97.84
0.025	0.00	0.178	0.00	1.262	4.55	8.934	42.77	63.246	86.66	447.74	97.84
0.028	0.00	0.200	0.00	1.416	5.28	10.024	46.04	70.963	88.62	500.00	97.84
0.032	0.00	0.224	0.00	1.589	6.12	11.247	49.19	79.621	90.37	1000.00	99.72
0.036	0.00	0.252	0.00	1.783	7.12	12.619	52.19	89.337	91.87	2000.00	100.00
0.040	0.00	0.283	0.00	2.000	8.30	14.159	55.04	100.237	93.13	10000.00	100.00
0.045	0.00	0.317	0.02	2.244	9.68	15.887	57.74	112.468	94.16		
0.050	0.00	0.356	0.13	2.518	11.29	17.825	60.31	126.191	94.98		
0.056	0.00	0.399	0.31	2.825	13.14	20.000	62.79	141.589	95.63		
0.063	0.00	0.448	0.54	3.170	15.25	22.440	65.20	158.866	96.15		
0.071	0.00	0.502	0.82	3.557	17.62	25.179	67.59	178.250	96.56		
0.080	0.00	0.564	1.15	3.991	20.23	28.251	69.99	200.000	96.89		
0.089	0.00	0.632	1.51	4.477	23.08	31.698	72.41	224.404	97.17		
0.100	0.00	0.710	1.92	5.024	26.12	35.566	74.87	251.785	97.41		
0.112	0.00	0.796	2.36	5.637	29.32	39.905	77.34	282.508	97.59		
0.126	0.00	0.893	2.83	6.325	32.64	44.774	79.79	316.979	97.74		

Note: Data from 500µm to 10000µm by wet screening, from 0.02µm to 500µm by laser diffraction.

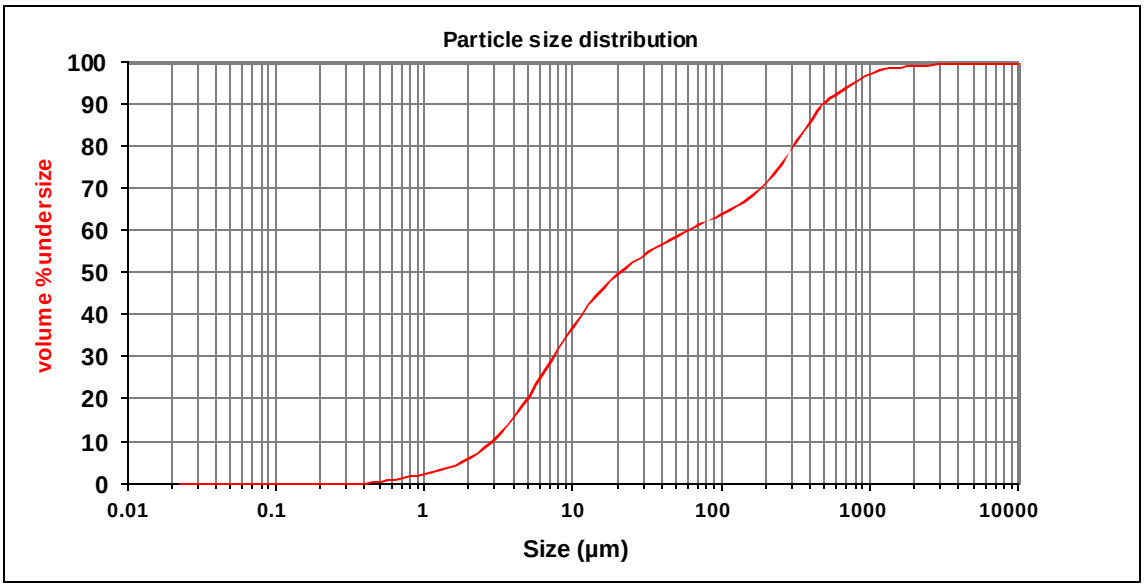
Analysed: Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)
Reported: Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)
Approved: Michael Simeoni, B.Sc.(Chemistry), M.Sc. (Science Administration), Ph.D.

37 Kensington Street
East Perth
WA 6004

Client:	AECOM Australia Pty Ltd
Sample Name :	CS02P
Batch No :	16_1453
Lab ID No :	16_1453_02

Analysis :	Size distribution by laser diffraction following ISO13320-1:2009 and wet sieving	**Result units:**	Volume
Dispersant:	Water	**Analysis model:**	General purpose
Additives:	10 millilitres sodium hexametaphosphate	**Total sample wt (g):**	13.9796
Sonication:	2 min sonication		

Span:	23.63	**Vol. Weighted mean D[4,3]:**	189.17 µm	**d(0.1)**	2.81 µm
		Surface weighted mean D[3,2]	6.65 µm	**d(0.5)**	20.03 µm
				d(0.9)	476.17 µm



Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %
0.020	0.00	0.142	0.00	1.002	2.51	7.096	29.36	50.238	59.04	355.66	83.94
0.022	0.00	0.159	0.00	1.125	2.91	7.962	32.20	56.368	59.97	399.05	86.53
0.025	0.00	0.178	0.00	1.262	3.36	8.934	34.98	63.246	60.86	447.74	88.90
0.028	0.00	0.200	0.00	1.416	3.88	10.024	37.66	70.963	61.71	500.00	90.92
0.032	0.00	0.224	0.00	1.589	4.51	11.247	40.19	79.621	62.52	1000.00	97.43
0.036	0.00	0.252	0.00	1.783	5.26	12.619	42.54	89.337	63.31	2000.00	99.27
0.040	0.00	0.283	0.00	2.000	6.17	14.159	44.69	100.237	64.11	10000.00	100.00
0.045	0.00	0.317	0.02	2.244	7.26	15.887	46.65	112.468	64.95		
0.050	0.00	0.356	0.11	2.518	8.55	17.825	48.41	126.191	65.89		
0.056	0.00	0.399	0.26	2.825	10.07	20.000	49.98	141.589	66.97		
0.063	0.00	0.448	0.45	3.170	11.82	22.440	51.40	158.866	68.27		
0.071	0.00	0.502	0.67	3.557	13.80	25.179	52.69	178.250	69.81		
0.080	0.00	0.564	0.92	3.991	16.00	28.251	53.88	200.000	71.62		
0.089	0.00	0.632	1.20	4.477	18.41	31.698	55.00	224.404	73.71		
0.100	0.00	0.710	1.50	5.024	20.99	35.566	56.06	251.785	76.04		
0.112	0.00	0.796	1.81	5.637	23.70	39.905	57.08	282.508	78.59		
0.126	0.00	0.893	2.15	6.325	26.51	44.774	58.08	316.979	81.25		

Note: Data from 500µm to 10000µm by wet screening, from 0.02µm to 500µm by laser diffraction.

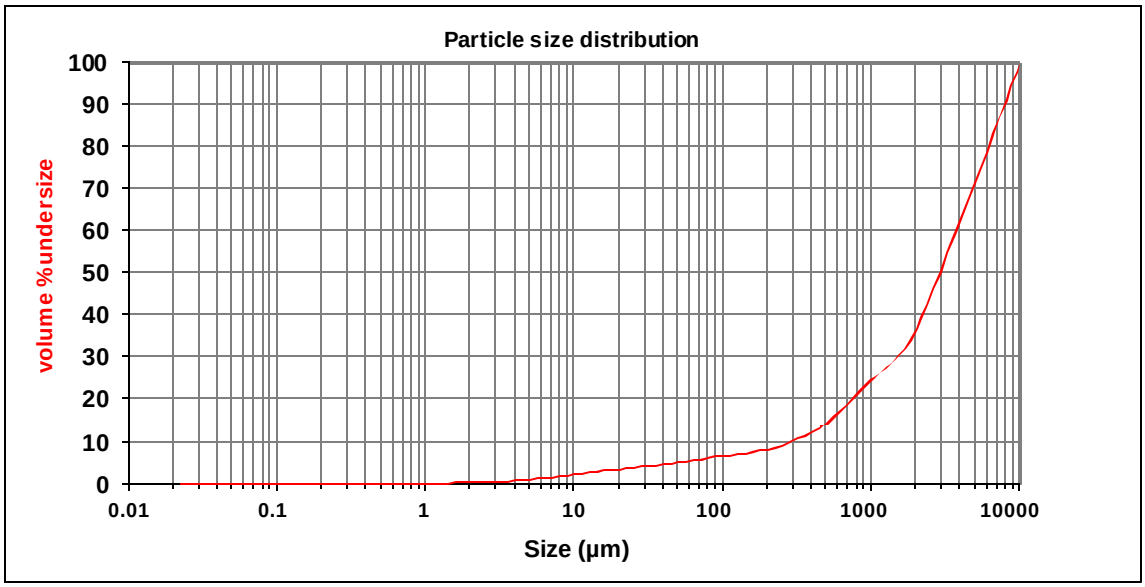
Analysed: Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)
Reported: Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)
Approved: Michael Simeoni, B.Sc.(Chemistry), M.Sc. (Science Administration), Ph.D.

37 Kensington Street
East Perth
WA 6004

Client:	AECOM Australia Pty Ltd
Sample Name :	CS03P
Batch No :	16_1453
Lab ID No :	16_1453_03

Analysis :	Size distribution by laser diffraction following ISO13320-1:2009 and wet sieving	**Result units:**	Volume
Dispersant:	Water	**Analysis model:**	General purpose
Additives:	10 millilitres sodium hexametaphosphate	**Total sample wt (g):**	20.9918
Sonication:	3 min sonication		

Span:	2.30	**Vol. Weighted mean D[4,3]:**	3098.10 µm	**d(0.1)**	294.19 µm
		Surface weighted mean D[3,2]	98.46 µm	**d(0.5)**	3677.69 µm
				d(0.9)	8735.54 µm



Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %
0.020	0.00	0.142	0.00	1.002	0.16	7.096	1.62	50.238	5.14	355.66	11.63
0.022	0.00	0.159	0.00	1.125	0.19	7.962	1.82	56.368	5.39	399.05	12.57
0.025	0.00	0.178	0.00	1.262	0.22	8.934	2.03	63.246	5.66	447.74	13.52
0.028	0.00	0.200	0.00	1.416	0.25	10.024	2.24	70.963	5.92	500.00	14.43
0.032	0.00	0.224	0.00	1.589	0.28	11.247	2.47	79.621	6.19	1000.00	24.66
0.036	0.00	0.252	0.00	1.783	0.32	12.619	2.69	89.337	6.44	2000.00	36.73
0.040	0.00	0.283	0.00	2.000	0.37	14.159	2.91	100.237	6.68	10000.00	100.00
0.045	0.00	0.317	0.00	2.244	0.42	15.887	3.12	112.468	6.91		
0.050	0.00	0.356	0.00	2.518	0.49	17.825	3.32	126.191	7.13		
0.056	0.00	0.399	0.01	2.825	0.56	20.000	3.52	141.589	7.35		
0.063	0.00	0.448	0.02	3.170	0.64	22.440	3.71	158.866	7.60		
0.071	0.00	0.502	0.03	3.557	0.73	25.179	3.90	178.250	7.89		
0.080	0.00	0.564	0.05	3.991	0.84	28.251	4.09	200.000	8.25		
0.089	0.00	0.632	0.07	4.477	0.97	31.698	4.28	224.404	8.70		
0.100	0.00	0.710	0.09	5.024	1.11	35.566	4.47	251.785	9.27		
0.112	0.00	0.796	0.11	5.637	1.26	39.905	4.68	282.508	9.95		
0.126	0.00	0.893	0.14	6.325	1.43	44.774	4.90	316.979	10.74		

Note: Data from 500µm to 10000µm by wet screening, from 0.02µm to 500µm by laser diffraction.

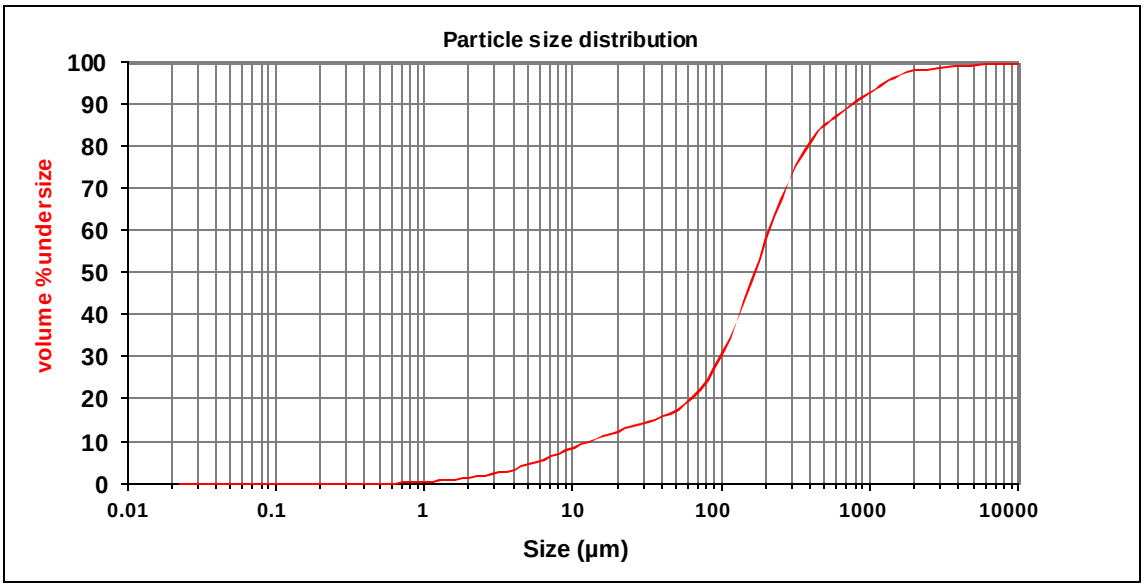
Analysed:	Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)
Reported:	Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)
Approved:	Michael Simeoni, B.Sc.(Chemistry), M.Sc. (Science Administration), Ph.D.

37 Kensington Street
East Perth
WA 6004

Client:	AECOM Australia Pty Ltd
Sample Name :	CS04P
Batch No :	16_1453
Lab ID No :	16_1453_04

Analysis :	Size distribution by laser diffraction following ISO13320-1:2009 and wet sieving	**Result units:**	Volume
Dispersant:	Water	**Analysis model:**	General purpose
Additives:	10 millilitres sodium hexametaphosphate	**Total sample wt (g):**	23.0153
Sonication:	2 min sonication		

Span:	4.75	**Vol. Weighted mean D[4,3]:**	343.37 µm	**d(0.1)**	12.50 µm
		Surface weighted mean D[3,2]	25.15 µm	**d(0.5)**	165.01 µm
				d(0.9)	797.09 µm



Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %
0.020	0.00	0.142	0.00	1.002	0.61	7.096	6.59	50.238	17.77	355.66	78.99
0.022	0.00	0.159	0.00	1.125	0.71	7.962	7.28	56.368	18.97	399.05	81.68
0.025	0.00	0.178	0.00	1.262	0.83	8.934	7.99	63.246	20.47	447.74	83.85
0.028	0.00	0.200	0.00	1.416	0.95	10.024	8.69	70.963	22.35	500.00	85.51
0.032	0.00	0.224	0.00	1.589	1.10	11.247	9.38	79.621	24.67	1000.00	93.07
0.036	0.00	0.252	0.00	1.783	1.27	12.619	10.06	89.337	27.48	2000.00	98.13
0.040	0.00	0.283	0.00	2.000	1.46	14.159	10.72	100.237	30.80	10000.00	100.00
0.045	0.00	0.317	0.00	2.244	1.69	15.887	11.36	112.468	34.61		
0.050	0.00	0.356	0.00	2.518	1.96	17.825	11.97	126.191	38.87		
0.056	0.00	0.399	0.00	2.825	2.28	20.000	12.56	141.589	43.51		
0.063	0.00	0.448	0.03	3.170	2.65	22.440	13.13	158.866	48.41		
0.071	0.00	0.502	0.09	3.557	3.07	25.179	13.68	178.250	53.44		
0.080	0.00	0.564	0.16	3.991	3.54	28.251	14.23	200.000	58.46		
0.089	0.00	0.632	0.24	4.477	4.07	31.698	14.79	224.404	63.32		
0.100	0.00	0.710	0.32	5.024	4.64	35.566	15.38	251.785	67.90		
0.112	0.00	0.796	0.41	5.637	5.26	39.905	16.04	282.508	72.07		
0.126	0.00	0.893	0.51	6.325	5.91	44.774	16.82	316.979	75.79		

Note: Data from 500µm to 10000µm by wet screening, from 0.02µm to 500µm by laser diffraction.

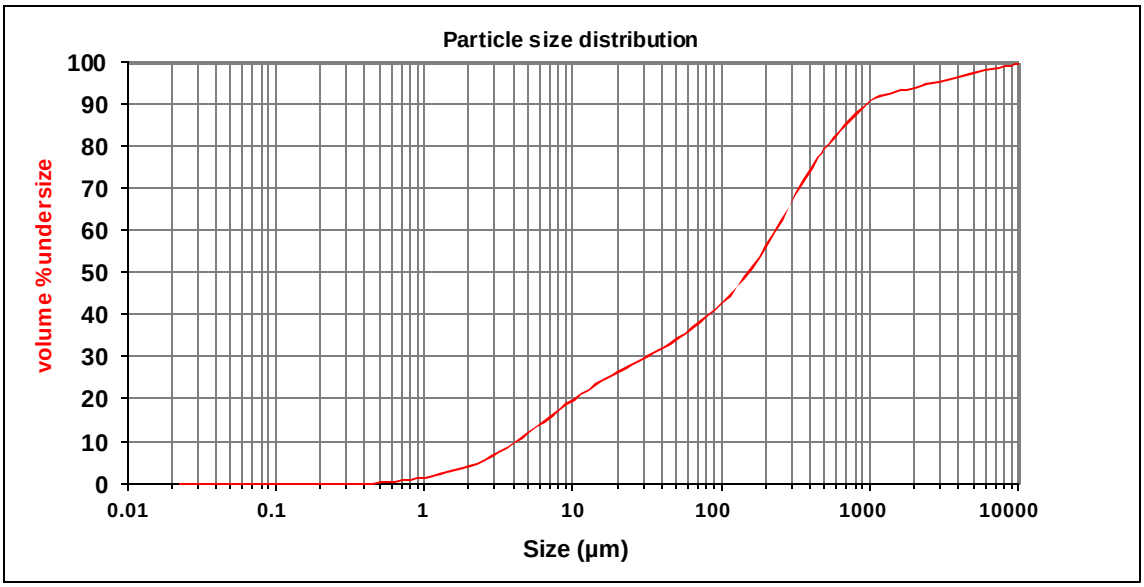
Analysed: Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)
Reported: Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)
Approved: Michael Simeoni, B.Sc.(Chemistry), M.Sc. (Science Administration), Ph.D.

37 Kensington Street
East Perth
WA 6004

Client:	AECOM Australia Pty Ltd
Sample Name :	CS05P
Batch No :	16_1453
Lab ID No :	16_1453_05

Analysis :	Size distribution by laser diffraction following ISO13320-1:2009 and wet sieving	**Result units:**	Volume
Dispersant:	Water	**Analysis model:**	General purpose
Additives:	10 millilitres sodium hexametaphosphate	**Total sample wt (g):**	17.6167
Sonication:	5 min sonication		

Span:	6.38	**Vol. Weighted mean D[4,3]:**	487.76 µm	**d(0.1)**	4.09 µm
		Surface weighted mean D[3,2]	10.93 µm	**d(0.5)**	149.32 µm
				d(0.9)	956.16 µm



Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %
0.020	0.00	0.142	0.00	1.002	1.68	7.096	16.26	50.238	34.53	355.66	72.16
0.022	0.00	0.159	0.00	1.125	1.98	7.962	17.59	56.368	35.72	399.05	75.09
0.025	0.00	0.178	0.00	1.262	2.32	8.934	18.88	63.246	36.98	447.74	77.75
0.028	0.00	0.200	0.00	1.416	2.71	10.024	20.14	70.963	38.33	500.00	80.04
0.032	0.00	0.224	0.00	1.589	3.15	11.247	21.34	79.621	39.77	1000.00	90.96
0.036	0.00	0.252	0.00	1.783	3.66	12.619	22.49	89.337	41.31	2000.00	94.23
0.040	0.00	0.283	0.00	2.000	4.25	14.159	23.58	100.237	42.98	10000.00	100.00
0.045	0.00	0.317	0.01	2.244	4.93	15.887	24.62	112.468	44.80		
0.050	0.00	0.356	0.06	2.518	5.71	17.825	25.61	126.191	46.78		
0.056	0.00	0.399	0.14	2.825	6.58	20.000	26.57	141.589	48.94		
0.063	0.00	0.448	0.25	3.170	7.55	22.440	27.51	158.866	51.31		
0.071	0.00	0.502	0.38	3.557	8.61	25.179	28.44	178.250	53.88		
0.080	0.00	0.564	0.54	3.991	9.76	28.251	29.37	200.000	56.65		
0.089	0.00	0.632	0.73	4.477	10.98	31.698	30.32	224.404	59.60		
0.100	0.00	0.710	0.93	5.024	12.26	35.566	31.31	251.785	62.69		
0.112	0.00	0.796	1.16	5.637	13.58	39.905	32.33	282.508	65.87		
0.126	0.00	0.893	1.41	6.325	14.92	44.774	33.40	316.979	69.05		

Note: Data from 500µm to 10000µm by wet screening, from 0.02µm to 500µm by laser diffraction.

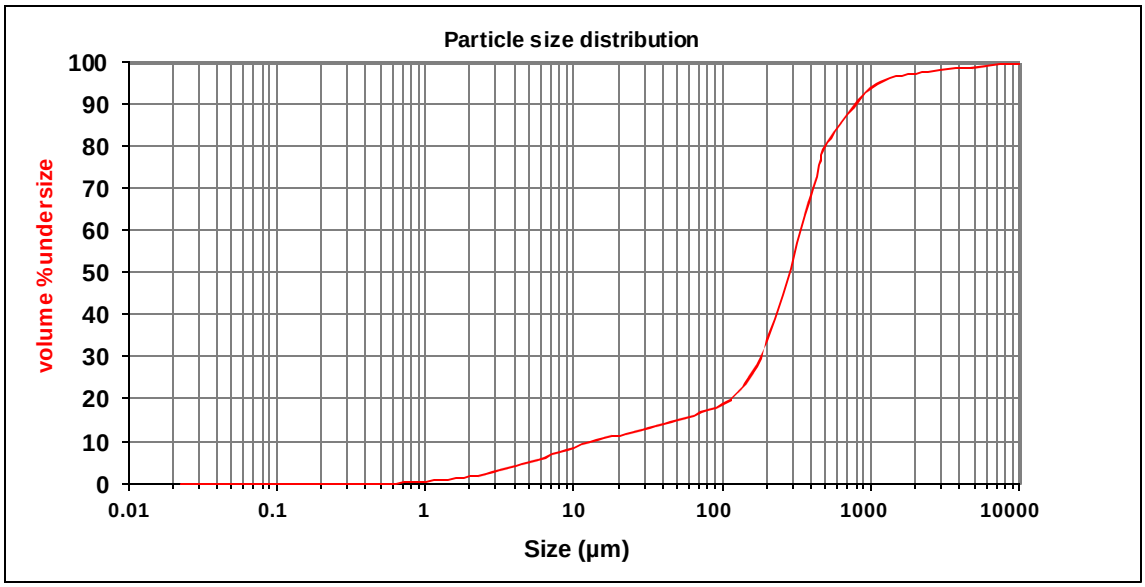
Analysed: Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)
Reported: Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)
Approved: Michael Simeoni, B.Sc.(Chemistry), M.Sc. (Science Administration), Ph.D.

37 Kensington Street
East Perth
WA 6004

Client:	AECOM Australia Pty Ltd
Sample Name :	CS06P
Batch No :	16_1453
Lab ID No :	16_1453_06

Analysis :	Size distribution by laser diffraction following ISO13320-1:2009 and wet sieving	**Result units:**	Volume
Dispersant:	Water	**Analysis model:**	General purpose
Additives:	10 millilitres sodium hexametaphosphate	**Total sample wt (g):**	11.8215
Sonication:	4 min sonication		

Span:	3.00	**Vol. Weighted mean D[4,3]:**	432.66 µm	**d(0.1)**	13.17 µm
		Surface weighted mean D[3,2]	24.68 µm	**d(0.5)**	277.84 µm
				d(0.9)	845.37 µm



Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %
0.020	0.00	0.142	0.00	1.002	0.72	7.096	6.96	50.238	15.36	355.66	63.86
0.022	0.00	0.159	0.00	1.125	0.86	7.962	7.57	56.368	15.87	399.05	70.12
0.025	0.00	0.178	0.00	1.262	1.01	8.934	8.16	63.246	16.39	447.74	75.89
0.028	0.00	0.200	0.00	1.416	1.19	10.024	8.74	70.963	16.91	500.00	80.95
0.032	0.00	0.224	0.00	1.589	1.38	11.247	9.30	79.621	17.49	1000.00	94.05
0.036	0.00	0.252	0.00	1.783	1.60	12.619	9.82	89.337	18.17	2000.00	97.58
0.040	0.00	0.283	0.00	2.000	1.85	14.159	10.32	100.237	19.03	10000.00	100.00
0.045	0.00	0.317	0.00	2.244	2.13	15.887	10.78	112.468	20.17		
0.050	0.00	0.356	0.00	2.518	2.45	17.825	11.23	126.191	21.72		
0.056	0.00	0.399	0.00	2.825	2.80	20.000	11.65	141.589	23.79		
0.063	0.00	0.448	0.03	3.170	3.20	22.440	12.07	158.866	26.52		
0.071	0.00	0.502	0.10	3.557	3.64	25.179	12.49	178.250	29.96		
0.080	0.00	0.564	0.17	3.991	4.13	28.251	12.92	200.000	34.19		
0.089	0.00	0.632	0.26	4.477	4.64	31.698	13.38	224.404	39.16		
0.100	0.00	0.710	0.36	5.024	5.19	35.566	13.85	251.785	44.79		
0.112	0.00	0.796	0.47	5.637	5.77	39.905	14.35	282.508	50.93		
0.126	0.00	0.893	0.59	6.325	6.36	44.774	14.85	316.979	57.37		

Note: Data from 500µm to 10000µm by wet screening, from 0.02µm to 500µm by laser diffraction.

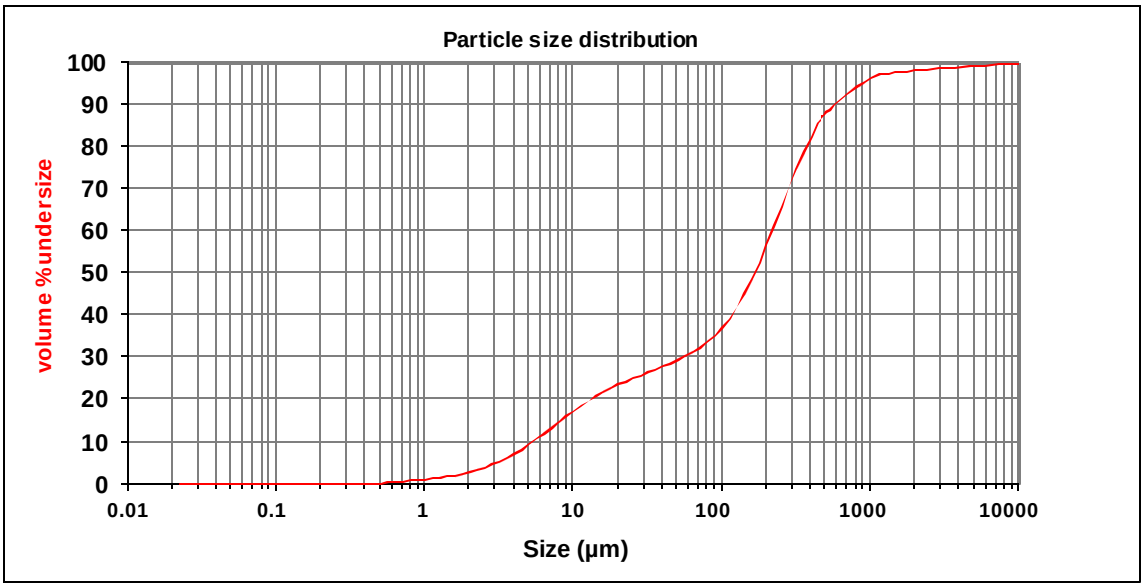
Analysed:	Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)
Reported:	Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)
Approved:	Michael Simeoni, B.Sc.(Chemistry), M.Sc. (Science Administration), Ph.D.

37 Kensington Street
East Perth
WA 6004

Client:	AECOM Australia Pty Ltd
Sample Name :	CS07P
Batch No :	16_1453
Lab ID No :	16_1453_07

Analysis :	Size distribution by laser diffraction following ISO13320-1:2009 and wet sieving	**Result units:**	Volume
Dispersant:	Water	**Analysis model:**	General purpose
Additives:	10 millilitres sodium hexametaphosphate	**Total sample wt (g):**	17.249
Sonication:	2 min sonication		

Span:	3.64	**Vol. Weighted mean D[4,3]:**	302.87 µm	**d(0.1)**	5.28 µm
		Surface weighted mean D[3,2]	13.86 µm	**d(0.5)**	165.49 µm
				d(0.9)	608.03 µm



Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %
0.020	0.00	0.142	0.00	1.002	1.20	7.096	13.38	50.238	29.44	355.66	78.92
0.022	0.00	0.159	0.00	1.125	1.40	7.962	14.73	56.368	30.27	399.05	82.56
0.025	0.00	0.178	0.00	1.262	1.62	8.934	16.06	63.246	31.21	447.74	85.68
0.028	0.00	0.200	0.00	1.416	1.87	10.024	17.35	70.963	32.29	500.00	88.24
0.032	0.00	0.224	0.00	1.589	2.16	11.247	18.57	79.621	33.58	1000.00	96.40
0.036	0.00	0.252	0.00	1.783	2.50	12.619	19.73	89.337	35.13	2000.00	98.14
0.040	0.00	0.283	0.00	2.000	2.90	14.159	20.80	100.237	37.01	10000.00	100.00
0.045	0.00	0.317	0.00	2.244	3.37	15.887	21.80	112.468	39.27		
0.050	0.00	0.356	0.00	2.518	3.94	17.825	22.72	126.191	41.96		
0.056	0.00	0.399	0.06	2.825	4.60	20.000	23.57	141.589	45.08		
0.063	0.00	0.448	0.15	3.170	5.36	22.440	24.37	158.866	48.65		
0.071	0.00	0.502	0.26	3.557	6.23	25.179	25.13	178.250	52.60		
0.080	0.00	0.564	0.38	3.991	7.22	28.251	25.85	200.000	56.88		
0.089	0.00	0.632	0.52	4.477	8.30	31.698	26.56	224.404	61.38		
0.100	0.00	0.710	0.68	5.024	9.48	35.566	27.26	251.785	65.97		
0.112	0.00	0.796	0.84	5.637	10.73	39.905	27.96	282.508	70.51		
0.126	0.00	0.893	1.02	6.325	12.04	44.774	28.68	316.979	74.87		

Note: Data from 500µm to 10000µm by wet screening, from 0.02µm to 500µm by laser diffraction.

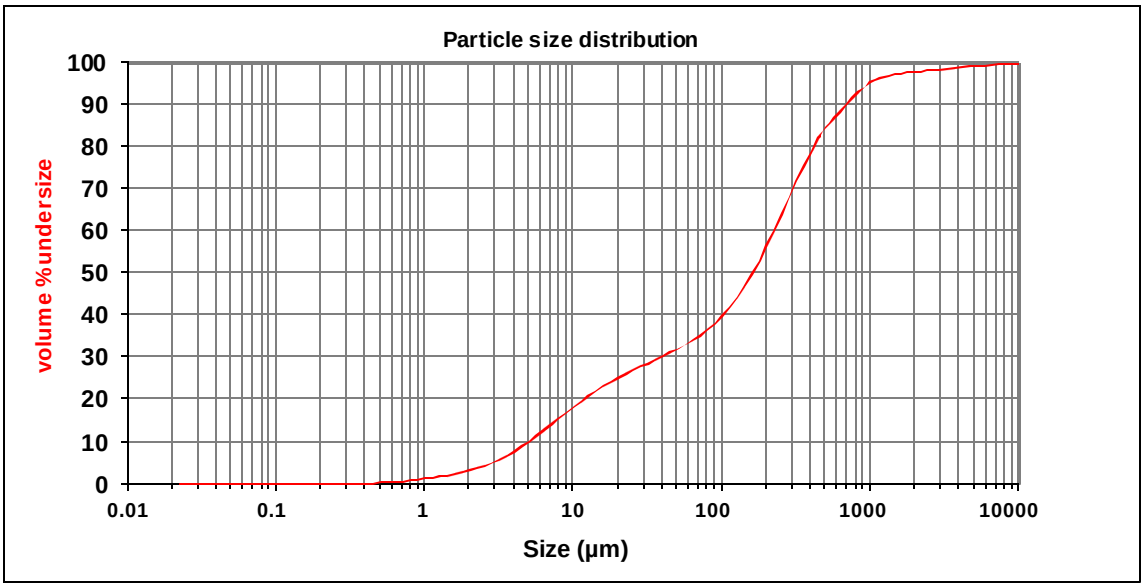
Analysed:	Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)
Reported:	Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)
Approved:	Michael Simeoni, B.Sc.(Chemistry), M.Sc. (Science Administration), Ph.D.

37 Kensington Street
East Perth
WA 6004

Client:	AECOM Australia Pty Ltd
Sample Name :	CS08P
Batch No :	16_1453
Lab ID No :	16_1453_08

Analysis :	Size distribution by laser diffraction following ISO13320-1:2009 and wet sieving	**Result units:**	Volume
Dispersant:	Water	**Analysis model:**	General purpose
Additives:	10 millilitres sodium hexametaphosphate	**Total sample wt (g):**	17.9321
Sonication:	4 min sonication		

Span:	4.64	**Vol. Weighted mean D[4,3]:**	327.83 µm	**d(0.1)**	4.98 µm
		Surface weighted mean D[3,2]	13.01 µm	**d(0.5)**	159.83 µm
				d(0.9)	746.04 µm



Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %
0.020	0.00	0.142	0.00	1.002	1.28	7.096	14.14	50.238	32.07	355.66	75.61
0.022	0.00	0.159	0.00	1.125	1.51	7.962	15.54	56.368	33.03	399.05	79.08
0.025	0.00	0.178	0.00	1.262	1.75	8.934	16.95	63.246	34.09	447.74	82.19
0.028	0.00	0.200	0.00	1.416	2.03	10.024	18.32	70.963	35.28	500.00	84.82
0.032	0.00	0.224	0.00	1.589	2.35	11.247	19.65	79.621	36.64	1000.00	95.35
0.036	0.00	0.252	0.00	1.783	2.73	12.619	20.92	89.337	38.18	2000.00	97.95
0.040	0.00	0.283	0.00	2.000	3.17	14.159	22.11	100.237	39.96	10000.00	100.00
0.045	0.00	0.317	0.00	2.244	3.69	15.887	23.24	112.468	41.99		
0.050	0.00	0.356	0.00	2.518	4.30	17.825	24.28	126.191	44.30		
0.056	0.00	0.399	0.07	2.825	5.00	20.000	25.26	141.589	46.92		
0.063	0.00	0.448	0.16	3.170	5.81	22.440	26.18	158.866	49.84		
0.071	0.00	0.502	0.27	3.557	6.73	25.179	27.05	178.250	53.06		
0.080	0.00	0.564	0.40	3.991	7.75	28.251	27.89	200.000	56.54		
0.089	0.00	0.632	0.55	4.477	8.88	31.698	28.70	224.404	60.24		
0.100	0.00	0.710	0.71	5.024	10.09	35.566	29.51	251.785	64.09		
0.112	0.00	0.796	0.89	5.637	11.39	39.905	30.33	282.508	68.01		
0.126	0.00	0.893	1.08	6.325	12.74	44.774	31.17	316.979	71.88		

Note: Data from 500µm to 10000µm by wet screening, from 0.02µm to 500µm by laser diffraction.

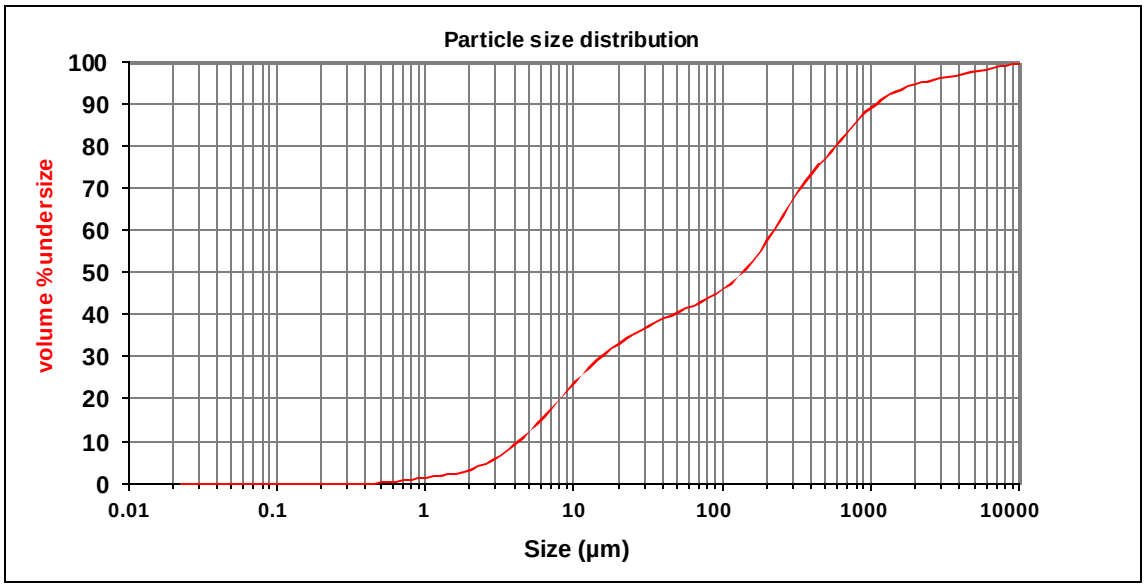
Analysed:	Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)
Reported:	Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)
Approved:	Michael Simeoni, B.Sc.(Chemistry), M.Sc. (Science Administration), Ph.D.

37 Kensington Street
East Perth
WA 6004

Client:	AECOM Australia Pty Ltd
Sample Name :	CS09P
Batch No :	16_1453
Lab ID No :	16_1453_09

Analysis :	Size distribution by laser diffraction following ISO13320-1:2009 and wet sieving	**Result units:**	Volume
Dispersant:	Water	**Analysis model:**	General purpose
Additives:	10 millilitres sodium hexametaphosphate	**Total sample wt (g):**	12.5977
Sonication:	1 min sonication		

Span:	8.22	**Vol. Weighted mean D[4,3]:**	474.93 µm	**d(0.1)**	4.17 µm
		Surface weighted mean D[3,2]	10.58 µm	**d(0.5)**	133.16 µm
				d(0.9)	1099.16 µm



Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %
0.020	0.00	0.142	0.00	1.002	1.49	7.096	18.25	50.238	40.89	355.66	71.87
0.022	0.00	0.159	0.00	1.125	1.72	7.962	20.23	56.368	41.68	399.05	74.19
0.025	0.00	0.178	0.00	1.262	1.98	8.934	22.20	63.246	42.47	447.74	76.16
0.028	0.00	0.200	0.00	1.416	2.28	10.024	24.12	70.963	43.30	500.00	77.71
0.032	0.00	0.224	0.00	1.589	2.63	11.247	25.96	79.621	44.20	1000.00	89.46
0.036	0.00	0.252	0.00	1.783	3.05	12.619	27.70	89.337	45.19	2000.00	94.95
0.040	0.00	0.283	0.00	2.000	3.56	14.159	29.32	100.237	46.33	10000.00	100.00
0.045	0.00	0.317	0.01	2.244	4.18	15.887	30.82	112.468	47.65		
0.050	0.00	0.356	0.06	2.518	4.93	17.825	32.20	126.191	49.19		
0.056	0.00	0.399	0.14	2.825	5.81	20.000	33.46	141.589	50.98		
0.063	0.00	0.448	0.25	3.170	6.86	22.440	34.61	158.866	53.05		
0.071	0.00	0.502	0.38	3.557	8.06	25.179	35.67	178.250	55.38		
0.080	0.00	0.564	0.53	3.991	9.43	28.251	36.66	200.000	57.95		
0.089	0.00	0.632	0.70	4.477	10.95	31.698	37.59	224.404	60.71		
0.100	0.00	0.710	0.88	5.024	12.62	35.566	38.46	251.785	63.58		
0.112	0.00	0.796	1.07	5.637	14.41	39.905	39.30	282.508	66.46		
0.126	0.00	0.893	1.27	6.325	16.30	44.774	40.10	316.979	69.26		

Note: Data from 500µm to 10000µm by wet screening, from 0.02µm to 500µm by laser diffraction.

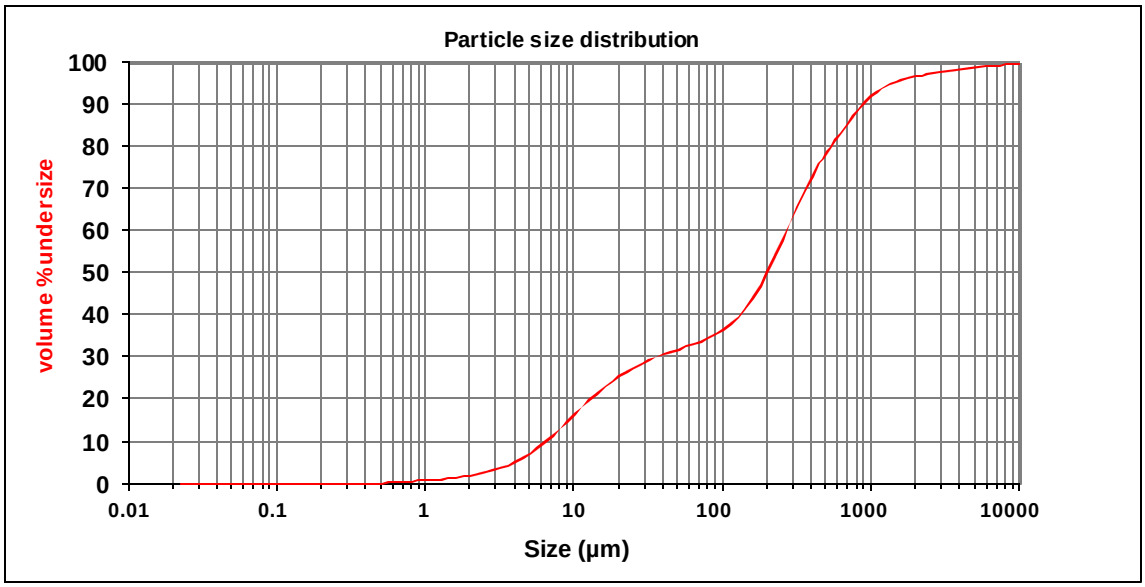
Analysed:	Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)
Reported:	Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)
Approved:	Michael Simeoni, B.Sc.(Chemistry), M.Sc. (Science Administration), Ph.D.

37 Kensington Street
East Perth
WA 6004

Client:	AECOM Australia Pty Ltd
Sample Name :	CS010P
Batch No :	16_1453
Lab ID No :	16_1453_10

Analysis :	Size distribution by laser diffraction following ISO13320-1:2009 and wet sieving	**Result units:**	Volume
Dispersant:	Water	**Analysis model:**	General purpose
Additives:	10 millilitres sodium hexametaphosphate	**Total sample wt (g):**	13.7616
Sonication:	0 min sonication		

Span:	4.64	**Vol. Weighted mean D[4,3]:**	420.05 µm	**d(0.1)**	6.33 µm
		Surface weighted mean D[3,2]	16.03 µm	**d(0.5)**	197.11 µm
				d(0.9)	920.28 µm



Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %
0.020	0.00	0.142	0.00	1.002	0.91	7.096	11.52	50.238	32.05	355.66	69.75
0.022	0.00	0.159	0.00	1.125	1.05	7.962	13.14	56.368	32.63	399.05	73.24
0.025	0.00	0.178	0.00	1.262	1.19	8.934	14.83	63.246	33.22	447.74	76.30
0.028	0.00	0.200	0.00	1.416	1.35	10.024	16.55	70.963	33.86	500.00	78.84
0.032	0.00	0.224	0.00	1.589	1.53	11.247	18.27	79.621	34.59	1000.00	92.12
0.036	0.00	0.252	0.00	1.783	1.74	12.619	19.94	89.337	35.47	2000.00	96.88
0.040	0.00	0.283	0.00	2.000	1.99	14.159	21.54	100.237	36.55	10000.00	100.00
0.045	0.00	0.317	0.00	2.244	2.30	15.887	23.04	112.468	37.91		
0.050	0.00	0.356	0.00	2.518	2.68	17.825	24.41	126.191	39.60		
0.056	0.00	0.399	0.05	2.825	3.15	20.000	25.66	141.589	41.68		
0.063	0.00	0.448	0.12	3.170	3.72	22.440	26.78	158.866	44.19		
0.071	0.00	0.502	0.20	3.557	4.41	25.179	27.78	178.250	47.12		
0.080	0.00	0.564	0.30	3.991	5.24	28.251	28.68	200.000	50.44		
0.089	0.00	0.632	0.41	4.477	6.21	31.698	29.47	224.404	54.10		
0.100	0.00	0.710	0.53	5.024	7.33	35.566	30.19	251.785	57.99		
0.112	0.00	0.796	0.65	5.637	8.59	39.905	30.85	282.508	61.99		
0.126	0.00	0.893	0.78	6.325	9.99	44.774	31.47	316.979	65.96		

Note: Data from 500µm to 10000µm by wet screening, from 0.02µm to 500µm by laser diffraction.

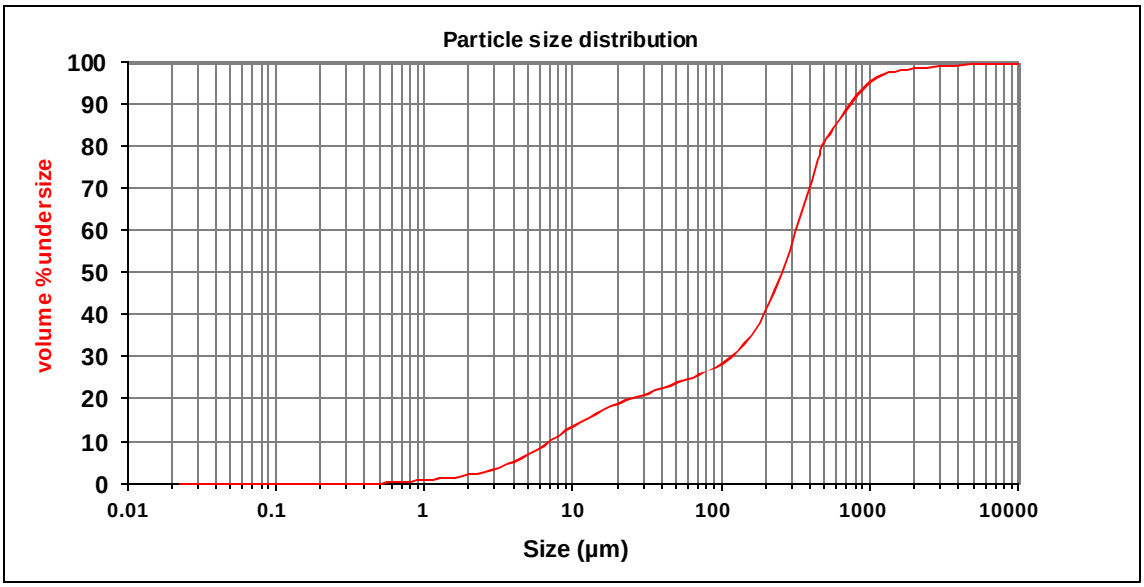
Analysed:	Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)
Reported:	Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)
Approved:	Michael Simeoni, B.Sc.(Chemistry), M.Sc. (Science Administration), Ph.D.

37 Kensington Street
East Perth
WA 6004

Client:	AECOM Australia Pty Ltd
Sample Name :	CS011P
Batch No :	16_1453
Lab ID No :	16_1453_11

Analysis :	Size distribution by laser diffraction following ISO13320-1:2009 and wet sieving	**Result units:**	Volume
Dispersant:	Water	**Analysis model:**	General purpose
Additives:	10 millilitres sodium hexametaphosphate	**Total sample wt (g):**	12.5256
Sonication:	2 min sonication		

Span:	3.16	**Vol. Weighted mean D[4,3]:**	359.41 µm	**d(0.1)**	6.84 µm
		Surface weighted mean D[3,2]	17.68 µm	**d(0.5)**	250.68 µm
				d(0.9)	798.94 µm



Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %
0.020	0.00	0.142	0.00	1.002	0.94	7.096	10.37	50.238	24.03	355.66	66.28
0.022	0.00	0.159	0.00	1.125	1.09	7.962	11.52	56.368	24.69	399.05	71.84
0.025	0.00	0.178	0.00	1.262	1.26	8.934	12.66	63.246	25.37	447.74	77.12
0.028	0.00	0.200	0.00	1.416	1.45	10.024	13.78	70.963	26.09	500.00	81.91
0.032	0.00	0.224	0.00	1.589	1.66	11.247	14.85	79.621	26.86	1000.00	95.44
0.036	0.00	0.252	0.00	1.783	1.91	12.619	15.86	89.337	27.71	2000.00	98.73
0.040	0.00	0.283	0.00	2.000	2.20	14.159	16.80	100.237	28.69	10000.00	100.00
0.045	0.00	0.317	0.00	2.244	2.54	15.887	17.66	112.468	29.86		
0.050	0.00	0.356	0.00	2.518	2.95	17.825	18.44	126.191	31.32		
0.056	0.00	0.399	0.04	2.825	3.43	20.000	19.16	141.589	33.13		
0.063	0.00	0.448	0.11	3.170	4.00	22.440	19.81	158.866	35.40		
0.071	0.00	0.502	0.20	3.557	4.65	25.179	20.43	178.250	38.21		
0.080	0.00	0.564	0.29	3.991	5.40	28.251	21.02	200.000	41.60		
0.089	0.00	0.632	0.40	4.477	6.24	31.698	21.60	224.404	45.61		
0.100	0.00	0.710	0.52	5.024	7.17	35.566	22.18	251.785	50.18		
0.112	0.00	0.796	0.65	5.637	8.18	39.905	22.78	282.508	55.26		
0.126	0.00	0.893	0.79	6.325	9.25	44.774	23.40	316.979	60.68		

Note: Data from 500µm to 10000µm by wet screening, from 0.02µm to 500µm by laser diffraction.

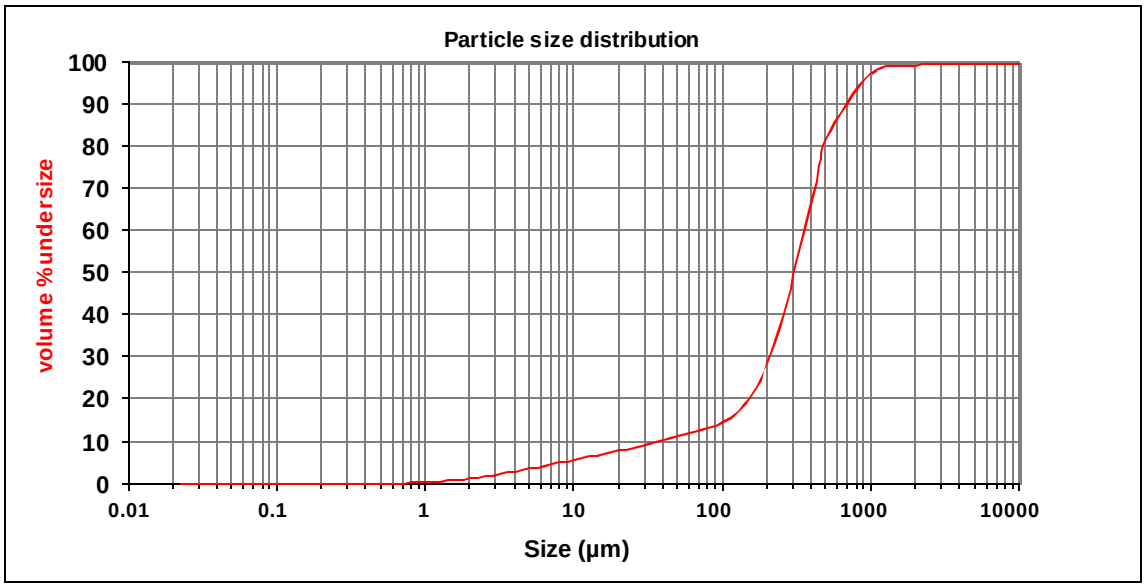
Analysed: Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)
Reported: Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)
Approved: Michael Simeoni, B.Sc.(Chemistry), M.Sc. (Science Administration), Ph.D.

37 Kensington Street
East Perth
WA 6004

Client:	AECOM Australia Pty Ltd
Sample Name :	CS012P
Batch No :	16_1453
Lab ID No :	16_1453_12

Analysis :	Size distribution by laser diffraction following ISO13320-1:2009 and wet sieving	**Result units:**	Volume
Dispersant:	Water	**Analysis model:**	General purpose
Additives:	10 millilitres sodium hexametaphosphate	**Total sample wt (g):**	13.8139
Sonication:	6 min sonication		

Span:	2.36	**Vol. Weighted mean D[4,3]:**	361.86 µm	**d(0.1)**	37.11 µm
		Surface weighted mean D[3,2]	34.66 µm	**d(0.5)**	300.87 µm
				d(0.9)	747.93 µm



Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %
0.020	0.00	0.142	0.00	1.002	0.46	7.096	4.70	50.238	11.22	355.66	60.86
0.022	0.00	0.159	0.00	1.125	0.57	7.962	5.07	56.368	11.70	399.05	68.44
0.025	0.00	0.178	0.00	1.262	0.70	8.934	5.44	63.246	12.21	447.74	75.77
0.028	0.00	0.200	0.00	1.416	0.84	10.024	5.81	70.963	12.73	500.00	82.53
0.032	0.00	0.224	0.00	1.589	1.00	11.247	6.18	79.621	13.30	1000.00	97.60
0.036	0.00	0.252	0.00	1.783	1.17	12.619	6.54	89.337	13.96	2000.00	99.51
0.040	0.00	0.283	0.00	2.000	1.37	14.159	6.89	100.237	14.77	10000.00	100.00
0.045	0.00	0.317	0.00	2.244	1.58	15.887	7.24	112.468	15.82		
0.050	0.00	0.356	0.00	2.518	1.82	17.825	7.59	126.191	17.23		
0.056	0.00	0.399	0.00	2.825	2.07	20.000	7.94	141.589	19.11		
0.063	0.00	0.448	0.00	3.170	2.35	22.440	8.29	158.866	21.60		
0.071	0.00	0.502	0.01	3.557	2.64	25.179	8.65	178.250	24.83		
0.080	0.00	0.564	0.06	3.991	2.95	28.251	9.03	200.000	28.90		
0.089	0.00	0.632	0.12	4.477	3.28	31.698	9.43	224.404	33.83		
0.100	0.00	0.710	0.19	5.024	3.62	35.566	9.84	251.785	39.63		
0.112	0.00	0.796	0.27	5.637	3.97	39.905	10.28	282.508	46.19		
0.126	0.00	0.893	0.36	6.325	4.33	44.774	10.74	316.979	53.34		

Note: Data from 500µm to 10000µm by wet screening, from 0.02µm to 500µm by laser diffraction.

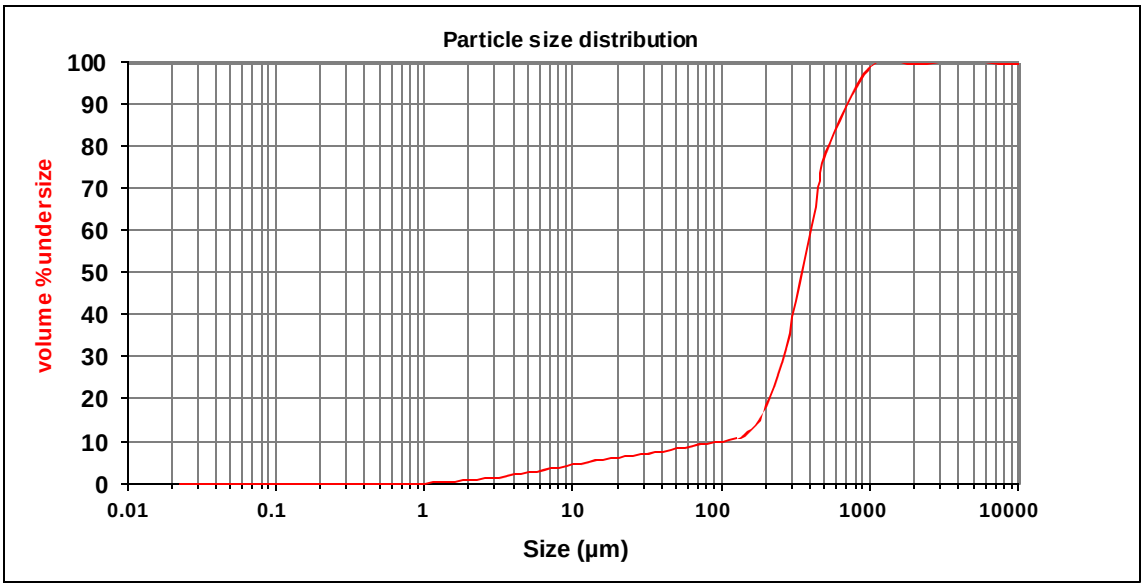
Analysed: Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)
Reported: Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)
Approved: Michael Simeoni, B.Sc.(Chemistry), M.Sc. (Science Administration), Ph.D.

37 Kensington Street
East Perth
WA 6004

Client:	AECOM Australia Pty Ltd
Sample Name :	CS013P
Batch No :	16_1453
Lab ID No :	16_1453_13

Analysis :	Size distribution by laser diffraction following ISO13320-1:2009 and wet sieving	**Result units:**	Volume
Dispersant:	Water	**Analysis model:**	General purpose
Additives:	10 millilitres sodium hexametaphosphate	**Total sample wt (g):**	11.5553
Sonication:	5 min sonication		

Span:	1.96	**Vol. Weighted mean D[4,3]:**	380.24 µm	**d(0.1)**	100.08 µm
		Surface weighted mean D[3,2]	48.25 µm	**d(0.5)**	345.08 µm
				d(0.9)	775.76 µm



Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %
0.020	0.00	0.142	0.00	1.002	0.23	7.096	3.64	50.238	8.45	355.66	52.38
0.022	0.00	0.159	0.00	1.125	0.31	7.962	3.96	56.368	8.79	399.05	61.45
0.025	0.00	0.178	0.00	1.262	0.41	8.934	4.28	63.246	9.12	447.74	70.42
0.028	0.00	0.200	0.00	1.416	0.51	10.024	4.60	70.963	9.40	500.00	78.84
0.032	0.00	0.224	0.00	1.589	0.63	11.247	4.92	79.621	9.63	1000.00	99.08
0.036	0.00	0.252	0.00	1.783	0.77	12.619	5.22	89.337	9.82	2000.00	99.96
0.040	0.00	0.283	0.00	2.000	0.92	14.159	5.52	100.237	10.00	10000.00	100.00
0.045	0.00	0.317	0.00	2.244	1.08	15.887	5.79	112.468	10.27		
0.050	0.00	0.356	0.00	2.518	1.27	17.825	6.05	126.191	10.74		
0.056	0.00	0.399	0.00	2.825	1.47	20.000	6.29	141.589	11.60		
0.063	0.00	0.448	0.00	3.170	1.69	22.440	6.52	158.866	13.05		
0.071	0.00	0.502	0.00	3.557	1.92	25.179	6.75	178.250	15.32		
0.080	0.00	0.564	0.00	3.991	2.18	28.251	6.98	200.000	18.61		
0.089	0.00	0.632	0.00	4.477	2.44	31.698	7.22	224.404	23.08		
0.100	0.00	0.710	0.03	5.024	2.73	35.566	7.49	251.785	28.79		
0.112	0.00	0.796	0.09	5.637	3.02	39.905	7.78	282.508	35.71		
0.126	0.00	0.893	0.16	6.325	3.32	44.774	8.11	316.979	43.67		

Note: Data from 500µm to 10000µm by wet screening, from 0.02µm to 500µm by laser diffraction.

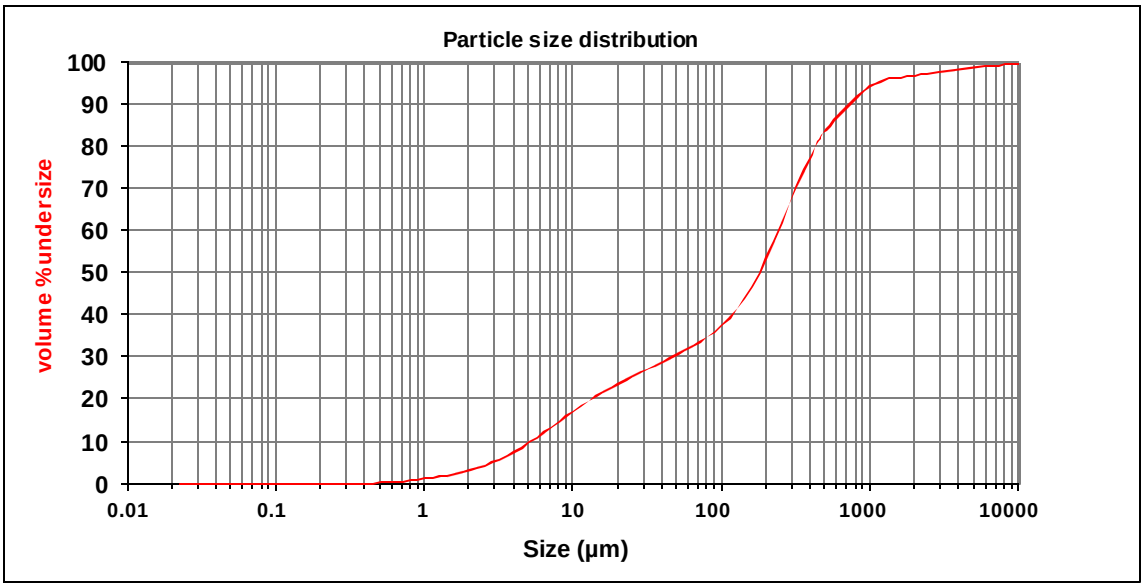
Analysed: Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)
Reported: Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)
Approved: Michael Simeoni, B.Sc.(Chemistry), M.Sc. (Science Administration), Ph.D.

37 Kensington Street
East Perth
WA 6004

Client:	AECOM Australia Pty Ltd
Sample Name :	CS014P
Batch No :	16_1453
Lab ID No :	16_1453_14

Analysis :	Size distribution by laser diffraction following ISO13320-1:2009 and wet sieving	**Result units:**	Volume
Dispersant:	Water	**Analysis model:**	General purpose
Additives:	10 millilitres sodium hexametaphosphate	**Total sample wt (g):**	12.8031
Sonication:	4 min sonication		

Span:	4.39	**Vol. Weighted mean D[4,3]:**	368.45 µm	**d(0.1)**	5.11 µm
		Surface weighted mean D[3,2]	13.26 µm	**d(0.5)**	177.53 µm
				d(0.9)	784.46 µm



Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %
0.020	0.00	0.142	0.00	1.002	1.32	7.096	13.54	50.238	30.84	355.66	74.59
0.022	0.00	0.159	0.00	1.125	1.55	7.962	14.82	56.368	31.77	399.05	78.28
0.025	0.00	0.178	0.00	1.262	1.81	8.934	16.11	63.246	32.75	447.74	81.49
0.028	0.00	0.200	0.00	1.416	2.10	10.024	17.36	70.963	33.80	500.00	84.12
0.032	0.00	0.224	0.00	1.589	2.43	11.247	18.58	79.621	34.95	1000.00	94.46
0.036	0.00	0.252	0.00	1.783	2.81	12.619	19.75	89.337	36.25	2000.00	97.14
0.040	0.00	0.283	0.00	2.000	3.26	14.159	20.86	100.237	37.75	10000.00	100.00
0.045	0.00	0.317	0.00	2.244	3.77	15.887	21.92	112.468	39.50		
0.050	0.00	0.356	0.00	2.518	4.37	17.825	22.92	126.191	41.57		
0.056	0.00	0.399	0.06	2.825	5.05	20.000	23.87	141.589	44.01		
0.063	0.00	0.448	0.15	3.170	5.83	22.440	24.78	158.866	46.86		
0.071	0.00	0.502	0.27	3.557	6.69	25.179	25.66	178.250	50.12		
0.080	0.00	0.564	0.40	3.991	7.66	28.251	26.52	200.000	53.78		
0.089	0.00	0.632	0.55	4.477	8.70	31.698	27.37	224.404	57.76		
0.100	0.00	0.710	0.72	5.024	9.83	35.566	28.22	251.785	61.97		
0.112	0.00	0.796	0.91	5.637	11.02	39.905	29.08	282.508	66.28		
0.126	0.00	0.893	1.10	6.325	12.26	44.774	29.95	316.979	70.54		

Note: Data from 500µm to 10000µm by wet screening, from 0.02µm to 500µm by laser diffraction.

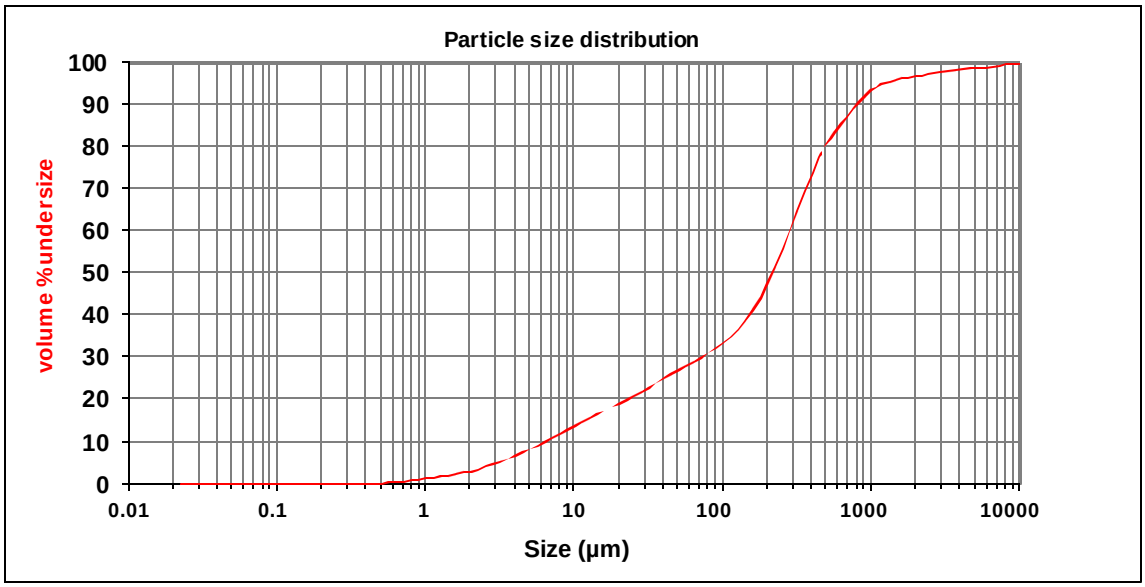
Analysed:	Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)
Reported:	Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)
Approved:	Michael Simeoni, B.Sc.(Chemistry), M.Sc. (Science Administration), Ph.D.

37 Kensington Street
East Perth
WA 6004

Client:	AECOM Australia Pty Ltd
Sample Name :	CS015P
Batch No :	16_1453
Lab ID No :	16_1453_15

Analysis :	Size distribution by laser diffraction following ISO13320-1:2009 and wet sieving	**Result units:**	Volume
Dispersant:	Water	**Analysis model:**	General purpose
Additives:	10 millilitres sodium hexametaphosphate	**Total sample wt (g):**	15.363
Sonication:	6 min sonication		

Span:	3.97	**Vol. Weighted mean D[4,3]:**	414.95 µm	**d(0.1)**	6.23 µm
		Surface weighted mean D[3,2]	15.13 µm	**d(0.5)**	214.76 µm
				d(0.9)	859.51 µm



Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %
0.020	0.00	0.142	0.00	1.002	1.25	7.096	11.04	50.238	27.04	355.66	69.59
0.022	0.00	0.159	0.00	1.125	1.48	7.962	11.96	56.368	28.04	399.05	73.91
0.025	0.00	0.178	0.00	1.262	1.73	8.934	12.89	63.246	29.04	447.74	77.78
0.028	0.00	0.200	0.00	1.416	2.01	10.024	13.80	70.963	30.06	500.00	81.04
0.032	0.00	0.224	0.00	1.589	2.33	11.247	14.71	79.621	31.12	1000.00	93.50
0.036	0.00	0.252	0.00	1.783	2.69	12.619	15.61	89.337	32.25	2000.00	96.84
0.040	0.00	0.283	0.00	2.000	3.10	14.159	16.50	100.237	33.52	10000.00	100.00
0.045	0.00	0.317	0.00	2.244	3.56	15.887	17.39	112.468	34.98		
0.050	0.00	0.356	0.00	2.518	4.07	17.825	18.29	126.191	36.72		
0.056	0.00	0.399	0.06	2.825	4.65	20.000	19.19	141.589	38.79		
0.063	0.00	0.448	0.14	3.170	5.28	22.440	20.12	158.866	41.27		
0.071	0.00	0.502	0.24	3.557	5.97	25.179	21.06	178.250	44.22		
0.080	0.00	0.564	0.36	3.991	6.72	28.251	22.03	200.000	47.65		
0.089	0.00	0.632	0.51	4.477	7.52	31.698	23.01	224.404	51.54		
0.100	0.00	0.710	0.67	5.024	8.36	35.566	24.02	251.785	55.81		
0.112	0.00	0.796	0.84	5.637	9.23	39.905	25.02	282.508	60.35		
0.126	0.00	0.893	1.04	6.325	10.13	44.774	26.03	316.979	65.01		

Note: Data from 500µm to 10000µm by wet screening, from 0.02µm to 500µm by laser diffraction.

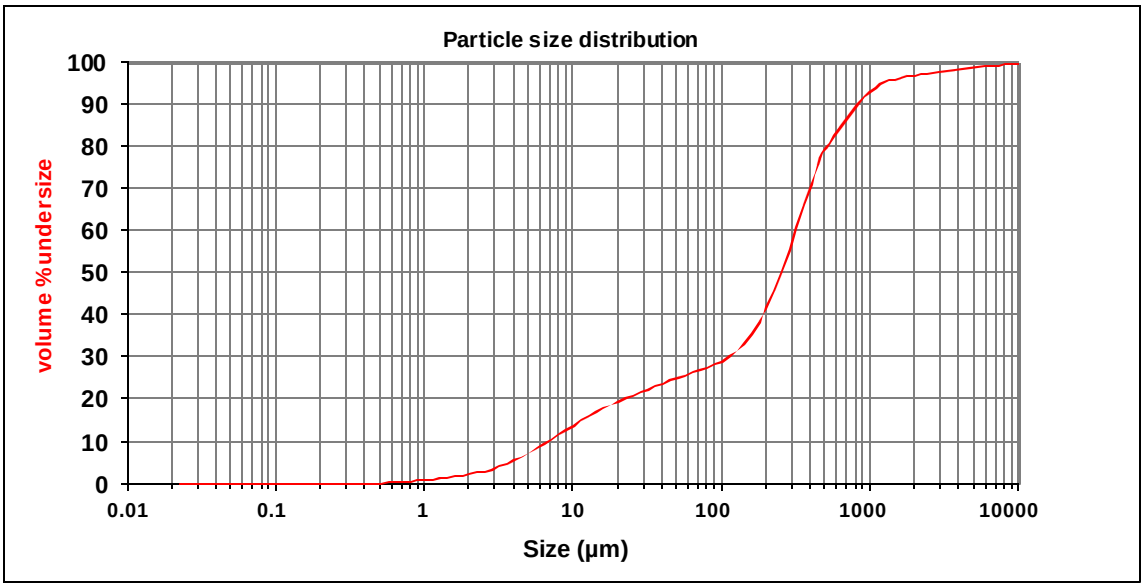
Analysed:	Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)
Reported:	Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)
Approved:	Michael Simeoni, B.Sc.(Chemistry), M.Sc. (Science Administration), Ph.D.

37 Kensington Street
East Perth
WA 6004

Client:	AECOM Australia Pty Ltd
Sample Name :	CS016P
Batch No :	16_1453
Lab ID No :	16_1453_16

Analysis :	Size distribution by laser diffraction following ISO13320-1:2009 and wet sieving	**Result units:**	Volume
Dispersant:	Water	**Analysis model:**	General purpose
Additives:	10 millilitres sodium hexametaphosphate	**Total sample wt (g):**	15.2318
Sonication:	3 min sonication		

Span:	3.51	**Vol. Weighted mean D[4,3]:**	429.84 µm	**d(0.1)**	6.70 µm
		Surface weighted mean D[3,2]	17.19 µm	**d(0.5)**	248.17 µm
				d(0.9)	878.29 µm



Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %
0.020	0.00	0.142	0.00	1.002	0.97	7.096	10.57	50.238	25.17	355.66	66.18
0.022	0.00	0.159	0.00	1.125	1.13	7.962	11.71	56.368	25.80	399.05	71.24
0.025	0.00	0.178	0.00	1.262	1.31	8.934	12.84	63.246	26.40	447.74	75.83
0.028	0.00	0.200	0.00	1.416	1.50	10.024	13.96	70.963	27.01	500.00	79.77
0.032	0.00	0.224	0.00	1.589	1.73	11.247	15.04	79.621	27.65	1000.00	93.29
0.036	0.00	0.252	0.00	1.783	1.99	12.619	16.07	89.337	28.35	2000.00	97.07
0.040	0.00	0.283	0.00	2.000	2.29	14.159	17.04	100.237	29.19	10000.00	100.00
0.045	0.00	0.317	0.00	2.244	2.65	15.887	17.95	112.468	30.24		
0.050	0.00	0.356	0.00	2.518	3.08	17.825	18.81	126.191	31.59		
0.056	0.00	0.399	0.05	2.825	3.58	20.000	19.61	141.589	33.35		
0.063	0.00	0.448	0.12	3.170	4.17	22.440	20.38	158.866	35.62		
0.071	0.00	0.502	0.20	3.557	4.84	25.179	21.11	178.250	38.46		
0.080	0.00	0.564	0.30	3.991	5.60	28.251	21.82	200.000	41.93		
0.089	0.00	0.632	0.42	4.477	6.45	31.698	22.52	224.404	46.00		
0.100	0.00	0.710	0.54	5.024	7.39	35.566	23.20	251.785	50.61		
0.112	0.00	0.796	0.68	5.637	8.40	39.905	23.87	282.508	55.64		
0.126	0.00	0.893	0.82	6.325	9.46	44.774	24.53	316.979	60.90		

Note: Data from 500µm to 10000µm by wet screening, from 0.02µm to 500µm by laser diffraction.

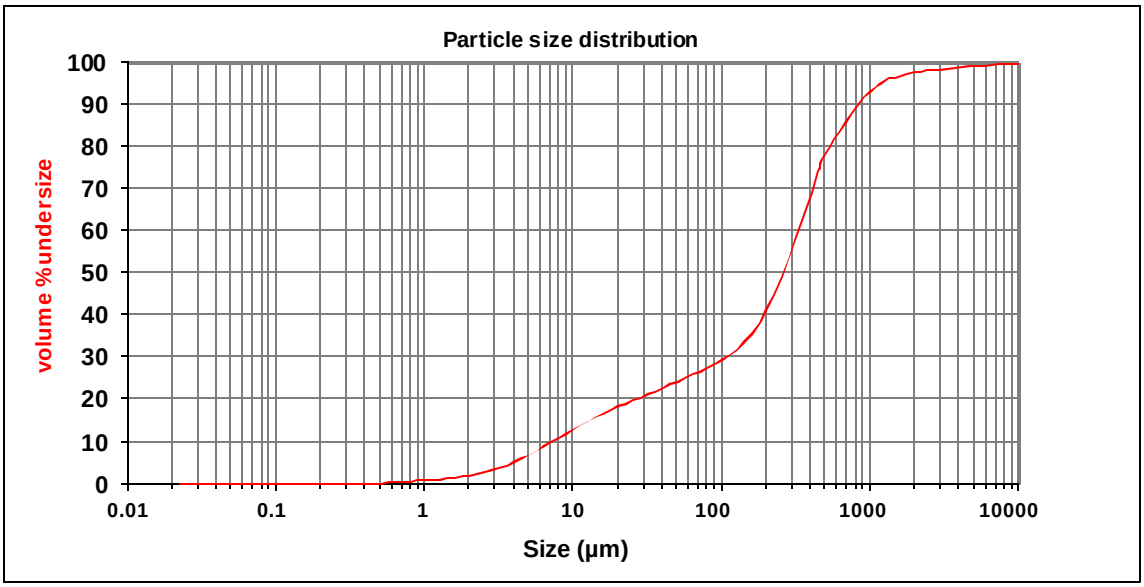
Analysed: Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)
Reported: Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)
Approved: Michael Simeoni, B.Sc.(Chemistry), M.Sc. (Science Administration), Ph.D.

37 Kensington Street
East Perth
WA 6004

Client:	AECOM Australia Pty Ltd
Sample Name :	CS017P
Batch No :	16_1453
Lab ID No :	16_1453_17

Analysis :	Size distribution by laser diffraction following ISO13320-1:2009 and wet sieving	**Result units:**	Volume
Dispersant:	Water	**Analysis model:**	General purpose
Additives:	10 millilitres sodium hexametaphosphate	**Total sample wt (g):**	17.3766
Sonication:	2 min sonication		

Span:	3.42	**Vol. Weighted mean D[4,3]:**	415.85 µm	**d(0.1)**	7.17 µm
		Surface weighted mean D[3,2]	18.34 µm	**d(0.5)**	257.78 µm
				d(0.9)	887.72 µm



Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %
0.020	0.00	0.142	0.00	1.002	0.88	7.096	9.91	50.238	24.39	355.66	64.05
0.022	0.00	0.159	0.00	1.125	1.03	7.962	10.97	56.368	25.19	399.05	69.26
0.025	0.00	0.178	0.00	1.262	1.19	8.934	12.02	63.246	26.00	447.74	74.23
0.028	0.00	0.200	0.00	1.416	1.36	10.024	13.06	70.963	26.82	500.00	78.73
0.032	0.00	0.224	0.00	1.589	1.57	11.247	14.06	79.621	27.66	1000.00	93.26
0.036	0.00	0.252	0.00	1.783	1.81	12.619	15.01	89.337	28.55	2000.00	97.78
0.040	0.00	0.283	0.00	2.000	2.09	14.159	15.92	100.237	29.53	10000.00	100.00
0.045	0.00	0.317	0.00	2.244	2.43	15.887	16.77	112.468	30.64		
0.050	0.00	0.356	0.00	2.518	2.84	17.825	17.58	126.191	31.98		
0.056	0.00	0.399	0.04	2.825	3.31	20.000	18.35	141.589	33.62		
0.063	0.00	0.448	0.11	3.170	3.87	22.440	19.09	158.866	35.66		
0.071	0.00	0.502	0.19	3.557	4.50	25.179	19.82	178.250	38.18		
0.080	0.00	0.564	0.28	3.991	5.23	28.251	20.55	200.000	41.25		
0.089	0.00	0.632	0.39	4.477	6.04	31.698	21.29	224.404	44.89		
0.100	0.00	0.710	0.50	5.024	6.92	35.566	22.04	251.785	49.09		
0.112	0.00	0.796	0.62	5.637	7.87	39.905	22.81	282.508	53.77		
0.126	0.00	0.893	0.75	6.325	8.87	44.774	23.59	316.979	58.81		

Note: Data from 500µm to 10000µm by wet screening, from 0.02µm to 500µm by laser diffraction.

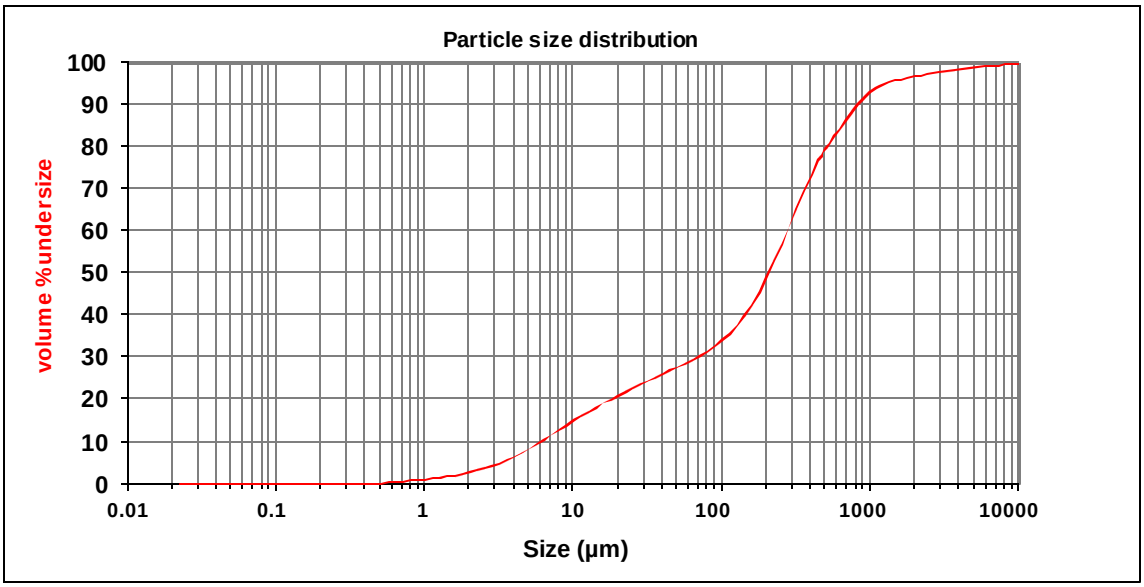
Analysed: Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)
Reported: Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)
Approved: Michael Simeoni, B.Sc.(Chemistry), M.Sc. (Science Administration), Ph.D.

37 Kensington Street
East Perth
WA 6004

Client:	AECOM Australia Pty Ltd
Sample Name :	CS018P
Batch No :	16_1453
Lab ID No :	16_1453_18

Analysis :	Size distribution by laser diffraction following ISO13320-1:2009 and wet sieving	**Result units:**	Volume
Dispersant:	Water	**Analysis model:**	General purpose
Additives:	10 millilitres sodium hexametaphosphate	**Total sample wt (g):**	21.0086
Sonication:	3 min sonication		

Span:	4.27	**Vol. Weighted mean D[4,3]:**	416.85 µm	**d(0.1)**	6.01 µm
		Surface weighted mean D[3,2]	15.29 µm	**d(0.5)**	206.11 µm
				d(0.9)	885.05 µm



Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %
0.020	0.00	0.142	0.00	1.002	1.13	7.096	11.65	50.238	27.80	355.66	69.58
0.022	0.00	0.159	0.00	1.125	1.32	7.962	12.80	56.368	28.67	399.05	73.45
0.025	0.00	0.178	0.00	1.262	1.54	8.934	13.96	63.246	29.57	447.74	76.90
0.028	0.00	0.200	0.00	1.416	1.77	10.024	15.09	70.963	30.53	500.00	79.82
0.032	0.00	0.224	0.00	1.589	2.05	11.247	16.20	79.621	31.58	1000.00	93.04
0.036	0.00	0.252	0.00	1.783	2.36	12.619	17.26	89.337	32.76	2000.00	96.89
0.040	0.00	0.283	0.00	2.000	2.72	14.159	18.27	100.237	34.13	10000.00	100.00
0.045	0.00	0.317	0.00	2.244	3.15	15.887	19.24	112.468	35.74		
0.050	0.00	0.356	0.00	2.518	3.65	17.825	20.17	126.191	37.64		
0.056	0.00	0.399	0.06	2.825	4.22	20.000	21.07	141.589	39.90		
0.063	0.00	0.448	0.13	3.170	4.88	22.440	21.94	158.866	42.54		
0.071	0.00	0.502	0.23	3.557	5.62	25.179	22.79	178.250	45.59		
0.080	0.00	0.564	0.35	3.991	6.45	28.251	23.63	200.000	49.05		
0.089	0.00	0.632	0.48	4.477	7.36	31.698	24.46	224.404	52.86		
0.100	0.00	0.710	0.63	5.024	8.35	35.566	25.29	251.785	56.94		
0.112	0.00	0.796	0.78	5.637	9.40	39.905	26.13	282.508	61.18		
0.126	0.00	0.893	0.95	6.325	10.51	44.774	26.96	316.979	65.44		

Note: Data from 500µm to 10000µm by wet screening, from 0.02µm to 500µm by laser diffraction.

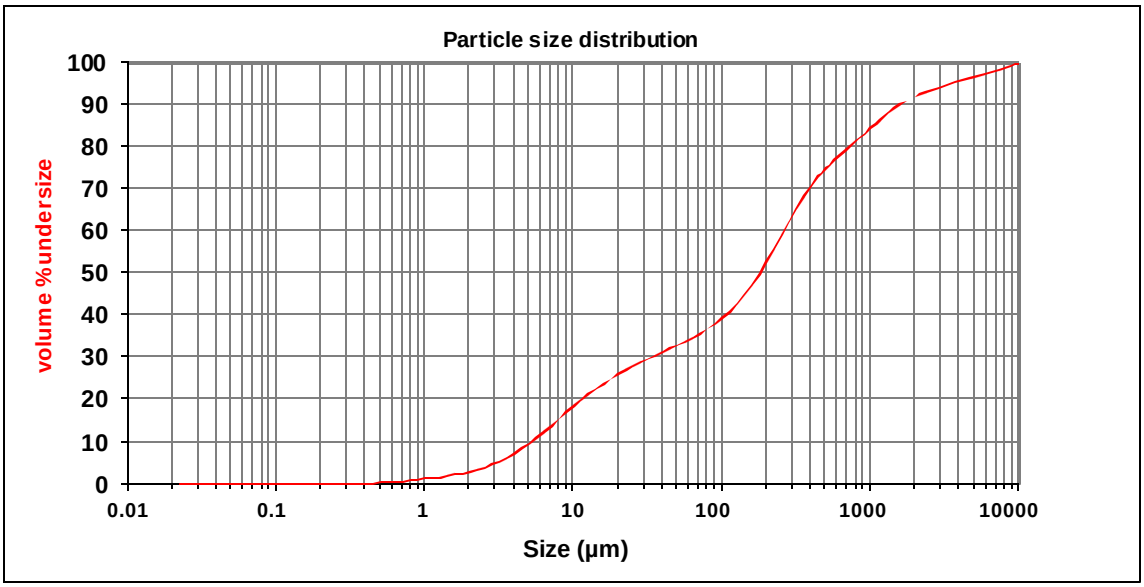
Analysed: Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)
Reported: Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)
Approved: Michael Simeoni, B.Sc.(Chemistry), M.Sc. (Science Administration), Ph.D.

37 Kensington Street
East Perth
WA 6004

Client:	AECOM Australia Pty Ltd
Sample Name :	CS019P
Batch No :	16_1453
Lab ID No :	16_1453_19

Analysis :	Size distribution by laser diffraction following ISO13320-1:2009 and wet sieving	**Result units:**	Volume
Dispersant:	Water	**Analysis model:**	General purpose
Additives:	10 millilitres sodium hexametaphosphate	**Total sample wt (g):**	14.8199
Sonication:	2 min sonication		

Span:	9.71	**Vol. Weighted mean D[4,3]:**	631.72 µm	**d(0.1)**	5.15 µm
		Surface weighted mean D[3,2]	13.21 µm	**d(0.5)**	178.62 µm
				d(0.9)	1740.15 µm



Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %
0.020	0.00	0.142	0.00	1.002	1.24	7.096	13.96	50.238	33.05	355.66	68.33
0.022	0.00	0.159	0.00	1.125	1.44	7.962	15.47	56.368	33.91	399.05	70.94
0.025	0.00	0.178	0.00	1.262	1.65	8.934	16.98	63.246	34.81	447.74	73.16
0.028	0.00	0.200	0.00	1.416	1.90	10.024	18.47	70.963	35.78	500.00	74.97
0.032	0.00	0.224	0.00	1.589	2.18	11.247	19.91	79.621	36.84	1000.00	84.43
0.036	0.00	0.252	0.00	1.783	2.51	12.619	21.29	89.337	38.04	2000.00	91.96
0.040	0.00	0.283	0.00	2.000	2.91	14.159	22.60	100.237	39.41	10000.00	100.00
0.045	0.00	0.317	0.01	2.244	3.39	15.887	23.82	112.468	41.00		
0.050	0.00	0.356	0.05	2.518	3.96	17.825	24.96	126.191	42.82		
0.056	0.00	0.399	0.11	2.825	4.63	20.000	26.03	141.589	44.92		
0.063	0.00	0.448	0.20	3.170	5.41	22.440	27.03	158.866	47.30		
0.071	0.00	0.502	0.31	3.557	6.31	25.179	27.97	178.250	49.95		
0.080	0.00	0.564	0.43	3.991	7.33	28.251	28.87	200.000	52.85		
0.089	0.00	0.632	0.57	4.477	8.47	31.698	29.73	224.404	55.93		
0.100	0.00	0.710	0.73	5.024	9.72	35.566	30.57	251.785	59.13		
0.112	0.00	0.796	0.89	5.637	11.06	39.905	31.39	282.508	62.33		
0.126	0.00	0.893	1.06	6.325	12.49	44.774	32.22	316.979	65.43		

Note: Data from 500µm to 10000µm by wet screening, from 0.02µm to 500µm by laser diffraction.

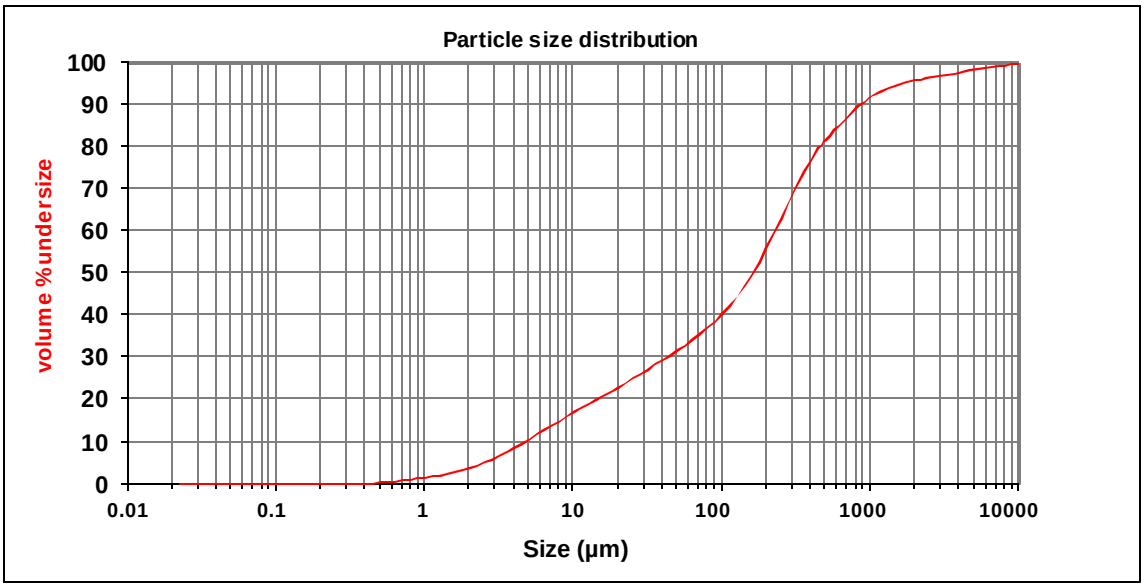
Analysed:	Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)
Reported:	Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)
Approved:	Michael Simeoni, B.Sc.(Chemistry), M.Sc. (Science Administration), Ph.D.

37 Kensington Street
East Perth
WA 6004

Client:	AECOM Australia Pty Ltd
Sample Name :	CS020P
Batch No :	16_1453
Lab ID No :	16_1453_20

Analysis :	Size distribution by laser diffraction following ISO13320-1:2009 and wet sieving	**Result units:**	Volume
Dispersant:	Water	**Analysis model:**	General purpose
Additives:	10 millilitres sodium hexametaphosphate	**Total sample wt (g):**	20.974
Sonication:	5 min sonication		

Span:	5.57	**Vol. Weighted mean D[4,3]:**	426.02 µm	**d(0.1)**	4.68 µm
		Surface weighted mean D[3,2]	12.25 µm	**d(0.5)**	161.40 µm
				d(0.9)	903.91 µm



Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %
0.020	0.00	0.142	0.00	1.002	1.52	7.096	13.86	50.238	31.79	355.66	74.05
0.022	0.00	0.159	0.00	1.125	1.80	7.962	14.91	56.368	33.00	399.05	77.12
0.025	0.00	0.178	0.00	1.262	2.11	8.934	15.95	63.246	34.26	447.74	79.75
0.028	0.00	0.200	0.00	1.416	2.46	10.024	16.97	70.963	35.60	500.00	81.86
0.032	0.00	0.224	0.00	1.589	2.86	11.247	17.97	79.621	37.04	1000.00	91.94
0.036	0.00	0.252	0.00	1.783	3.33	12.619	18.96	89.337	38.60	2000.00	95.91
0.040	0.00	0.283	0.00	2.000	3.86	14.159	19.95	100.237	40.33	10000.00	100.00
0.045	0.00	0.317	0.01	2.244	4.46	15.887	20.95	112.468	42.25		
0.050	0.00	0.356	0.05	2.518	5.15	17.825	21.95	126.191	44.42		
0.056	0.00	0.399	0.13	2.825	5.91	20.000	22.97	141.589	46.86		
0.063	0.00	0.448	0.22	3.170	6.75	22.440	24.01	158.866	49.60		
0.071	0.00	0.502	0.35	3.557	7.65	25.179	25.07	178.250	52.65		
0.080	0.00	0.564	0.49	3.991	8.61	28.251	26.14	200.000	55.99		
0.089	0.00	0.632	0.66	4.477	9.62	31.698	27.23	224.404	59.56		
0.100	0.00	0.710	0.84	5.024	10.66	35.566	28.34	251.785	63.26		
0.112	0.00	0.796	1.05	5.637	11.73	39.905	29.47	282.508	67.00		
0.126	0.00	0.893	1.27	6.325	12.79	44.774	30.61	316.979	70.64		

Note: Data from 500µm to 10000µm by wet screening, from 0.02µm to 500µm by laser diffraction.

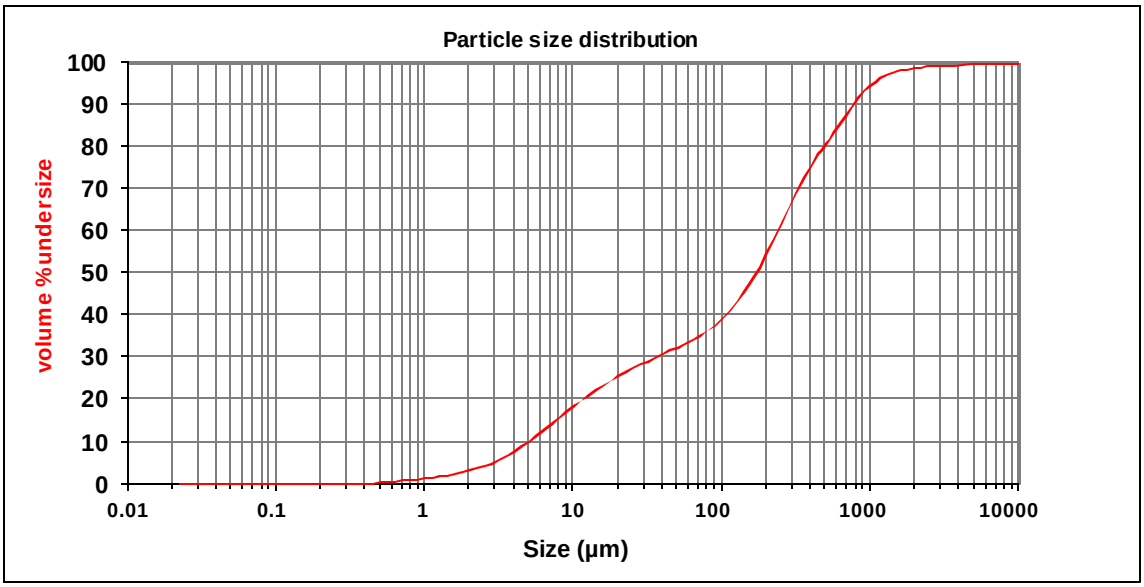
Analysed:	Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)
Reported:	Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)
Approved:	Michael Simeoni, B.Sc.(Chemistry), M.Sc. (Science Administration), Ph.D.

37 Kensington Street
East Perth
WA 6004

Client:	AECOM Australia Pty Ltd
Sample Name :	CS021P
Batch No :	16_1453
Lab ID No :	16_1453_21

Analysis :	Size distribution by laser diffraction following ISO13320-1:2009 and wet sieving	**Result units:**	Volume
Dispersant:	Water	**Analysis model:**	General purpose
Additives:	10 millilitres sodium hexametaphosphate	**Total sample wt (g):**	11.8408
Sonication:	2 min sonication		

Span:	4.89	**Vol. Weighted mean D[4,3]:**	325.23 µm	**d(0.1)**	4.96 µm
		Surface weighted mean D[3,2]	12.82 µm	**d(0.5)**	169.23 µm
				d(0.9)	832.65 µm



Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %
0.020	0.00	0.142	0.00	1.002	1.31	7.096	14.24	50.238	32.47	355.66	72.61
0.022	0.00	0.159	0.00	1.125	1.52	7.962	15.66	56.368	33.32	399.05	75.71
0.025	0.00	0.178	0.00	1.262	1.76	8.934	17.08	63.246	34.23	447.74	78.41
0.028	0.00	0.200	0.00	1.416	2.03	10.024	18.46	70.963	35.24	500.00	80.65
0.032	0.00	0.224	0.00	1.589	2.34	11.247	19.80	79.621	36.38	1000.00	94.70
0.036	0.00	0.252	0.00	1.783	2.71	12.619	21.07	89.337	37.71	2000.00	98.80
0.040	0.00	0.283	0.00	2.000	3.15	14.159	22.29	100.237	39.25	10000.00	100.00
0.045	0.00	0.317	0.01	2.244	3.66	15.887	23.43	112.468	41.07		
0.050	0.00	0.356	0.05	2.518	4.27	17.825	24.51	126.191	43.18		
0.056	0.00	0.399	0.12	2.825	4.98	20.000	25.53	141.589	45.61		
0.063	0.00	0.448	0.21	3.170	5.80	22.440	26.50	158.866	48.36		
0.071	0.00	0.502	0.32	3.557	6.73	25.179	27.43	178.250	51.43		
0.080	0.00	0.564	0.45	3.991	7.77	28.251	28.32	200.000	54.76		
0.089	0.00	0.632	0.60	4.477	8.91	31.698	29.18	224.404	58.29		
0.100	0.00	0.710	0.76	5.024	10.15	35.566	30.02	251.785	61.95		
0.112	0.00	0.796	0.93	5.637	11.46	39.905	30.84	282.508	65.62		
0.126	0.00	0.893	1.11	6.325	12.83	44.774	31.65	316.979	69.21		

Note: Data from 500µm to 10000µm by wet screening, from 0.02µm to 500µm by laser diffraction.

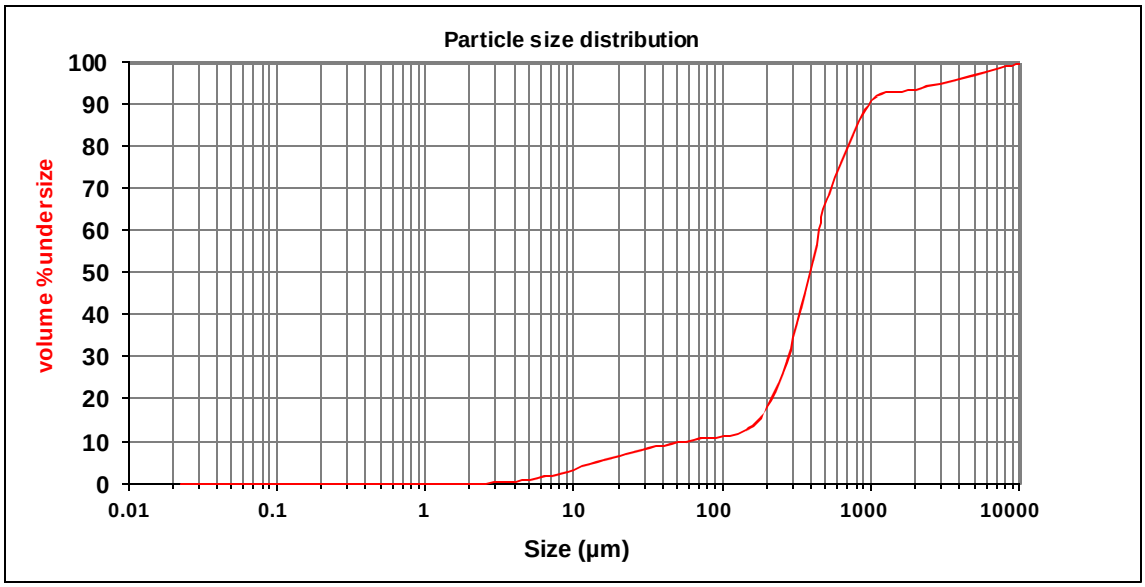
Analysed:	Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)
Reported:	Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)
Approved:	Michael Simeoni, B.Sc.(Chemistry), M.Sc. (Science Administration), Ph.D.

37 Kensington Street
East Perth
WA 6004

Client:	AECOM Australia Pty Ltd
Sample Name :	CS022P
Batch No :	16_1453
Lab ID No :	16_1453_22

Analysis :	Size distribution by laser diffraction following ISO13320-1:2009 and wet sieving	**Result units:**	Volume
Dispersant:	Water	**Analysis model:**	General purpose
Additives:	10 millilitres sodium hexametaphosphate	**Total sample wt (g):**	16.2791
Sonication:	0 min sonication		

Span:	2.43	**Vol. Weighted mean D[4,3]:**	668.06 µm	**d(0.1)**	52.81 µm
		Surface weighted mean D[3,2]	77.90 µm	**d(0.5)**	381.70 µm
				d(0.9)	979.29 µm



Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %
0.020	0.00	0.142	0.00	1.002	0.00	7.096	2.15	50.238	9.87	355.66	45.48
0.022	0.00	0.159	0.00	1.125	0.00	7.962	2.57	56.368	10.19	399.05	53.01
0.025	0.00	0.178	0.00	1.262	0.00	8.934	3.05	63.246	10.48	447.74	60.56
0.028	0.00	0.200	0.00	1.416	0.00	10.024	3.56	70.963	10.74	500.00	67.76
0.032	0.00	0.224	0.00	1.589	0.00	11.247	4.10	79.621	10.97	1000.00	90.96
0.036	0.00	0.252	0.00	1.783	0.03	12.619	4.66	89.337	11.16	2000.00	93.74
0.040	0.00	0.283	0.00	2.000	0.09	14.159	5.21	100.237	11.36	10000.00	100.00
0.045	0.00	0.317	0.00	2.244	0.15	15.887	5.76	112.468	11.61		
0.050	0.00	0.356	0.00	2.518	0.23	17.825	6.29	126.191	12.03		
0.056	0.00	0.399	0.00	2.825	0.32	20.000	6.79	141.589	12.74		
0.063	0.00	0.448	0.00	3.170	0.43	22.440	7.26	158.866	13.90		
0.071	0.00	0.502	0.00	3.557	0.56	25.179	7.69	178.250	15.69		
0.080	0.00	0.564	0.00	3.991	0.72	28.251	8.10	200.000	18.28		
0.089	0.00	0.632	0.00	4.477	0.92	31.698	8.47	224.404	21.80		
0.100	0.00	0.710	0.00	5.024	1.15	35.566	8.83	251.785	26.34		
0.112	0.00	0.796	0.00	5.637	1.44	39.905	9.19	282.508	31.89		
0.126	0.00	0.893	0.00	6.325	1.77	44.774	9.53	316.979	38.34		

Note: Data from 500µm to 10000µm by wet screening, from 0.02µm to 500µm by laser diffraction.

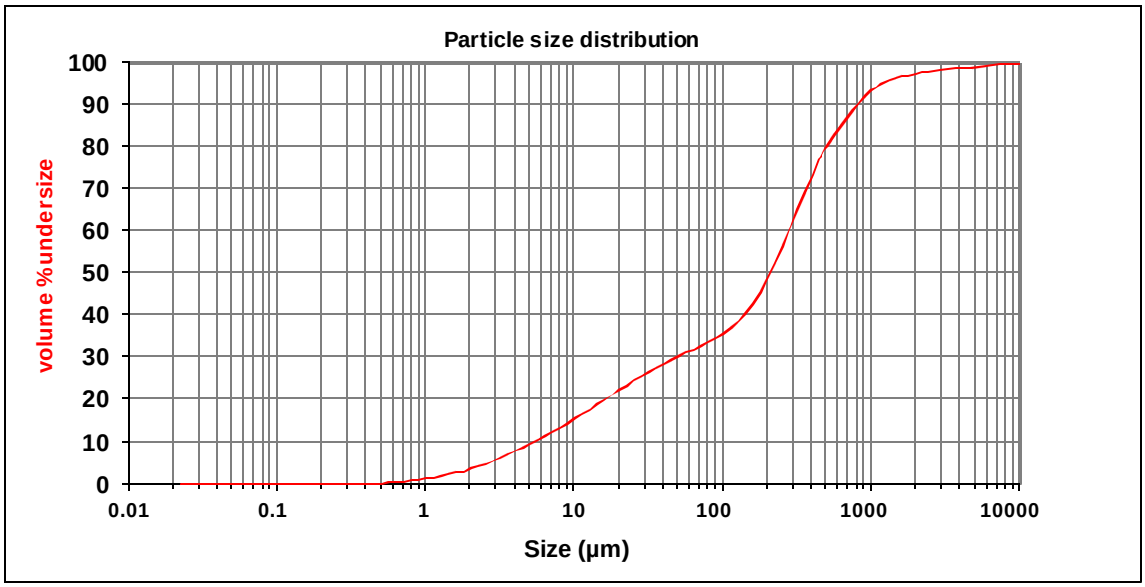
Analysed:	Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)
Reported:	Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)
Approved:	Michael Simeoni, B.Sc.(Chemistry), M.Sc. (Science Administration), Ph.D.

37 Kensington Street
East Perth
WA 6004

Client:	AECOM Australia Pty Ltd
Sample Name :	CS023P
Batch No :	16_1453
Lab ID No :	16_1453_23

Analysis :	Size distribution by laser diffraction following ISO13320-1:2009 and wet sieving	**Result units:**	Volume
Dispersant:	Water	**Analysis model:**	General purpose
Additives:	10 millilitres sodium hexametaphosphate	**Total sample wt (g):**	19.0234
Sonication:	4 min sonication		

Span:	4.14	**Vol. Weighted mean D[4,3]:**	392.84 µm	**d(0.1)**	5.30 µm
		Surface weighted mean D[3,2]	13.53 µm	**d(0.5)**	208.15 µm
				d(0.9)	867.85 µm



Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %
0.020	0.00	0.142	0.00	1.002	1.32	7.096	12.42	50.238	30.34	355.66	69.46
0.022	0.00	0.159	0.00	1.125	1.59	7.962	13.41	56.368	31.17	399.05	73.55
0.025	0.00	0.178	0.00	1.262	1.90	8.934	14.44	63.246	31.99	447.74	77.23
0.028	0.00	0.200	0.00	1.416	2.25	10.024	15.51	70.963	32.83	500.00	80.37
0.032	0.00	0.224	0.00	1.589	2.65	11.247	16.60	79.621	33.70	1000.00	93.46
0.036	0.00	0.252	0.00	1.783	3.10	12.619	17.72	89.337	34.66	2000.00	97.47
0.040	0.00	0.283	0.00	2.000	3.61	14.159	18.87	100.237	35.75	10000.00	100.00
0.045	0.00	0.317	0.00	2.244	4.18	15.887	20.03	112.468	37.03		
0.050	0.00	0.356	0.00	2.518	4.81	17.825	21.19	126.191	38.59		
0.056	0.00	0.399	0.06	2.825	5.49	20.000	22.35	141.589	40.49		
0.063	0.00	0.448	0.14	3.170	6.23	22.440	23.49	158.866	42.79		
0.071	0.00	0.502	0.24	3.557	7.01	25.179	24.60	178.250	45.55		
0.080	0.00	0.564	0.36	3.991	7.84	28.251	25.67	200.000	48.78		
0.089	0.00	0.632	0.51	4.477	8.70	31.698	26.69	224.404	52.44		
0.100	0.00	0.710	0.67	5.024	9.58	35.566	27.67	251.785	56.47		
0.112	0.00	0.796	0.86	5.637	10.50	39.905	28.60	282.508	60.75		
0.126	0.00	0.893	1.08	6.325	11.45	44.774	29.49	316.979	65.14		

Note: Data from 500µm to 10000µm by wet screening, from 0.02µm to 500µm by laser diffraction.

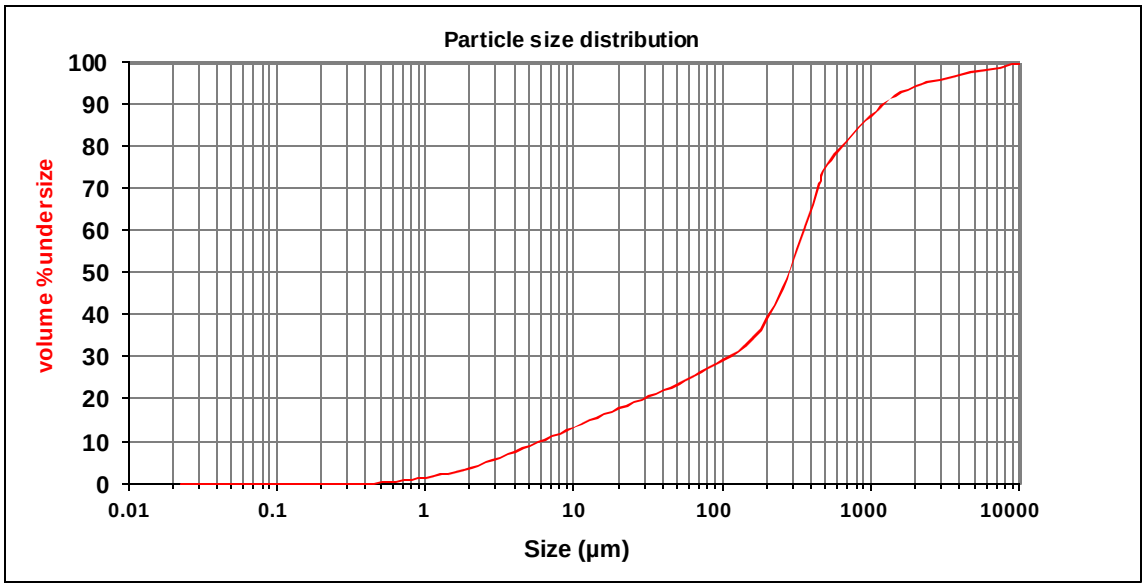
Analysed: Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)
Reported: Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)
Approved: Michael Simeoni, B.Sc.(Chemistry), M.Sc. (Science Administration), Ph.D.

37 Kensington Street
East Perth
WA 6004

Client:	AECOM Australia Pty Ltd
Sample Name :	CS024P
Batch No :	16_1453
Lab ID No :	16_1453_24

Analysis :	Size distribution by laser diffraction following ISO13320-1:2009 and wet sieving	**Result units:**	Volume
Dispersant:	Water	**Analysis model:**	General purpose
Additives:	10 millilitres sodium hexametaphosphate	**Total sample wt (g):**	24.0052
Sonication:	5 min sonication		

Span:	4.86	**Vol. Weighted mean D[4,3]:**	570.96 µm	**d(0.1)**	5.76 µm
		Surface weighted mean D[3,2]	13.88 µm	**d(0.5)**	276.04 µm
				d(0.9)	1348.65 µm



Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %
0.020	0.00	0.142	0.00	1.002	1.54	7.096	11.34	50.238	23.80	355.66	60.99
0.022	0.00	0.159	0.00	1.125	1.84	7.962	12.08	56.368	24.68	399.05	66.21
0.025	0.00	0.178	0.00	1.262	2.17	8.934	12.83	63.246	25.59	447.74	71.21
0.028	0.00	0.200	0.00	1.416	2.54	10.024	13.58	70.963	26.53	500.00	75.78
0.032	0.00	0.224	0.00	1.589	2.94	11.247	14.33	79.621	27.47	1000.00	87.57
0.036	0.00	0.252	0.00	1.783	3.40	12.619	15.09	89.337	28.42	2000.00	94.54
0.040	0.00	0.283	0.00	2.000	3.89	14.159	15.84	100.237	29.38	10000.00	100.00
0.045	0.00	0.317	0.01	2.244	4.43	15.887	16.58	112.468	30.41		
0.050	0.00	0.356	0.05	2.518	5.02	17.825	17.30	126.191	31.55		
0.056	0.00	0.399	0.12	2.825	5.64	20.000	18.00	141.589	32.91		
0.063	0.00	0.448	0.21	3.170	6.30	22.440	18.69	158.866	34.59		
0.071	0.00	0.502	0.33	3.557	6.98	25.179	19.37	178.250	36.71		
0.080	0.00	0.564	0.47	3.991	7.69	28.251	20.04	200.000	39.36		
0.089	0.00	0.632	0.63	4.477	8.41	31.698	20.72	224.404	42.62		
0.100	0.00	0.710	0.82	5.024	9.13	35.566	21.43	251.785	46.49		
0.112	0.00	0.796	1.04	5.637	9.87	39.905	22.17	282.508	50.94		
0.126	0.00	0.893	1.28	6.325	10.60	44.774	22.96	316.979	55.83		

Note: Data from 500µm to 10000µm by wet screening, from 0.02µm to 500µm by laser diffraction.

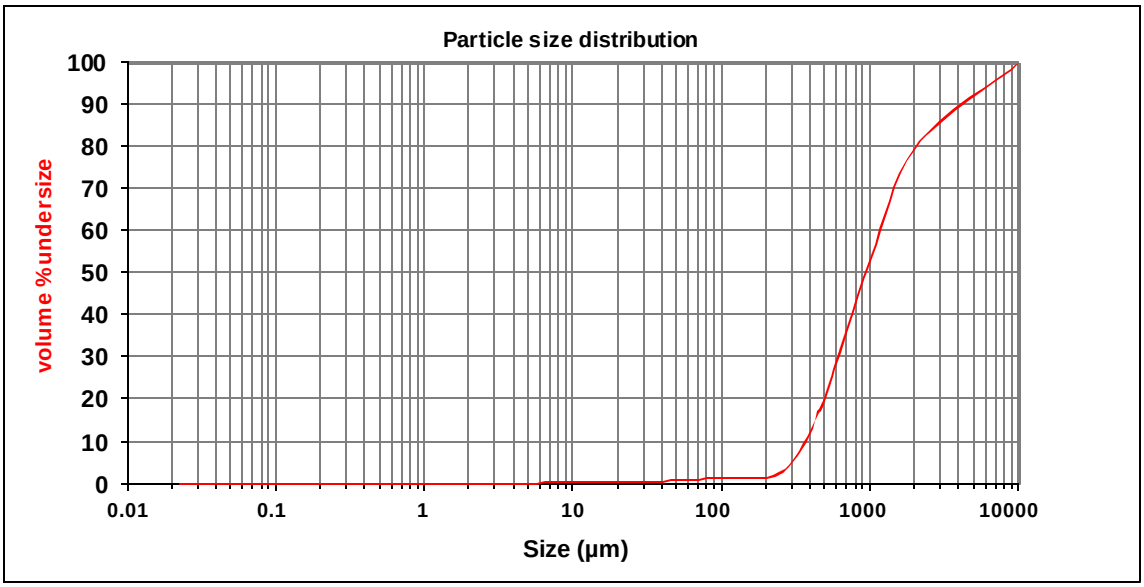
Analysed:	Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)
Reported:	Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)
Approved:	Michael Simeoni, B.Sc.(Chemistry), M.Sc. (Science Administration), Ph.D.

37 Kensington Street
East Perth
WA 6004

Client:	AECOM Australia Pty Ltd
Sample Name :	CS025P
Batch No :	16_1453
Lab ID No :	16_1453_25

Analysis :	Size distribution by laser diffraction following ISO13320-1:2009 and wet sieving	**Result units:**	Volume
Dispersant:	Water	**Analysis model:**	General purpose
Additives:	10 millilitres sodium hexametaphosphate	**Total sample wt (g):**	65.9183
Sonication:	4 min sonication		

Span:	5.54	**Vol. Weighted mean D[4,3]:**	1575.02 µm	**d(0.1)**	726.54 µm
		Surface weighted mean D[3,2]	382.81 µm	**d(0.5)**	951.74 µm
				d(0.9)	5999.83 µm



Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %
0.020	0.00	0.142	0.00	1.002	0.00	7.096	0.31	50.238	0.84	355.66	9.42
0.022	0.00	0.159	0.00	1.125	0.00	7.962	0.34	56.368	0.94	399.05	13.08
0.025	0.00	0.178	0.00	1.262	0.00	8.934	0.37	63.246	1.05	447.74	17.13
0.028	0.00	0.200	0.00	1.416	0.00	10.024	0.41	70.963	1.15	500.00	21.22
0.032	0.00	0.224	0.00	1.589	0.00	11.247	0.44	79.621	1.24	1000.00	53.07
0.036	0.00	0.252	0.00	1.783	0.01	12.619	0.47	89.337	1.29	2000.00	80.00
0.040	0.00	0.283	0.00	2.000	0.04	14.159	0.51	100.237	1.31	10000.00	100.00
0.045	0.00	0.317	0.00	2.244	0.06	15.887	0.54	112.468	1.31		
0.050	0.00	0.356	0.00	2.518	0.08	17.825	0.56	126.191	1.31		
0.056	0.00	0.399	0.00	2.825	0.11	20.000	0.59	141.589	1.31		
0.063	0.00	0.448	0.00	3.170	0.13	22.440	0.61	158.866	1.31		
0.071	0.00	0.502	0.00	3.557	0.16	25.179	0.62	178.250	1.31		
0.080	0.00	0.564	0.00	3.991	0.19	28.251	0.62	200.000	1.44		
0.089	0.00	0.632	0.00	4.477	0.21	31.698	0.63	224.404	1.84		
0.100	0.00	0.710	0.00	5.024	0.24	35.566	0.66	251.785	2.69		
0.112	0.00	0.796	0.00	5.637	0.26	39.905	0.70	282.508	4.17		
0.126	0.00	0.893	0.00	6.325	0.29	44.774	0.76	316.979	6.41		

Note: Data from 500µm to 10000µm by wet screening, from 0.02µm to 500µm by laser diffraction.

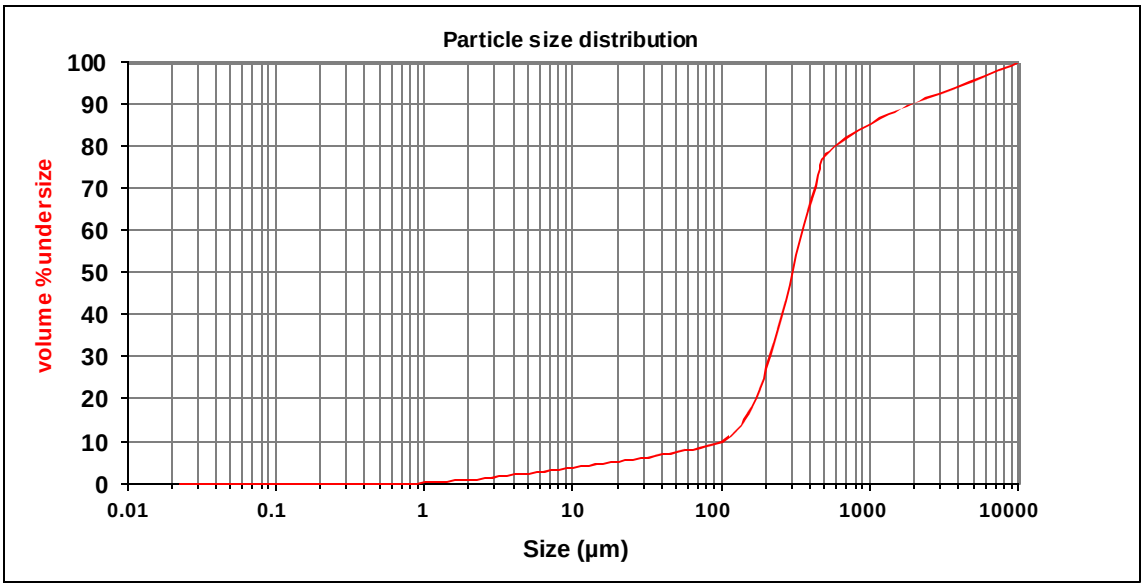
Analysed:	Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)
Reported:	Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)
Approved:	Michael Simeoni, B.Sc.(Chemistry), M.Sc. (Science Administration), Ph.D.

37 Kensington Street
East Perth
WA 6004

Client:	AECOM Australia Pty Ltd
Sample Name :	CS026P
Batch No :	16_1453
Lab ID No :	16_1453_26

Analysis :	Size distribution by laser diffraction following ISO13320-1:2009 and wet sieving	**Result units:**	Volume
Dispersant:	Water	**Analysis model:**	General purpose
Additives:	10 millilitres sodium hexametaphosphate	**Total sample wt (g):**	66.2784
Sonication:	8 min sonication		

Span:	6.06	**Vol. Weighted mean D[4,3]:**	737.63 µm	**d(0.1)**	97.63 µm
		Surface weighted mean D[3,2]	47.39 µm	**d(0.5)**	295.72 µm
				d(0.9)	1890.26 µm



Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %
0.020	0.00	0.142	0.00	1.002	0.32	7.096	3.26	50.238	7.69	355.66	61.43
0.022	0.00	0.159	0.00	1.125	0.41	7.962	3.49	56.368	8.02	399.05	67.91
0.025	0.00	0.178	0.00	1.262	0.51	8.934	3.71	63.246	8.33	447.74	73.60
0.028	0.00	0.200	0.00	1.416	0.63	10.024	3.94	70.963	8.64	500.00	78.34
0.032	0.00	0.224	0.00	1.589	0.75	11.247	4.16	79.621	9.00	1000.00	85.69
0.036	0.00	0.252	0.00	1.783	0.89	12.619	4.39	89.337	9.47	2000.00	90.53
0.040	0.00	0.283	0.00	2.000	1.04	14.159	4.60	100.237	10.17	10000.00	100.00
0.045	0.00	0.317	0.00	2.244	1.21	15.887	4.82	112.468	11.24		
0.050	0.00	0.356	0.00	2.518	1.38	17.825	5.04	126.191	12.87		
0.056	0.00	0.399	0.00	2.825	1.56	20.000	5.26	141.589	15.19		
0.063	0.00	0.448	0.00	3.170	1.76	22.440	5.49	158.866	18.38		
0.071	0.00	0.502	0.00	3.557	1.96	25.179	5.74	178.250	22.50		
0.080	0.00	0.564	0.00	3.991	2.16	28.251	6.02	200.000	27.58		
0.089	0.00	0.632	0.04	4.477	2.37	31.698	6.32	224.404	33.52		
0.100	0.00	0.710	0.10	5.024	2.59	35.566	6.64	251.785	40.16		
0.112	0.00	0.796	0.16	5.637	2.81	39.905	6.99	282.508	47.24		
0.126	0.00	0.893	0.24	6.325	3.03	44.774	7.34	316.979	54.44		

Note: Data from 500µm to 10000µm by wet screening, from 0.02µm to 500µm by laser diffraction.

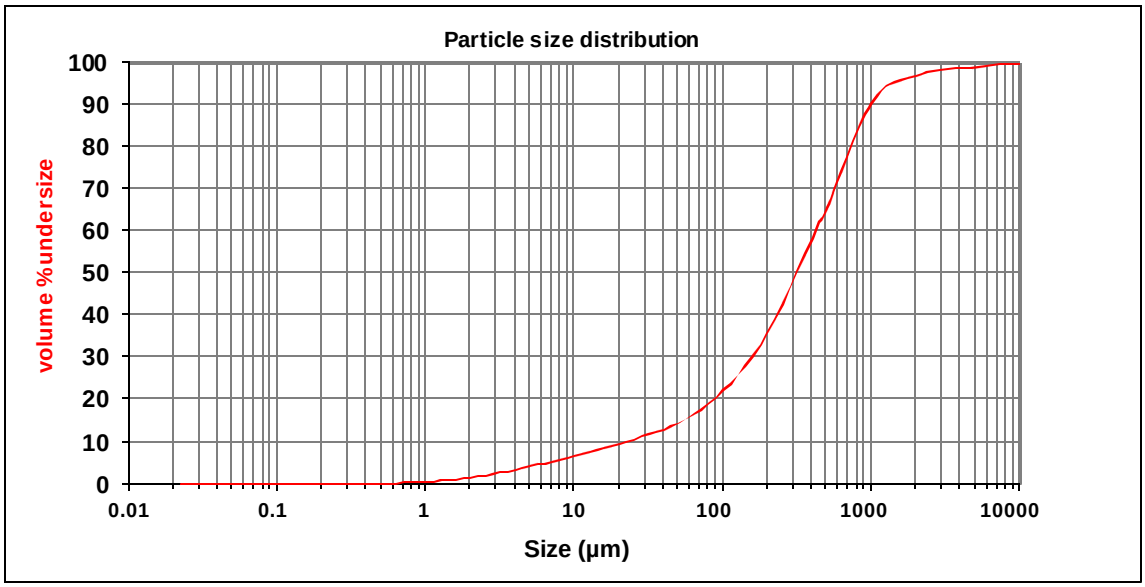
Analysed: Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)
Reported: Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)
Approved: Michael Simeoni, B.Sc.(Chemistry), M.Sc. (Science Administration), Ph.D.

37 Kensington Street
East Perth
WA 6004

Client:	AECOM Australia Pty Ltd
Sample Name :	CS027P
Batch No :	16_1453
Lab ID No :	16_1453_27

Analysis :	Size distribution by laser diffraction following ISO13320-1:2009 and wet sieving	**Result units:**	Volume
Dispersant:	Water	**Analysis model:**	General purpose
Additives:	10 millilitres sodium hexametaphosphate	**Total sample wt (g):**	78.5651
Sonication:	4 min sonication		

Span:	3.11	**Vol. Weighted mean D[4,3]:**	525.05 µm	**d(0.1)**	21.35 µm
		Surface weighted mean D[3,2]	29.08 µm	**d(0.5)**	312.62 µm
				d(0.9)	992.34 µm



Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %
0.020	0.00	0.142	0.00	1.002	0.58	7.096	5.40	50.238	14.49	355.66	54.57
0.022	0.00	0.159	0.00	1.125	0.70	7.962	5.84	56.368	15.44	399.05	58.54
0.025	0.00	0.178	0.00	1.262	0.84	8.934	6.29	63.246	16.52	447.74	62.26
0.028	0.00	0.200	0.00	1.416	1.00	10.024	6.76	70.963	17.74	500.00	65.58
0.032	0.00	0.224	0.00	1.589	1.17	11.247	7.24	79.621	19.09	1000.00	90.38
0.036	0.00	0.252	0.00	1.783	1.37	12.619	7.74	89.337	20.57	2000.00	97.14
0.040	0.00	0.283	0.00	2.000	1.59	14.159	8.23	100.237	22.19	10000.00	100.00
0.045	0.00	0.317	0.00	2.244	1.84	15.887	8.73	112.468	23.95		
0.050	0.00	0.356	0.00	2.518	2.11	17.825	9.23	126.191	25.86		
0.056	0.00	0.399	0.00	2.825	2.41	20.000	9.73	141.589	27.97		
0.063	0.00	0.448	0.02	3.170	2.72	22.440	10.22	158.866	30.31		
0.071	0.00	0.502	0.07	3.557	3.06	25.179	10.71	178.250	32.93		
0.080	0.00	0.564	0.13	3.991	3.41	28.251	11.21	200.000	35.85		
0.089	0.00	0.632	0.20	4.477	3.78	31.698	11.74	224.404	39.10		
0.100	0.00	0.710	0.28	5.024	4.17	35.566	12.31	251.785	42.67		
0.112	0.00	0.796	0.37	5.637	4.57	39.905	12.94	282.508	46.50		
0.126	0.00	0.893	0.47	6.325	4.98	44.774	13.67	316.979	50.51		

Note: Data from 500µm to 10000µm by wet screening, from 0.02µm to 500µm by laser diffraction.

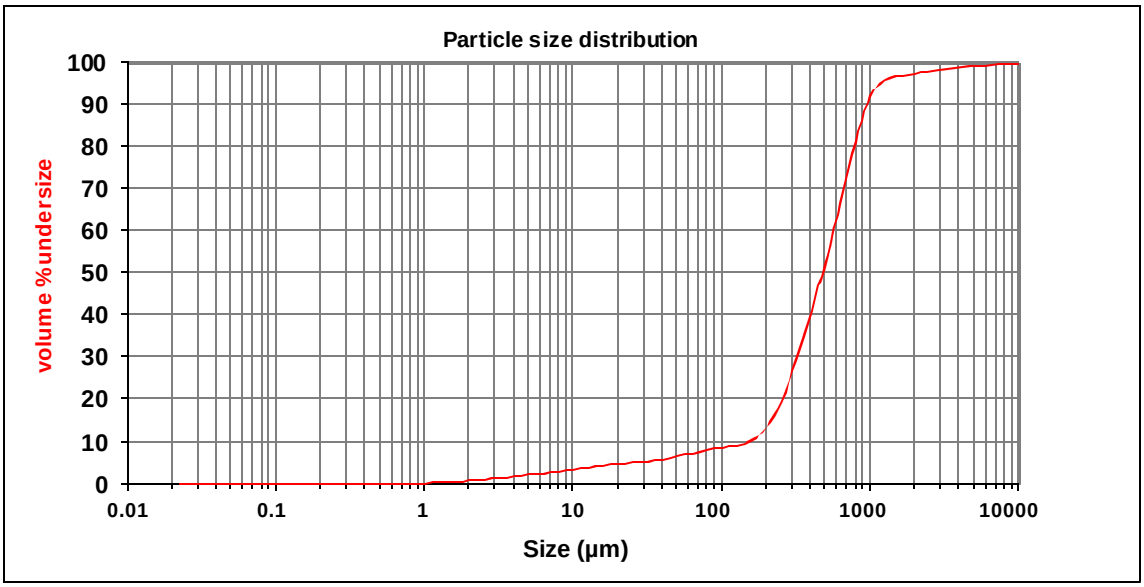
Analysed:	Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)
Reported:	Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)
Approved:	Michael Simeoni, B.Sc.(Chemistry), M.Sc. (Science Administration), Ph.D.

37 Kensington Street
East Perth
WA 6004

Client:	AECOM Australia Pty Ltd
Sample Name :	CS028P
Batch No :	16_1453
Lab ID No :	16_1453_28

Analysis :	Size distribution by laser diffraction following ISO13320-1:2009 and wet sieving	**Result units:**	Volume
Dispersant:	Water	**Analysis model:**	General purpose
Additives:	10 millilitres sodium hexametaphosphate	**Total sample wt (g):**	80.1468
Sonication:	6 min sonication		

Span:	1.74	**Vol. Weighted mean D[4,3]:**	607.99 µm	**d(0.1)**	150.03 µm
		Surface weighted mean D[3,2]	57.17 µm	**d(0.5)**	473.73 µm
				d(0.9)	972.79 µm



Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %
0.020	0.00	0.142	0.00	1.002	0.24	7.096	2.83	50.238	6.60	355.66	35.20
0.022	0.00	0.159	0.00	1.125	0.32	7.962	3.04	56.368	6.98	399.05	41.23
0.025	0.00	0.178	0.00	1.262	0.40	8.934	3.25	63.246	7.38	447.74	47.21
0.028	0.00	0.200	0.00	1.416	0.50	10.024	3.47	70.963	7.77	500.00	52.82
0.032	0.00	0.224	0.00	1.589	0.61	11.247	3.69	79.621	8.12	1000.00	92.14
0.036	0.00	0.252	0.00	1.783	0.73	12.619	3.91	89.337	8.42	2000.00	97.62
0.040	0.00	0.283	0.00	2.000	0.86	14.159	4.13	100.237	8.66	10000.00	100.00
0.045	0.00	0.317	0.00	2.244	1.01	15.887	4.34	112.468	8.89		
0.050	0.00	0.356	0.00	2.518	1.16	17.825	4.54	126.191	9.18		
0.056	0.00	0.399	0.00	2.825	1.33	20.000	4.73	141.589	9.63		
0.063	0.00	0.448	0.00	3.170	1.50	22.440	4.91	158.866	10.39		
0.071	0.00	0.502	0.00	3.557	1.68	25.179	5.09	178.250	11.64		
0.080	0.00	0.564	0.00	3.991	1.86	28.251	5.27	200.000	13.54		
0.089	0.00	0.632	0.03	4.477	2.05	31.698	5.47	224.404	16.24		
0.100	0.00	0.710	0.07	5.024	2.24	35.566	5.69	251.785	19.81		
0.112	0.00	0.796	0.12	5.637	2.43	39.905	5.95	282.508	24.25		
0.126	0.00	0.893	0.18	6.325	2.63	44.774	6.25	316.979	29.44		

Note: Data from 500µm to 10000µm by wet screening, from 0.02µm to 500µm by laser diffraction.

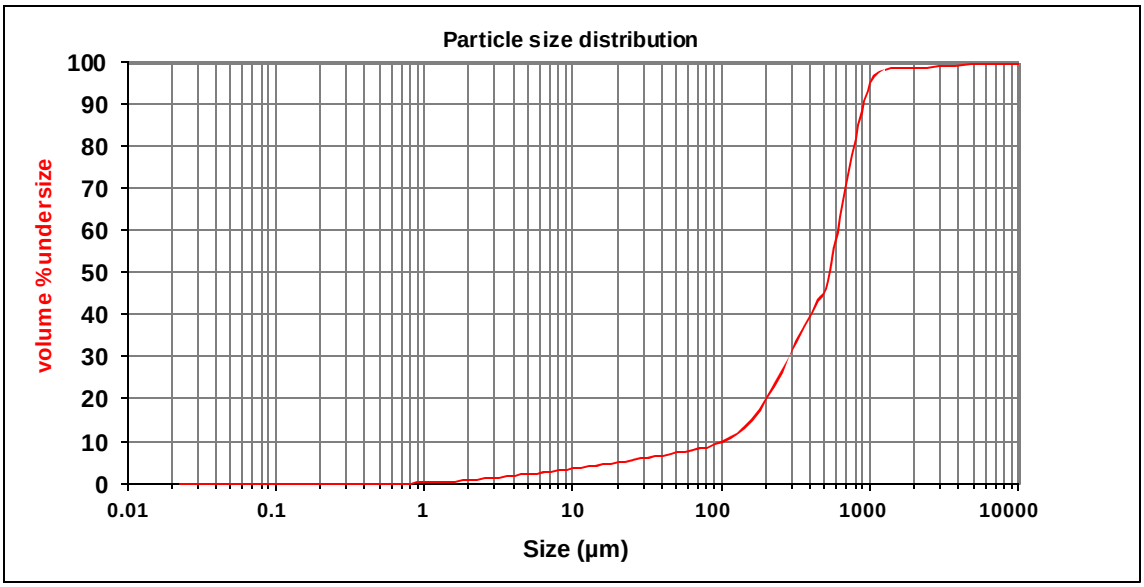
Analysed:	Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)
Reported:	Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)
Approved:	Michael Simeoni, B.Sc.(Chemistry), M.Sc. (Science Administration), Ph.D.

37 Kensington Street
East Perth
WA 6004

Client:	AECOM Australia Pty Ltd
Sample Name :	CS029P
Batch No :	16_1453
Lab ID No :	16_1453_29

Analysis :	Size distribution by laser diffraction following ISO13320-1:2009 and wet sieving	**Result units:**	Volume
Dispersant:	Water	**Analysis model:**	General purpose
Additives:	10 millilitres sodium hexametaphosphate	**Total sample wt (g):**	117.5552
Sonication:	6 min sonication		

Span:	1.57	**Vol. Weighted mean D[4,3]:**	555.09 µm	**d(0.1)**	100.65 µm
		Surface weighted mean D[3,2]	49.37 µm	**d(0.5)**	536.71 µm
				d(0.9)	945.01 µm



Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %
0.020	0.00	0.142	0.00	1.002	0.36	7.096	3.02	50.238	7.40	355.66	37.37
0.022	0.00	0.159	0.00	1.125	0.44	7.962	3.25	56.368	7.70	399.05	40.75
0.025	0.00	0.178	0.00	1.262	0.52	8.934	3.48	63.246	8.02	447.74	43.80
0.028	0.00	0.200	0.00	1.416	0.61	10.024	3.71	70.963	8.38	500.00	46.40
0.032	0.00	0.224	0.00	1.589	0.72	11.247	3.94	79.621	8.79	1000.00	95.39
0.036	0.00	0.252	0.00	1.783	0.84	12.619	4.18	89.337	9.31	2000.00	98.70
0.040	0.00	0.283	0.00	2.000	0.96	14.159	4.43	100.237	9.97	10000.00	100.00
0.045	0.00	0.317	0.00	2.244	1.10	15.887	4.67	112.468	10.84		
0.050	0.00	0.356	0.00	2.518	1.26	17.825	4.93	126.191	11.97		
0.056	0.00	0.399	0.00	2.825	1.42	20.000	5.18	141.589	13.44		
0.063	0.00	0.448	0.01	3.170	1.59	22.440	5.44	158.866	15.28		
0.071	0.00	0.502	0.04	3.557	1.78	25.179	5.70	178.250	17.52		
0.080	0.00	0.564	0.08	3.991	1.97	28.251	5.98	200.000	20.18		
0.089	0.00	0.632	0.12	4.477	2.17	31.698	6.25	224.404	23.22		
0.100	0.00	0.710	0.17	5.024	2.38	35.566	6.53	251.785	26.57		
0.112	0.00	0.796	0.23	5.637	2.59	39.905	6.82	282.508	30.13		
0.126	0.00	0.893	0.29	6.325	2.80	44.774	7.11	316.979	33.78		

Note: Data from 500µm to 10000µm by wet screening, from 0.02µm to 500µm by laser diffraction.

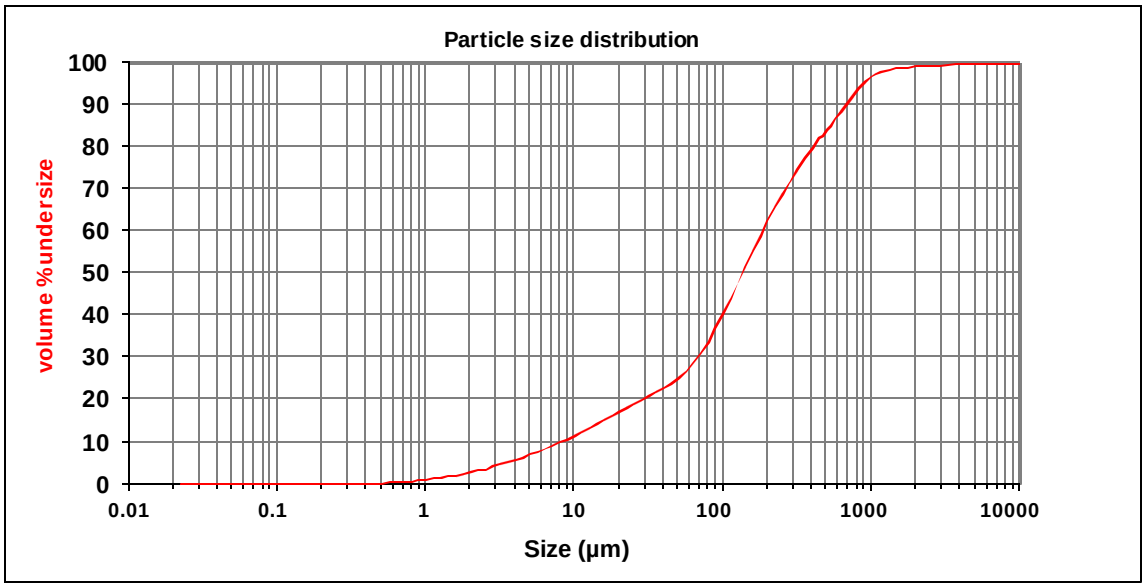
Analysed: Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)
Reported: Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)
Approved: Michael Simeoni, B.Sc.(Chemistry), M.Sc. (Science Administration), Ph.D.

37 Kensington Street
East Perth
WA 6004

Client:	AECOM Australia Pty Ltd
Sample Name :	CS030P
Batch No :	16_1453
Lab ID No :	16_1453_30

Analysis :	Size distribution by laser diffraction following ISO13320-1:2009 and wet sieving	**Result units:**	Volume
Dispersant:	Water	**Analysis model:**	General purpose
Additives:	10 millilitres sodium hexametaphosphate	**Total sample wt (g):**	61.8297
Sonication:	4 min sonication		

Span:	5.94	**Vol. Weighted mean D[4,3]:**	278.47 µm	**d(0.1)**	8.16 µm
		Surface weighted mean D[3,2]	17.06 µm	**d(0.5)**	122.43 µm
				d(0.9)	734.99 µm



Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %
0.020	0.00	0.142	0.00	1.002	1.02	7.096	9.08	50.238	25.14	355.66	77.35
0.022	0.00	0.159	0.00	1.125	1.22	7.962	9.84	56.368	26.76	399.05	79.83
0.025	0.00	0.178	0.00	1.262	1.45	8.934	10.64	63.246	28.74	447.74	82.07
0.028	0.00	0.200	0.00	1.416	1.71	10.024	11.49	70.963	31.10	500.00	84.04
0.032	0.00	0.224	0.00	1.589	2.00	11.247	12.39	79.621	33.85	1000.00	96.72
0.036	0.00	0.252	0.00	1.783	2.33	12.619	13.33	89.337	36.97	2000.00	99.11
0.040	0.00	0.283	0.00	2.000	2.71	14.159	14.30	100.237	40.39	10000.00	100.00
0.045	0.00	0.317	0.00	2.244	3.12	15.887	15.30	112.468	44.02		
0.050	0.00	0.356	0.00	2.518	3.58	17.825	16.30	126.191	47.78		
0.056	0.00	0.399	0.04	2.825	4.07	20.000	17.28	141.589	51.56		
0.063	0.00	0.448	0.11	3.170	4.60	22.440	18.22	158.866	55.30		
0.071	0.00	0.502	0.19	3.557	5.16	25.179	19.13	178.250	58.92		
0.080	0.00	0.564	0.29	3.991	5.75	28.251	20.01	200.000	62.39		
0.089	0.00	0.632	0.40	4.477	6.37	31.698	20.86	224.404	65.71		
0.100	0.00	0.710	0.53	5.024	7.00	35.566	21.74	251.785	68.86		
0.112	0.00	0.796	0.67	5.637	7.67	39.905	22.70	282.508	71.84		
0.126	0.00	0.893	0.83	6.325	8.36	44.774	23.81	316.979	74.68		

Note: Data from 500µm to 10000µm by wet screening, from 0.02µm to 500µm by laser diffraction.

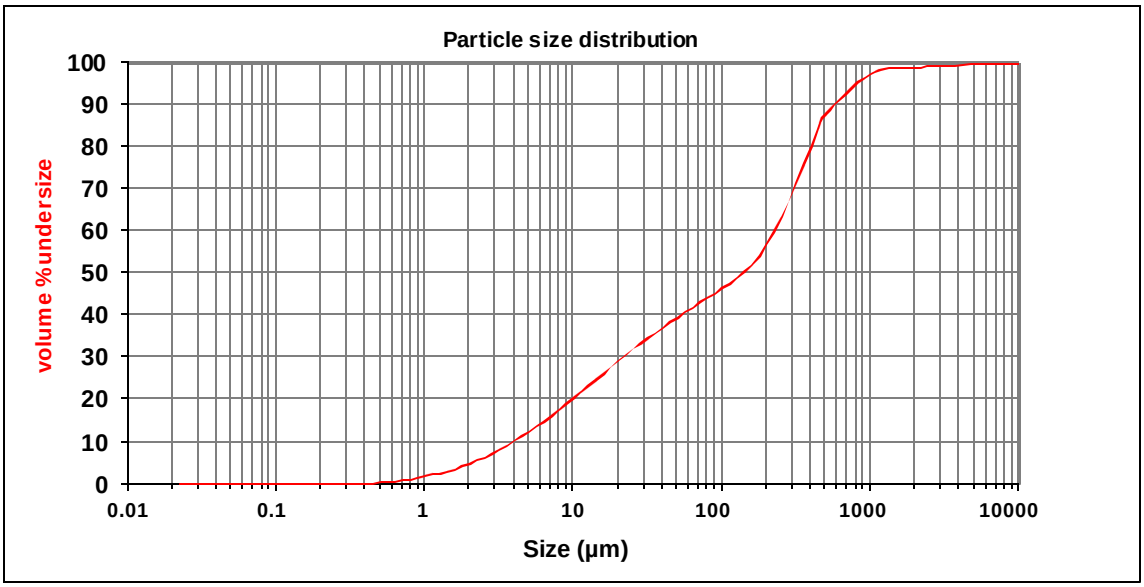
Analysed:	Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)
Reported:	Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)
Approved:	Michael Simeoni, B.Sc.(Chemistry), M.Sc. (Science Administration), Ph.D.

37 Kensington Street
East Perth
WA 6004

Client:	AECOM Australia Pty Ltd
Sample Name :	CS031P
Batch No :	16_1453
Lab ID No :	16_1453_31

Analysis :	Size distribution by laser diffraction following ISO13320-1:2009 and wet sieving	**Result units:**	Volume
Dispersant:	Water	**Analysis model:**	General purpose
Additives:	10 millilitres sodium hexametaphosphate	**Total sample wt (g):**	55.3263
Sonication:	3 min sonication		

Span:	4.24	**Vol. Weighted mean D[4,3]:**	265.05 µm	**d(0.1)**	3.89 µm
		Surface weighted mean D[3,2]	10.25 µm	**d(0.5)**	142.55 µm
				d(0.9)	608.44 µm



Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %
0.020	0.00	0.142	0.00	1.002	1.81	7.096	16.16	50.238	39.53	355.66	75.96
0.022	0.00	0.159	0.00	1.125	2.17	7.962	17.48	56.368	40.72	399.05	80.30
0.025	0.00	0.178	0.00	1.262	2.58	8.934	18.86	63.246	41.90	447.74	84.37
0.028	0.00	0.200	0.00	1.416	3.05	10.024	20.28	70.963	43.07	500.00	87.95
0.032	0.00	0.224	0.00	1.589	3.57	11.247	21.74	79.621	44.21	1000.00	97.40
0.036	0.00	0.252	0.00	1.783	4.17	12.619	23.24	89.337	45.33	2000.00	98.96
0.040	0.00	0.283	0.00	2.000	4.84	14.159	24.76	100.237	46.45	10000.00	100.00
0.045	0.00	0.317	0.01	2.244	5.58	15.887	26.27	112.468	47.62		
0.050	0.00	0.356	0.06	2.518	6.39	17.825	27.78	126.191	48.89		
0.056	0.00	0.399	0.14	2.825	7.26	20.000	29.25	141.589	50.35		
0.063	0.00	0.448	0.24	3.170	8.20	22.440	30.67	158.866	52.09		
0.071	0.00	0.502	0.37	3.557	9.20	25.179	32.05	178.250	54.20		
0.080	0.00	0.564	0.54	3.991	10.25	28.251	33.38	200.000	56.76		
0.089	0.00	0.632	0.73	4.477	11.34	31.698	34.66	224.404	59.81		
0.100	0.00	0.710	0.95	5.024	12.48	35.566	35.90	251.785	63.34		
0.112	0.00	0.796	1.20	5.637	13.66	39.905	37.12	282.508	67.30		
0.126	0.00	0.893	1.48	6.325	14.89	44.774	38.33	316.979	71.56		

Note: Data from 500µm to 10000µm by wet screening, from 0.02µm to 500µm by laser diffraction.

Analysed:	Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)
Reported:	Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)
Approved:	Michael Simeoni, B.Sc.(Chemistry), M.Sc. (Science Administration), Ph.D.

DRAFT

Appendix D

Laboratory report - Benthic fauna

Revision A – 27-Apr-2017
Prepared for – Shell Australia Pty Ltd – ABN: 14009663576

Table 12 Benthic Fauna sample data

		Sample ID	CS14F	CS19F	CS15F	CH16F	CS18F	CS10F	CS11F	CS12F	CS13F	CS20F	CS21F	CS08F	CS07F	CS09F	CS06F	CS05F
		Site Name	DC1_0	DC1_500SE	DC1_500NW	DC1_1000NW	DC1_2000NW	DC2_0	DC2_500NE	DC2_1000NE	DC2_2000NE	DC2_1000SW	DC2_2000W	DC3_0	DC3_500SE	DC3_500NW	DC3_1000SE	DC3_2000SE
PHYLUM	SUB PHYLUM or CLASS	Morphospecies																
PORIFERA	DEMOSPONGIA	Demospongia 1		1								1		1				
		Demospongia 2		5	1	12		1				1			1	1		
		Demospongia 3			10													
		Demospongia 4										1						
	HEXACTINELLIDA	Hexactinellid 1			2										2			
		Hexactinellid 2														1		
	UNKNOWN	Unknown Porifera 1													3			
		Unknown Porifera 2																
NEMERTEA	UNDETERMINED	Nemertea 1				1	1											
		Nemertea 2			5													
ANNELIDA	ECHIURA	Echiura 1				1												
		Echiura 2													1			
ANNELIDA	POLYCHAETA	Ampharetidae 1	1															
		Ampharetidae 2		2		2	1		1			10	1			2	1	
		Ampharetidae 3										1						
		Amphinomidae 1										1						
		Capitellidae 1																
		Capitellidae 2								1								
		Capitellidae 3																
		Capitellidae 4			1													
		Chrysopetalidae 1										1						
		Cirratulidae 1		1														
		Eunicidae 1										5						
		Eunicidae 2																
		Flabelligeridae 1		1														
		Glyceridae 1			1													
		Goniadidae 1																
		Goniadidae 2					1											
		Goniadidae 3					1											
		Lumbrineridae 1																
		Lumbrineridae 2										1						
		Lumbrineridae 3										1						
		Lumbrineridae 4																
		Magelonidae 1		2								1						
		Magelonidae 3															1	
		Maldanidae 1				1												
		Maldanidae 2										1						
		Nereididae 1		1														
		Nephtyidae 1																
		Nephtyidae 2														1		
		Nephtyidae 3																
		Onuphidae 1										1						
		Onuphidae 2										1						
		Onuphidae 3										1						
		Onuphidae 4	1															
		Onuphidae 5																
		Onuphidae 6		1		2								1				
		Onuphidae 7										1						
		Onuphidae 8																
		Ophelidae 1																
		Orbinidae 1													1			
		Paraonidae 1																
		Paraonidae 2					1											
		Pectineridae 1													10			
		Polynoidae 1																
		Pisionidae 1																
		Sigalionidae 1																
		Sigalionidae 2																
		Sternapsidae 1																
		Syllidae 1		3								3			1			
		Syllidae 2													1			
		Syllidae 3							1			1						
		Syllidae 4																
		Trichobranchidae 1																
		Trichobranchidae 2													1			
		Trochochaetidae 1																
		Unknown Polychaete 1													1			
ANNELIDA	SIPUNCULA	Golfingiidae 1													1			
		Golfingiidae 2													1			
		Phascolionidae 1			2	1		1				1						
		Phascolionidae 2																
		Phascolosomatidae 1																
		Themistidae 1				2			2			1						
		Themistidae 2																
		Unknown Sipuncula 1		1	1													
		Unknown Sipuncula 2																
		Unknown Sipuncula 3																

		Sample ID	CS14F	CS19F	CS15F	CH16F	CS18F	CS10F	CS11F	CS12F	CS13F	CS20F	CS21F	CS08F	CS07F	CS09F	CS06F	CS05F
		Site Name	DC1_0	DC1_500SE	DC1_500NW	DC1_1000NW	DC1_2000NW	DC2_0	DC2_500NE	DC2_1000NE	DC2_2000NE	DC2_1000SW	DC2_2000W	DC3_0	DC3_500SE	DC3_500NW	DC3_1000SE	DC3_2000SE
MOLLUSCA	APLACOPHORA	Aplacophra 1																
		Aplacophra 2																
		Aplacophra 3													1			
	BIVALVIA	Bivalvia 1																
		Bivalvia 2																
		Bivalvia 3																
		Bivalvia 4				1												
		Bivalvia 5				1												
		Bivalvia 6										1		1	2			
		Bivalvia 7					1											
		Bivalvia 8																
		Bivalvia 9										1						
		Bivalvia 10																
	GASTROPODA	Natacidae 1																
		Crepidula 1													14			
	SCAPHOPODA	Scaphopoda 1				1						1						
		Scaphopoda 2										1						
		Scaphopoda 3							1									
NEMATODA	UNDETERMINED	Nematode 5				2						2			1			
		Nematode 7	1			1												
		Nematode 8																
		Nematode 10						1										
ARTHROPODA	CRUSTACEA	Cirripedia 1													1			
		Lepadomorpha 1																
		Lepadomorpha 2													1			
		Lepadomorpha 3																
		Alpheidae 1													2			
		Anthuridae 1			1							1						
		Anthuridae 2					1											
		Anthuridae 3													3			
		Brachyura 1		1														
		Brachyura 2													1			
		Callianassidae 1																
		Callianassidae 2				1												
		Corophiida 1										1						
		Corophiidae 2																
		Diogenidae 1					1											
		Diogenidae 2													2			
		Euphausiacea 1																
		Gammaridea 1		1														
		Gammaridea 2			1													
		Gammaridea 3							1									
		Gammaridea 4			1										1			
		Gammaridea 5			3										9			
		Gammaridea 6													1			
		Gammaridea 7				1									4			
		Gammaridea 8																
		Gnathiidae 1																
		Gnathiidae 2													1			
		Mysidacea 1						1										
		Tanaidacea 1																
		Tanaidacea 2																
		Tanaidacea 3				1												
		Tanaidacea 4																
		Tanaidacea 5														1		
		Tanaidacea 6																
		Solenoceridae 1																
		Thalassinidea 1																
		Ostracoda 1															1	
BRYOZOA	UNDETERMINED	Bryozoa 1																
		Bryozoa 2																
		Bryozoa 3																
ECHINODERMATA	ASTEROIDEA	Asteroidea 1			1													
	CRINOIDEA	Crinoidea 1													2			
		Crinoidea 2			3													
	HOLOTHUROIDEA	Holothuroidea 1				1												
		Holothuroidea 2		1														
		Holothuroidea 3												1				
		Holothuroidea 4																
	OPHIUROIDEA	Ophiuroidea 1			1													
		Ophiuroidea 2														1		
		Ophiuroidea 3										1						
		Ophiuroidea 4			1							1			4			
		Ophiuroidea 5															1	
		Ophiuroidea 6			1													
CHORDATA	UROCHORDATA	Ascideacea 1																
		Species richness	3	13	17	17	8	4	5	1	0	29	1	4	29	6	4	0
		Number of individuals	3	21	36	32	8	4	6	1	0	45	1	4	74	7	4	0

		Sample ID	CS01F	CS02F	CS31F	CS30F	CS29F	CS28F	CS27F	CS26F	CS25F	CS24F	CS23F	CS60F	CS61F	CS03F	CS04F	CS62F	CS64F	CH17F	CS35F	CS65F	CS22F	CS66F	CS67F	
		Site Name	PL_S1	PL_S2	PL_S3	PL_S4	PL_S5.5	PL_S7	PL_S8	PL_S9.5	PL_S11	PL_S12.5	PL_S14	REF_NE	REF_NE	REF_NE	REF_SE	REF_SE	REF_SE	REF_NW	REF_NW	REF_NW	REF_SW	REF_SW	REF_SW	Total
PHYLUM	SUB PHYLUM or CLASS	Morphospecies																								
PORIFERA	DEMOSPONGIA	Demospongia 1																								3
		Demospongia 2		1																					1	24
		Demospongia 3														1										11
		Demospongia 4																								1
	HEXACTINELLIDA	Hexactinellid 1																								4
		Hexactinellid 2																								1
	UNKNOWN	Unknown Porifera 1																								3
		Unknown Porifera 2																				3				3
NEMERTEA	UNDETERMINED	Nemertea 1																	1							3
		Nemertea 2																								5
ANNELIDA	ECHIURA	Echiura 1																								1
		Echiura 2																								1
ANNELIDA	POLYCHAETA	Ampharetidae 1				1																				2
		Ampharetidae 2							1			1	1												1	24
		Ampharetidae 3																								1
		Amphinomidae 1																								1
		Capitellidae 1			1																		1			2
		Capitellidae 2																								1
		Capitellidae 3										1														1
		Capitellidae 4											1													2
		Chrysopetalidae 1																								1
		Cirratulidae 1																								1
		Eunicidae 1											1			2					1	1			2	12
		Eunicidae 2																	1							1
		Flabelligeridae 1																								1
		Glyceridae 1																1								2
		Goniadidae 1				3											1								1	5
		Goniadidae 2																								1
		Goniadidae 3											2													3
		Lumbrineridae 1				1																				1
		Lumbrineridae 2																								1
		Lumbrineridae 3																	1							2
		Lumbrineridae 4														1										1
		Magelonidae 1																								3
		Magelonidae 3																								1
		Maldanidae 1																	1							2
		Maldanidae 2																								1
		Nereididae 1																								1
		Nephtyidae 1										1														1
		Nephtyidae 2																								1
		Nephtyidae 3														1										1
		Onuphidae 1																								1
		Onuphidae 2																								1
		Onuphidae 3														1										2
		Onuphidae 4																				1				2
		Onuphidae 5													1											1
		Onuphidae 6							1										1					1		7
		Onuphidae 7																				1				2
		Onuphidae 8																				1				1
		Ophelidae 1																					1			1
		Orbinidae 1																								1
		Paraonidae 1																						1		1
		Paraonidae 2																		1						2
		Pectineridae 1																								10
		Polynoidae 1		1																						1
		Pisionidae 1						1																		1
		Sigalionidae 1								1																1
		Sigalionidae 2																							1	1
		Sternapsidae 1																	1							1
		Syllidae 1				1														1						9
		Syllidae 2			1				1							2						1				6
		Syllidae 3						1																		3
		Syllidae 4																							1	1
		Trichobranchidae 1														1										1
		Trichobranchidae 2																								1
		Trochochaetidae 1					1																			1
		Unknown Polychaete 1																								1
ANNELIDA	SIPUNCULA	Golfingiidae 1																								1
		Golfingiidae 2																								1
		Phascolionidae 1				2							1		1							3				12
		Phascolionidae 2											1			1										2
		Phascolosomatidae 1																				1				1
		Themistidae 1																								5
		Themistidae 2	2																							2
		Unknown Sipuncula 1														1										3
		Unknown Sipuncula 2											1													1
		Unknown Sipuncula 3			3																					3

		Sample ID	CS01F	CS02F	CS31F	CS30F	CS29F	CS28F	CS27F	CS26F	CS25F	CS24F	CS23F	CS60F	CS61F	CS03F	CS04F	CS62F	CS64F	CH17F	CS35F	CS65F	CS22F	CS66F	CS67F	
		Site Name	PL_S1	PL_S2	PL_S3	PL_S4	PL_S5.5	PL_S7	PL_S8	PL_S9.5	PL_S11	PL_S12.5	PL_S14	REF_NE	REF_NE	REF_NE	REF_SE	REF_SE	REF_SE	REF_NW	REF_NW	REF_NW	REF_SW	REF_SW	REF_SW	Total
MOLLUSCA	APLACOPHORA	Aplacophra 1			1																					1
		Aplacophra 2											1													1
		Aplacophra 3																								1
	BIVALVIA	Bivalvia 1		2		2	41	4		4	1	1	7										2		2	66
		Bivalvia 2			2																					2
		Bivalvia 3																1								1
		Bivalvia 4																								1
		Bivalvia 5																								1
		Bivalvia 6										5														9
		Bivalvia 7																								1
		Bivalvia 8					1																		1	2
		Bivalvia 9																							1	2
		Bivalvia 10																					1			1
	GASTROPODA	Natacidae 1			1																					1
		Crepidula 1																								14
	SCAPHOPODA	Scaphopoda 1																								2
		Scaphopoda 2																								1
		Scaphopoda 3																								1
NEMATODA	UNDETERMINED	Nematode 5			1	3			1				1													11
		Nematode 7																								2
		Nematode 8							1														1			2
		Nematode 10																								1
ARTHROPODA	CRUSTACEA	Cirripedia 1																								1
		Lepadomorpha 1			1																					1
		Lepadomorpha 2																								1
		Lepadomorpha 3												1												1
		Alpheidae 1																								2
		Anthuridae 1							1																	3
		Anthuridae 2																								1
		Anthuridae 3																								3
		Brachyura 1																								1
		Brachyura 2																								1
		Callianassidae 1				1																				1
		Callianassidae 2																	1							2
		Corophiida 1			1																					2
		Corophiidae 2					1																			1
		Diogenidae 1																								1
		Diogenidae 2																								2
		Euphausiacea 1															1									1
		Gammaridea 1																								1
		Gammaridea 2																								1
		Gammaridea 3																				1				2
		Gammaridea 4																								2
		Gammaridea 5																				1				13
		Gammaridea 6																			1					2
		Gammaridea 7					2								1											8
		Gammaridea 8																				1				1
		Gnathiidae 1																							1	1
		Gnathiidae 2																								1
		Mysidacea 1																								1
		Tanaidacea 1			2	1																				3
		Tanaidacea 2			1																					1
		Tanaidacea 3																								1
		Tanaidacea 4										1	1													2
		Tanaidacea 5																								1
		Tanaidacea 6																				1				1
		Solenoceridae 1																	1							1
		Thalassinidea 1														1										1
		Ostracoda 1																								1
BRYOZOA	UNDETERMINED	Bryozoa 1					2																			2
		Bryozoa 2												2												2
		Bryozoa 3												1												1
ECHINODERMATA	ASTEROIDEA	Asteroidea 1																								1
	CRINOIDEA	Crinoidea 1																								2
		Crinoidea 2																								3
	HOLOTHUROIDEA	Holothuroidea 1																								1
		Holothuroidea 2			1																					2
		Holothuroidea 3																								1
		Holothuroidea 4																								1
	OPHIUROIDEA	Ophiuroidea 1			2																					3
		Ophiuroidea 2																								2
		Ophiuroidea 3																							2	3
		Ophiuroidea 4																					1		1	8
		Ophiuroidea 5																								1
		Ophiuroidea 6																								1
CHORDATA	UROCHORDATA	Ascideacea 1				1																				1
		Species richness	1	3	13	10	6	3	6	2	1	6	11	3	3	10	2	2	8	2	5	12	5	2	12	153
		Number of individuals	2	4	18	16	48	6	6	5	1	10	18	4	3	12	2	2	8	2	5	16	6	2	15	457

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Appendix E

Water quality sonde calibration certificates

CTD Reference Checks

Instrument: CTD 19plus V2

Instrument Serial Number: 6243

Calibration Date: 12/04/2016

Sensor	Reference	Value	Residual	Pass/Fail	Expected Accuracy
Salinity (PSU)	29.83526	29.77190	0.06336	Pass	+/- 0.16
	32.90661	32.75784	0.14877	Pass	
Temperature (°C)	19.10000	19.09941	0.00059	Pass	+/- 0.0192
Depth (dB)	0.49033	0.41142	0.07892	Pass	+/- 0.12
Turbidity (NTU)	0.00000	0.30000	-0.30000	Pass	+/- 5% Linearity
	20.00000	18.80000	1.20000	Pass	
	100.00000	102.90000	-2.90000	Pass	
Dissolved Oxygen (ml/L)	9.01600	9.04900	-0.03300	Pass	+/- 2%
pH	4.00000	3.99500	0.00500	Pass	pH probe was calibrated with these values.
	7.00000	7.01100	-0.01100	Pass	
	10.00000	9.99500	0.00500	Pass	

Notes:

- Salinity tests were conducted using RPS MetOcean salinity baths, the reference values of the salinity baths have been generated from averaging 20 SBE37 salinity values.
- Temperature test was conducted against calibrated digital FLUKE thermometer, with CTD instrument submerged in freshwater.
- Depth test was conducted with instrument submerged to a known height.
- Turbidity tests were conducted against 3 known turbidty standards.
- Dissolved Oxygen was cross checked against a secondary dissolved oxygen sensor.
- pH tests were conducted by Imbros (SBE contractor) the values found were used to calibrate the sensor configuration.

Technician: M. MATSON Signed: Date: 20/04/16

QC Checker: G. WARK Signed: Date: 20-4-16

SEA-BIRD ELECTRONICS, INC.

1808 136th Place N.E., Bellevue, Washington, 98005 USA

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SENSOR SERIAL NUMBER: 6243
CALIBRATION DATE: 20-Dec-08

SBE19plus CONDUCTIVITY CALIBRATION DATA
PSS 1978: C(35,15,0) = 4.2914 Siemens/meter

COEFFICIENTS:

```
g = -1.006465e+000
h =  1.539737e-001
i = -1.985717e-004
j =  3.753773e-005

CPcor = -9.5700e-008
CTcor =  3.2500e-006
```

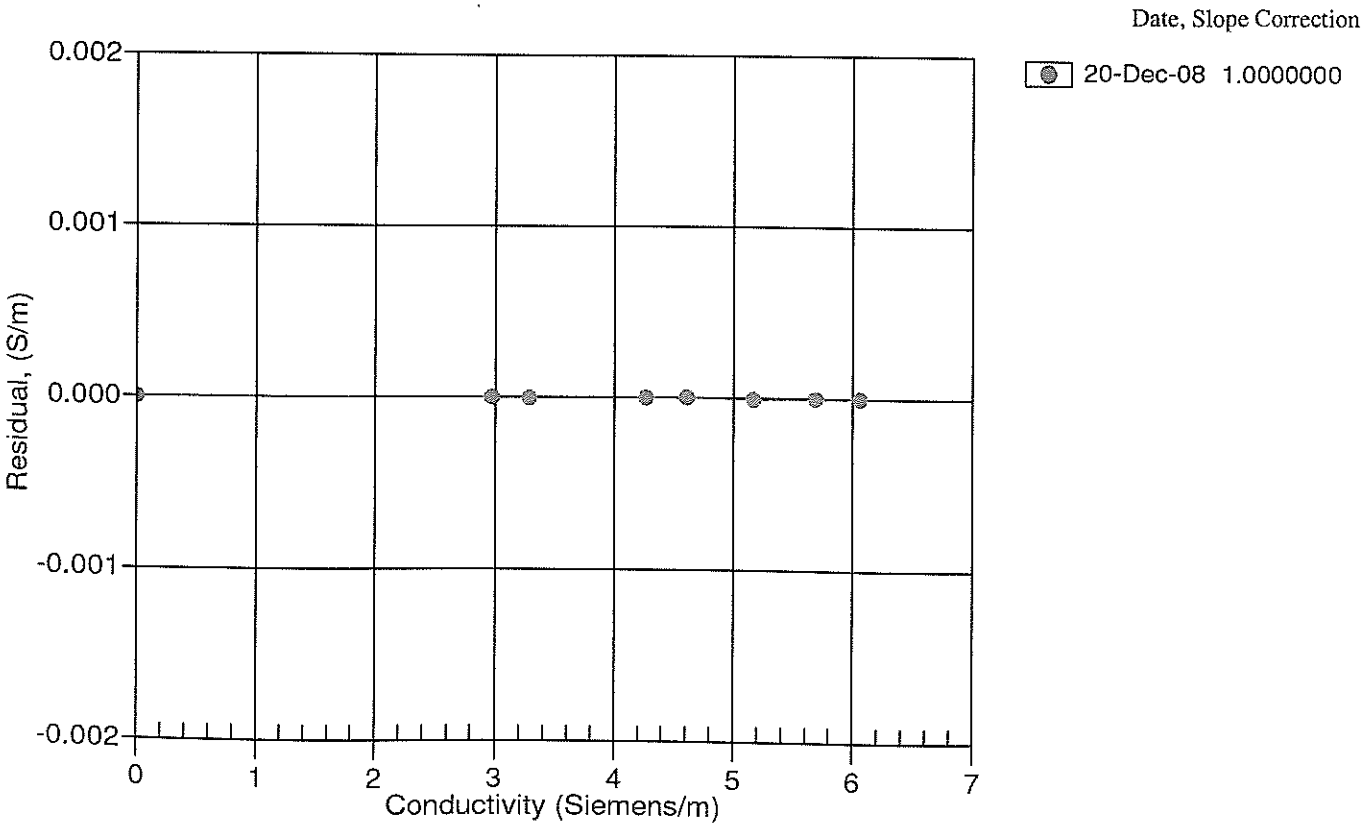
BATH TEMP (ITS-90)	BATH SAL (PSU)	BATH COND (Siemens/m)	INST FREQ (Hz)	INST COND (Siemens/m)	RESIDUAL (Siemens/m)
22.0000	0.0000	0.00000	2558.86	0.0000	0.00000
1.0000	34.7888	2.97384	5085.00	2.9738	0.00000
4.5000	34.7688	3.28068	5276.76	3.2807	-0.00000
15.0000	34.7253	4.26163	5847.09	4.2616	0.00000
18.5001	34.7150	4.60639	6034.51	4.6064	0.00001
24.0000	34.7029	5.16362	6325.43	5.1636	-0.00001
29.0000	34.6951	5.68470	6585.57	5.6847	-0.00000
32.5001	34.6889	6.05629	6764.82	6.0563	0.00000

f = INST FREQ / 1000.0

Conductivity = $(g + hf^2 + if^3 + jf^4) / (1 + \delta t + \varepsilon p)$ Siemens/meter

t = temperature[°C)]; p = pressure[decibars]; δ = CTcor; ε = CPcor;

Residual = instrument conductivity - bath conductivity



Sea-Bird Electronics, Inc.

13431 NE 20th Street, Bellevue, WA 98005-2010 USA

Phone: (+1) 425-643-9866 Fax (+1) 425-643-9954 Email: seabird@seabird.com

SENSOR SERIAL NUMBER: 1887
CALIBRATION DATE: 03-Jul-12

SBE 43 OXYGEN CALIBRATION DATA

COEFFICIENTS

Soc = 0.4325
Voffset = -0.4265
Tau20 = 4.72

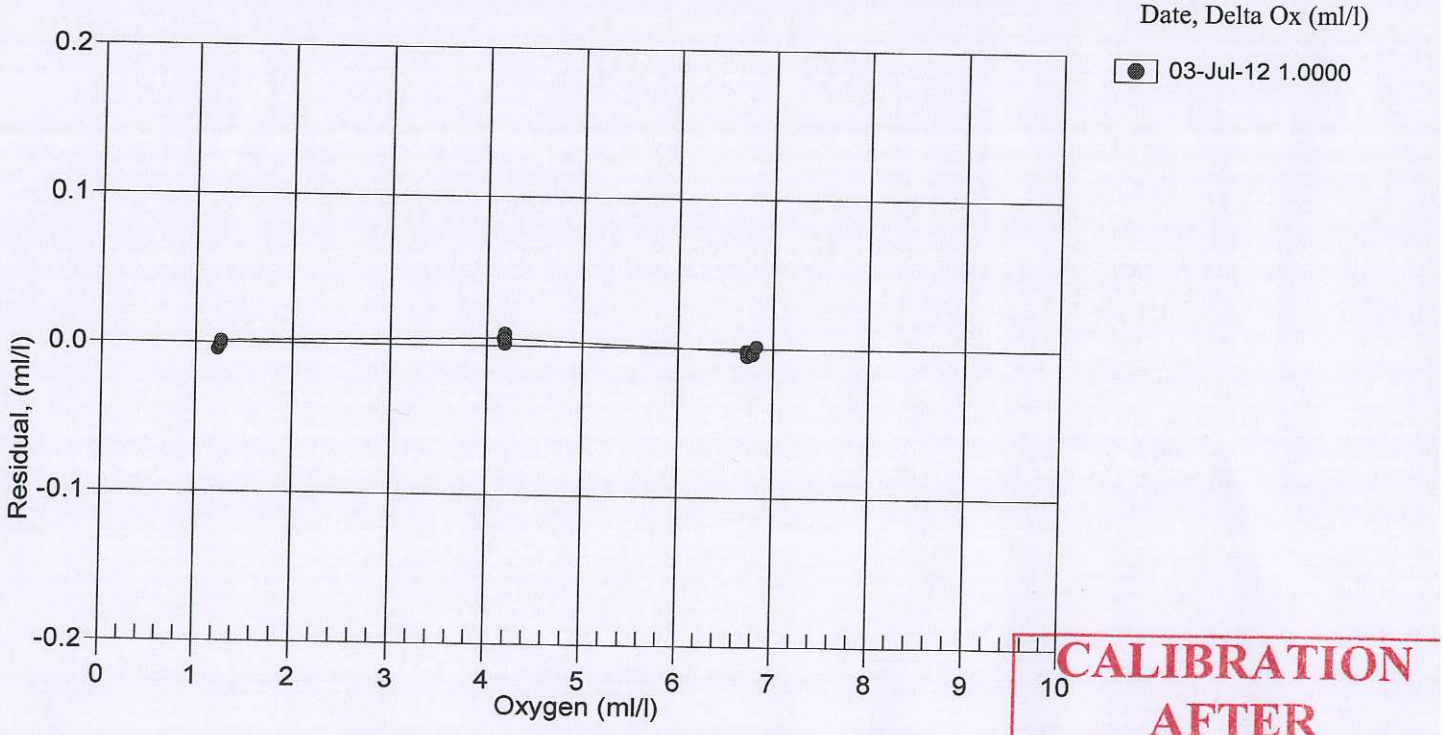
A = -2.2783e-003
B = 1.3259e-004
C = -2.7826e-006
E nominal = 0.036

NOMINAL DYNAMIC COEFFICIENTS

D1 = 1.92634e-4 H1 = -3.30000e-2
D2 = -4.64803e-2 H2 = 5.00000e+3
H3 = 1.45000e+3

BATH OX (ml/l)	BATH TEMP ITS-90	BATH SAL PSU	INSTRUMENT OUTPUT(VOLTS)	INSTRUMENT OXYGEN(ml/l)	RESIDUAL (ml/l)
1.23	2.00	0.16	0.720	1.22	-0.00
1.23	6.00	0.14	0.757	1.23	-0.00
1.24	12.00	0.13	0.812	1.24	-0.00
1.25	26.00	0.09	0.947	1.25	-0.00
1.26	20.00	0.11	0.889	1.25	-0.00
1.26	30.00	0.08	0.993	1.26	0.00
4.17	2.00	0.16	1.430	4.18	0.01
4.18	26.00	0.09	2.162	4.18	0.00
4.18	30.00	0.08	2.301	4.18	0.00
4.18	12.00	0.12	1.726	4.18	0.00
4.18	6.00	0.14	1.550	4.19	0.01
4.19	20.00	0.11	1.974	4.19	0.00
6.72	12.00	0.12	2.514	6.72	-0.00
6.72	20.00	0.11	2.906	6.72	-0.00
6.74	6.00	0.14	2.235	6.74	-0.00
6.78	30.00	0.08	3.463	6.78	-0.00
6.78	2.00	0.16	2.054	6.78	-0.00
6.82	26.00	0.08	3.257	6.82	0.00

Oxygen (ml/l) = Soc * (V + Voffset) * (1.0 + A * T + B * T^2 + C * T^3) * OxSol(T,S) * exp(E * P / K)
V = voltage output from SBE43, T = temperature [deg C], S = salinity [PSU], K = temperature [Kelvin]
OxSol(T,S) = oxygen saturation [ml/l], P = pressure [dbar], Residual = instrument oxygen - bath oxygen



CALIBRATION AFTER MODIFICATIONS

PO Box 518
620 Applegate St.
Philomath, OR 97370

(541) 929-5650
Fax (541) 929-5277
www.wetlabs.com

NTU Characterization Sheet

Date: 17/04/2012 S/N: NTURT-263

Nephelometric Turbidity Unit (NTU) Scale Factor

Turbidity units expressed in NTU can be derived using the equation:

NTU = Scale Factor x (Output - Dark Counts)

	ASV1	ASV2	ASV4		Digital	
Dark Counts	0.058	0.027	0.011	V	50	counts
NTU Solution Value	4.64	2.32	1.16	V	3800	counts
Scale Factor (SF)	47	95	189	NTU/V	0.0579	NTU/count
Maximum Output	4.97	4.97	4.97	V	16380	counts
Resolution	0.0	0.0	0.0	mV	1.0	counts
Ambient temperature during calibration	22		°C			

Dark Counts: Signal output of the meter in clean water with black tape over detector.

SF: Scale factor is determined using the following equation: SF = xx ÷ (Output - Dark Counts), where xx is the value of a Formazin concentration. For example: 12.2 ÷ (2011 - 50) = 0.0062.

Maximum Output: Maximum signal output the meter is cabable of.

Resolution: standard deviation of 1 minute of collected data.

Imbros
1059 Cambridge Road, Cambridge, Tasmania Australia 7170
info@imbros.com.au
www.imbros.com.au
ABN 29 009 525 053
Ph: (03) 6216 1500
Fax: (03) 6216 1555

SENSOR SERIAL NUMBER: 180786
CALIBRATION DATE: 14-Apr-16

SBE18 pH CALIBRATION DATA

pH COEFFICENTS

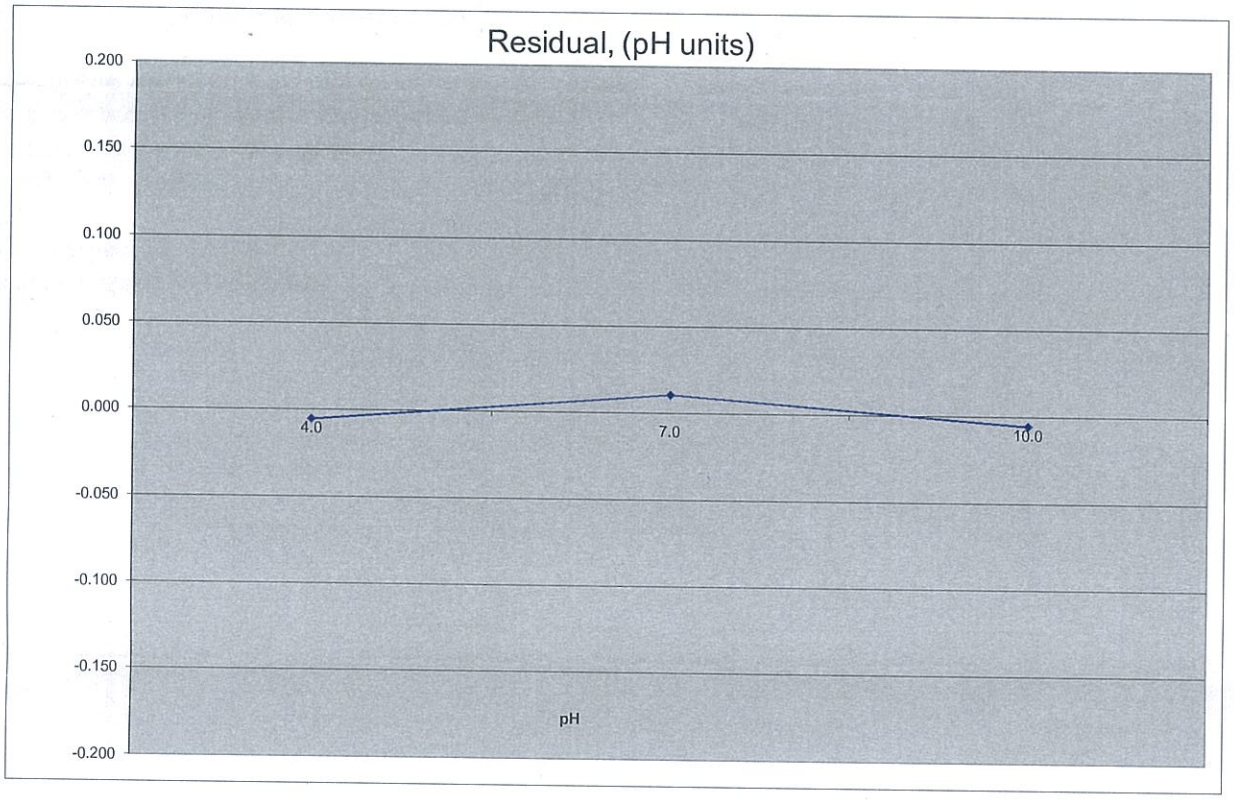
pH slope = 4.5790
pHoffset = 2.5452

pH	Temperature (Deg C)	Vout	Instrument Output	Residual (pH units)
4.0	21.0	1.742	3.995	-0.005
7.0	21.0	2.548	7.011	0.011
10.0	21.0	3.346	9.995	-0.005

pH = 7.0 + (Vout - pHoffset) / (pHslope * K * 1.98416E-4)

Where:

Vout = pH sensor output in volts
K is the water temperature in degrees Kelvin
Risidual = instrument pH - buffer pH



* New pH/ORP Sensor (SBE 27)
Installed on CTD for ENI Indo.

Sea-Bird Electronics, Inc.

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SENSOR SERIAL NUMBER: 0288
CALIBRATION DATE: 10-Oct-13

SBE27 pH/ORP CALIBRATION DATA

pH COEFFICIENTS

pHslope = 4.6115
pHoffset = 2.5243

ORP COEFFICIENTS

ORP M = -0.4948
ORP B = 2.5009

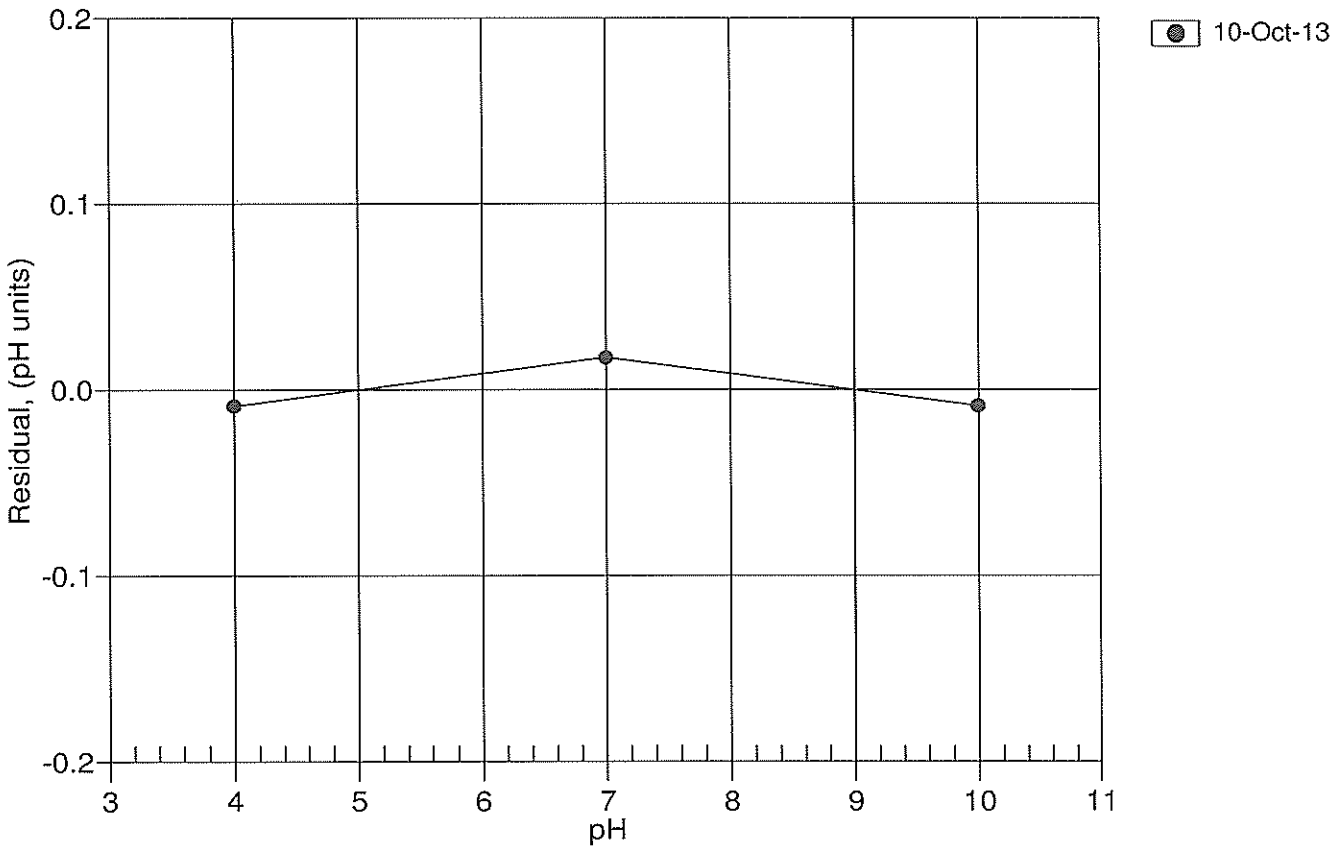
pH	Temperature (deg C)	VpH	Instrument Output (pH units)	Residual (pH units)
4.0	22.3	1.711	3.991	-0.009
7.0	22.3	2.529	7.017	0.017
10.0	22.3	3.333	9.991	-0.009

pH = 7.0 + (Vph - pHoffset) / (pHslope * °K * 1.98416E-4)

ORP = M * (Vorp - B) * 1000.0

Where:

VpH = pH sensor output in volts
K is the water temperature in degrees Kelvin
Residual = instrument pH - buffer pH
Vorp = ORP sensor output in volts



SEA-BIRD ELECTRONICS, INC.

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SENSOR SERIAL NUMBER: 6243
CALIBRATION DATE: 16-Dec-08

SBE19plus PRESSURE CALIBRATION DATA
870 psia S/N 2765845

COEFFICIENTS:

PA0 =	3.077128e+000	PTCA0 =	5.234050e+005
PA1 =	2.630359e-003	PTCA1 =	8.740152e+001
PA2 =	2.752442e-011	PTCA2 =	-9.439609e-001
PTEMPA0 =	-6.230415e+001	PTCB0 =	2.505900e+001
PTEMPA1 =	5.124582e+001	PTCB1 =	4.000000e-004
PTEMPA2 =	-1.763591e-002	PTCB2 =	0.000000e+000

PRESSURE SPAN CALIBRATION

PRESSURE PSIA	INST OUTPUT	THERMISTOR OUTPUT	COMPUTED PRESSURE	ERROR %FSR
14.72	528971.0	1.5	14.63	-0.01
179.98	591767.0	1.5	179.87	-0.01
360.01	660104.0	1.5	359.96	-0.01
540.01	728315.0	1.5	539.96	-0.01
720.02	796447.0	1.5	720.02	-0.00
875.01	855009.0	1.5	874.97	-0.00
720.03	796482.0	1.5	720.10	0.01
540.03	728358.0	1.5	540.06	0.00
360.00	660146.0	1.5	360.05	0.01
179.98	591838.0	1.5	180.04	0.01
14.72	529061.0	1.5	14.83	0.01

THERMAL CORRECTION

TEMP ITS90	THERMISTOR OUTPUT	INST OUTPUT
32.50	1.85	529747.24
29.00	1.78	529662.57
24.00	1.69	529482.56
18.50	1.58	529218.55
15.00	1.51	529007.63
4.50	1.30	528254.73
1.00	1.24	528029.87

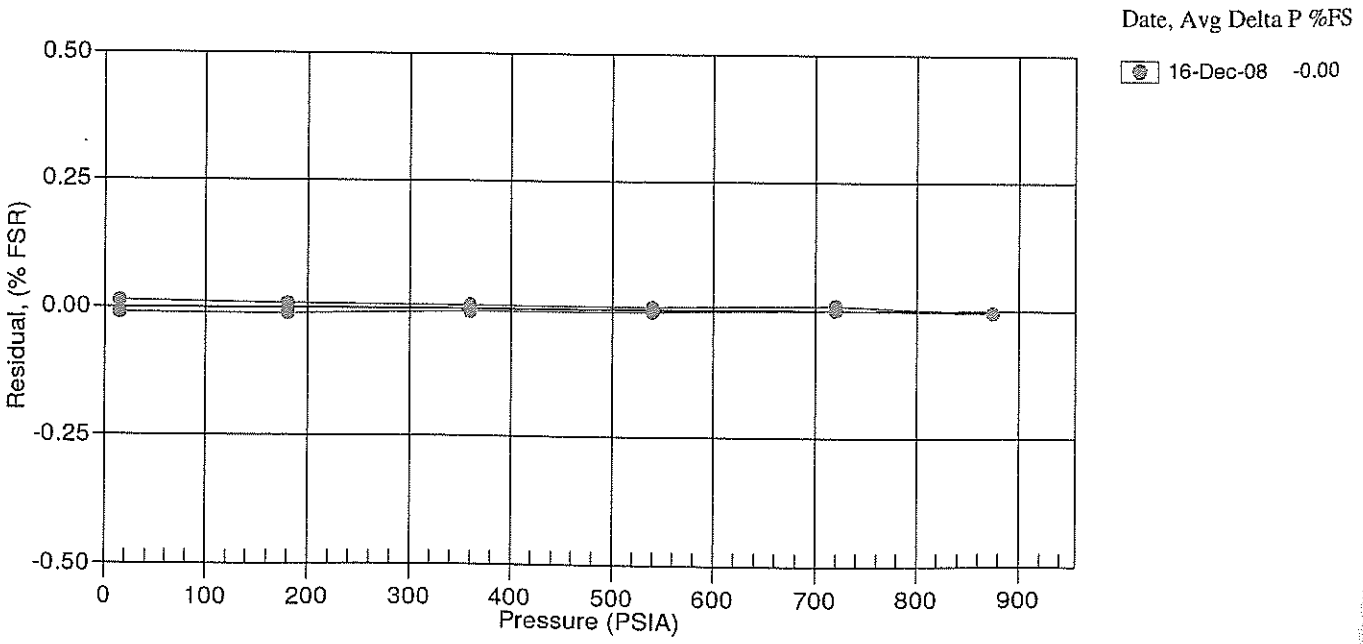
TEMP(ITS90)	SPAN(mV)
-5.00	25.06
35.00	25.07

y = thermistor output; $t = PTEMPA0 + PTEMPA1 * y + PTEMPA2 * y^2$

x = pressure output - $PTCA0 - PTCA1 * t - PTCA2 * t^2$

$n = x * PTCB0 / (PTCB0 + PTCB1 * t + PTCB2 * t^2)$

pressure (psia) = $PA0 + PA1 * n + PA2 * n^2$



SEA-BIRD ELECTRONICS, INC.
13431 NE 20th St. Bellevue, Washington 98005 USA
Phone: (425) 643-9866 Fax: (425) 643-9954 www.seabird.com

Pressure Test Certificate

Customer	Imbros
Job Number	69109
Date	6/20/2012
Technician	RH

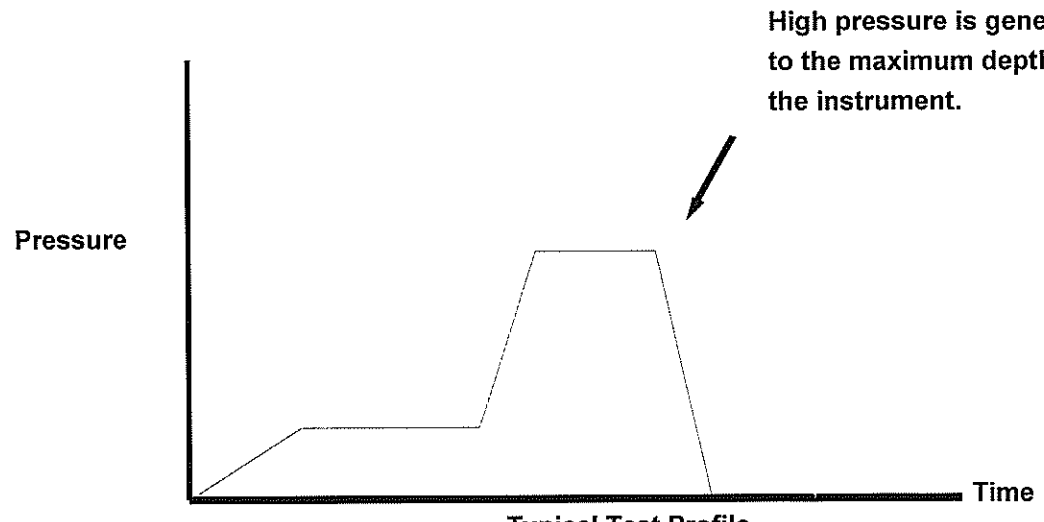
Serial Number	431887	
Low Pressure (PSI)	50	PSI
Time (Minutes)	15	Minutes
High Pressure (PSI)	750	PSI
Time (Minutes)	30	Minutes

Pass ☑

Fail ☐

Comments

Replaced spar, anode, getter, housing, connector and the main piston O-rings.



Typical Test Profile

SEA-BIRD ELECTRONICS, INC.

1808 136th Place N.E., Bellevue, Washington, 98005 USA

Phone: (425) 643 - 9866 Fax (425) 643 - 9954 Email: seabird@seabird.com

SENSOR SERIAL NUMBER: 6243
CALIBRATION DATE: 20-Dec-08

SBE19plus TEMPERATURE CALIBRATION DATA
ITS-90 TEMPERATURE SCALE

ITS-90 COEFFICIENTS

a0 = 1.280611e-003
a1 = 2.605966e-004
a2 = -3.977704e-007
a3 = 1.545821e-007

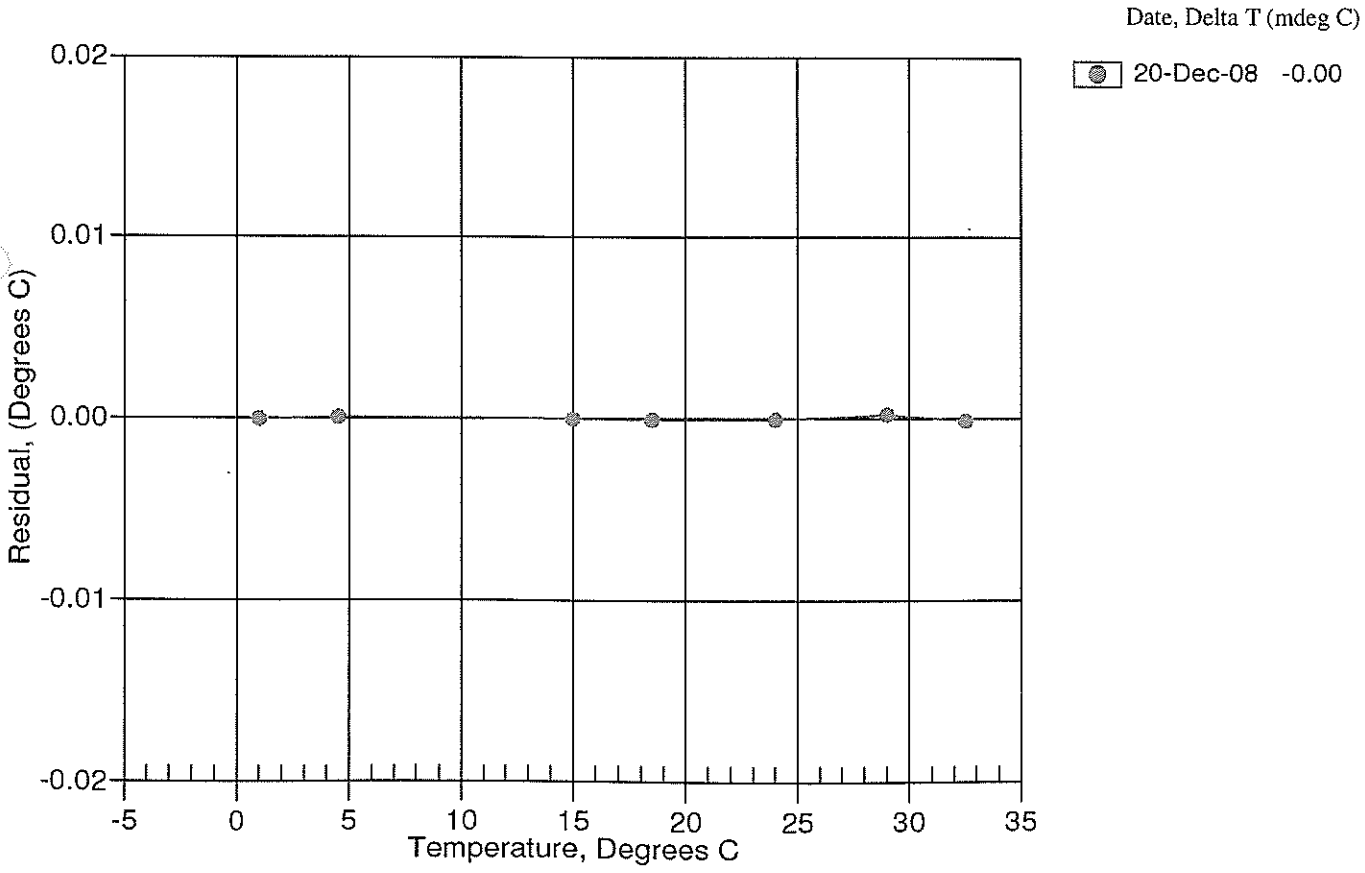
BATH TEMP (ITS-90)	INSTRUMENT OUTPUT(n)	INST TEMP (ITS-90)	RESIDUAL (ITS-90)
1.0000	649730.458	1.0000	-0.0000
4.5000	576602.881	4.5001	0.0001
15.0000	394676.898	15.0000	-0.0000
18.5001	345810.576	18.5000	-0.0001
24.0000	279538.525	23.9999	-0.0001
29.0000	229187.186	29.0002	0.0002
32.5001	198841.068	32.5000	-0.0001

MV = (n - 524288) / 1.6e+007

R = (MV * 2.900e+009 + 1.024e+008) / (2.048e+004 - MV * 2.0e+005)

Temperature ITS-90 = $1/\{a0 + a1[ln(R)] + a2[ln^2(R)] + a3[ln^3(R)]\} - 273.15$ (°C)

Residual = instrument temperature - bath temperature



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Appendix F

Physicochemical water column profile data

D R A F T

Appendix F Physicochemical water column profile data

Table 13 Water column profile site locations

Site	Latitude/ Longitude (GDA94)	Water depth (MSL)	Deployed (WST)
DC0	12°58.341'S 124°26.680'E	166m	1606 02/11/16
DC0_SW2000	12°59.106'S 124°25.914'E	165m	1505 02/11/16
DC1_NW2000	12°57.113'S 124°25.749'E	166m	1812 02/11/16
DC2_NE2000	12°57.233'S 124°27.866'E	166m	1736 02/11/16
FPSO_0	12°58.941'S 124°27.773'E	166m	1631 02/11/16
FPSO_NE2000	12°58.236'S 124°28.492'E	160m	1705 02/11/16
PL-1 (KP103)	13°27.578'S 123°39.726'E	210m	1553 30/10/16
PL-2 (KP65)	13°14.413'S 123°56.000'E	200m	1245 30/10/16
PL-3 (KP18)	13°01.841'S 124°18.380'E	180m	0640 30/10/16
REF_NE	12°55.310'S 124°34.543'E	95m	0640 02/11/16

Table 14 Temperature (°C) / depth profiles at sites surrounding proposed Drill Centre locations

Depth	DC0		DC0_SW2000		DC1_NW2000		DC2_NE2000	
	Apr/May	Nov	Apr/May	Nov	Apr/May	Nov	Apr/May	Nov
1 - 10 m	31.1	30.7	31.2	30.6	31.3	30.5	31.3	30.8
10 - 20 m	31.1	30.4	31.2	30.4	31.1	30.3	31.1	30.3
20 - 30 m	30.9	29.8	31.1	30.3	31.1	29.6	31.1	30.0
30 - 40 m	29.7	28.9	31.1	29.4	31.1	28.7	31.1	29.6
40 - 50 m	28.2	28.2	30.6	28.8	30.7	28.4	30.5	28.9
50 - 60 m	27.0	28.0	29.3	28.4	29.1	27.6	29.1	27.8
60 - 70 m	26.5	27.4	27.7	27.8	27.8	26.8	27.4	27.3
70 - 80 m	25.8	26.6	26.6	27.1	26.6	26.4	26.4	26.9
80 - 90 m	25.1	26.2	25.4	26.5	25.5	25.9	25.6	26.2
90 - 100 m	24.3	25.5	24.6	26.1	24.8	25.5	24.6	25.5
100 - 110 m	23.1	24.8	23.4	25.3	24.0	25.0	23.5	24.9
110 - 120 m	22.6	24.0	22.3	24.3	21.8	24.4	22.4	24.0
120 - 130 m	20.8	22.4	20.8	23.6	20.6	23.6	20.7	22.7
130 - 140 m	18.8	20.7	19.7	22.3	19.2	22.2	19.1	20.8
140 - 150 m	17.9	19.5	18.0	20.3	18.0	20.3	17.7	20.2
150 - 160 m	17.2	19.2	17.3	19.1	17.2	18.5	17.4	19.9
160 - 170 m	16.8	19.2	17.0	18.6	16.9	17.8	17.1	19.6
170 - 180 m	-	-	16.7	18.5	-	-	-	-

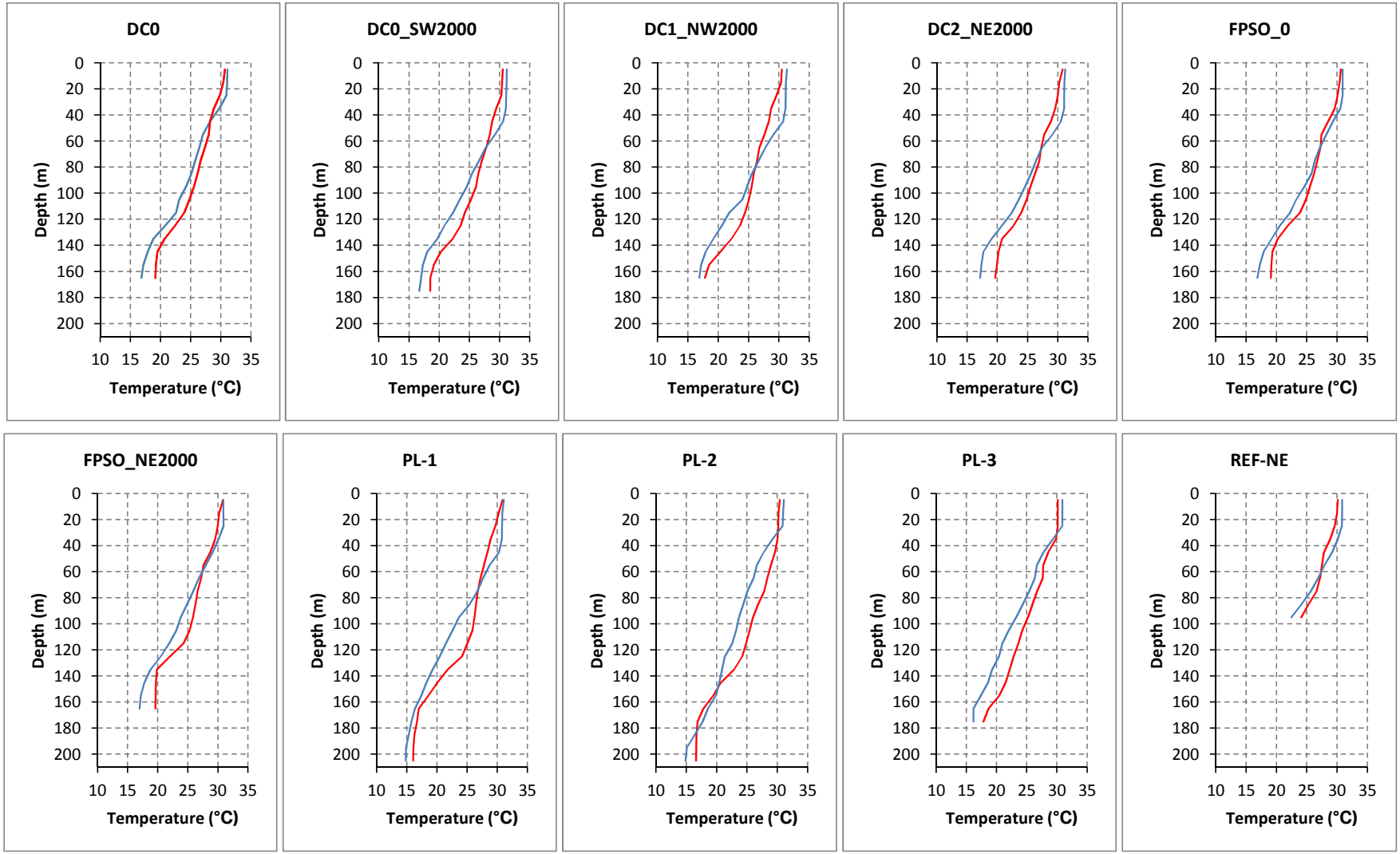
D R A F T

Table 15 Temperature (°C) / depth profiles at sites surrounding proposed FPSO Locations

Depth	FPSO_0		FPSO_NE2000	
	Apr/May	Nov	Apr/May	Nov
1 - 10 m	30.9	30.6	30.9	30.9
10 - 20 m	30.9	30.4	30.9	30.2
20 - 30 m	30.9	30.1	30.9	30.0
30 - 40 m	30.5	29.6	30.1	29.6
40 - 50 m	29.3	28.5	29.1	28.7
50 - 60 m	28.2	27.5	28.0	27.6
60 - 70 m	27.2	27.3	26.9	27.2
70 - 80 m	26.3	26.8	25.9	26.6
80 - 90 m	25.8	26.2	24.9	26.3
90 - 100 m	24.6	25.5	23.8	25.9
100 - 110 m	23.2	24.9	23.1	25.3
110 - 120 m	22.3	23.9	21.9	24.3
120 - 130 m	20.6	21.9	20.5	22.0
130 - 140 m	19.2	20.2	18.8	19.9
140 - 150 m	17.9	19.3	17.8	19.7
150 - 160 m	17.3	19.2	17.2	19.6
160 - 170 m	16.9	19.1	17.0	19.6

Table 16 Temperature (°C) / depth profiles at sites along the Pipeline and reference sites

Depth	PL-1		PL-2		PL-3		REF_NE	
	Apr/May	Nov	Apr/May	Nov	Apr/May	Nov	Apr/May	Nov
1 - 10 m	31.1	30.9	31.1	30.4	30.9	30.2	30.8	30.1
10 - 20 m	30.8	30.2	31.0	30.2	30.9	30.2	30.9	30.0
20 - 30 m	30.8	29.7	30.9	30.2	30.9	30.2	30.8	29.6
30 - 40 m	30.8	28.9	29.2	30.0	29.4	29.9	30.1	28.9
40 - 50 m	30.3	28.4	27.8	29.6	27.8	28.6	29.2	27.9
50 - 60 m	28.7	27.8	26.6	29.0	26.7	27.7	28.0	27.5
60 - 70 m	27.6	27.2	26.1	28.4	26.3	27.6	26.9	27.2
70 - 80 m	26.7	26.8	25.1	27.8	25.4	26.7	25.7	26.6
80 - 90 m	25.4	26.5	24.4	26.8	24.3	26.0	24.2	25.3
90 - 100 m	23.7	26.3	23.7	26.0	23.2	25.2	22.5	24.1
100 - 110 m	22.6	25.9	23.2	25.5	22.0	24.3	-	-
110 - 120 m	21.5	25.0	22.6	24.9	21.0	23.6	-	-
120 - 130 m	20.5	24.2	21.4	24.2	20.4	22.8	-	-
130 - 140 m	19.3	21.8	20.9	22.9	19.3	22.2	-	-
140 - 150 m	18.3	20.1	20.4	20.7	18.6	21.5	-	-
150 - 160 m	17.4	18.6	19.9	19.5	17.4	20.4	-	-
160 - 170 m	16.4	17.0	18.6	17.8	16.2	18.7	-	-
170 - 180 m	15.8	16.7	17.7	16.8	16.2	17.8	-	-
180 - 190 m	15.4	16.3	16.4	16.7	-	-	-	-
190 - 200 m	14.9	16.1	15.1	16.6	-	-	-	-
200 - 210 m	14.8	16.1	14.9	16.6	-	-	-	-



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Water Column Profiles Survey 1 (May 2016) Vs Survey 2 (October 2016): Temperature

Survey 1 (May 2016)
Survey 2 (October 2016)

D R A F T

Table 17 Salinity (PSU) / depth profiles at sites surrounding proposed Drill Centre locations

Depth	DC0		DC0_SW2000		DC1_NW2000		DC2_NE2000	
	Apr/May	Nov	Apr/May	Nov	Apr/May	Nov	Apr/May	Nov
1 - 10 m	34.94	34.76	34.94	34.75	34.95	34.75	34.94	34.72
10 - 20 m	34.94	34.75	34.94	34.75	34.94	34.74	34.94	34.65
20 - 30 m	34.90	34.71	34.94	34.74	34.94	34.72	34.94	34.76
30 - 40 m	34.73	34.64	34.93	34.72	34.94	34.65	34.93	34.77
40 - 50 m	34.61	34.68	34.83	34.72	34.84	34.77	34.82	34.71
50 - 60 m	34.58	34.81	34.69	34.80	34.67	34.85	34.65	34.68
60 - 70 m	34.57	34.83	34.60	34.87	34.62	34.83	34.59	34.72
70 - 80 m	34.56	34.84	34.56	34.83	34.57	34.84	34.58	34.82
80 - 90 m	34.56	34.84	34.55	34.86	34.55	34.81	34.56	34.81
90 - 100 m	34.53	34.80	34.55	34.88	34.55	34.80	34.55	34.80
100 - 110 m	34.53	34.77	34.52	34.80	34.54	34.75	34.53	34.74
110 - 120 m	34.52	34.75	34.52	34.79	34.49	34.74	34.51	34.76
120 - 130 m	34.48	34.73	34.50	34.78	34.50	34.76	34.50	34.77
130 - 140 m	34.50	34.72	34.50	34.73	34.50	34.75	34.47	34.72
140 - 150 m	34.51	34.67	34.49	34.70	34.51	34.69	34.52	34.68
150 - 160 m	34.51	34.64	34.52	34.66	34.51	34.60	34.52	34.65
160 - 170 m	34.52	34.62	34.52	34.63	34.53	34.57	34.53	34.65
170 - 180 m	-	-	34.53	34.61	-	-	-	-

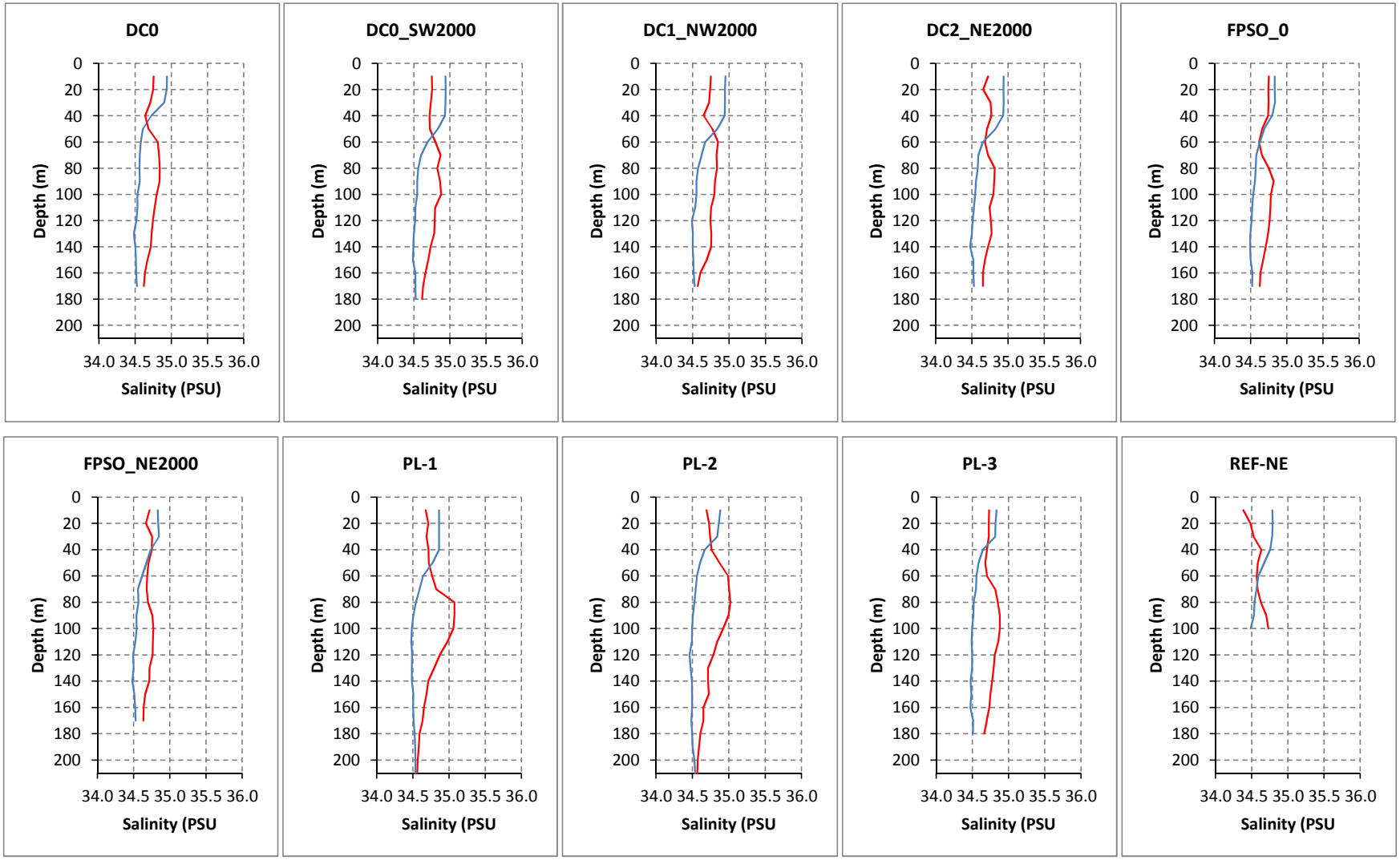
Table 18 Salinity (PSU) / depth profiles at sites surrounding proposed FPSO Locations

Depth	FPSO_0		FPSO_NE2000	
	Apr/May	Nov	Apr/May	Nov
1 - 10 m	34.83	34.75	34.83	34.72
10 - 20 m	34.83	34.75	34.84	34.67
20 - 30 m	34.84	34.75	34.85	34.76
30 - 40 m	34.80	34.74	34.74	34.75
40 - 50 m	34.69	34.66	34.68	34.71
50 - 60 m	34.63	34.62	34.62	34.69
60 - 70 m	34.58	34.66	34.56	34.68
70 - 80 m	34.57	34.75	34.57	34.70
80 - 90 m	34.56	34.82	34.54	34.76
90 - 100 m	34.53	34.78	34.54	34.78
100 - 110 m	34.52	34.77	34.53	34.77
110 - 120 m	34.51	34.76	34.50	34.76
120 - 130 m	34.50	34.74	34.50	34.72
130 - 140 m	34.49	34.71	34.48	34.72
140 - 150 m	34.50	34.67	34.51	34.66
150 - 160 m	34.53	34.64	34.52	34.64
160 - 170 m	34.52	34.63	34.53	34.64

D R A F T

Table 19 Salinity (PSU) / depth profiles at sites along the Pipeline and reference sites

Depth	PL-1		PL-2		PL-3		REF_NE	
	Apr/May	Nov	Apr/May	Nov	Apr/May	Nov	Apr/May	Nov
1 - 10 m	34.86	34.68	34.88	34.69	34.83	34.73	34.79	34.39
10 - 20 m	34.86	34.71	34.86	34.73	34.82	34.73	34.79	34.48
20 - 30 m	34.86	34.69	34.84	34.74	34.81	34.73	34.78	34.53
30 - 40 m	34.86	34.72	34.67	34.76	34.65	34.70	34.75	34.63
40 - 50 m	34.78	34.72	34.60	34.87	34.58	34.68	34.67	34.58
50 - 60 m	34.64	34.77	34.56	34.99	34.56	34.70	34.59	34.57
60 - 70 m	34.59	34.82	34.55	35.01	34.55	34.81	34.57	34.58
70 - 80 m	34.54	35.08	34.53	35.02	34.52	34.85	34.54	34.63
80 - 90 m	34.51	35.08	34.51	35.00	34.51	34.88	34.53	34.70
90 - 100 m	34.49	35.06	34.50	34.92	34.50	34.88	34.49	34.73
100 - 110 m	34.48	34.98	34.49	34.84	34.49	34.86	-	-
110 - 120 m	34.49	34.87	34.46	34.79	34.50	34.81	-	-
120 - 130 m	34.49	34.80	34.48	34.72	34.50	34.79	-	-
130 - 140 m	34.49	34.72	34.49	34.71	34.47	34.77	-	-
140 - 150 m	34.51	34.69	34.50	34.73	34.49	34.75	-	-
150 - 160 m	34.51	34.66	34.50	34.65	34.47	34.73	-	-
160 - 170 m	34.51	34.64	34.49	34.65	34.51	34.70	-	-
170 - 180 m	34.53	34.59	34.49	34.61	34.51	34.66	-	-
180 - 190 m	34.53	34.58	34.50	34.59	-	-	-	-
190 - 200 m	34.54	34.57	34.53	34.57	-	-	-	-
200 - 210 m	34.54	34.56	34.54	34.56	-	-	-	-



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Water Column Profiles Survey 1 (May 2016) Vs Survey 2 (October 2016): Salinity

D R A F T

Table 20 Dissolved Oxygen (% Saturation) / depth profiles at sites surrounding proposed Drill Centre locations

Depth	DC0		DC0_SW2000		DC1_NW2000		DC2_NE2000	
	Apr/May	Nov	Apr/May	Nov	Apr/May	Nov	Apr/May	Nov
1 - 10 m	91.63	102.4	91.60	108.3	95.99	106.3	93.96	106.6
10 - 20 m	99.18	107.3	99.58	108.1	100.79	106.5	100.18	107.1
20 - 30 m	99.23	108.5	99.81	108.1	100.94	108.5	100.33	107.9
30 - 40 m	98.66	107.6	99.87	110.0	100.98	106.4	100.47	108.3
40 - 50 m	90.01	105.8	99.63	108.9	100.64	106.0	100.34	107.3
50 - 60 m	74.29	106.0	98.99	108.1	99.64	102.0	98.86	101.0
60 - 70 m	70.47	99.8	86.26	104.8	90.10	91.0	82.32	95.7
70 - 80 m	71.09	89.9	72.02	96.7	80.50	86.7	78.23	92.9
80 - 90 m	68.93	85.6	71.36	87.0	72.13	83.9	72.40	86.4
90 - 100 m	65.12	83.0	65.98	84.1	67.22	81.5	66.41	82.0
100 - 110 m	60.26	78.9	61.37	81.4	64.44	79.8	62.94	79.4
110 - 120 m	60.08	74.8	58.05	75.4	58.83	76.6	60.37	74.0
120 - 130 m	54.72	67.3	54.85	71.0	55.06	72.1	55.87	66.9
130 - 140 m	49.70	61.5	52.23	67.7	51.75	65.8	51.39	61.7
140 - 150 m	46.40	57.2	47.70	60.6	47.99	59.6	46.43	58.6
150 - 160 m	44.28	55.5	44.75	56.2	45.46	51.3	44.76	57.7
160 - 170 m	42.99	55.2	43.66	53.3	43.89	48.2	43.92	55.9
170 - 180 m	-	-	42.96	53.0	-	-	-	-

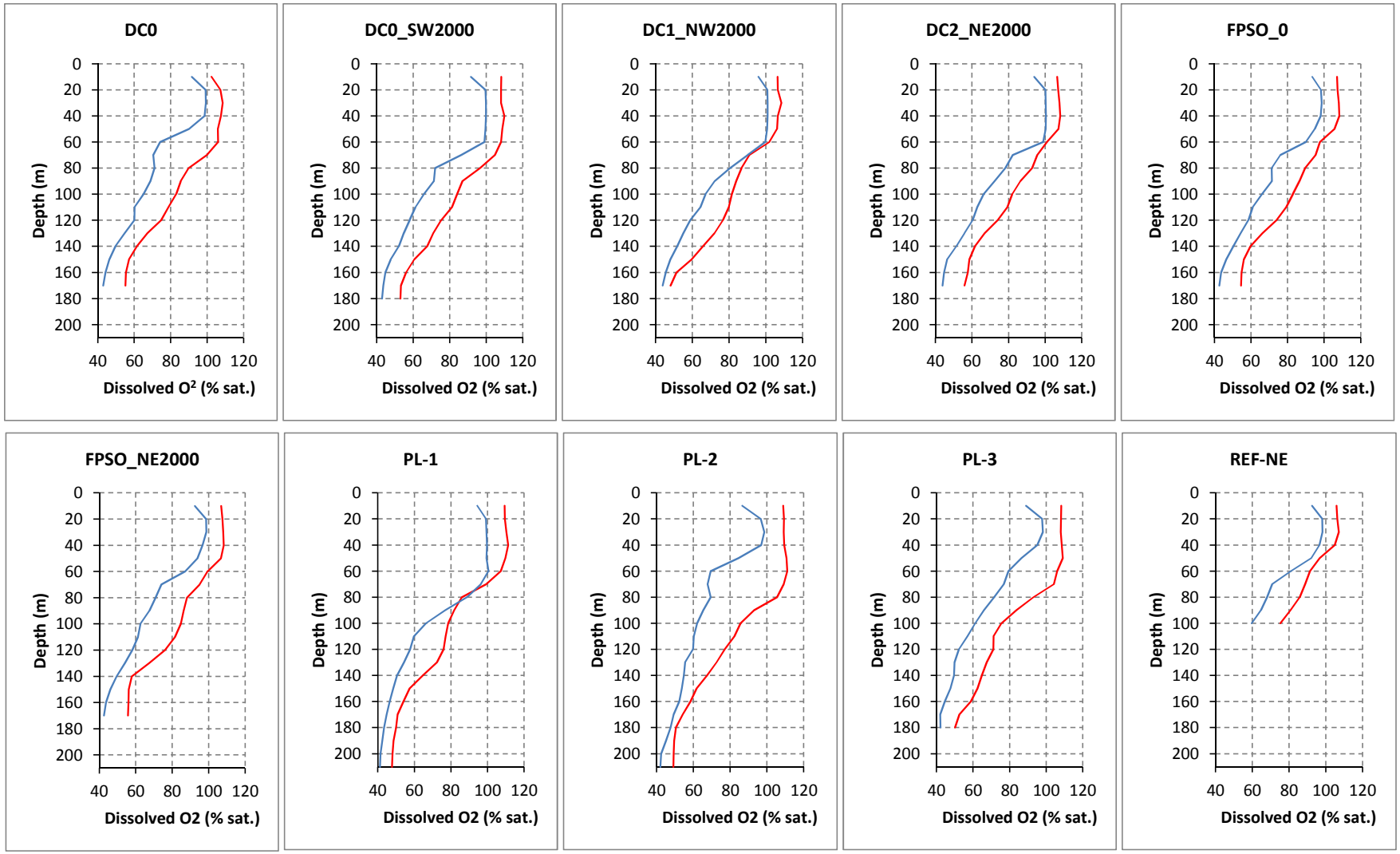
Table 21 Dissolved Oxygen (% Saturation) / depth profiles at sites surrounding proposed FPSO Locations

Depth	FPSO_0		FPSO_NE2000	
	Apr/May	Nov	Apr/May	Nov
1 - 10 m	93.47	107.1	92.47	106.9
10 - 20 m	98.30	107.3	98.54	107.5
20 - 30 m	98.67	108.0	98.79	108.0
30 - 40 m	98.11	108.3	96.63	108.3
40 - 50 m	94.87	105.7	93.82	106.8
50 - 60 m	89.95	97.7	87.15	99.5
60 - 70 m	76.11	95.3	74.15	95.2
70 - 80 m	71.27	89.5	70.92	88.1
80 - 90 m	71.37	86.5	67.54	86.2
90 - 100 m	65.99	82.9	62.56	84.8
100 - 110 m	60.97	79.2	61.17	81.5
110 - 120 m	58.53	74.0	58.17	76.1
120 - 130 m	54.42	66.3	54.12	67.4
130 - 140 m	50.27	59.6	49.53	57.8
140 - 150 m	46.38	56.0	46.05	56.2
150 - 160 m	43.70	54.8	43.62	56.0
160 - 170 m	42.61	54.6	42.62	55.7

D R A F T

Table 22 Dissolved Oxygen (% Saturation) / depth profiles at sites along the Pipeline and reference sites

Depth	PL-1		PL-2		PL-3		REF_NE	
	Apr/May	Nov	Apr/May	Nov	Apr/May	Nov	Apr/May	Nov
1 - 10 m	94.38	109.4	86.63	108.9	88.94	108.2	92.50	105.8
10 - 20 m	99.14	109.5	96.65	109.3	97.84	108.2	98.07	106.3
20 - 30 m	99.45	110.3	98.59	109.1	98.23	108.0	98.25	107.1
30 - 40 m	99.68	111.4	96.88	109.4	95.20	108.5	96.53	104.8
40 - 50 m	99.39	109.8	84.57	110.6	86.48	109.1	92.01	96.6
50 - 60 m	100.52	107.3	69.37	111.1	79.30	106.1	80.93	91.4
60 - 70 m	96.37	99.4	67.68	109.2	76.84	104.2	70.77	88.8
70 - 80 m	88.80	86.0	69.47	105.5	71.51	93.0	68.11	85.8
80 - 90 m	76.94	81.8	65.32	93.0	65.90	83.7	64.68	80.8
90 - 100 m	66.29	78.5	62.02	85.7	61.19	75.6	59.67	75.3
100 - 110 m	59.83	77.2	60.27	82.3	57.03	71.3	-	-
110 - 120 m	57.73	75.9	59.83	77.0	52.23	71.2	-	-
120 - 130 m	54.26	72.4	55.56	72.6	49.88	67.4	-	-
130 - 140 m	50.48	64.7	54.80	67.4	49.56	64.9	-	-
140 - 150 m	48.51	57.3	53.76	61.8	47.72	62.5	-	-
150 - 160 m	46.49	54.1	52.32	58.4	44.59	58.8	-	-
160 - 170 m	44.87	50.9	49.23	54.2	42.12	52.6	-	-
170 - 180 m	43.45	49.9	47.59	50.6	42.18	50.1	-	-
180 - 190 m	42.48	48.6	45.08	49.6	-	-	-	-
190 - 200 m	41.45	48.0	42.50	49.3	-	-	-	-
200 - 210 m	41.25	47.7	42.06	49.2	-	-	-	-



AECOM

Water Column Profiles Survey 1 (May 2016) Vs Survey 2 (October 2016)
Dissolved Oxygen

Survey 1 (May 2016)
Survey 2 (October 2016)

D R A F T

Table 23 pH / depth profiles at sites surrounding proposed Drill Centre locations

Depth	DC0		DC0_SW2000		DC1_NW2000		DC2_NE2000	
	Apr/May	Nov	Apr/May	Nov	Apr/May	Nov	Apr/May	Nov
1 - 10 m	8.13	8.13	8.08	7.94	8.13	8.24	8.09	8.20
10 - 20 m	8.13	8.14	8.08	7.94	8.13	8.25	8.09	8.22
20 - 30 m	8.13	8.15	8.08	7.95	8.12	8.27	8.08	8.23
30 - 40 m	8.12	8.16	8.08	7.97	8.11	8.28	8.08	8.25
40 - 50 m	8.09	8.17	8.08	7.99	8.11	8.28	8.08	8.26
50 - 60 m	8.05	8.17	8.06	7.99	8.09	8.29	8.06	8.27
60 - 70 m	8.03	8.17	8.03	8.00	8.07	8.28	8.02	8.27
70 - 80 m	8.03	8.17	7.99	8.01	8.04	8.27	8.00	8.26
80 - 90 m	8.02	8.17	7.98	8.01	8.01	8.27	7.98	8.25
90 - 100 m	8.00	8.16	7.95	8.00	7.99	8.26	7.96	8.25
100 - 110 m	7.98	8.16	7.93	8.01	7.97	8.26	7.94	8.25
110 - 120 m	7.97	8.16	7.91	8.01	7.94	8.26	7.92	8.25
120 - 130 m	7.95	8.16	7.89	8.01	7.92	8.25	7.90	8.24
130 - 140 m	7.93	8.17	7.87	8.01	7.90	8.25	7.87	8.25
140 - 150 m	7.90	8.16	7.84	8.02	7.87	8.25	7.84	8.23
150 - 160 m	7.88	8.14	7.82	8.01	7.85	8.06	7.82	8.21
160 - 170 m	7.87	8.13	7.80	7.99	7.83	7.97	7.81	8.20
170 - 180 m	-	-	7.80	7.98	-	-	-	-

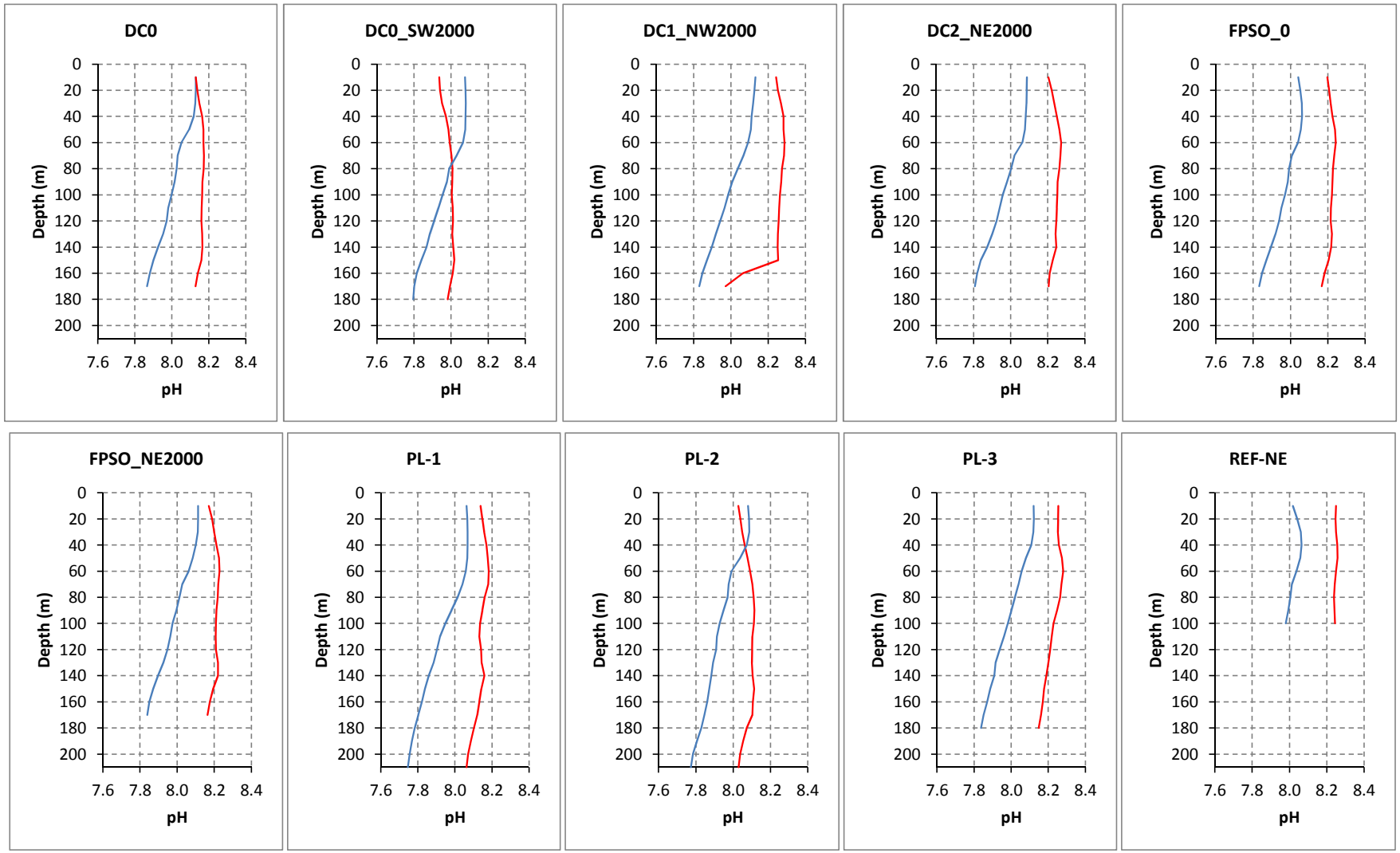
Table 24 pH / depth profiles at sites surrounding proposed FPSO Locations

Depth	FPSO_0		FPSO_NE2000	
	Apr/May	Nov	Apr/May	Nov
1 - 10 m	8.04	8.20	8.11	8.17
10 - 20 m	8.05	8.21	8.11	8.19
20 - 30 m	8.06	8.22	8.11	8.20
30 - 40 m	8.06	8.22	8.10	8.21
40 - 50 m	8.05	8.24	8.09	8.23
50 - 60 m	8.04	8.24	8.06	8.23
60 - 70 m	8.01	8.23	8.03	8.22
70 - 80 m	7.99	8.23	8.01	8.22
80 - 90 m	7.99	8.22	8.00	8.21
90 - 100 m	7.97	8.22	7.98	8.21
100 - 110 m	7.95	8.22	7.96	8.21
110 - 120 m	7.94	8.22	7.95	8.21
120 - 130 m	7.92	8.22	7.93	8.22
130 - 140 m	7.90	8.22	7.90	8.22
140 - 150 m	7.87	8.20	7.87	8.19
150 - 160 m	7.85	8.18	7.85	8.18
160 - 170 m	7.83	8.17	7.84	8.16

D R A F T

Table 25 pH / depth profiles at sites along the Pipeline and reference sites

Depth	PL-1		PL-2		PL-3		REF_NE	
	Apr/May	Nov	Apr/May	Nov	Apr/May	Nov	Apr/May	Nov
1 - 10 m	8.06	8.14	8.08	8.03	8.12	8.25	8.02	8.25
10 - 20 m	8.07	8.15	8.09	8.04	8.12	8.25	8.04	8.25
20 - 30 m	8.07	8.16	8.09	8.05	8.12	8.25	8.06	8.25
30 - 40 m	8.07	8.17	8.07	8.06	8.11	8.26	8.07	8.26
40 - 50 m	8.07	8.18	8.04	8.08	8.08	8.27	8.06	8.26
50 - 60 m	8.06	8.18	7.99	8.09	8.06	8.28	8.04	8.25
60 - 70 m	8.04	8.18	7.98	8.10	8.04	8.27	8.01	8.24
70 - 80 m	8.02	8.16	7.97	8.11	8.02	8.26	8.00	8.24
80 - 90 m	7.98	8.15	7.95	8.11	8.00	8.25	7.99	8.24
90 - 100 m	7.95	8.14	7.93	8.11	7.98	8.23	7.98	8.24
100 - 110 m	7.92	8.13	7.91	8.10	7.96	8.22	-	-
110 - 120 m	7.90	8.14	7.91	8.10	7.94	8.21	-	-
120 - 130 m	7.89	8.14	7.89	8.10	7.92	8.20	-	-
130 - 140 m	7.86	8.16	7.88	8.10	7.91	8.19	-	-
140 - 150 m	7.84	8.14	7.87	8.11	7.89	8.18	-	-
150 - 160 m	7.82	8.13	7.86	8.11	7.87	8.17	-	-
160 - 170 m	7.80	8.12	7.85	8.10	7.85	8.16	-	-
170 - 180 m	7.78	8.10	7.83	8.07	7.84	8.15	-	-
180 - 190 m	7.77	8.09	7.81	8.05	-	-	-	-
190 - 200 m	7.76	8.07	7.78	8.04	-	-	-	-
200 - 210 m	7.75	8.06	7.77	8.03	-	-	-	-



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Water Column Profiles Survey 1 (May 2016) Vs Survey 2 (October 2016): pH

Survey 1 (May 2016)
Survey 2 (October 2016)

D R A F T

Table 26 Turbidity (NTU) / depth profiles at sites surrounding proposed Drill Centre locations

Depth	DC0		DC0_SW2000		DC1_NW2000		DC2_NE2000	
	Apr/May	Nov	Apr/May	Nov	Apr/May	Nov	Apr/May	Nov
1 - 10 m	0.31	0.13	0.32	0.11	0.26	0.35	0.33	0.16
10 - 20 m	0.25	0.09	0.28	0.08	0.32	0.29	0.29	0.11
20 - 30 m	0.26	0.16	0.30	0.14	0.27	0.23	0.36	0.11
30 - 40 m	0.26	0.22	0.29	0.12	0.25	0.25	0.32	0.24
40 - 50 m	0.29	0.22	0.30	0.14	0.24	0.34	0.29	0.28
50 - 60 m	0.30	0.23	0.27	0.19	0.21	0.32	0.31	0.28
60 - 70 m	0.35	0.22	0.29	0.21	0.24	0.32	0.27	0.27
70 - 80 m	0.28	0.15	0.29	0.20	0.21	0.26	0.26	0.21
80 - 90 m	0.33	0.19	0.31	0.18	0.23	0.30	0.26	0.27
90 - 100 m	0.37	0.15	0.30	0.16	0.22	0.31	0.40	0.26
100 - 110 m	0.45	0.20	0.46	0.20	0.40	0.31	0.47	0.27
110 - 120 m	0.34	0.17	0.49	0.21	0.33	0.34	0.40	0.24
120 - 130 m	0.48	0.19	0.51	0.23	0.33	0.31	0.33	0.26
130 - 140 m	0.47	0.21	0.40	0.22	0.34	0.38	0.41	0.26
140 - 150 m	0.47	0.23	0.51	0.22	0.42	0.38	0.48	0.26
150 - 160 m	0.46	0.55	0.51	0.21	0.42	0.46	0.49	0.46
160 - 170 m	0.44	0.81	0.50	0.63	0.43	0.49	0.45	0.97
170 - 180 m	-	-	0.50	0.58	-	-	-	-

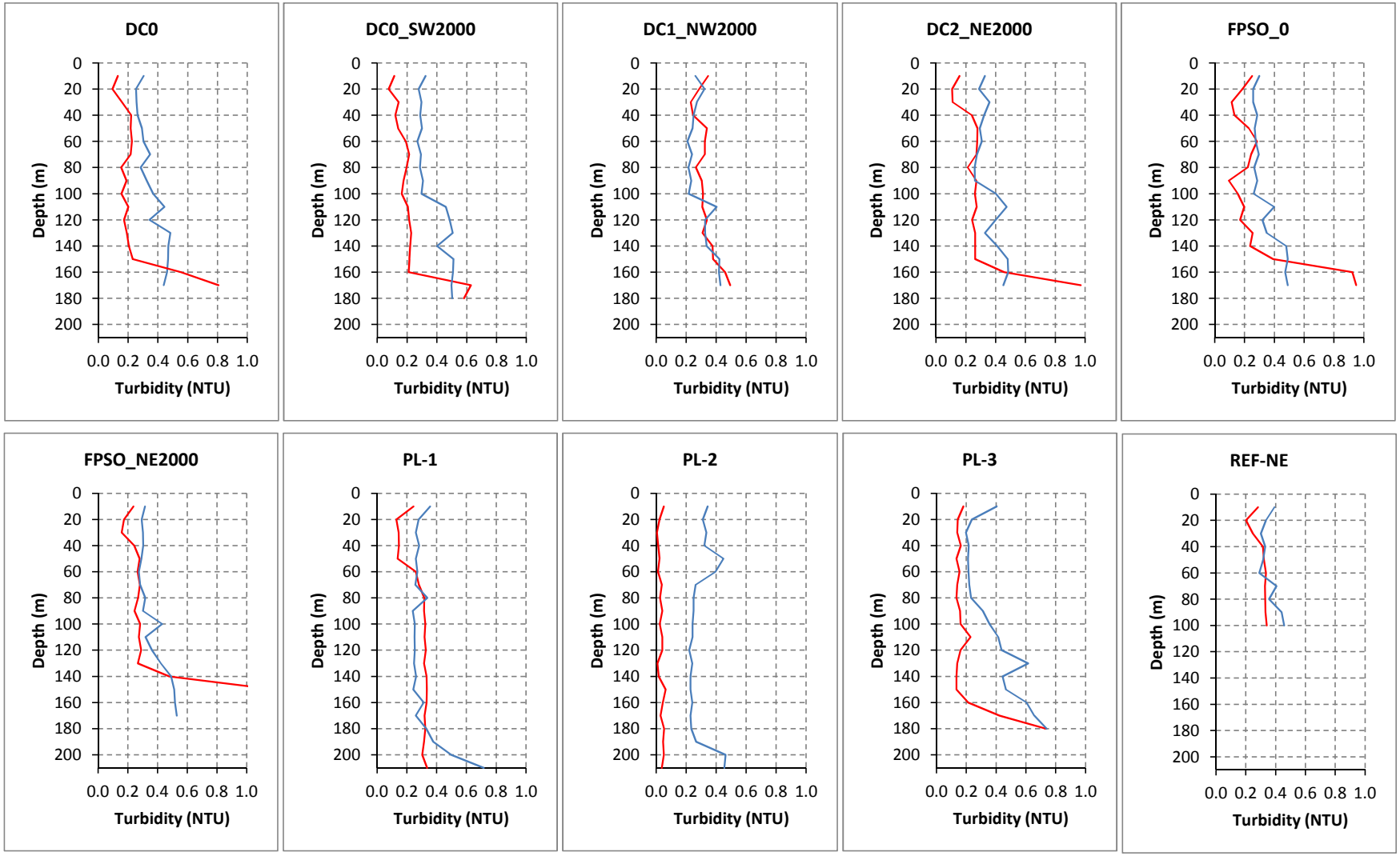
Table 27 Turbidity (NTU) / depth profiles at sites surrounding proposed FPSO Locations

Depth	FPSO_0		FPSO_NE2000	
	Apr/May	Nov	Apr/May	Nov
1 - 10 m	0.30	0.25	0.32	0.24
10 - 20 m	0.26	0.18	0.29	0.18
20 - 30 m	0.26	0.11	0.30	0.16
30 - 40 m	0.28	0.13	0.30	0.24
40 - 50 m	0.27	0.23	0.29	0.28
50 - 60 m	0.28	0.28	0.28	0.27
60 - 70 m	0.30	0.24	0.28	0.28
70 - 80 m	0.26	0.22	0.32	0.27
80 - 90 m	0.29	0.09	0.30	0.25
90 - 100 m	0.26	0.16	0.43	0.28
100 - 110 m	0.40	0.20	0.32	0.27
110 - 120 m	0.32	0.17	0.36	0.29
120 - 130 m	0.35	0.25	0.42	0.27
130 - 140 m	0.48	0.24	0.49	0.48
140 - 150 m	0.49	0.39	0.51	1.19
150 - 160 m	0.47	0.92	0.52	1.52
160 - 170 m	0.49	0.95	0.53	1.98

D R A F T

Table 28 Turbidity (NTU) / depth profiles at sites along the Pipeline and reference sites

Depth	PL-1		PL-2		PL-3		REF_NE	
	Apr/May	Nov	Apr/May	Nov	Apr/May	Nov	Apr/May	Nov
1 - 10 m	0.36	0.25	0.34	0.05	0.40	0.18	0.39	0.28
10 - 20 m	0.28	0.13	0.31	0.02	0.24	0.14	0.33	0.20
20 - 30 m	0.26	0.15	0.33	0.01	0.20	0.14	0.30	0.25
30 - 40 m	0.28	0.15	0.32	0.01	0.22	0.16	0.33	0.31
40 - 50 m	0.26	0.14	0.45	0.02	0.21	0.13	0.32	0.32
50 - 60 m	0.27	0.26	0.40	0.01	0.21	0.16	0.29	0.34
60 - 70 m	0.26	0.28	0.26	0.04	0.22	0.14	0.41	0.33
70 - 80 m	0.34	0.32	0.25	0.03	0.23	0.13	0.36	0.33
80 - 90 m	0.24	0.32	0.25	0.04	0.31	0.16	0.44	0.33
90 - 100 m	0.25	0.32	0.24	0.02	0.36	0.16	0.46	0.34
100 - 110 m	0.25	0.32	0.24	0.04	0.41	0.23	-	-
110 - 120 m	0.25	0.33	0.22	0.04	0.44	0.16	-	-
120 - 130 m	0.25	0.31	0.24	0.01	0.62	0.14	-	-
130 - 140 m	0.26	0.33	0.23	0.02	0.44	0.13	-	-
140 - 150 m	0.24	0.34	0.23	0.06	0.47	0.13	-	-
150 - 160 m	0.31	0.33	0.24	0.04	0.60	0.21	-	-
160 - 170 m	0.26	0.32	0.23	0.03	0.66	0.42	-	-
170 - 180 m	0.33	0.32	0.23	0.05	0.74	0.73	-	-
180 - 190 m	0.38	0.32	0.27	0.04	-	-	-	-
190 - 200 m	0.50	0.30	0.46	0.05	-	-	-	-
200 - 210 m	0.72	0.34	0.45	0.04	-	-	-	-



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Water Column Profiles Survey 1 (May 2016) Vs Survey 2 (October 2016): Turbidity

Survey 1 (May 2016)
Survey 2 (October 2016)

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Appendix G

Water sample analytical results

D R A F T

Appendix G Water sample analytical results

Table 29 Water sampling site locations

Location	Latitude/Longitude (GDA94)	Collected (WST)
DC0_1	12°58.356'S 124°26.691'E	1530 02/11/16
DC0_2 (triplicate)	12°58.374'S 124°26.667'E	1542 02/11/16
DC0_3 (triplicate)	12°58.336'S 124°26.690'E	1554 02/11/16
DC0_SW2000	12°59.119'S 124°25.906'E	1440 02/11/16
DC1_NW2000	12°57.058'S 124°25.786'E	1825 02/11/16
DC2_NE2000	12°57.215'S 124°27.874'E	1750 02/11/16
FPSO_0	12°59.017'S 124°27.735'E	1647 02/11/16
FPSO_NE2000	12°58.200'S 124°28.518'E	1720 02/11/16
PL-1 (KP103)	13°28.178'S 123°39.023'E	1515 03/11/16
PL-2 (KP65)	13°14.513'S 123°55.937'E	1103 03/11/16
PL-3_1 (KP18)	13°02.199'S 124°17.316'E	0628 03/11/16
PL-3_2 (KP18) (duplicate)	13°02.159'S 124°17.364'E	0640 03/11/16
REF_NE	12°55.374'S 124°34.499'E	0710 02/11/16

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Table 30 Laboratory analytical results summary

				DCO_SW2000	DCO	DCO	FPSO_0	FPSO_NE2000	DC2_NE2000	DC1_NW2000	PL_3	PL_3	PL_2	PL_1	REF_NE
Analyte	**Unit**	**Trigger[a]**	**PQL**												
Hydrocarbons															
TPH Low Level	µg/L	-	10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
BTEX															
Benzene	mg/L	0.5	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Toluene	mg/L	0.18[b]	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Ethylbenzene	mg/L	0.005[b]	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Xylenes (Total)	mg/L	0.625[b]	0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
Metals															
Aluminium - Total	mg/L	-	0.01	<0.01	<0.01	<0.01	<0.01	**0.06**	<0.01	<0.01	<0.01	<0.01	**0.01**	**0.02**	<0.01
Arsenic - Total	mg/L	-	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Barium - Total	mg/L	-	0.01	**0.01**	**0.01**	**0.01**	**0.02**	**0.01**	<0.01	**0.02**	<0.01	<0.01	<0.01	<0.01	**0.02**
Iron - Total	mg/L	-	0.01	**0.1**	**0.06**	**0.05**	**0.04**	**0.04**	**0.09**	**0.04**	**0.03**	**0.03**	**0.02**	**0.02**	**0.2**
Cadmium - Total	mg/L	0.0007	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Cobalt - Total	mg/L	0.001[c]	0.001	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.002**
Chromium - Total	mg/L	0.0077	0.001	<0.001	<0.001	**0.002**	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Copper - Total	mg/L	0.0013[c]	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Mercury - Total	mg/L	0.0001	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Nickel - Total	mg/L	0.007	0.001	<0.001	**0.001**	**0.001**	**0.001**	<0.001	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	<0.001
Lead - Total	mg/L	0.0022	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Zinc - Total	mg/L	0.007	0.005	**0.035**	**0.029**	**0.029**	**0.026**	**0.026**	**0.011**	**0.01**	**0.02**	**0.02**	**0.015**	**0.014**	**0.046**
Nutrients															
Total Nitrogen	mg/L	0.1[d]	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Total Phosphorus	mg/L	0.01[c]	0.005	**0.011**	**0.012**	**0.011**	**0.011**	**0.01**	**0.011**	**0.011**	**0.01**	**0.01**	**0.011**	**0.01**	**0.012**
NOx-N	mg/L	0.004[d]	0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Photosynthetic pigments															
CHLORO 'a'	µg/L	0.9[d]	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
CHLORO 'b'	µg/L	-	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
CHLORO 'c'	µg/L	-	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
CHLOROPHYLL'a'	µg/L	0.9[d]	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
PHAEOPHYTIN'a'	µg/L	-	0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2

Concentrations above PQL in **bold**

a - ANZECC / ARMCANZ 99% species protection level

b - ANZECC / ARMCANZ low reliability trigger vlaues

c - ANZECC / ARMCANZ 95% species protection level

d - ANZECC / ARMCANZ Default trigger level. Site specific trigger level to be developed using baseline data

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Appendix H

Laboratory reports – Water Chemistry

Analytical Reference Laboratory

LABORATORY REPORT

Job Number: 16-08651
Revision: 00
Date: 25 November 2016

ADDRESS: **AECOM Services Pty Ltd**
GPO Box B59
Perth WA 6849

ATTENTION: Peter Young

DATE RECEIVED: 5/11/2016

YOUR REFERENCE: N/A

PURCHASE ORDER:

APPROVALS:

DouglasTodd	Fiona Reid	Min How	Paul Nottle	Sam Becker
Laboratory Manager	Inorganics Supervisor	Chemist - Organics	Organics Manager	Inorganics Manager

REPORT COMMENTS:

Samples are analysed on an as received basis unless otherwise noted.
Gross Alpha and Beta analysis subcontracted to SGS, NATA Accred No. 2562, Report Number 9893

METHOD REFERENCES:

ARL No. 010	Total Petroleum Hydrocarbons (TPH) in Soil
ARL No. 058	Oil and Grease in Soil by Gravimetric Analysis
ARL No. 401	Metals in Soil and Sediment by ICPOES
ARL No. 406	Mercury by Cold Vapour Atomic Absorption Spectrophotometry
ARL No. 118	Total Phosphorus and TKN in Soil and Biosolids
ARL No. 314	NOx in Soil and Sediment by Discrete Analyser
ARL No. 009	Total Petroleum Hydrocarbons (TPH) in Water
ARL No. 007	Benzene, Toluene, Ethylbenzene and Xylenes in Water
ARL No. 331	Persulphate Method Determination of Low Level Total Nitrogen
ARL No. 049	Low Level Total and Filtered Reactive Phosphorus In Water
ARL No. 033	NOx in Water
ARL No. 29/402/403	Metals in Water by AAS/ICPOES/ICPMS
Subcontracting	See Report Comments section for more information.

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NATA Accreditation No. 2377

Analytical Reference Laboratory (WA) Pty. Ltd.
46-48 Banksia Road, Welshpool, Western Australia 6106 Telephone: 08 6253 4444 Facsimile: 08 6253 4440
www.arlwa.com.au ABN: 91 050 159 898

TPH Low Level 1 in Water Sample No: Sample Description: Sample Date:	**LOR**	**UNITS**	**16-08651-1 CW01 2/11/16**	**16-08651-2 CW02 2/11/16**	**16-08651-3 CW03 2/11/16**	**16-08651-4 CW04 2/11/16**	**16-08651-5 CW05 2/11/16**
TPH Low Level 1*	10	µg/L	<10	<10	<10	<10	<10

TPH Low Level 1 in Water Sample No: Sample Description: Sample Date:	**LOR**	**UNITS**	**16-08651-6 CW06 2/11/16**	**16-08651-7 CW07 2/11/16**	**16-08651-8 CW08 2/11/16**	**16-08651-9 CW09 3/11/16**	**16-08651-10 CW10 3/11/16**
TPH Low Level 1*	10	µg/L	<10	<10	<10	<10	<10

TPH Low Level 1 in Water Sample No: Sample Description: Sample Date:	**LOR**	**UNITS**	**16-08651-11 CW11 3/11/16**	**16-08651-12 CW12 3/11/16**	**16-08651-13 CB01 2/11/16**
TPH Low Level 1*	10	µg/L	<10	<10	<10

BTEX in Water Sample No: Sample Description: Sample Date:	**LOR**	**UNITS**	**16-08651-1 CW01 2/11/16**	**16-08651-2 CW02 2/11/16**	**16-08651-3 CW03 2/11/16**	**16-08651-4 CW04 2/11/16**	**16-08651-5 CW05 2/11/16**
Benzene	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Toluene	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Ethylbenzene	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Xylenes (Total)	0.003	mg/L	<0.003	<0.003	<0.003	<0.003	<0.003

BTEX in Water Sample No: Sample Description: Sample Date:	**LOR**	**UNITS**	**16-08651-6 CW06 2/11/16**	**16-08651-7 CW07 2/11/16**	**16-08651-8 CW08 2/11/16**	**16-08651-9 CW09 3/11/16**	**16-08651-10 CW10 3/11/16**
Benzene	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Toluene	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Ethylbenzene	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Xylenes (Total)	0.003	mg/L	<0.003	<0.003	<0.003	<0.003	<0.003

BTEX in Water Sample No: Sample Description: Sample Date:	**LOR**	**UNITS**	**16-08651-11 CW11 3/11/16**	**16-08651-12 CW12 3/11/16**	**16-08651-13 CB01 2/11/16**
Benzene	0.001	mg/L	<0.001	<0.001	<0.001
Toluene	0.001	mg/L	<0.001	<0.001	<0.001
Ethylbenzene	0.001	mg/L	<0.001	<0.001	<0.001
Xylenes (Total)	0.003	mg/L	<0.003	<0.003	<0.003

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Total Nitrogen in Water Sample No: Sample Description: Sample Date:	LOR	UNITS	16-08651-1 CW01 2/11/16	16-08651-2 CW02 2/11/16	16-08651-3 CW03 2/11/16	16-08651-4 CW04 2/11/16	16-08651-5 CW05 2/11/16
Total Nitrogen	0.1	mg/L	<0.1	<0.1	<0.1	<0.1	<0.1

Total Nitrogen in Water Sample No: Sample Description: Sample Date:	LOR	UNITS	16-08651-6 CW06 2/11/16	16-08651-7 CW07 2/11/16	16-08651-8 CW08 2/11/16	16-08651-9 CW09 3/11/16	16-08651-10 CW10 3/11/16
Total Nitrogen	0.1	mg/L	<0.1	<0.1	<0.1	<0.1	<0.1

Total Nitrogen in Water Sample No: Sample Description: Sample Date:	LOR	UNITS	16-08651-11 CW11 3/11/16	16-08651-12 CW12 3/11/16	16-08651-13 CB01 2/11/16
Total Nitrogen	0.1	mg/L	<0.1	<0.1	<0.1

Total Phosphorus in Water Sample No: Sample Description: Sample Date:	LOR	UNITS	16-08651-1 CW01 2/11/16	16-08651-2 CW02 2/11/16	16-08651-3 CW03 2/11/16	16-08651-4 CW04 2/11/16	16-08651-5 CW05 2/11/16
Total Phosphorus	0.005	mg/L	0.012	0.011	0.012	0.011	0.011

Total Phosphorus in Water Sample No: Sample Description: Sample Date:	LOR	UNITS	16-08651-6 CW06 2/11/16	16-08651-7 CW07 2/11/16	16-08651-8 CW08 2/11/16	16-08651-9 CW09 3/11/16	16-08651-10 CW10 3/11/16
Total Phosphorus	0.005	mg/L	0.010	0.011	0.011	0.010	0.010

Total Phosphorus in Water Sample No: Sample Description: Sample Date:	LOR	UNITS	16-08651-11 CW11 3/11/16	16-08651-12 CW12 3/11/16	16-08651-13 CB01 2/11/16
Total Phosphorus	0.005	mg/L	0.011	0.010	0.005

Ions by Discrete Analyser Sample No: Sample Description: Sample Date:	LOR	UNITS	16-08651-1 CW01 2/11/16	16-08651-2 CW02 2/11/16	16-08651-3 CW03 2/11/16	16-08651-4 CW04 2/11/16	16-08651-5 CW05 2/11/16
NOx-N	0.002	mg/L	<0.002	<0.002	<0.002	<0.002	<0.002

Analytical Reference Laboratory (WA) Pty. Ltd.
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www.arlwa.com.au ABN: 91 050 159 898

LABORATORY REPORT

AECOM Services Pty Ltd

ARL Job No: 16-08651 *Revision: 00* *Date:* 25 November 2016

Ions by Discrete Analyser Sample No: Sample Description: Sample Date:	LOR	UNITS	16-08651-6 CW06 2/11/16	16-08651-7 CW07 2/11/16	16-08651-8 CW08 2/11/16	16-08651-9 CW09 3/11/16	16-08651-10 CW10 3/11/16
NOx-N	0.002	mg/L	<0.002	<0.002	<0.002	<0.002	<0.002

Ions by Discrete Analyser Sample No: Sample Description: Sample Date:	LOR	UNITS	16-08651-11 CW11 3/11/16	16-08651-12 CW12 3/11/16	16-08651-13 CB01 2/11/16
NOx-N	0.002	mg/L	<0.002	<0.002	<0.002

Metals in Water Sample No: Sample Description: Sample Date:	LOR	UNITS	16-08651-1 CW01 2/11/16	16-08651-2 CW02 2/11/16	16-08651-3 CW03 2/11/16	16-08651-4 CW04 2/11/16	16-08651-5 CW05 2/11/16
Arsenic - Total	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Barium - Total	0.01	mg/L	0.02	0.01	0.01	0.01	0.02
Iron - Total	0.01	mg/L	0.20	0.10	0.06	0.05	0.04
Aluminium - Total	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01
Cadmium - Total	0.0001	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Cobalt - Total	0.001	mg/L	0.002	0.001	0.001	0.001	0.001
Chromium - Total	0.001	mg/L	<0.001	<0.001	<0.001	0.002	<0.001
Copper - Total	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Mercury - Total	0.0001	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Nickel - Total	0.001	mg/L	<0.001	<0.001	0.001	0.001	0.001
Lead - Total	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Zinc - Total	0.005	mg/L	0.046	0.035	0.029	0.029	0.026

Metals in Water Sample No: Sample Description: Sample Date:	LOR	UNITS	16-08651-6 CW06 2/11/16	16-08651-7 CW07 2/11/16	16-08651-8 CW08 2/11/16	16-08651-9 CW09 3/11/16	16-08651-10 CW10 3/11/16
Arsenic - Total	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Barium - Total	0.01	mg/L	0.01	<0.01	0.02	<0.01	<0.01
Iron - Total	0.01	mg/L	0.04	0.09	0.04	0.03	0.03
Aluminium - Total	0.01	mg/L	0.06	<0.01	<0.01	<0.01	<0.01
Cadmium - Total	0.0001	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Cobalt - Total	0.001	mg/L	0.001	0.001	0.001	0.001	0.001
Chromium - Total	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Copper - Total	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Mercury - Total	0.0001	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Nickel - Total	0.001	mg/L	<0.001	0.001	0.001	0.001	0.001
Lead - Total	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Zinc - Total	0.005	mg/L	0.026	0.011	0.010	0.020	0.020

Analytical Reference Laboratory (WA) Pty. Ltd.
46-48 Banksia Road, Welshpool, Western Australia 6106 Telephone: 08 6253 4444 Facsimile: 08 6253 4440
www.arlwa.com.au ABN: 91 050 159 898

LABORATORY REPORT

AECOM Services Pty Ltd

ARL Job No: 16-08651 *Revision: 00* *Date:* 25 November 2016

Metals in Water Sample No: Sample Description: Sample Date:	LOR	UNITS	16-08651-11 CW11 3/11/16	16-08651-12 CW12 3/11/16	16-08651-13 CB01 2/11/16
Arsenic - Total	0.001	mg/L	<0.001	<0.001	<0.001
Barium - Total	0.01	mg/L	<0.01	<0.01	<0.01
Iron - Total	0.01	mg/L	0.02	0.02	0.05
Aluminium - Total	0.01	mg/L	0.01	0.02	0.07
Cadmium - Total	0.0001	mg/L	<0.0001	<0.0001	<0.0001
Cobalt - Total	0.001	mg/L	0.001	0.001	<0.001
Chromium - Total	0.001	mg/L	<0.001	<0.001	<0.001
Copper - Total	0.001	mg/L	<0.001	<0.001	<0.001
Mercury - Total	0.0001	mg/L	<0.0001	<0.0001	<0.0001
Nickel - Total	0.001	mg/L	0.001	0.001	0.001
Lead - Total	0.001	mg/L	<0.001	<0.001	<0.001
Zinc - Total	0.005	mg/L	0.015	0.014	<0.005

Subcontracting Sample No: Sample Description: Sample Date:	LOR	UNITS	16-08651-14 CS61 1/11/16	16-08651-15 CS65 2/11/16
Gross Alpha	0.1	Bq/g	0.13	0.27
Gross Beta	0.25	Bq/g	<0.25	0.41

Result Definitions

LOR Limit of Reporting

[ND] Not Detected at indicated Limit of Reporting

* Denotes test not covered by NATA Accreditation

[NT] Not Tested

[NR] Analysis Not Requested

Analytical Reference Laboratory (WA) Pty. Ltd.
46-48 Banksia Road, Welshpool, Western Australia 6106 Telephone: 08 6253 4444 Facsimile: 08 6253 4440
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ALS Environmental

CERTIFICATE OF ANALYSIS

Work Order	: **EP1610572**	Page	: 1 of 7
Client	: **AECOM SERVICES PTY LTD**	Laboratory	: Environmental Division Perth
Contact	: PETER YOUNG	Contact	: ShukHui Li
Address	: ALS LABORATORY GROUP PERTH WA	Address	: 10 Hod Way Malaga WA Australia 6090
Telephone	: +61 08 9326 0100	Telephone	: 08 9209 7655
Project	: 42908883 Shell Crux Sediment Baseline Survey	Date Samples Received	: 07-Nov-2016 08:00
Order number	: 60495521/1.4	Date Analysis Commenced	: 08-Nov-2016
C-O-C number	: ----	Issue Date	: 14-Nov-2016 16:59
Sampler	: IAN BAXTER		
Site	: ----		
Quote number	: ----		
No. of samples received	: 7		
No. of samples analysed	: 7		

Accreditation No. 825
Accredited for compliance with
ISO/IEC 17025 - Testing

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted. This document shall not be reproduced, except in full.

This Certificate of Analysis contains the following information:

- General Comments
- Analytical Results
- Surrogate Control Limits

Additional information pertinent to this report will be found in the following separate attachments: Quality Control Report, QA/QC Compliance Assessment to assist with Quality Review and Sample Receipt Notification.

Signatories

This document has been electronically signed by the authorized signatories below. Electronic signing is carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Chris Lemaitre	Non-Metals Team Leader	Melbourne Inorganics, Springvale, VIC
Edwandy Fadjar	Organic Coordinator	Sydney Organics, Smithfield, NSW
Efua Wilson	Metals Chemist	Perth Inorganics, Malaga, WA
Jeremy Truong	Laboratory Manager	Perth Inorganics, Malaga, WA

General Comments

The analytical procedures used by the Environmental Division have been developed from established internationally recognized procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are employed in the absence of documented standards or by client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insufficient sample for analysis.

Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

When sampling time information is not provided by the client, sampling dates are shown without a time component. In these instances, the time component has been assumed by the laboratory for processing purposes.

Where a result is required to meet compliance limits the associated uncertainty must be considered. Refer to the ALS Contact for details.

Key : CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting
ø = ALS is not NATA accredited for these tests.
~ = Indicates an estimated value.

- TKN & TP conducted by ALS Melbourne, NATA accreditation no. 825, site no 13778
- EP071, EP080 conducted by ALS Sydney, NATA accreditation no. 825, site no 10911.
- EG020: Metals LOR for particular sample(s) raised due to high TDS content.

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)				Client sample ID	CB02	CR01	CR02	CR03	CW13/CR13
				Client sampling date / time	[01-Nov-2016]	[01-Nov-2016]	[02-Nov-2016]	[03-Nov-2016]	[02-Nov-2016]
Compound	CAS Number	LOR	Unit		EP1610572-001	EP1610572-002	EP1610572-003	EP1610572-004	EP1610572-005
					Result	Result	Result	Result	Result
EG020T: Total Metals by ICP-MS									
Arsenic	7440-38-2	0.001	mg/L		----	<0.001	<0.001	<0.001	<0.005
Cadmium	7440-43-9	0.0001	mg/L		----	<0.0001	<0.0001	<0.0001	<0.0005
Chromium	7440-47-3	0.001	mg/L		----	<0.001	<0.001	<0.001	<0.005
Copper	7440-50-8	0.001	mg/L		----	<0.001	<0.001	<0.001	<0.005
Nickel	7440-02-0	0.001	mg/L		----	<0.001	<0.001	<0.001	<0.005
Lead	7439-92-1	0.001	mg/L		----	<0.001	<0.001	<0.001	<0.005
Zinc	7440-66-6	0.005	mg/L		----	<0.005	<0.005	**0.006**	<0.025
EG035T: Total Recoverable Mercury by FIMS									
Mercury	7439-97-6	0.0001	mg/L		----	<0.0001	<0.0001	<0.0001	<0.0001
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser									
Nitrite + Nitrate as N	----	0.01	mg/L		----	<0.01	<0.01	<0.01	<0.01
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser									
Total Kjeldahl Nitrogen as N	----	0.1	mg/L		----	**0.3**	**0.3**	**0.3**	**0.2**
EK062G: Total Nitrogen as N (TKN + NOx) by Discrete Analyser									
^ Total Nitrogen as N	----	0.1	mg/L		----	**0.3**	**0.3**	**0.3**	**0.2**
EK067G: Total Phosphorus as P by Discrete Analyser									
Total Phosphorus as P	----	0.01	mg/L		----	<0.01	<0.01	<0.01	**0.09**
EP080/071: Total Petroleum Hydrocarbons									
C6 - C9 Fraction	----	20	µg/L		<20	<20	<20	<20	<20
C10 - C14 Fraction	----	50	µg/L		<50	<50	<50	<50	<50
C15 - C28 Fraction	----	100	µg/L		<100	<100	<100	<100	<100
C29 - C36 Fraction	----	50	µg/L		<50	<50	<50	<50	<50
^ C10 - C36 Fraction (sum)	----	50	µg/L		<50	<50	<50	<50	<50
EP080/071: Total Recoverable Hydrocarbons - NEPM 2013 Fractions									
C6 - C10 Fraction	C6_C10	20	µg/L		<20	<20	<20	<20	<20
^ C6 - C10 Fraction minus BTEX (F1)	C6_C10-BTEX	20	µg/L		<20	<20	<20	<20	<20
>C10 - C16 Fraction	----	100	µg/L		<100	<100	<100	<100	<100
>C16 - C34 Fraction	----	100	µg/L		<100	<100	<100	<100	<100
>C34 - C40 Fraction	----	100	µg/L		<100	<100	<100	<100	<100
^ >C10 - C40 Fraction (sum)	----	100	µg/L		<100	<100	<100	<100	<100
^ >C10 - C16 Fraction minus Naphthalene (F2)	----	100	µg/L		<100	<100	<100	<100	<100
EP080: BTEXN									

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)				Client sample ID	CB02	CR01	CR02	CR03	CW13/CR13
				Client sampling date / time	[01-Nov-2016]	[01-Nov-2016]	[02-Nov-2016]	[03-Nov-2016]	[02-Nov-2016]
Compound	CAS Number	LOR	Unit		EP1610572-001	EP1610572-002	EP1610572-003	EP1610572-004	EP1610572-005
					Result	Result	Result	Result	Result
EP080: BTEXN - Continued									
Benzene	71-43-2	1	µg/L		<1	<1	<1	<1	<1
Toluene	108-88-3	2	µg/L		<2	<2	<2	<2	<2
Ethylbenzene	100-41-4	2	µg/L		<2	<2	<2	<2	<2
meta- & para-Xylene	108-38-3 106-42-3	2	µg/L		<2	<2	<2	<2	<2
ortho-Xylene	95-47-6	2	µg/L		<2	<2	<2	<2	<2
^ **Total Xylenes**	1330-20-7	2	µg/L		<2	<2	<2	<2	<2
^ **Sum of BTEX**	----	1	µg/L		<1	<1	<1	<1	<1
Naphthalene	91-20-3	5	µg/L		<5	<5	<5	<5	<5
EP080S: TPH(V)/BTEX Surrogates									
1.2-Dichloroethane-D4	17060-07-0	2	%		**97.6**	**101**	**94.6**	**96.2**	**117**
Toluene-D8	2037-26-5	2	%		**99.1**	**103**	**86.6**	**84.5**	**115**
4-Bromofluorobenzene	460-00-4	2	%		**97.1**	**99.2**	**91.9**	**91.2**	**109**

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)			Client sample ID	TBW 1031	TBW 1032	----	----	----
			Client sampling date / time	[02-Nov-2016]	[02-Nov-2016]	----	----	----
Compound	CAS Number	LOR	Unit	EP1610572-006	EP1610572-007	--------	--------	--------
				Result	Result	----	----	----
EG020T: Total Metals by ICP-MS								
Arsenic	7440-38-2	0.001	mg/L	----	----	----	----	----
Cadmium	7440-43-9	0.0001	mg/L	----	----	----	----	----
Chromium	7440-47-3	0.001	mg/L	----	----	----	----	----
Copper	7440-50-8	0.001	mg/L	----	----	----	----	----
Nickel	7440-02-0	0.001	mg/L	----	----	----	----	----
Lead	7439-92-1	0.001	mg/L	----	----	----	----	----
Zinc	7440-66-6	0.005	mg/L	----	----	----	----	----
EG035T: Total Recoverable Mercury by FIMS								
Mercury	7439-97-6	0.0001	mg/L	----	----	----	----	----
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser								
Nitrite + Nitrate as N	----	0.01	mg/L	----	----	----	----	----
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser								
Total Kjeldahl Nitrogen as N	----	0.1	mg/L	----	----	----	----	----
EK062G: Total Nitrogen as N (TKN + NOx) by Discrete Analyser								
^ Total Nitrogen as N	----	0.1	mg/L	----	----	----	----	----
EK067G: Total Phosphorus as P by Discrete Analyser								
Total Phosphorus as P	----	0.01	mg/L	----	----	----	----	----
EP080/071: Total Petroleum Hydrocarbons								
C6 - C9 Fraction	----	20	µg/L	<20	<20	----	----	----
C10 - C14 Fraction	----	50	µg/L	----	----	----	----	----
C15 - C28 Fraction	----	100	µg/L	----	----	----	----	----
C29 - C36 Fraction	----	50	µg/L	----	----	----	----	----
^ C10 - C36 Fraction (sum)	----	50	µg/L	----	----	----	----	----
EP080/071: Total Recoverable Hydrocarbons - NEPM 2013 Fractions								
C6 - C10 Fraction	C6_C10	20	µg/L	<20	<20	----	----	----
^ C6 - C10 Fraction minus BTEX (F1)	C6_C10-BTEX	20	µg/L	<20	<20	----	----	----
>C10 - C16 Fraction	----	100	µg/L	----	----	----	----	----
>C16 - C34 Fraction	----	100	µg/L	----	----	----	----	----
>C34 - C40 Fraction	----	100	µg/L	----	----	----	----	----
^ >C10 - C40 Fraction (sum)	----	100	µg/L	----	----	----	----	----
^ >C10 - C16 Fraction minus Naphthalene (F2)	----	100	µg/L	----	----	----	----	----
EP080: BTEXN								

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)				Client sample ID	TBW 1031	TBW 1032	----	----	----
				Client sampling date / time	[02-Nov-2016]	[02-Nov-2016]	----	----	----
Compound	CAS Number	LOR	Unit		EP1610572-006	EP1610572-007	--------	--------	--------
					Result	Result	----	----	----
EP080: BTEXN - Continued									
Benzene	71-43-2	1	µg/L		<1	<1	----	----	----
Toluene	108-88-3	2	µg/L		<2	<2	----	----	----
Ethylbenzene	100-41-4	2	µg/L		<2	<2	----	----	----
meta- & para-Xylene	108-38-3 106-42-3	2	µg/L		<2	<2	----	----	----
ortho-Xylene	95-47-6	2	µg/L		<2	<2	----	----	----
^ **Total Xylenes**	1330-20-7	2	µg/L		<2	<2	----	----	----
^ **Sum of BTEX**	----	1	µg/L		<1	<1	----	----	----
Naphthalene	91-20-3	5	µg/L		<5	<5	----	----	----
EP080S: TPH(V)/BTEX Surrogates									
1.2-Dichloroethane-D4	17060-07-0	2	%		**100**	**106**	----	----	----
Toluene-D8	2037-26-5	2	%		**104**	**111**	----	----	----
4-Bromofluorobenzene	460-00-4	2	%		**102**	**107**	----	----	----

Surrogate Control Limits

Sub-Matrix: **WATER**		Recovery Limits (%)	
Compound	*CAS Number*	*Low*	*High*
EP080S: TPH(V)/BTEX Surrogates			
1.2-Dichloroethane-D4	17060-07-0	71	137
Toluene-D8	2037-26-5	79	131
4-Bromofluorobenzene	460-00-4	70	128

Marine and Freshwater
Research Laboratory
Environmental Science
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Accreditation Number: 10603
This document is issued in accordance with
NATA's accreditation requirements.
Accredited for compliance with ISO/IEC 17025.

Murdoch UNIVERSITY

WATER QUALITY DATA

Contact: Peter Young
Customer: AECOM Australia Pty Ltd
Address: Level 6, 3 Forrest Place, Perth, WA, 6000

Date of Issue: 18/11/2016
Date Received: 11/11/2016
Our Reference: AEC16-3
Your Reference: 60478944

METHOD SAMPLE CODE	Sampling Date	3020 CHLORO 'a' µg/L	3020 CHLORO 'b' µg/L	3020 CHLORO 'c' µg/L	3000 CHLOROPHYLL'a' µg/L	3000 PHAEOPHYTIN'a' µg/L
Reporting Limit		**<0.1**	**<0.1**	**<0.1**	**<0.1**	**<0.2**
File			**16111601**		**16111601**	
CW01	2/11/2016	<0.1	<0.1	<0.1	<0.1	<0.2
CW02	2/11/2016	<0.1	<0.1	<0.1	<0.1	<0.2
CW03	2/11/2016	<0.1	<0.1	<0.1	<0.1	<0.2
CW04	2/11/2016	<0.1	<0.1	<0.1	<0.1	<0.2
CW05	2/11/2016	<0.1	<0.1	<0.1	<0.1	<0.2
CW06	2/11/2016	<0.1	<0.1	<0.1	<0.1	<0.2
CW07	2/11/2016	<0.1	<0.1	<0.1	<0.1	<0.2
CW08	2/11/2016	<0.1	<0.1	<0.1	<0.1	<0.2
CW09	3/11/2016	<0.1	<0.1	<0.1	<0.1	<0.2
CW10	3/11/2016	<0.1	<0.1	<0.1	<0.1	<0.2
CW11	3/11/2016	<0.1	<0.1	<0.1	<0.1	<0.2
CW12	3/11/2016	<0.1	<0.1	<0.1	<0.1	<0.2
CW13	2/11/2016	<0.1	<0.1	<0.1	<0.1	<0.2
BLANK		<0.1	<0.1	<0.1	<0.1	<0.2

Signatory: Lirong Han
Date: 18/11/2016

All test items tested as received. Spare test items will be held for two months unless otherwise requested.

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Appendix C: Benthic Habitat Study (Fugro 2017)

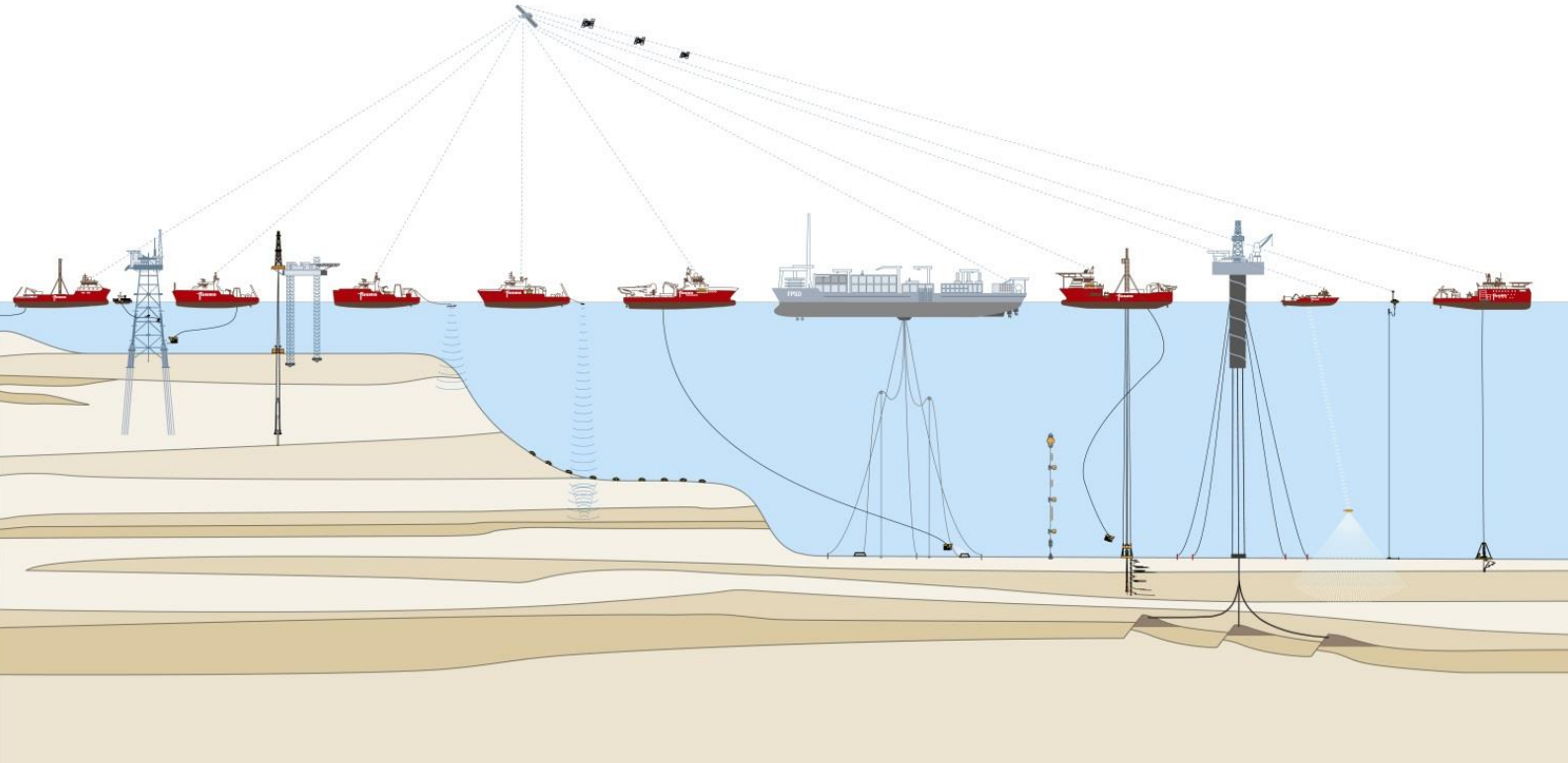
FUGRO SURVEY PTY LTD

Provision of Geomatic Services (Crux Development)

Volume 1D – Environmental Habitat

Survey Period: 7 April to 3 May 2017
Fugro Document No: FRPT GP1569

Shell Australia Pty Ltd



Provision of Geomatic Services (Crux Development)

Volume 1D – Environmental Habitat

Survey Period: 7 April – 3 May 2017
Fugro Document No. FRPT GP1569

Prepared For: Shell Australia Pty Ltd
562 Wellington St
Perth, WA, 6000

Shell Contract No. IG73840

Rev	Description	Prepared	Checked	Approved	Date
2	Revised final, incorporating client's comments	R. Parsotan	L. Bush	J. Shottin	04 July 2018
1	Final, incorporating client's comments	S. Ballard	P. Falkner		20 July 2017
0	Draft final for client's comments	S. Ballard	R. Parsotan	P. Falkner	16 June 2017

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ABBREVIATIONS

AGDEE	Australian Government Department of the Environment and Energy
BPP	Benthic Primary Producers
BMS	Business Management System
Cm	Centimetre
Cu in	Cubic inch
DVD	Digital Versatile Disc
EOL	End of Line
Fugro	Fugro Survey Pty Ltd and all Fugro entities involved with this project
GNSS	Global Navigation Satellite System
INPEX	INPEX Corporation
IUCN	International Union for Conservation of Nature
kHz	Kilohertz
KM	Kilometre(s)
kts	Knots
KP	Kilometre Point
LAT	Lowest Astronomical Tide
MBES	Multibeam Echo Sounder
Ms	Milliseconds
MV	Motor Vessel
psi	Pounds Per Square Inch
QC	Quality Control
RIGSS	Remote Intelligent Geotechnical Seabed Surveys
SBP	Sub-Bottom Profiler
Shell	Shell Australia Pty Ltd
SOL	Start of Line
SSS	Sidescan Sonar
USBL	Ultra Short Baseline
UTM	Universal Transverse Mercator

1. INTRODUCTION

1.1 Report Structure

The report structure for the project is summarised in Table 1.1.

Table 1.1: Report Structure

Fugro Report No.	Volume	Report Titles
FRPT GP1569	1A	Crux Site Geophysical Results and Drawings
FRPT GP1569	1B	Crux to Prelude Geophysical Results and Drawings
FRPT GP1569	1C	Geotechnical Factual Data
FRPT GP1569	**1D (this report)**	**Environmental Habitat**
FRPT GP1569	2	Geophysical, Geotechnical and Environmental Survey Operations

1.2 Project Description

Shell Australia Pty Ltd (Shell) contracted Fugro Survey Pty Ltd (Fugro) to carry out geophysical geotechnical and environmental survey services for the Crux Field development. The Crux Field is located approximately 620 km to the north-east of Broome and 740 km to the west of Darwin. It is seen as a possible tie-in to the Prelude Field which is located 160 km to the south-west of the Crux Field. An overview of the proposed Crux Field development is shown as Figure 1.1.

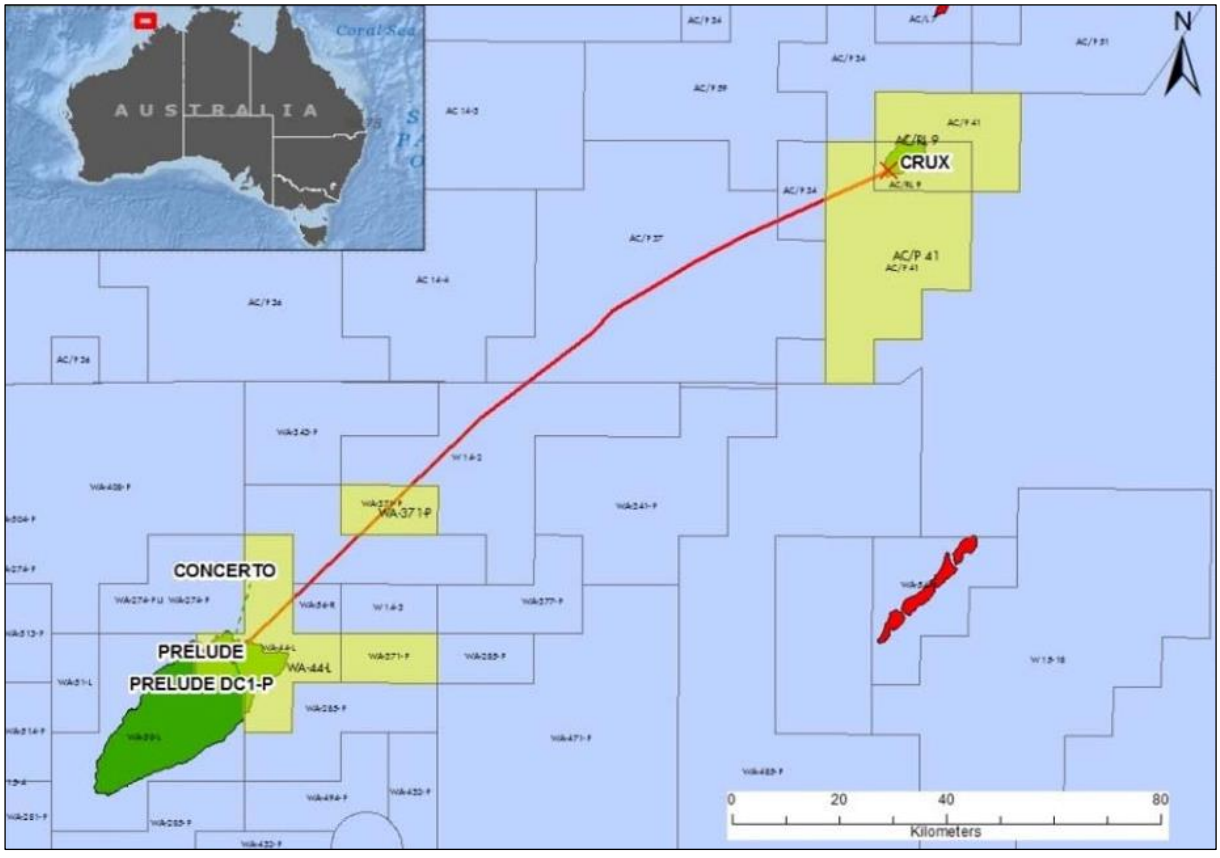


Figure 1.1: General location diagram

The survey was carried out between 06 April and 02 May 2017 on the MV Fugro Equator. Fugro were contracted to undertake the survey, which comprised a combination of geophysical data acquisition,

geotechnical sampling and testing and environmental camera operations. Additional sample field testing and sub-sampling was conducted by the Remote Intelligent Geotechnical Seabed Surveys (RIGSS) division of the University of Western Australia (UWA) on behalf of RPS Group.

The full range of geophysical, geotechnical and environmental survey information collected included:

- Survey positioning;
- Multibeam Bathymetry Echo Sounding (MBES);
- Side Scan Sonar (SSS);
- Magnetometer;
- Chirp Sub-Bottom Profiling (SBP);
- Airgun multi-channel seismic reflection;
- Gravity Piston Core (GPC) and Box Core (BC) sampling;
- Offshore geotechnical laboratory testing;
- Riggs in situ sample testing (conducted by UWA);
- Sediment sub-sampling (conducted by UWA on behalf of RPS);
- Seabed photography and video transects.

This document reports the results of the habitat assessment conducted at the Crux site and provisional pipeline route to connect the Crux Field with the Prelude Field. The proposed well locations at the Crux site are provided in Table 1.2 and displayed spatially in Figure 4.1. All survey related works were carried out in accordance with Shell technical specifications and the Fugro Business Management System (BMS).

Table 1.2: Proposed Well Locations

GDA94, MGA94, UTM Zone 51, CM123 °East		
Name	**Easting [m]**	**Northing [m]**
DC-C1	656 470	8 566 340
DC-CA1	657 510	8 566 000
DC-CAL1	657 550	8 565 000

2. SCOPE OF WORK

2.1 Survey Area

A provisional pipeline route was surveyed to connect the Crux Field back to the Prelude Field. This survey included a primary route 160 km in length and an alternate route at the southwestern end where the route crosses a seabed ridge. Two areas of further development were surveyed where the primary route and the alternate route transverse the seabed ridge. A site survey of 8 km by 14.6 km was also conducted at the Crux Field.

2.2 Survey Objectives

The survey objectives are shown in Table 2.1.

Table 2.1: Survey Objectives

Priority	Acquisition/Reporting Objective	Project Objective
1.1	Mapping of seabed features, sediments, bathymetry and morphology across the survey site. This is to be achieved through the acquisition of MBES and SSS data from a hull mounted or towed survey platform, augmented by seabed soil samples	○ General mapping of seabed; ○ Identification and mapping of seafloor geohazards throughout the site; ○ Narrowing of site selection for drill centre and preferred foundation concepts; ○ Support exploratory pipeline routing and optimisation; ○ Optimise placement and/or assess risks for future geotechnical program.
1.2	Mapping of the shallow soil units, geological features and anomalies at least in the top 200 m (below seafloor) across the site. This is to be achieved through the acquisition of SBP data augmented where possible by shallow soil samples and piston cores. Where possible using the use of two SBP systems would be preferred as to optimise the shallow imaging as well as achieving the deeper penetration of 200 m required by the project for concept decisions	○ General mapping of shallow soil units and geology across site; ○ Perform tie lines at well and legacy seismic locations within the Crux field; ○ Identification and mapping of sub-surface geohazards; ○ Narrowing of site selection for drill centre and preferred foundation concepts; ○ Assess top soil unit thickness along indicative pipeline route and optimise; ○ Optimise placement and/or assess risks to the future geotechnical program; ○ Provide a dataset that can be used to map geotechnical soil units across the site (provide a basis for narrowing of concepts for future geotechnical campaigns).
1.3	Sampling and classification of seabed and shallow soils across the Crux site. This is to be achieved through the acquisition of box and/or piston cores in support of the above objectives	○ Provide basis and ground truth data for mapping objectives defined above; ○ Provide early, basic geotechnical information to the project prior to the execution of the detailed geotechnical campaign.
2	Sampling, testing and classification of shallow soils along the indicative Crux pipeline route. This is to be achieved through the acquisition of box cores along the route. Seabed soil profiles along the route are to be generated through interpolation using SSS, SBP and MBES data	○ Assess soil unit thickness and properties along indicative pipeline route and optimise were possible with the available time and data gathered; ○ Integrate with geophysical datasets to develop seabed soil profiles along the pipeline route.

Priority	Acquisition/Reporting Objective	Project Objective
3	Identification and mapping of shallow localised magnetic anomalies. This is to be achieved through the acquisition of data from a vessel-towed magnetometer or gradiometer. Anomalies are to be reviewed in context with supporting SBP, MBES and SSS data	○ Integrate magnetic data with MBES, SSS and SBP datasets to identify any possible anthropogenic hazards such as dropped objects, remnants of war or unexploded ordnance (buried or on seabed).
4	Visual identification of seabed anomalies and benthic environment. This is to be achieved through the use of an eyeball camera that can be lowered from the vessel and positioned using USBL and an attached transponder	○ Identify benthic environment with video evidence; ○ Visual confirmation of any anomalies found with site survey; ○ Help with the SSS seabed classifications.
5	RIGSS JIP – Testing	○ R&D: First field tests of RIGSS equipment, testing methodology and comparison of results of standard testing. If successful data can be used for pipeline design.
6	Sedimentology Studies	○ R&D: Gain a better understanding of sediment transport in the region and its effects on near seafloor visibility.

2.3 Environmental Background Information

The Kimberley Commonwealth Marine Reserve is a 74,469 km^2 protected area located approximately 90 km south-east of the Crux site (AGDEE, 2017).

Protected areas in Australia are assigned one of six categories as outlined in the International Union for Conservation of Nature (IUCN) document (Dudley, 2008). The Kimberley Commonwealth protected area consists of three zones. The largest zone (66,563 km^2) is a multiple use zone (IUCN VI) which is a protected area with sustainable use of natural resources, located approximately 90 km from Crux site. The next largest zone (6,777 km^2) is the Marine National Park Zone (IUCN II) which is approximately 250 km away from the Crux site. The National Park is a protected area managed mainly for ecosystem conservation and recreation. The smallest area of the reserve (1,129 km^2) is a Habitat Protection Zone (IUCN VI) located approximately 350 km from Crux site. A habitat/species management area is where the protected area is managed mainly for conservation through management intervention.

2.4 Geodetic Parameters

All coordinates detailed in this report are referenced to the International Terrestrial Reference Frame 2008, projected to the Geocentric Datum of Australia 1994, Central Meridian 123°East (UTM Zone 51). Detailed geodetic and projection parameters are provided in Table 2.2.

Table 2.2: Project Geodetic and Projection Parameters

Global Navigation Satellite System (GNSS) Geodetic Parameters [1)]		
Datum:	International Terrestrial Reference Frame 2008 (ITRF2008)	EPSG Code: 1061
Ellipsoid:	Geodetic Reference System 1980 (GRS80)	
Semi-major Axis:	a = 6 378 137.000 m	
Inverse Flattening:	$^1/_f$ = 298.257 222 101	
Local Datum Geodetic Parameters [2)]		
Datum:	Geocentric Datum of Australia 1994 (GDA94)	EPSG Code: 6283
Ellipsoid:	Geodetic Reference System 1980 (GRS80)	
Semi-major Axis:	a = 6 378 137.000 m	
Inverse Flattening:	$^1/_f$ = 298.257 222 101	
Datum Transformation Parameters [3)] from ITRF2008 to GDA94		
Shift dX: -0.05131 m	Rotation rX: +0.0359080 arcsec	Scale Factor: +0.01227150 ppm
Shift dY: +0.01207 m	Rotation rY: +0.0300348 arcsec	Coordinate Frame Rotation
Shift dZ: +0.05316 m	Rotation rZ: +0.0295464 arcsec	EPSG Code: 41357
Project Projection Parameters		
Map Projection:	Transverse Mercator	
Grid System:	Map Grid of Australia 1994 (MGA94)	EPSG Code: 17351
Central Meridian:	123° East (UTM Zone 51)	
Latitude of Origin:	0° (Equator)	
False Easting:	500 000 m	
False Northing:	10 000 000 m	
Scale Factor on Central Meridian:	0.9996	
Units:	Metres	
Project Coordinate Reference System (CRS)		
Projected:	GDA94/MGA Zone 51	EPSG Code: 28351

Notes:
1. The geodetic datum of Fugro's global GNSS correction data is ITRF2008.
2. Source: Client.
3. Transformation parameters from ITRF2008 to GDA94 calculated for Epoch 2017.5 in accordance with the paper ITRF to GDA94 Coordinate Transformations, John Dawson and Alex Woods, Journal of Applied Geodesy 4 (2010).

3. METHODS

3.1 Habitat Assessment

3.1.1 Ground-Truthing Rationale

The habitat survey was required to establish broad characterisation of benthic habitats across the project area. To identify the specific regions for ground-truthing with the camera system, sidescan sonar and bathymetric data were reviewed by environmental scientists in conjunction with the onboard geophysicist. Individual sidescan sonar lines were viewed. Particular emphasis was placed on locating potential reefs and anomalous features, on boundaries between areas of differing sonar reflectivity and changes in bathymetry as well as areas characteristic of background conditions of the survey area. The client's request to cover previously sampled locations were also incorporated into the survey design. The potential occurrence of sensitive species and habitats was also taken into account.

The survey strategy was devised and prioritised based on the following:

- Areas of different acoustic facies (high and low reflectivity) on the sidescan sonar data which are indicative of broad changes in substrate type or the presence of areas that may support ecological diverse benthic communities;
- Bathymetric features such as mound or ridge features.

3.1.2 Survey Strategy

Twenty-nine camera transects were proposed. Ten transects were proposed at the Crux site, two of which covered previously sampled locations (DC3_500SE and DC1_500_NW), one covered the abandoned well CRUX 1 and seven which were chosen from the reviewed geophysical data. Fifteen transects were proposed along the primary route, one of which covered a previously sampled location (PLS10). The fourteen other stations along the primary route were chosen on review of the geophysical data and for coverage along the entire pipeline route. Four transects were proposed along the alternate pipeline route.

The coordinates, data to be acquired and rationale for each camera transect is provided in Table 3.1.

At the client's request, all transects were given the prefix 'SA1702_' as shown in Table 3.1. However, for ease of reporting and clarity of figures and tables, this prefix will not be used hereon in.

Table 3.1: Proposed Environmental Camera Transects

GDA94, MGA94, UTM Zone 51, CM123 °East				
Transects	**Easting [m]**	**Northing [m]**	**Rationale**	**Sample Acquisition**
SA1702_ENV01 SOL	663 691.15	8 570 765.95	Mottled area north-east of site, possible reef structure	Stills, Video
SA1702_ENV01 EOL	663 576.92	8 570 588.16		
SA1702_ENV02 SOL	661 424.09	8 571 313.14	Down slope	Stills, Video
SA1702_ENV02 EOL	661 206.69	8 571 036.78		
SA1702_ENV03 SOL	657 564.76	8 568 835.13	Sand waves and passing over abandoned well CRUX 1	Stills, Video
SA1702_ENV03 EOL	657 766.50	8 568 726.43		
SA1702_ENV04 SOL	656 182.05	8 566 616.90		Stills, Video

GDA94, MGA94, UTM Zone 51, CM123 °East				
Transects	**Easting [m]**	**Northing [m]**	**Rationale**	**Sample Acquisition**
SA1702_ENV04 EOL	656 105.59	8 566 554.26	Hard substrate passing through previous survey station DC1_500_NW	
SA1702_ENV05 SOL	656 436.82	8 565 655.97	Area of high reflectivity changing to sand	Stills, Video
SA1702_ENV05 EOL	656 727.20	8 565 838.78		
SA1702_ENV06 SOL	657 811.18	8 564 660.75	Area of hard substrate passing through previous survey station DC3_500SE	Stills, Video
SA1702_ENV06 EOL	657 889.94	8 564 727.53		
SA1702_ENV07 SOL	654 237.87	8 562 349.02	Area of high and low reflectivity changing to sand waves	Stills, Video
SA1702_ENV07 EOL	654 463.56	8 562 215.44		
SA1702_ENV08 SOL	656 192.87	8 559 557.34	Depressions in area of variable reflectivity	Stills, Video
SA1702_ENV08 EOL	656 281.77	8 559 506.91		
SA1702_ENV09 SOL	629 648.25	8 554 221.82	Sand with high reflectivity contacts	Stills, Video
SA1702_ENV09 EOL	629 526.17	8 554 255.25		
SA1702_ENV10 SOL	618 604.16	8 548 495.23	Transition between area of ripples to high reflectivity area, possible soft sediment	Stills, Video
SA1702_ENV10 EOL	618 423.74	8 548 495.23		
SA1702_ENV11 SOL	604 623.81	8 540 007.26	Down ridge to hard substrate passing through previous survey station PLS10	Stills, Video
SA1702_ENV11 EOL	604 565.12	8 539 852.62		
SA1702_ENV12 SOL	602 414.35	8 537 228.10	Area of mottled high reflectivity. Rough hard sediment	Stills, Video
SA1702_ENV12 EOL	602 289.06	8 537 028.20		
SA1702_ENV13 SOL	597 069.10	8 533 025.79	Sand waves with sand ripples	Stills, Video
SA1702_ENV13 EOL	597 102.77	8 532 836.93		
SA1702_ENV14 SOL	585 583.41	8 524 299.65	Undulating sand seabed with depressions	Stills, Video
SA1702_ENV14 EOL	585 552.71	8 524 174.52		
SA1702_ENV15 SOL	579 249.33	8 519 395.76	Depressions	Stills, Video
SA1702_ENV15 EOL	579 237.63	8 519 243.68		
SA1702_ENV16 SOL	572 916.72	8 513 079.05	Sand waves	Stills, Video
SA1702_ENV16 EOL	572 812.90	8 513 081.57		
SA1702_ENV17 SOL	564 544.02	8 504 942.07	Area of high reflectivity and sand waves	Stills, Video
SA1702_ENV17 EOL	564 338.17	8 504 920.40		
SA1702_ENV18 SOL	559 546.59	8 500 658.78	Top of ridge, mottled areas of reflectivity and raised outcropping	Stills, Video
SA1702_ENV18 EOL	559 410.52	8 500 556.73		
SA1702_ENV19 SOL	558 524.61	8 499 087.33	Outcropping on slope of ridge, potential reef. Transect passes through area of high and low reflectivity and two raised areas	Stills, Video
SA1702_ENV19 EOL	558 211.51	8 499 163.72		
SA1702_ENV20 SOL	556 578.81	8 498 053.76	Raised area, potential reef structure transitioning to soft sediment	Stills, Video
SA1702_ENV20 EOL	556 899.50	8 497 755.83		
SA1702_ENV21 SOL	551 906.91	8 492 893.77	Soft sediment	Stills, Video
SA1702_ENV21 EOL	552 010.42	8 492 893.27		
SA1702_ENV22 EOL	546 438.14	8 487 540.79	Soft sediment with two areas of potential outcropping	Stills, Video
SA1702_ENV22 SOL	546 322.32	8 487 638.26		
SA1702_ENV23 EOL	539 807.25	8 481 170.65	Soft sediment with potential rocky outcropping	Stills, Video
SA1702_ENV23 SOL	539 893.33	8 481 246.60		
SA1702_ENV24 EOL	549 157.34	8 484 632.54	Soft sediment - characterisation of alternative pipeline route	Stills, Video
SA1702_ENV24 SOL	549 274.78	8 484 603.90		
SA1702_ENV25 EOL	557 379.21	8 490 677.78	Hard substrate to Soft sediment	Stills, Video
SA1702_ENV25 SOL	557 284.48	8 490 608.82		

GDA94, MGA94, UTM Zone 51, CM123 °East				
Transects	**Easting [m]**	**Northing [m]**	**Rationale**	**Sample Acquisition**
SA1702_ENV26 EOL	559 072.19	8 491 572.02	Down ridge	Stills, Video
SA1702_ENV26 SOL	558 711.46	8 491 371.95		
SA1702_ENV27 EOL	566 442.70	8 504 748.69	Soft flat sediment transitioning to sand waves	Stills, Video
SA1702_ENV27 SOL	566 474.02	8 504 645.98		
SA1702_ENV28 EOL	657 941.64	8 561 882.37	Area of variable reflectivity coverage to south-east of site	Stills, Video
SA1702_ENV28 SOL	658 101.15	8 561 953.77		
SA1702_ENV29 EOL	661 390.26	8 566 820.76	Low reflectivity coverage to east of site	Stills, Video
SA1702_ENV29 SOL	661 489.73	8 566 820.76		

3.2 Survey Methods

3.2.1 Geophysical survey

Multibeam echo sounder (MBES) bathymetry data were recorded using two different hull-mounted MBES systems – a Kongsberg EM2040 and a Kongsberg EM302, which were operated at nominal frequencies of 200 kHz to 300 kHz and 30 kHz, respectively.

Two different sidescan sonar systems were deployed during the geophysical surveys. Along the pipeline route, an EdgeTech 4200 MP digital sidescan sonar was utilised simultaneously acquiring data at 300 kHz and 600 kHz with nominal slant ranges of 250 m and 125 m for the low and high frequency channels. However, signal attenuation in the water column reduced the interpretable slant range to approximately 170 m and 100 m, respectively.

The same system was used during the Crux site survey for all crosslines whilst data along the mainlines were acquired by a GeoAcoustics 159D analogue sidescan sonar with a lower frequency of 100 kHz and a slant range of 325 m.

Sub-bottom profiler (SBP) data were recorded with a Kongsberg SBP300. After assessing various settings a frequency band of 2.5 kHz to 6.5 kHz with a pulse length of 2 ms was chosen in order to optimise the signal quality and resolution in the near-surface sector. The maximum vertical resolution was approximately 0.25 m (i.e. only horizons with a thickness of at least 0.25 m could be resolved). Depth penetration was up to 45 ms, which corresponds to approximately 35 m, dependent on the prevailing shallow geological conditions. Initial data quality control (QC) and preliminary interpretation was conducted offshore in order to guide the determination of geotechnical sampling and environmental camera transect locations.

Multi-channel seismic reflection data were acquired for the Crux site using a small volume airgun and a 24-channel hydrophone streamer. The airgun used was either a 5 cu in mini-airgun or a 10 cu in sleeve gun. The hydrophone streamer uses a single element per channel with an interval of 2 m giving an active length of 46 m. Shots were fired with a pressure of 1000 psi at a fixed distance interval of 2 m (equivalent to approximately 1.3 s at a survey speed of 3.2 kts) providing half-fold data. Both the source and the hydrophone streamer were towed off stern about 0.7 m below water surface. The offsets between source and the first receiver channel were initially about 3.4 m across-track and 8 m along-track but changed to about 5.9 m across-track and 16 m along-track late in the survey. Recording delays were set between

0 ms and 100 ms and record lengths varied between 400 ms and 500 ms in order to log the required 200 m of sub-seabed data.

3.2.2 Environmental Survey

Seabed photography was acquired using a Seatronics DTS 6000 towed system mounted within a purpose-built camera frame fitted with a Kongsberg OE14-208 digital stills camera and a Kongsberg OE14-366 colour zoom video camera, a separate strobe, laser and four underwater LED lamps.

Seabed video footage was displayed on a computer monitor and recorded directly onto the hard drive of the DVD recorder with photographic stills being stored on the camera and then transferred to the computer. A video overlay was used to display a navigation string from an attached USBL beacon, including the time, date, depth and location (easting and northing) of the camera system. The survey location and station number were also displayed (manually updated). Footage was viewed in real-time, assisting in the control of the camera in the water. The laser was measured as 52 cm.

Operational procedures for seabed photography were as follows:

- The camera was setup on deck prior to deployment and a test photograph taken;
- The camera was deployed into the water just below the sea surface and lamps and laser turned on;
- The camera was lowered to the seabed using the winch and when the seabed was visible recording started. The camera system was suspended approximately 0.5 m off the seabed and allowed to drift around at the start of line (SOL). Adjustments to the vessel could then be made to ensure the camera was within horizontal tolerance for the transect line before proceeding;
- The vessel manoeuvred along the line at approximately 0.4 knots with the winch adjusted to keep the seabed visible on the live feed;
- Still photography commenced with the environmental scientist manually triggering the camera while the camera moved over the seabed. Whenever a photograph was taken the surveyor captured a position fix. Photographs were taken at regular intervals when seabed conditions allowed, additional photographs were taken when new fauna was present or the habitat changed;
- The camera was recovered to the deck and washed down to prevent personnel coming into contact with any marine stingers that may have been on the equipment.
- On completion, video footage was copied to digital versatile disc (DVD) and backed up onto the ship's system. Photographs were downloaded and backed up onto the ship's system and an external hard drive.

3.3 Interpretation Methods

To assess the habitats within the survey area, analysis of video and stills photographic data was undertaken by experienced Fugro marine biologists/taxonomists. Video photographic data were reviewed in conjunction with the still photographs, noting the location of any observed changes in the sediment type and/or associated faunal community.

As the requirement for this survey was to provide general habitat descriptions to characterise the benthic habitats of the region rather than to provide detailed transect analysis and species level data, a classification system was used. The classification system applied was based on the that used by INPEX

(INPEX 2012) during the habitat survey for the Ichthys Project in the Browse Basin, with the following modifications:

- Near shore habitats such as seagrasses and macroalgae communities were removed from the habitat classification as they were not encountered;
- Soft sediment habitats 'burrowing macrofauna' was added as a biota class.

The classification provides a hierarchical system that groups low level classes (Figure 3.1) into broader higher level classes. Using a hierarchical system allows habitat types and any associated benthic communities to be described in a consistent and comparable way.

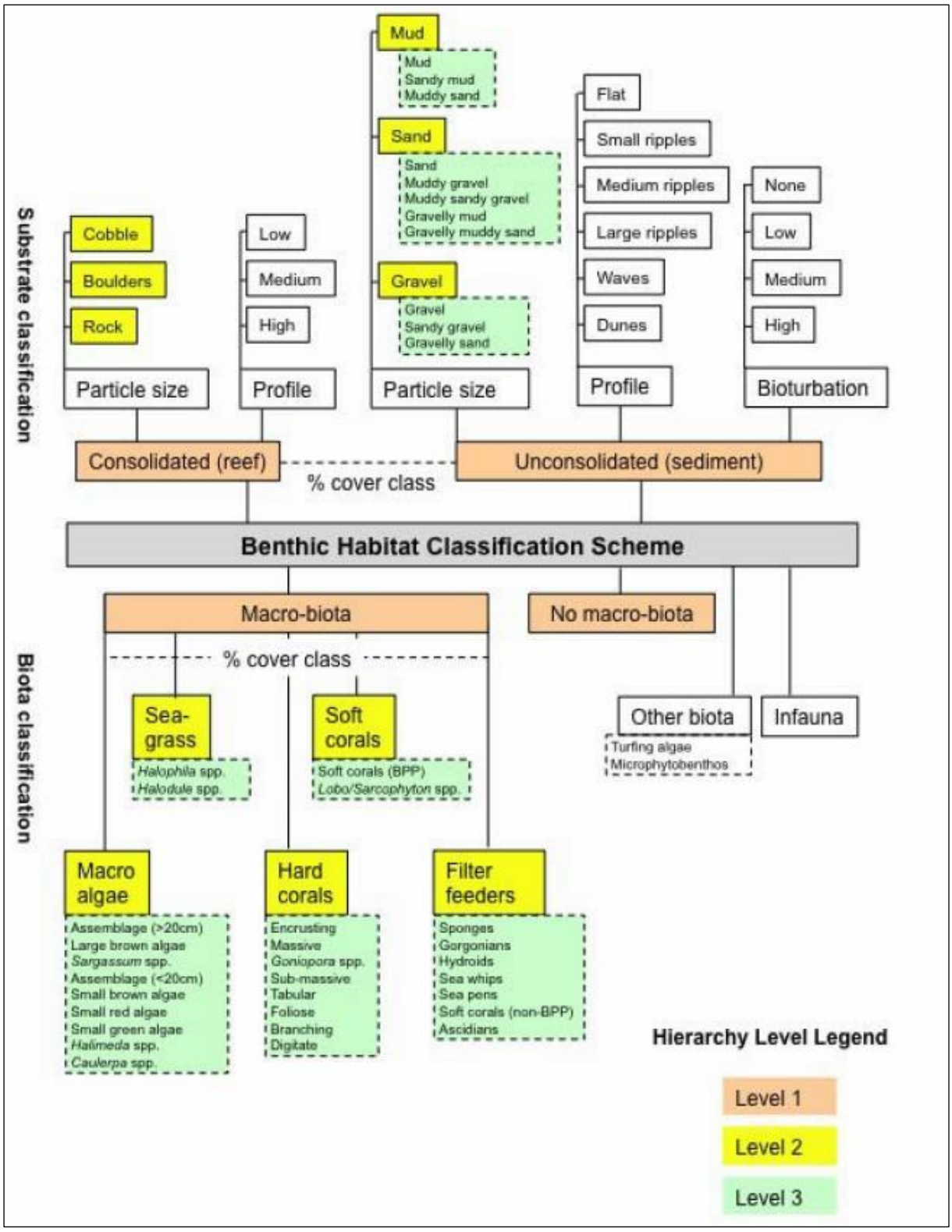


Figure 3.1: Habitat classification scheme hierarchical flow chart (from INPEX, 2012)

3.3.1 Sediment Particle Size

Seabed sediments have been described based on observations on seabed video/photographic data and the interpretation of geophysical data. Due to the difficulty in interpreting sediment particle sizes from video and photographic data, descriptions are based on the Folk classification (Folk, 1954) which uses

the descriptive terms ‘mud’, ‘sand’ and ‘gravel’ in combinations depending on the estimated proportions of each component (Figure 3.2).

The terms pebble, cobble and boulder have also been used to described larger sized sediment, which are terms used in the Wentworth classification (Wentworth, 1922) where sediment particles are graded depending on their size (in millimetres).

Additional information such as reef particle size (rock, boulders, cobbles), reef profile (low, medium, high) and sediment profile, flat, low ripples, medium, ripples, high ripples) were also recorded according to the decision rules outlined in Table 3.2. Levels of bioturbation were estimated from the burrows and tracks observed on the seabed per metre.

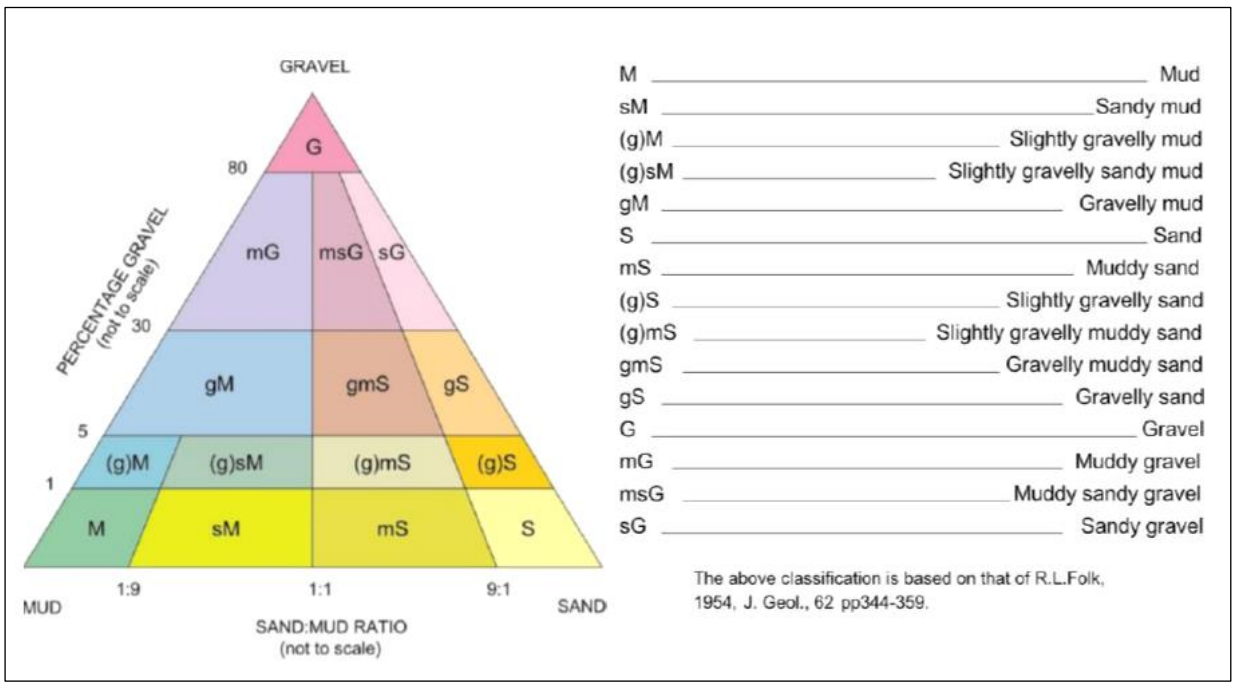


Figure 3.2: Sediment classification triangle (Folk, 1954)

Table 3.2: Substrate Class Definitions (Adapted from INPEX, 2012)

Substrate Type	Decision Rules
Consolidated Reef	Substrate predominantly made up of particles of cobble size (> 64 mm diameter) or larger
Unconsolidated (sediment)	Substrate predominantly made up of particles of pebble size (< 64 mm diameter) or smaller
Substrate Composition	
All sediment	Sediment 100 %
Mixed sediment and reef	Reef 1 – 24 % (i.e. sand 76 – 99 %)
	Reef 25 – 49 %
	Reef 50 %
	Reef 51 – 74 %
	Reef 75 – 99 %
All reef	Reef 100 %
Reef	
Reef Particle Size	
Cobble	Particles 64 – 256 mm
Boulder	Particles > 256 mm
Rock (unbroken)	Unbroken rock substrate
Reef Profile	
High	> 4 m rise over 2 m
Medium	1 – 4 m rise over 2 m
Low	< 1 m rise over 2 m
Sediment	
Sediment Particle Size	
Pebble	Particle 4 – 64 mm
Gravel	Particle 2 – 4 mm
Sand	Particles 63 µm – 2 mm
Mud	Particles < 63 µm
Sediment Profile	
Flat	No profile (undulations < 1 cm)
Small ripples	Undulations 1 – 10 cm high
Medium ripples	Undulations 10 – 50 cm high
Large ripples	Undulations 50 – 100 cm high
Waves	Undulations 1 – 5 m high
Dunes	Undulations > 5 m high
Bioturbation	
None	No evidence of bioturbation
Low	1 – 2 disturbances (e.g. burrows or mounds) per meter
Medium	3 – 10 disturbances per meter
High	> 10 disturbances per meter

3.3.2 Seabed Habitats/Biotope Classification

The video and still images were analysed using qualitative community class per cent cover estimates consistent with the habitat classification scheme in Table 3.3. Biota classes (Table 3.4) were used to group observed epifauna. Fauna not categorised under a biota class were recorded as present and left at a higher taxonomic level.

Table 3.3: Biota Coverage Classification Definitions (Adapted from INPEX, 2012)

Biota Cover Class	Decision Rules
> 80 %	No substrate visible
60 – 80 %	Some substrate visible
40 – 60 %	Substrate is clearly visible but biota dominates the image frame
20 – 40 %	Substrate dominates most of the image
10 – 20 %	Substrate dominates most of the image
5 – 10 %	Substrate dominates most of the image
1 – 5 %	Trace densities
0 – 1 %	No significant macrobiota

Table 3.4: Habitat Classification Definitions (Adapted from INPEX, 2012)

Biota Classes	Morphological Groups	Definitions and Examples
Hard coral assemblages > 10 % over 10 m^2	Branching	At least 20 branching (e.g. *Seriatopora hystrix*)
	Digitate	Less than 20 branching (e.g. *Acropora digitifera*)
	Tabular	Horizontal flattened plates (e.g. *Acropora hyacinthus*)
	Encrusting	Major portion attached to substrate as a laminar plate (e.g. *Porites vaughani*)
	Foliose	Coral attached at one or more points, leaf like appearance (e.g. *Turbinaria* spp.)
	Massive	Solid boulder or mound (e.g. *Favites* spp.)
	Submassive	Tends to small columns, knobs or wedges
Soft coral (BPP) assemblages > 10 % over 10 m^2	Sarco-/lobo- phyton sp. *Sinularia* sp.	Photosynthetic soft corals (e.g. Alcyonidae spp.)
Filter feeders (non BPP) assemblages > 10 % over 10 m^2		Ahermatypic animals (not defined as BPP)
	Soft coral (non-BPP)	Non-photosynthetic soft corals (e.g. Gorgonian fans, Alcyoniidae (non-BPP) Dendronepthia spp.)
	Sponges	Can note morphological groups
	Ascidians	Stalked, encrusting, solitary
	Hydroids	
	Sea Whips	
	Gorgonian fans	
	Sea pens	
	Bryozoan	Foliose, stalked
	Anemones	Tube, solitary
	Polychaetes	
Burrowing Macrofauna	Polychaetes Crustacea	1-2 burrows (low bioturbation) or higher per meter

Where biota coverage exceeded 10 % over 10 m^2, a community type was assigned. The community types were defined by the dominant and codominant biota classes, as summarised in Table 3.5.

Table 3.5: Community Type Classification and Rules Nomenclature

Community Type Classification	Example	Biota Class Composition
Dominated by biota class	Hard coral	Biota class is > 90 % composition of total biota
Dominant biota class *with* other biota classes present	Hard coral *with* macroalgae	Dominant biota class < 90 % with other biota 10 % to 30 % composition of total biota
Codominant biota classes (*and*)	Hard coral *and* macroalgae	Codominant biota classes each > 30 % composition of total biota

Habitats based on their geophysical characteristics were described in line with the hierarchy (Figure 3.1) and their characterising fauna recorded.

4. RESULTS

4.1 Field Operations

Video footage was successfully acquired at 25 of the 29 proposed locations. Transect ENV28 was removed from the survey plan at the client's request. Transects ENV29, ENV27 and ENV17 were aborted due to insufficient visibility at the seabed for camera operations.

Digital still images were acquired at 23 of the 25 completed transects. No digital stills were acquired at transects ENV06 and ENV07 due to a technical fault, therefore screen captures were captured from the video footage at these locations.

Transects ENV05 and ENV09 were completed in two sections due to an equipment fault part way along the transect. A 30 m overlap ensured coverage across each of the transects. The resumed transects are labelled ENV05A and ENV09A respectively, and are referred to as two separate transects at each location in the following sections. A full list of the completed camera transects is shown in Table 4.1.

Poor visibility was encountered during several transects especially nearer the Prelude end of the pipeline route where the sediment was finer. Tropical Cyclone Frances passed over the survey area on 28 April 2017, and seabed visibility was noticeably worse after this event.

Table 4.1: Completed Camera Transects

GDA94, MGA94, UTM Zone 51, CM123 °East						
Station	**Easting [m]**	**Northing [m]**	**Depth [m]**	**Length [m]**	**Video footage [HH:MM:SS]**	**No. of Stills**
ENV01_SOL	663 708.71	8 570 789.01	89	252	00:25:15	36
ENV01_EOL	663 570.85	8 570 578.62	93			
ENV02_SOL	661 531.53	8 571 433.04	104	515	00:49:25	53
ENV02_EOL	661 202.72	8 571 033.20	132			
ENV03_SOL	657 509.58	8 568 862.76	166	345	00:32:51	35
ENV03_EOL	657 814.66	8 568 700.43	167			
ENV04_SOL	656 229.20	8 566 668.33	170	204	00:15:59	21
ENV04_EOL	656 078.04	8 566 531.18	171			
ENV05_SOL	656 387.08	8 565 625.02	171	277	00:25:35	32
ENV05_EOL	656 619.49	8 565 775.63	167			
ENV05A_SOL	656 566.11	8 565 740.66	168	198	00:18:39	33
ENV05A_EOL	656 735.03	8 565 844.19	171			
ENV06_SOL	657 760.40	8 564 621.35	172	185	00:14:08	0
ENV06_EOL	657 902.12	8 564 740.05	172			
ENV07_SOL	654 189.30	8 562 374.60	178	332	00:31:42	0
ENV07_EOL	654 475.98	8 562 207.63	178			
ENV08_SOL	656 141.51	8 559 588.55	180	183	00:19:25	28
ENV08_EOL	656 298.64	8 559 495.57	179			
ENV09_SOL	629 714.45	8 554 194.01	197	63	00:10:42	11
ENV09_EOL	629 653.94	8 554 211.67	198			

ENV09A_SOL	629 457.86	8 554 276.82	198	213	00:17:35	22
ENV09A_EOL	629 663.36	8 554 219.02	198			
ENV10_SOL	618 673.46	8 548 464.64	209	127	00:26:04	40
ENV10_EOL	618 386.56	8 548 508.30	206			
ENV11_SOL	604 638.61	8 540 051.69	212	276	00:22:06	35
ENV11_EOL	604 559.80	8 539 839.63	214			
ENV12_SOL	602 451.71	8 537 279.04	204	312	00:29:39	49
ENV12_EOL	602 283.90	8 537 016.35	204			
ENV13_SOL	597 039.12	8 533 100.50	203	287	00:30:14	33
ENV13_EOL	597 117.33	8 532 824.13	204			
ENV14_SOL	585 598.47	8 524 336.86	210	181	00:20:09	28
ENV14_EOL	585 551.40	8 524 163.03	210			
ENV15_SOL	579 254.05	8 519 450.22	211	236	00:21:49	36
ENV15_EOL	579 313.23	8 519 224.71	210			
ENV16_SOL	572 970.58	8 513 099.97	206	173	00:16:45	25
ENV16_EOL	572 799.07	8 513 078.15	207			
ENV18_SOL	559 581.08	8 500 701.19	223	234	00:30:05	52
ENV18_EOL	559 399.17	8 500 553.92	229			
ENV19_SOL	558 593.31	8 499 068.71	234	408	00:31:49	56
ENV19_EOL	558 197.58	8 499 170.16	241			
ENV20_SOL	556 518.21	8 498 104.46	247	529	00:47:16	82
ENV20_EOL	556 905.36	8 497 744.97	245			
ENV21_SOL	551 827.71	8 492 890.98	270	194	00:19:25	28
ENV21_EOL	552 021.36	8 492 888.26	270			
ENV22_SOL	546 512.10	8 487 478.14	266	265	00:27:53	44
ENV22_EOL	546 309.53	8 487 649.05	267			
ENV23_SOL	539 749.30	8 481 133.38	257	196	00:21:15	36
ENV23_EOL	539 902.12	8 481 255.46	256			
ENV24_SOL	549 099.63	8 484 644.79	261	196	00:19:28	32
ENV24_EOL	549 290.68	8 484 600.66	260			
ENV25_SOL	557 436.38	8 490 735.70	266	211	00:21:53	30
ENV25_EOL	557 278.17	8 490 595.75	271			
ENV26_SOL	559 082.60	8 491 595.79	220	446	01:03:20	95
ENV26_EOL	558 942.68	8 491 495.02	244			

4.2 Bathymetry

The bathymetry of the survey area is displayed with the environmental transect locations in Figure 4.1.

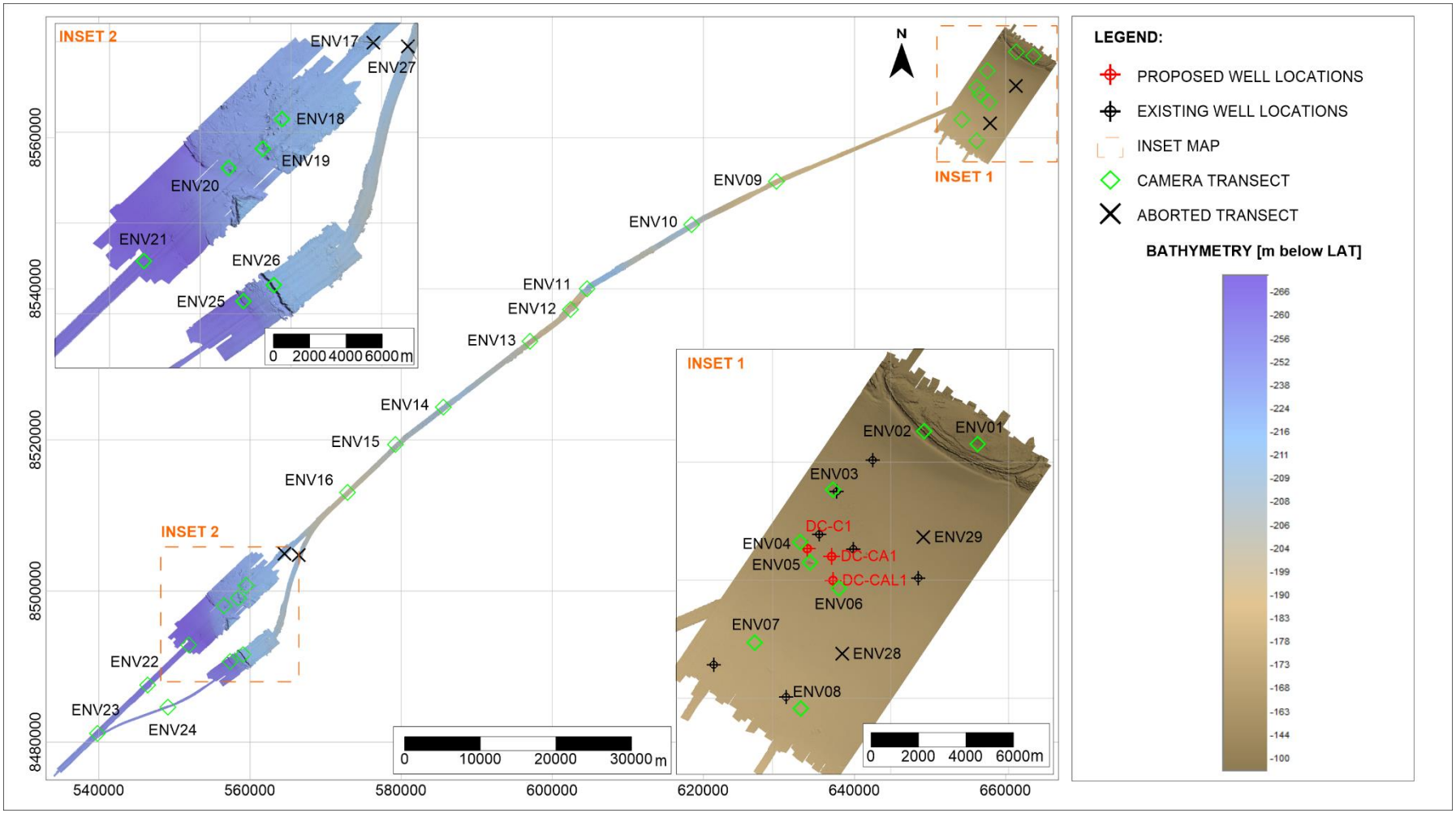


Figure 4.1: Environmental transect locations and bathymetry of survey

4.2.1 Crux Site

Water depths across the Crux site range between a minimum depth of 84.4 m in the north-eastern part and a maximum depth of 186.5 m in the southwestern corner. The majority of the site is gently dipping towards the south-west with general seabed gradients of approximately 0.1°.

In the north-east a large outcropping reef complex stretches across the whole width of the survey area with a steep southern wall and scouring along the foot of the slope. Gradients exceed 50° in some places and commonly the seabed rises by 10 m to 20 m over a distance of 30 m along the steepest sections. Several minor escarpments along the reef flank are interpreted as different stages of growth and erosion. Further, smaller reef developments in the shallow section on top of the main structure contribute to very irregular morphology. Two additional build-ups to the west and south-east of the main complex are observed. Overall, this reef structure is considered to be of similar origin to the many shoals in this region, such as Scott Reef or Heywood Shoal. A bathymetric image of the reef area is presented in Figure 4.2.

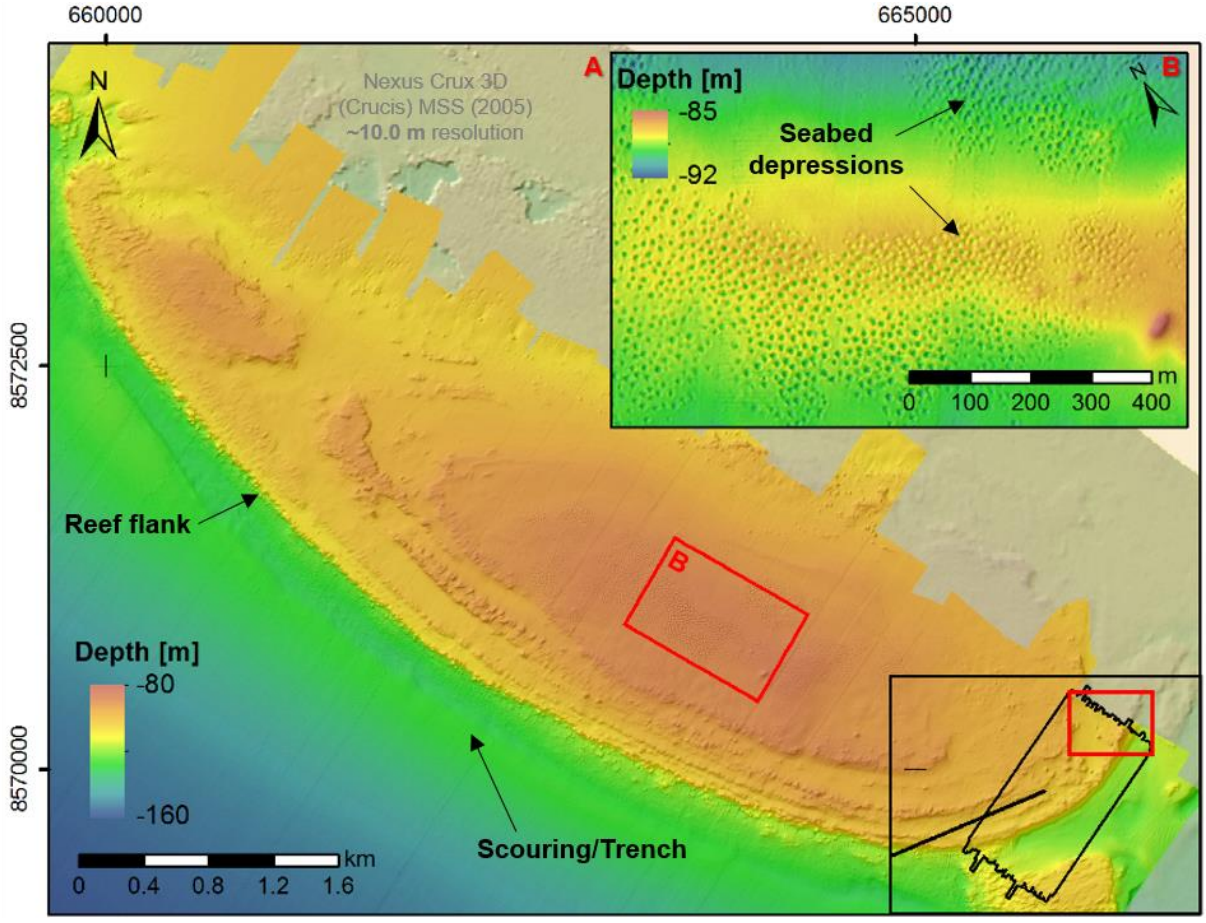


Figure 4.2: (A) Reef complex in northern part of the Crux site and (B) close-up view of seabed depressions

An area of approximately 3.2 km by 1.2 km on top of the reef complex exhibits numerous seabed depressions or pits that appear to be arranged in clusters. These are usually of nearly circular shape, about 10 m to 15 m wide and 0.8 m to 1.3 m deep but can reach diameters of up to 20 m and depths of up to 2 m in some places.

A second area of seabed depressions is found in the south-eastern part of the Crux site in water depths between 177.0 m and 183.0 m. Here, several pockmark clusters up to 550 m across feature slightly oval-shaped individual depressions between 10 and 15 m in diameter. The pockmark depths are beyond the resolution of the MBES data and, hence, are not expected to exceed a few tens of centimetres. Nevertheless, they show up clearly in the sidescan sonar data (see Figure 4.3) due to a rim of sediment around the edge of the depression. See Volume 1A - Crux Site Results and Drawings – for more details.

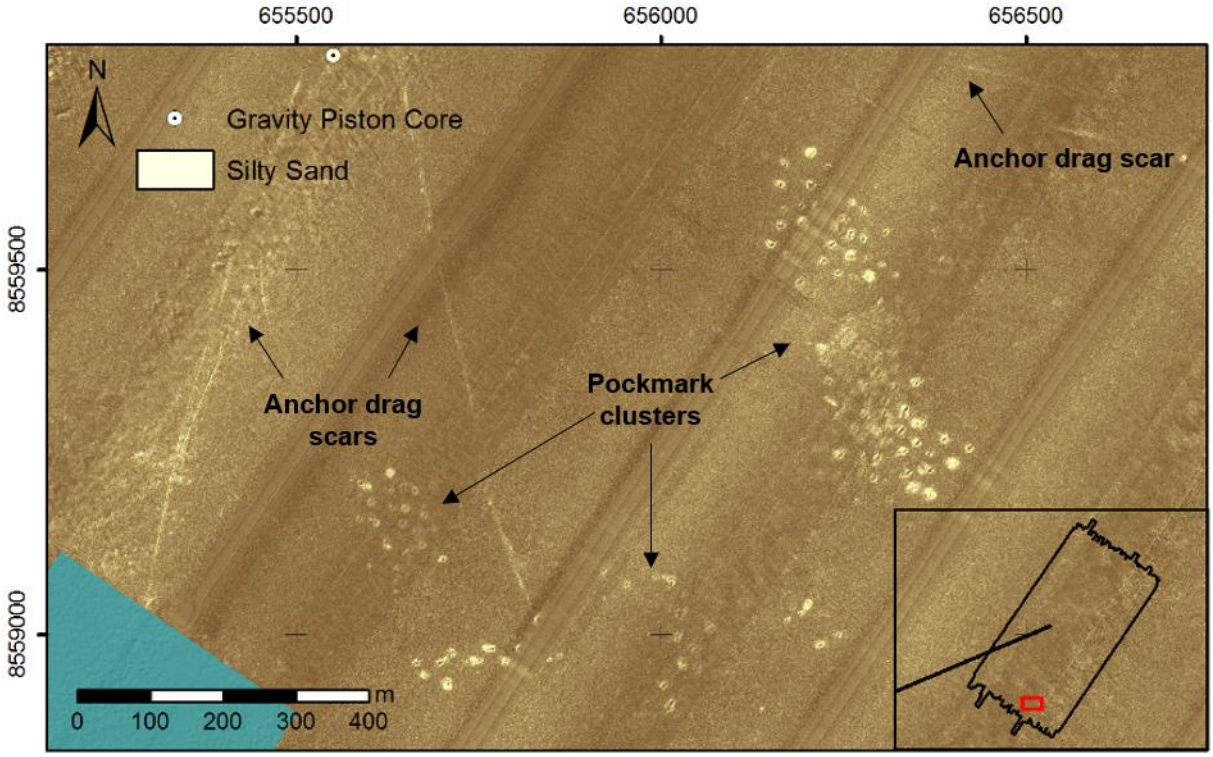


Figure 4.3: Pockmark clusters are clearly visible in sidescan sonar data

4.2.2 Route P1/P1S: KP 0 to KP 105.3

Water depths along this part of the proposed P1/P1S route range from 165.1 m below LAT within the Crux site to 216.9 m below LAT near KP 55.5. Overall, the seabed is gently dipping in the first half of this section with general seabed gradients between 0.1° and 0.2° corresponding to a change in water depth of a few metres over 1 km. See Volume 1B – Crux to Prelude Survey Results and Drawings – for more details.

The route crosses a morphological escarpment or ridge between KP 61 and KP 62, where the seabed shoals to 191.7 m. The escarpment features localised seabed gradients of up to 9.7° representing a change in water depth of 6 m over 80 m. For the remaining section of the route the water depth varies between 196.9 m and 212.0 m with gradients of less than 0.1°. See Volume 1B – Crux to Prelude Survey Results and Drawings – for more details.

4.2.3 Route P1: KP 105.3 to KP 154.1 (end of route) Including PD2

The seabed is gently dipping with general gradients of less than 0.1° until KP 118.9 and water depths decreasing from 204.0 m at KP 105.3 and 226.0 m at KP 118.9. Megaripples, running in a north-south direction, occur along or in vicinity of the route until KP 117.2 while sandwaves are limited to the area

between KP 109.1 and 110.7. Between KP 117.3 and KP 118.3 the route traverses through irregular, outcropping terrain that features elevations of up to 5 m compared to the surrounding seabed. Local seabed gradient are up to 20° is this segment.

Immediately after, the pipeline route crosses an area of seabed depressions. These are of similar dimensions as the ones observed 30 km further north, usually featuring diameters in the order of tens of metres and depths of up to 1.5 m, but are thought to have developed due to erosion of the sub-cropping seabed with subsequent sediment deposition.

From KP 118.9 onwards, the seabed slightly steepens but general seabed gradients do not exceed 1.0°. The deepest point along the pipeline route is reached at approximately KP 128.5. Subsequently the seabed gently rises until the end of the route at KP 154.1, where the water depth is approximately 248.0 m. Undulations due to sub-cropping or outcropping cemented sediments are observed towards the end of the route between KP 144.0 and KP 151.0 m.

The area of PD2 as shown in Figure 4.4A, presents the most complex segment of the P1 pipeline route in regards to its morphology. Widely abundant subcropping and outcropping seabed as well as current-induced bedforms such as sandwaves and megaripples result in highly variable morphology with steep seabed gradients of up to 45°. The two most pronounced feature are a trench in the northern central part of PD2, where the seabed drops by up to 25 m over a distance of 50 m, and a sharply rising platform in the southern central part. The platform marks an elevation of 20 m to 30 m in relation to the surrounding seabed and widens towards the south-east. The tip is aligned with the trench although not directly connected. Both features, the trench and the platform, extend beyond the coverage of this survey. However, the revised pipeline route evades both features and does not cross any of the steep flanks. See Volume 1B – Crux to Prelude Survey Results and Drawings – for more details.

4.3 Route P1S: KP 105.3 to KP 156.5 (end of Route) including PD1

Route P1S separates from P1 at KP 105.3 and continues in south-south-westerly direction before turning south-west at KP 124.0, eventually reconnecting with P1 at KP 151.6 (P1 KP 149.2). Additional data were acquired between KP 122.5 and KP 132.5 (PD1) widening the survey corridor to approximately 2500 m in order to identify the best route through this area of difficult and irregular terrain.

From KP 105.3 until KP 112.0 the route passes through areas of megaripples and sandwaves trending in a north-south direction. Apart from that, the seabed is generally smooth and gently dipping with gradients of less than 0.1° until approximately KP 127.4. At KP 127.4 the P1S route passes the southern flank of the platform where the seabed abruptly drops approximately 35 m over a distance of 120 m (~ 23° slope angle). This feature may present an obstruction for the proposed pipeline and cannot be avoided within the PD1 area (Figure 4.5). Furthermore, historical bathymetry data suggest a continuation of the escarpment towards the north, into the PD2 area, and to the south for at least 14 km.

Scouring is observed along the entire south-western side of the platform resulting in a parallel running trench about 170 m wide and 8 m deep. Locally, seabed gradients on the south-western flank of the trench exceed 10° corresponding to a depth change of several metres over a distance of 20 m (Figure 4.5 B and C).

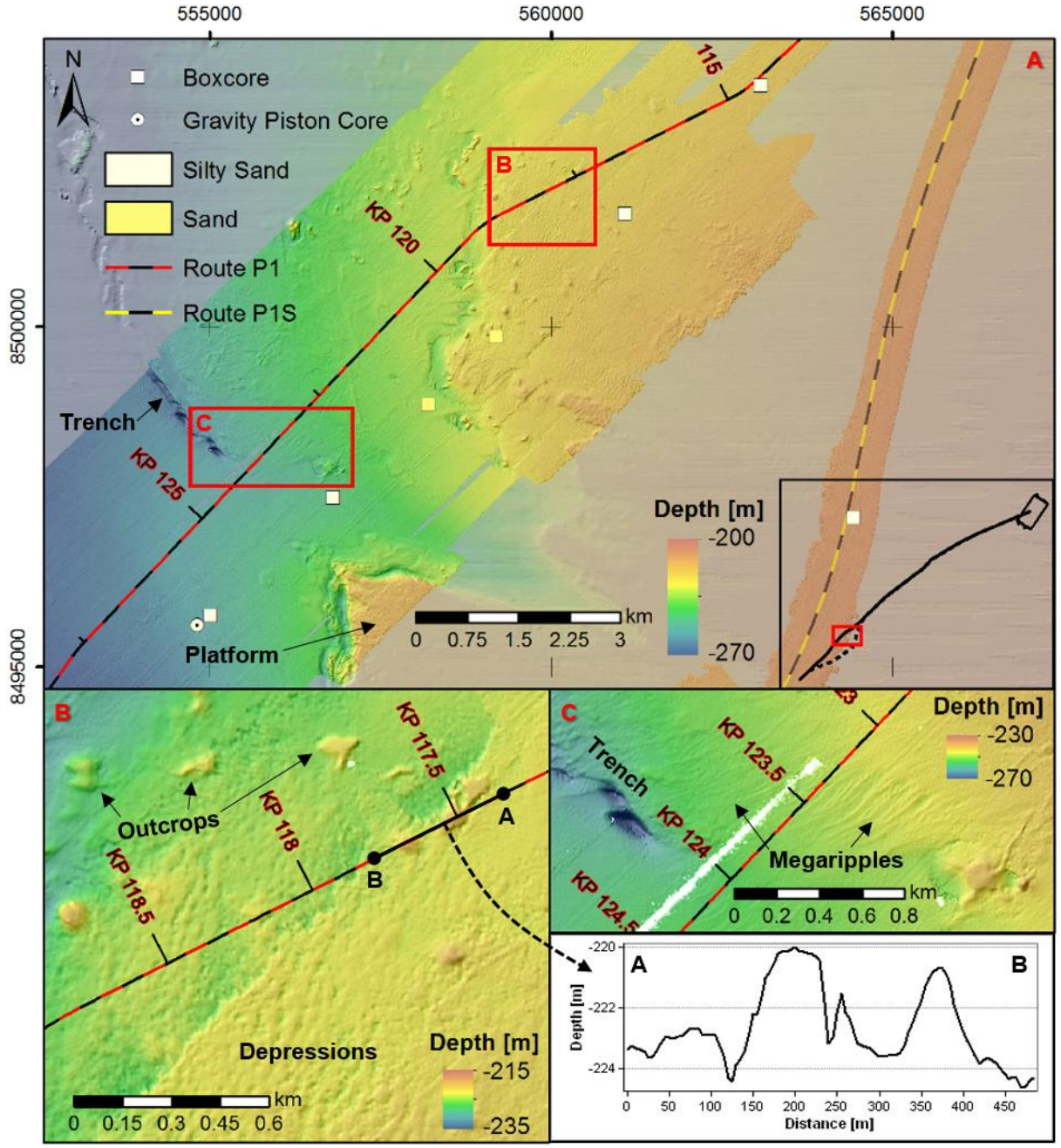


Figure 4.4: Bathymetry data of the (A) PD2 area demonstrating complex seabed morphology with close up views of (B) seabed depressions, outcrops crossed by the pipeline route including (D) cross section and (C) the north-west trending trench

After the trench, the seabed starts to dip gently and water depth increases from 240.0 m to 262.0 m over a distance of approximately 1300 m. The remaining section until KP 151.6, where the P1S route merges with P1 again, is nearly flat with water depths slightly decreasing to 252.5 m. The last segment from KP 148.2 to KP 151.6 features irregular seabed surface due to subcropping and outcropping strata. See Volume 1B - Crux to Prelude Survey Results and Drawings - for more details.

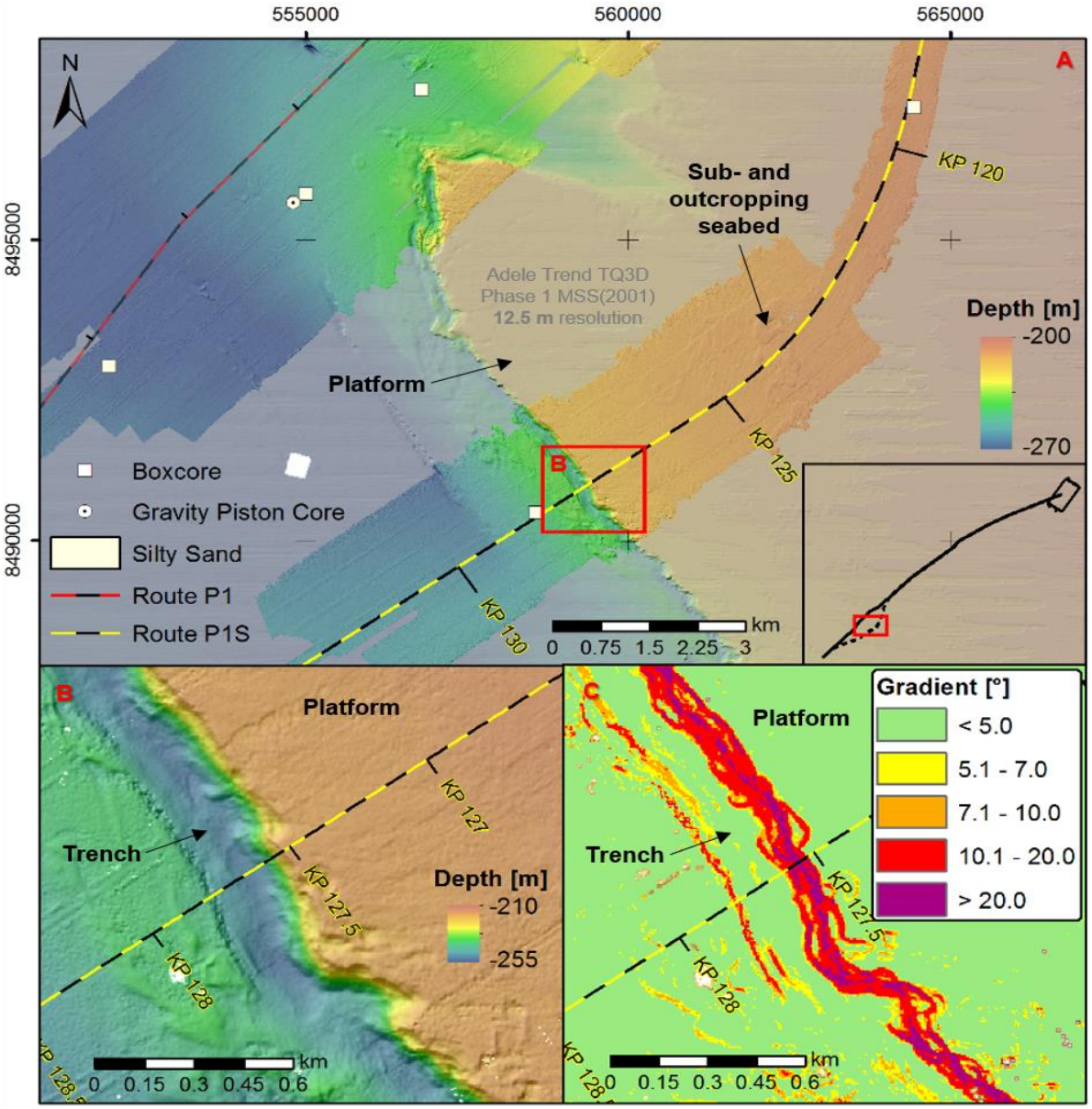


Figure 4.5: Multibeam echo sounder data examples showing (A) an overview of the PD1 area and surroundings, (B) the crossing of the southern flank of the platform and (C) a gradient map of the same section as (B)

4.4 Seabed Features

The seabed features of the survey area are displayed with the environmental transect locations in Figure 4.6.

4.4.1 Crux Site

The surface sediment throughout the majority of the Crux site consists of fine to medium or fine to coarse carbonate sand with different proportions of silt and, in many cases, gravel-sized shells and shell fragments. For simplicity reasons “silty sand” (silt component larger than 12 %) and “sand with silt” (silt component between 5 % and 12 %) are jointly described as “silty sand” in both report and drawings.

On top of the reef complex in the north-east the seabed composition varies between silty sand, sand and outcropping reef facies. In between individual reef structures the seabed is usually covered with sandy sediments and a surface layer of very poorly sorted shells, shell fragments and coral fragments of various sizes eroded from adjacent reefs. The seabed depressions are concentrated on the top central part of the outcrop, where a layer of loose sediment has been deposited.

Seven wellheads are found within the site. Their as-found positions and surface expressions in relation to the surrounding seabed based on MBES data are provided in Table 4.2. See Volume 1A – Crux Site Results and Drawings – for more details.

Table 4.2: As-Found Positions of Seabed Elevations of Existing Wells

GDA94, MGA94, UTM Zone 51, CM123 °East			
Name	**Easting [m]**	**Northing [m]**	**Elevation [m]**
Crux-1	657 707	8 568 755	1.3
Crux-2	659 237	8 570 083	1.1
Crux-3	656 982	8 566 947	1.0
Crux-4	658 430	8 566 317	2.0
Auriga West-1	661 183	8 565 082	0.6
Libra-1	655 572	8 560 056	0.2
Octans-1	652 504	8 561 424	Not measurable

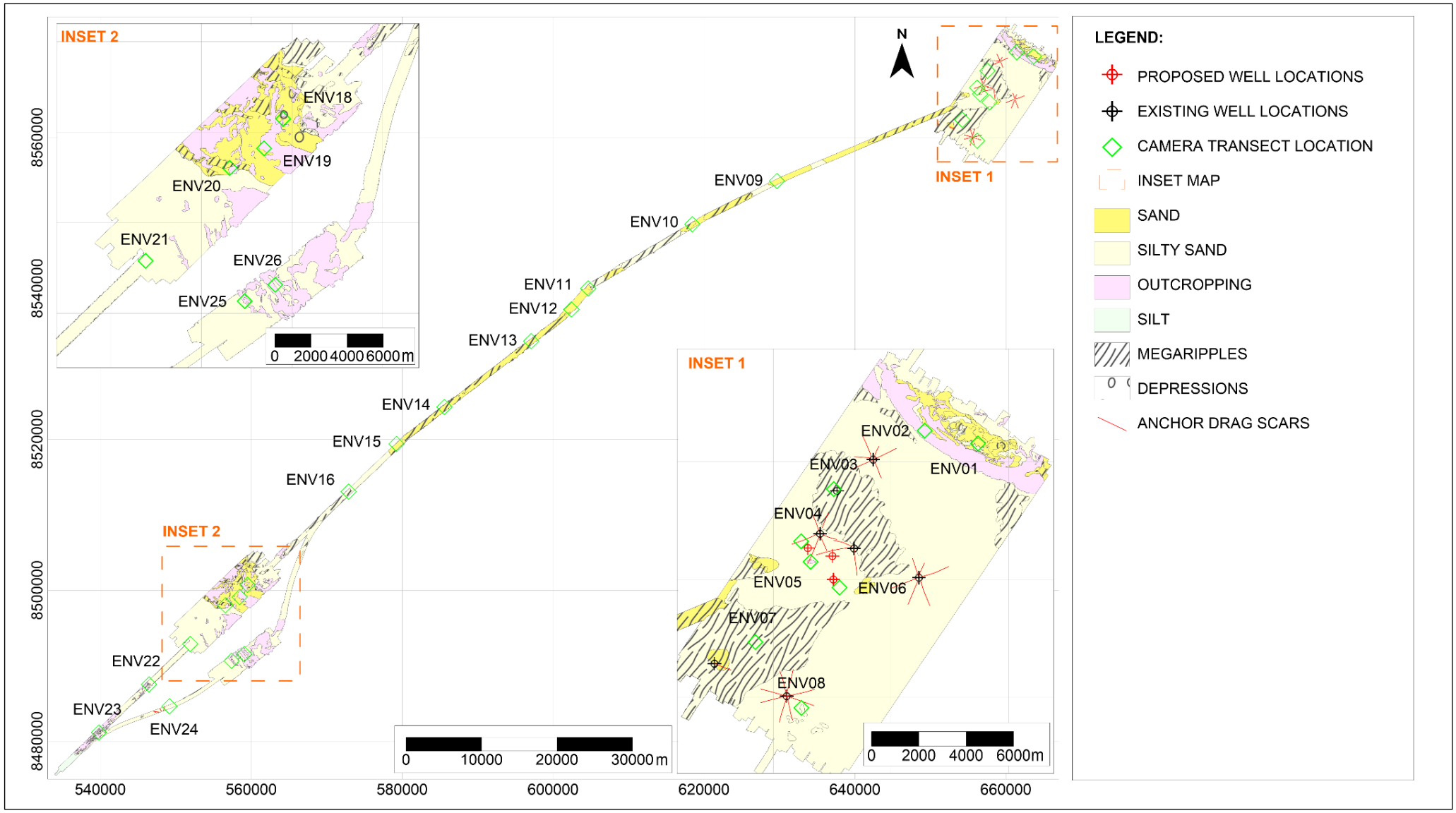


Figure 4.6: Environmental transect locations and seabed features

4.4.2 Route P1/P1S: KP 0 to KP 105.3

Surface sediments along this segment of the route comprise a variety of sand (approximately 70 %) and silty sand (approximately 30 %) usually with a fraction of up to coarse gravel sized shells and shell fragments. Apart from sand waves and megaripples, no other natural or anthropogenic seabed features were identified within this route segment. See Volume 1B – Crux to Prelude Survey Results and Drawings – for more details.

4.4.3 Route P1: KP 105.3 to KP 154.1 (end of route) Including PD2

Along this segment of the route the seabed is composed of silty sand (approximately 70 %), fine to medium sand (approximately 12 %), outcrops and subcrops (approximately 12 %) and silt (approximately 6 %).

Apart from areas of cemented seabed between KP 112.6 and KP 113.4, silty sand with a small fraction of coarse sand and fine gravel sized shells and shell fragments prevails from KP 105.3 to KP 117.4. Towards the centre of PD2, from KP 117.4 to KP 124.4, the route traverses a few areas of subcropping or outcropping reef/calcarenite. Here, the silt component disappears and the coarse fraction of gravel sized shells and shell fragments increases.

After KP124.4 fine sediments become more dominant. The seabed comprises silty sand with decreased or without a coarser fraction of shells and shell fragments. The route crosses two sections of sub- and outcropping calcarenite between KP 137.7 and KP 141.0 and between KP 143.4 and KP 151.3. Within this section a slight increase in the gravel component of the surface sediment was noted. Beyond the outcropping area, silty sediment prevails until the end of the route at KP 154.1. The alternative pipeline route P1S ties in with P1 at KP 149.204. See Volume 1B – Crux to Prelude Survey Results and Drawings – for more details.

4.4.4 Route P1S: KP 105.3 to KP 156.5 (end of route) Including PD1

Along this section of the route the seabed is composed of silty sand (approximately 81 %), outcrops and subcrops (approximately 14 %) and silt (approximately 5 %).

Except for the sandwaves and megaripples observed in the beginning of the route, the seabed is benign and featureless until KP 120.4. The prevailing sediment type in this section is silty fine to medium sand. Between KP 120.4 and KP 129.1, located within the PD1 area, the seabed composition alternates between silty fine to medium sand and outcropping or subcropping cemented sediments. After the scarp the dominating surface sediment is silty fine to medium sand and the seabed is mostly featureless and benign until KP 148.0. From this point on outcrops and subcrops are the dominant seabed type, intersected by layers of silty fine to medium sand. The last segment from KP 153.8 to KP 156.5 is characterised by a mostly featureless silty seabed. See Volume 1B – Crux to Prelude Survey Results and Drawings – for more details.

4.5 Overview of Seabed Habitats and Fauna

The review of the seabed video and digital stills (Appendix B) showed a very low abundance of epifauna across the survey area. Eight different habitats were identified based on geomorphological structures

and the sediments they comprised (Figure 4.8). Table 4.3 displays the criteria of the classification system adopted and the distribution of the habitats identified across the completed transects.

A threshold of 10 % cover by macrobiota was defined by the classification scheme before a community type could be assigned. Macrobenthic epifauna only exceeded this threshold in sections of three transects (ENV02, ENV05A and ENV18), all located in the 'Consolidated Unbroken Rock' habitat. Although some epifauna were observed along other transects, all other transects had epifauna coverage below 10 % and thus were classed as either 'no macrobiota' or 'burrowing macrofauna' dependent on the associated presence of burrows (Figure 4.8). Details of fauna observed in areas of <10 % coverage are included in Section 4.6.1 to 4.6.8, divided by habitat type.

The community classification of 'Filter feeders' was given to a 140 m section of ENV02, a 68 m section of ENV05A and a 60 m section of ENV18. The filter feeders along ENV02 and ENV05A consisted of sponges (Porifera), hydroids (Hydrozoa), branching coral (Alcyonacea) and sea whips (Alcyonacea). The filter feeders along ENV18 consisted of crinoids (Crinoidea), soft coral (Alcyonaria) and sea pens (Pennatulacea). Example photographs of filter feeder are presented in Figure 4.7.

Mixed sediments were present along many of the transects and were split into consolidated or unconsolidated sediments based on the proportion of hard substrate present (> 50 % consolidated, > 50 % unconsolidated). The amount of hard substrate present appeared to have the greatest effect on the benthic community present as the hard substrate provides a surface for sessile epifauna to attach and increases the biodiversity present. Therefore, the faunal assemblages found in consolidated sediment (Section 4.6.1) were not greatly influenced by the presence of unconsolidated sediments. However, within the unconsolidated habitats even a small amount of reef substrate (1 % to 24 %) has a noticeable effect on the epifaunal composition and unconsolidated sediments with hard substrate have been described as separate habitats (Section 4.6.4, Section 4.6.6 and Section 4.6.8).

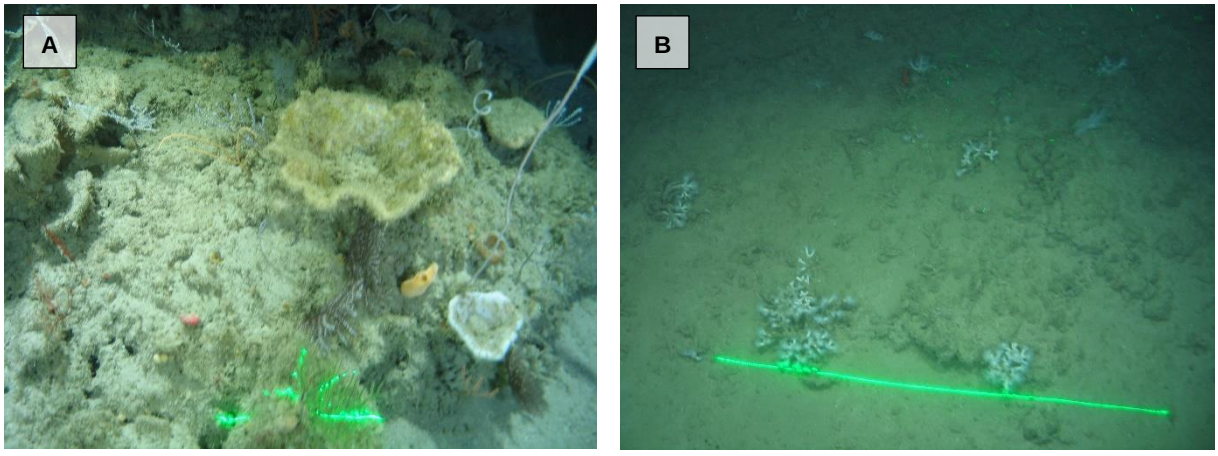


Photo A: SA1702_ENV02_14 Filter feeders (soft coral and sea whips (Alcyonaria), hydrozoa)
Photo B: SA1702_ENV11_11 Filter feeders (soft coral (Alcyonaria))

Figure 4.7: Example photographs of 'Filter feeders'

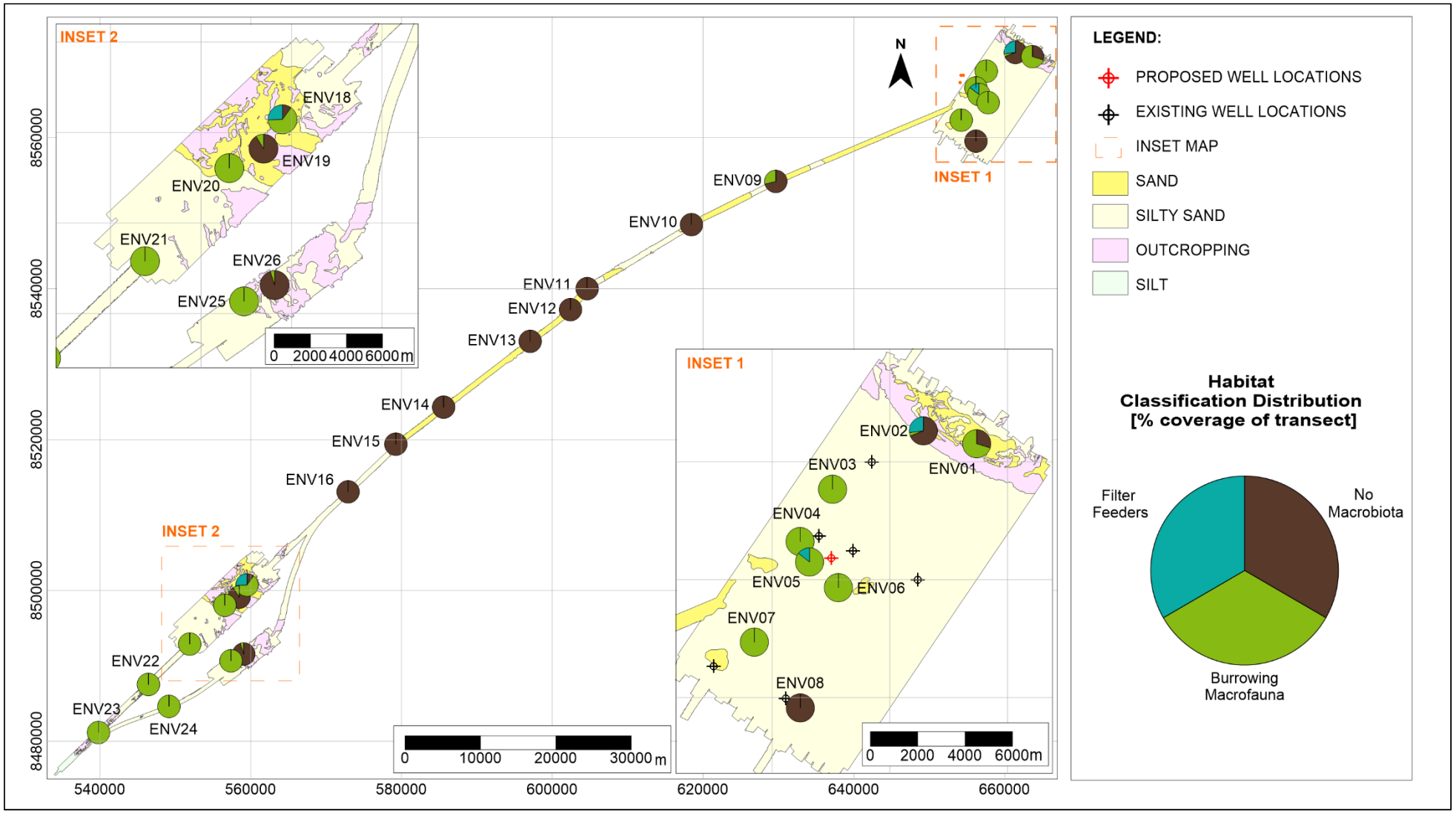


Figure 4.8: Habitat classification distribution

Table 4.3: Habitat Classification Hierarchy

Level 1	Level 2	Level 3				Distribution
Substrate Type	**Particle Size**	**Sediment Particle Size**	**Sediment Description**	**Profile**	**Characterising Fauna**	
Consolidated	Rock	Rock (unbroken)	Reef with sand veneer high relief	High	Burrows, soft coral (Alcyonaria), sponge (Porifera), sea anemone (Actiniaria), branching coral (Alcyonacea),	ENV19
			Reef with sand veneer, medium relief	Medium	Sea whips (Alcyonacea), Branching coral (Alcyonacea), sponges	ENV02, ENV18, ENV19
			Reef with veneer of sediment, low relief	Low	Hydroids (Hydrozoa, sponge (Porifera), branching coral (Alcyonacea)	ENV01, ENV02, ENV05A, ENV11, ENV12
Unconsolidated	Gravel	Sandy gravel	Sandy gravel	Flat	Sparse to no visible fauna	ENV11
		Gravelly sand	Gravelly Sand	Flat to small ripples	Soft coral (Alcyonacea), hydroids (Hydrozoa)	ENV01, ENV05, ENV05A, ENV26
					Faunal Burrows	ENV09A
					Sparse to no visible fauna	ENV09, ENV09A, ENV11,
		Gravelly sand over hard substrate	1 % – 49 % reef	Flat	Sea whips (Alcyonacea), hydroids (Hydrozoa), sponge (Porifera)	ENV02, ENV09A, ENV15
	Sand	Sand	Sand	Flat to medium ripples	Faunal burrows	ENV02, ENV03, ENV07, ENV18, ENV19, ENV26
					Sea anemones (Actiniaria), tubular glass sponges (Porifera), sea urchin (Echinoidea)	ENV04, ENV06, ENV08,
					Sparse to no visible fauna	ENV11, ENV10, ENV16, ENV02, ENV13, ENV14, ENV15
		Sand with hard substrate	1 % – 49 % reef	Flat	Sponges (Porifera) crinoids (Crinoidea), faunal burrows	ENV05, ENV05A, ENV14, ENV18, ENV19, ENV26
			Volcanic rock	Small to medium waves	Sparse to no visible fauna	ENV10
	Mud	Muddy sand	Muddy sand	Flat	Faunal burrows	ENV18, ENV20, ENV25, ENV21, ENV22, ENV24, ENV23
		Muddy sand with hard substrate	1 % – 24 % Reef	Flat	Sponges (Porifera), faunal burrows	ENV20, ENV25

4.6 Habitat Descriptions

4.6.1 Consolidated Unbroken Rock

Table 4.4 summarises the classification and characteristics of this habitat.

Table 4.4: Summary Classification and Characteristics of 'Consolidated Unbroken Rock'

Hierarchical Classification				
Level 1	**Substrate Type**	**Consolidated**		
Level 2	Particle size	Rock (51 % – 99 %) with sediment veneer (1 % – 49 %)		
Level 3	Sediment particle size	Unbroken rock		
	Sediment description	Reef with sediment veneer		
	Profile	Low	Medium	High
	Characteristic fauna	Burrows, soft coral (Alcyonaria), sponge (Porifera), sea anemone (Actiniaria), branching coral (Alcyonacea),	Sea whips (Alcyonacea), Branching coral (Alcyonacea), sponges (Porifera)	Hydroids (Hydrozoa), sponge (Porifera), branching coral (Alcyonacea)
Physical Characteristics				
Depth [m]		66 m – 242 m		

This habitat was observed at several locations across the survey area; in the shallower waters to the north of the Crux site (66 m to 94 m), a raised mound in the centre of the Crux site (168 m to 170 m) and at the escarpments along the pipeline route (204 m to 242 m). Although predominantly hard substrate a veneer of sediment was still present partially covering the hard substrate. The presence of unconsolidated sediments in this habitat had a smaller influence on the community structure than the hard substrate. Therefore, a similar faunal assemblage was present in areas of nearly 100 % reef to areas which were 51 % reef to 49 % soft sediment. The faunal composition in this habitat varied little with depth.

'Consolidated unbroken rock' was the only habitat where the community type 'Filter feeders' was observed as this was the only habitat where epifauna exceeded 10 % coverage. All Fauna, including fauna below 10 % coverage, were split into three different biological assemblages which changed with the relief that was recorded for the rock substrate (see Table 4.4). Table 4.3 details the transects where each of these faunal assemblages were found. The majority of the rock substrate observed with the camera was low profile (<1 m over 2 m) which allowed the attachment of soft corals (Alcyonaria), sponge (Porifera), sea anemones (Actiniaria) and branching coral (Alcyonacea) as well as faunal burrows present in the unconsolidated sediment between the rock substrate. Areas of medium profile (1 m to 4 m over 2 m) were characterised by sea whips (Alcyonacea), branching coral (Alcyonacea) and sponges (Porifera). One area of high profile reef (>2 m over 2 m) was present during transect ENV19 and was characterised by Hydroids (Hydrozoa), sponges (Porifera) and branching coral (Alcyonacea). The community type 'Filter feeders' was present in low and medium relief areas.

Example photographs of the different fauna identified in the three biotopes within the habitat 'Consolidated unbroken rock' and displayed in Figure 4.9.

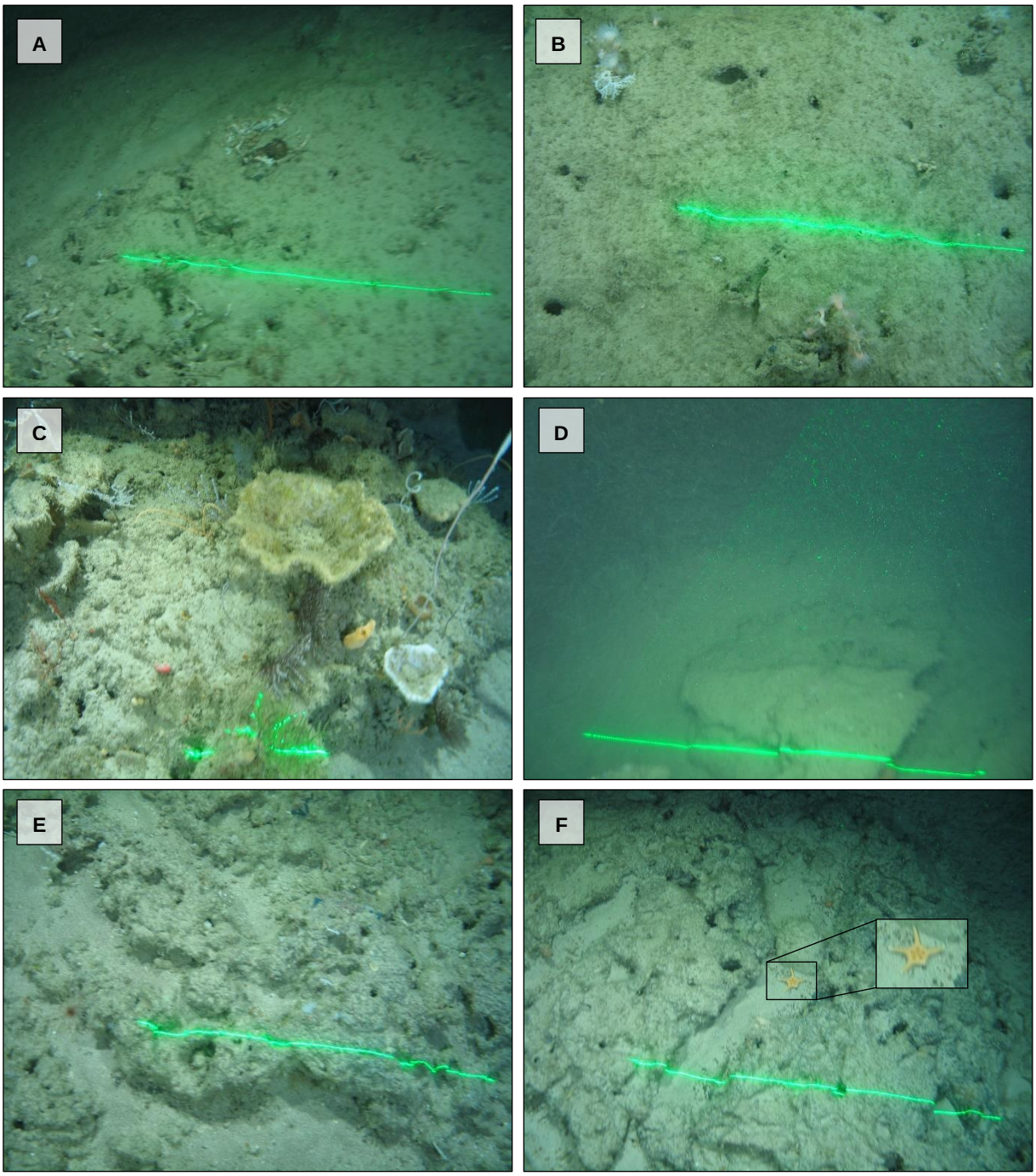


Photo A: SA1702_ENV19_14 Unbroken rock substrate with sand veneer, faunal burrows;
Photo B: SA1702_ENV19_18 Unbroken rock substrate with sand veneer, faunal burrows, soft corals (Alcyonaria), bryozoan;
Photo C: SA1702_ENV02_14 Unbroken rock substrate with sand veneer, sponges (Porifera), hydroids (Hydrozoa), bryozoan, sea whips (Alcyonacea);
Photo D: SA1702_ENV19_46 Unbroken rock substrate with sand veneer, no visible fauna;
Photo E: SA1702_ENV11_29 Unbroken rock substrate with sand veneer, faunal burrows;
Photo F: SA1702_ENV12_41 Unbroken rock substrate with sand veneer, faunal burrows, starfish (Asteroidea).

Figure 4.9: Example photographs of 'Consolidated Unbroken Rock' and associated fauna

4.6.2 Unconsolidated Sandy Gravel

Table 4.5 summarises the classification and characteristics of this habitat.

Table 4.5: Summary Classification and Characteristics of 'Unconsolidated Sandy Gravel'

Hierarchical Classification		
Level 1	**Substrate Type**	**Unconsolidated**
Level 2	Particle size	Gravel
Level 3	Sediment particle size	Sandy Gravel
	Sediment description	Sandy Gravel
	Profile	Flat
	Characteristic fauna	Sparse to no visible fauna
Physical Characteristics		
Depth [m]		212 m – 215 m

Although only identified from a single transect (ENV11) during the survey, it is possible that this habitat occurs more widely within the Crux site. This sediment occurred adjacent to the 'Unconsolidated Gravelly Sand' habitat discussed in Section 4.6.3.

The sediment within this habitat appeared, from seabed photographic data, to principally comprise of gravel and shell material with some sand content.

No benthic macrofauna were observed within this habitat. An unidentified fish was observed on the video footage.

Example photographs of this habitat are provided in Figure 4.10.

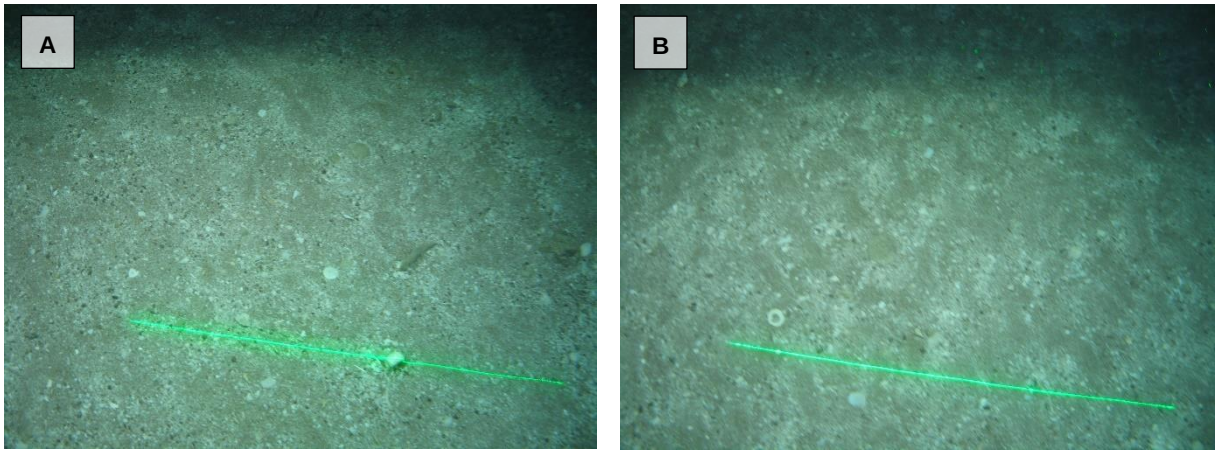


Photo A: SA1702_ENV11_02 Sandy Gravel, no visible fauna;
Photo B: SA1702_ENV11_11 Sandy Gravel, no visible fauna.

Figure 4.10: Example photographs of 'Unconsolidated Sandy Gravel'

4.6.3 Unconsolidated Gravelly Sand

Table 4.6 summarises the classification and characteristics of this habitat.

Table 4.6: Summary Classification and Characteristics of 'Unconsolidated Gravelly Sand'

Hierarchical Classification				
Level 1	**Substrate Type**	**Unconsolidated**		
Level 2	Particle size	Gravel		
Level 3	Sediment particle size	Gravelly sand		
	Sediment description	Gravelly sand		
	Profile	Flat to small ripples		
	Characteristic fauna	Soft coral (Alcyonacea), hydroids (Hydrozoa)	Faunal burrows	Sparse to no visible fauna
Physical Characteristics				
Depth [m]		89 m – 249 m		

This habitat was observed at several locations, three transects at the Crux site (transects ENV01, ENV05 and ENV05A) and four transects along the pipeline route (transects ENV09, ENV09A, ENV11 and ENV26).

Three different faunal assemblages were observed. Four transects (ENV01, ENV05, ENV05A and ENV26) showed faunal assemblages consisting of sporadic soft corals (Alcyonacea) and hydroids (Hydrozoa) with sea cucumbers (Holothuroidea), sea pens (Pennatulacea), sea urchins (Echinoidea), sea anemones (Actiniaria) and sea whips (Alcyonacea) also present. The attached sessile epifauna may indicate that a harder substrate is present beneath the gravelly sand sediment. One section of transect (ENV09A) was characterised by the presence of faunal burrows but most observations of this habitat showed no bioturbation indicating the sediment was not cohesive enough to provide a stable environment for burrows. Sections of transects ENV09, ENV09A and ENV15 showed little evidence of epifauna or faunal burrows however a few unidentified fish were observed.

Water depths at which this habitat was observed ranged from 89 m (ENV01) to 249 m (ENV26).

Example photographs of the 'Unconsolidated Gravelly Sand' habitat are displayed in Figure 4.11.

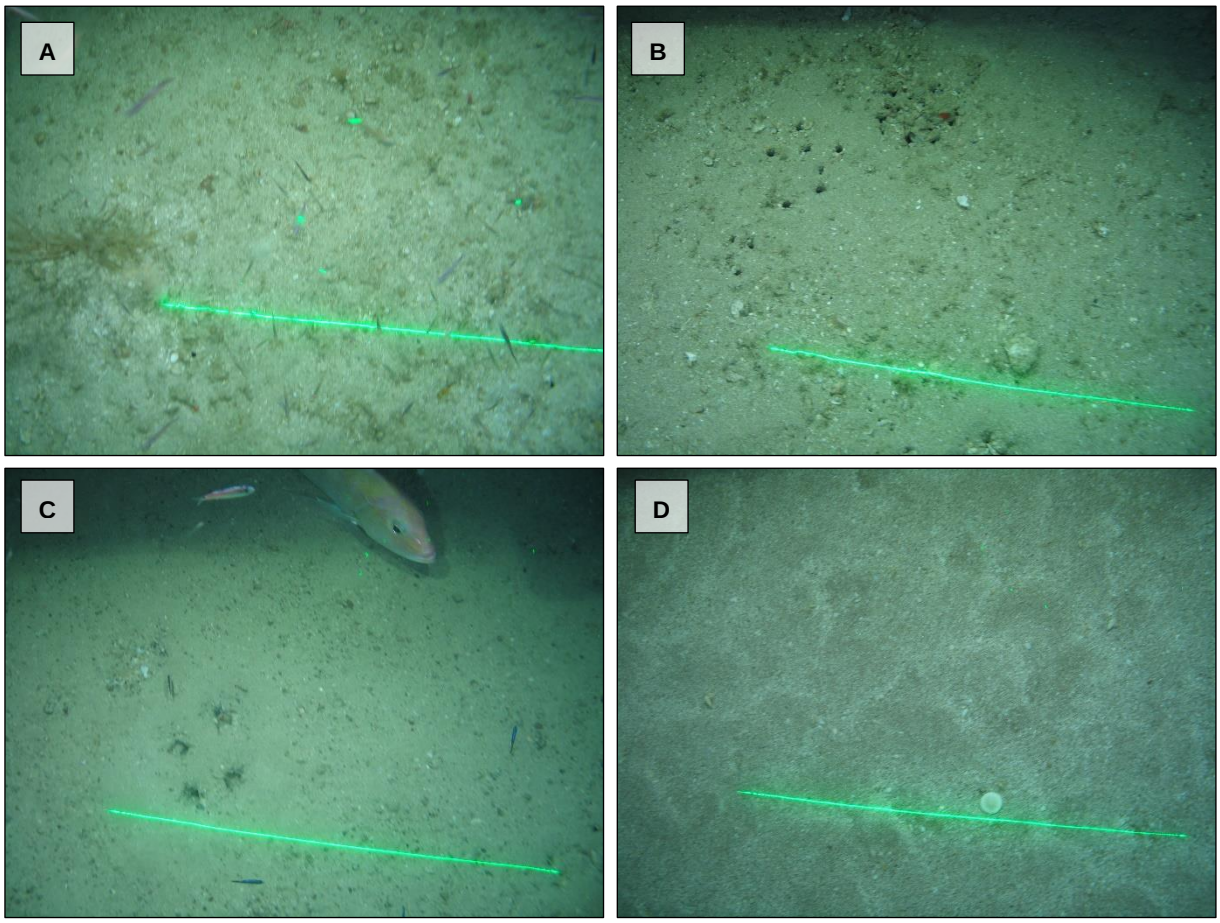


Photo A: SA1702_ENV01_15 Gravelly sand, hydroids (Hydrozoa), fish;
Photo B: SA1702_ENV05_56 Gravelly sand, faunal burrows;
Photo C: SA1702_ENV09A_30 Gravelly sand, faunal burrows, unidentified fish;
Photo D: SA1702_ENV11_7 Gravelly sand, no visible fauna.

Figure 4.11: Example photographs of 'Unconsolidated Gravelly Sand'

4.6.4 Unconsolidated Gravelly Sand over Hard Substrate

Table 4.7 summarises the classification and characteristics of this habitat.

Table 4.7: Summary Classification and Characteristics of 'Unconsolidated Gravelly Sand over Hard Substrate'

Hierarchical Classification		
Level 1	**Substrate Type**	**Unconsolidated**
Level 2	Particle size	Gravel
Level 3	Sediment particle size	Gravelly sand
	Sediment description	Gravelly sand forming veneer over reef material (1 – 49 %)
	Profile	Flat sediment, low reef
	Characteristic fauna	Sea whips (Alcyonacea), sponge (Porifera), hydroids (Hydrozoa)
Physical Characteristics		
Depth [m]		66 m – 214 m

This habitat was observed at three locations (transects ENV02, ENV09A and ENV15). This habitat consisted of a mixed sediment with predominantly gravelly sand (> 50 %) with patches of unbroken reef and reef rubble (cobbles). The water depths at which this habitat occurred ranged from 66 m (transect ENV02) to 214 m (transect ENV15).

The habitat was characterised by the epifaunal community growing on the hard substrate, including sea whips (Alcyonacea), hydroids (Hydrozoa) and sponges (Porifera). Stalked crinoids (Isselicrinidae) were also present in this habitat. No bioturbation was apparent in the unconsolidated gravelly sand between the hard substrate, indicating a sediment unsuitable for faunal burrows.

Example photographs of the 'Unconsolidated Gravelly Sand over Hard Substrate' habitat are displayed in Figure 4.12.

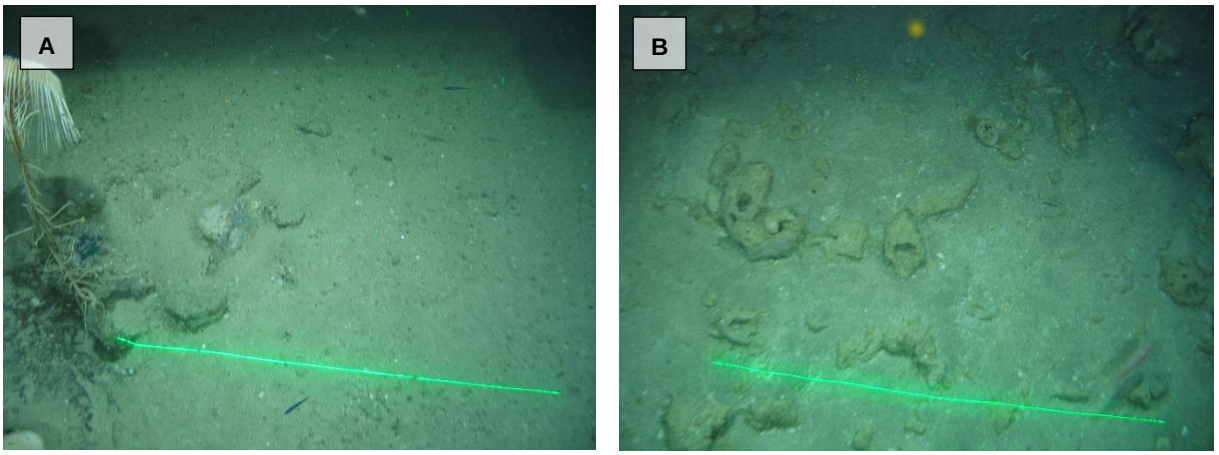


Photo A: SA1702_ENV09A_24 Gravelly sand with reef rubble (cobbles), stalked crinoid (Isselicrinidae);
Photo B: SA1702_ENV15_18 Gravelly sand with reef rubble (cobbles), unidentified fish.

Figure 4.12: Example photographs of 'Unconsolidated Gravelly Sand over Hard Substrate'

4.6.5 Unconsolidated Sand

Table 4.8 summarises the classification and characteristics of this habitat.

Table 4.8: Summary Classification and Characteristics of 'Unconsolidated Sand'

Hierarchical Classification				
Level 1	**Substrate Type**	**Unconsolidated**		
Level 2	Particle size	Sand		
Level 3	Sediment particle size	Sand		
	Sediment description	Sand (100 %)		
	Profile	Flat to medium ripples		
	Characteristic fauna	Faunal burrows	Sea anemones (Actiniaria), tubular glass sponges (Porifera), sea urchin (Echinoidea)	Sparse to no visible fauna
Physical Characteristics				
Depth [m]		66 m – 247 m		

This was the predominant sediment type observed across the survey area and consisted areas of flat sand or sand forming small (1 cm to 10 cm high) to medium ripples (10 cm to 50 cm high).

Based on the fauna observed three different biological assemblages were observed. Seven transects showed areas where there was little to no evidence of epifauna and faunal burrows (< 1 disturbance per meter) indicating the sand in these areas was not cohesive enough for to provide a stable environment for burrows. Sections of six transects showed higher levels of bioturbation ranging from low (1 to 2 disturbances per meter) to medium (3 to 10 disturbances per meter). The bioturbation consisted largely of faunal burrows although the occasional faunal track was also observed. Three transects showed sessile fauna associated with the sand substrate with sea anemones (Actiniaria) and glass tubular sponges (Porifera) being present in low abundance. Sand is not usually a suitable substratum for sessile attaching fauna so they may be indicative of a hard substrate beneath a thin sand layer.

Example photographs of this 'Unconsolidated Sand' habitat and associated fauna are displayed in Figure 4.13.

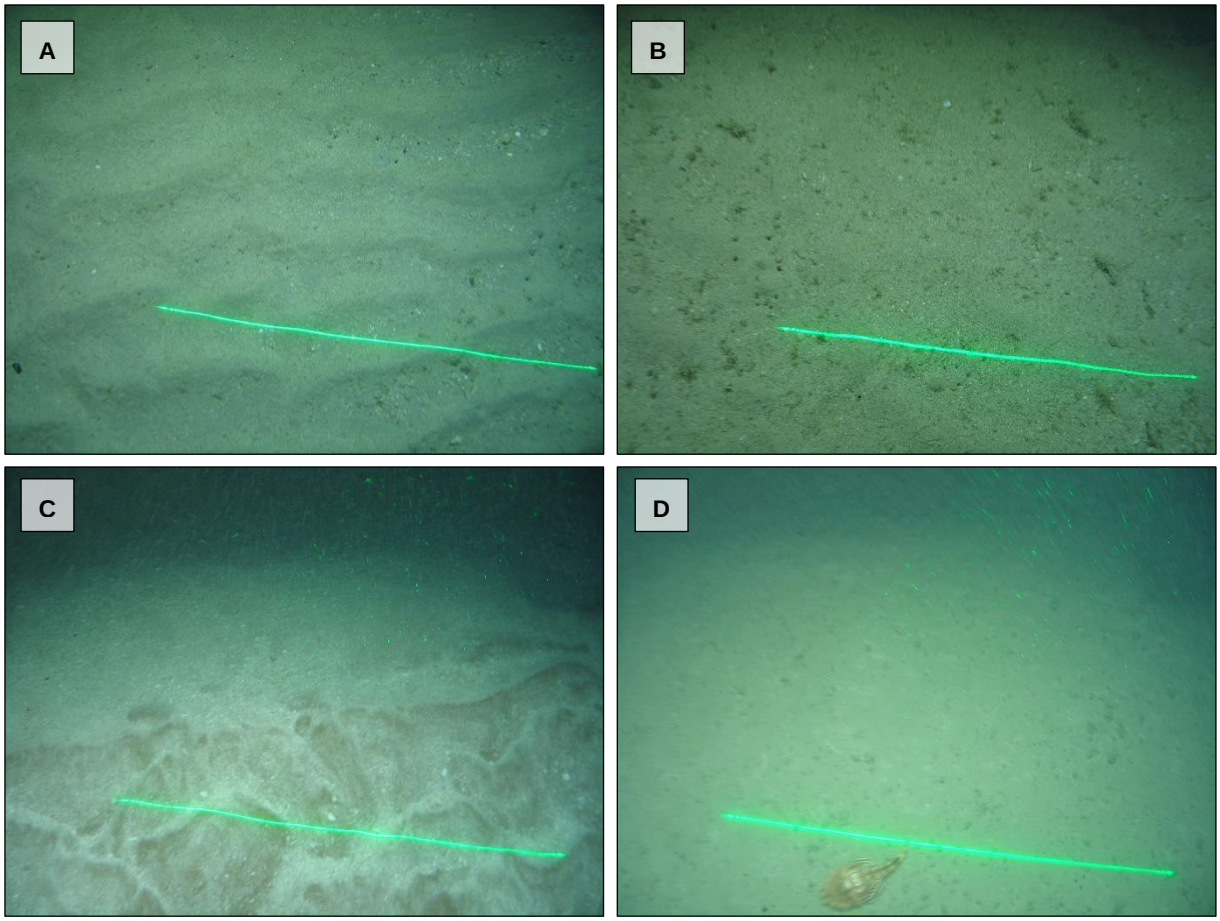


Photo A: SA1702_ENV02_23 Sand forming sand waves, no visible fauna;
Photo B: SA1702_ENV04_11 Sand, hydroids (Hydrozoa);
Photo C: SA1702_ENV13_19 Sand forming sand waves, no visible fauna;
Photo D: SA1702_ENV18_13 Sand, unidentified fish.

Figure 4.13: Example photographs of 'Unconsolidated Sand'

4.6.6 Unconsolidated Sand with Hard Substrate

Table 4.9 summarises the classification and characteristics of this habitat.

Table 4.9: Summary Classification and Characteristics of 'Unconsolidated Sand with Hard Substrate'

Hierarchical Classification			
Level 1	**Substrate Type**	**Unconsolidated**	
Level 2	Particle size	Sand	
Level 3	Sediment particle size	Sand	
	Sediment description	Sand (41 % – 99 %) forming veneer over reef material (1 % – 49 %)	Sand forming veneer over volcanic rock
	Profile	Flat sediment, low reef	Small to medium ripples, low rock
	Characteristic fauna	Sponges (Porifera) crinoids (Crinoidea), faunal burrows	No visible fauna
Physical Characteristics			
Depth [m]		167 m – 257 m	

This habitat was only observed at two transect at the Crux site (ENV05, ENV05A) and five transects along the pipeline route (ENV14, ENV18, ENV19, ENV26 and ENV10). The habitat consisted predominantly of sand sediment with a smaller proportion (< 49 %) of hard substrate. Two types of hard substrate were identified. Old unbroken reef and reef rubble was the same as that observed in other habitats across the survey area (Section 4.6.1, Section 4.6.4 and Section 4.6.8). A different hard substrate was observed at transect ENV10 and appeared to be of volcanic origin. On the sidescan sonar data, the acoustic return of this habitat was similar to that of rippled sand seen elsewhere across the survey area.

The volcanic sediment covered by a veneer of sand sediment had no visible fauna present. This may indicate a mobile and dynamic environment with the sand scouring the surface of the hard substrate and preventing epifauna from attaching. Low to medium sand waves were also present and are indicative of mobile shifting sediments.

The presence of hard reef substrate among the sand sediment provided a surface for attachment for a variety of sessile epifauna, predominantly sponges (Porifera) but including soft corals (Alcyonacea), hydroids (Hydrozoa), branching coral (Alcyonacea) and sea pens (Pennatulacea) as well as mobile epifauna such as crinoids (Crinoidea), starfish (Asteroidea), crabs (Decapoda) and sea urchins (Echinoidea).

Example photographs of this 'Unconsolidated Sand with Hard Substrate' habitat and associated fauna are displayed in Figure 4.14.

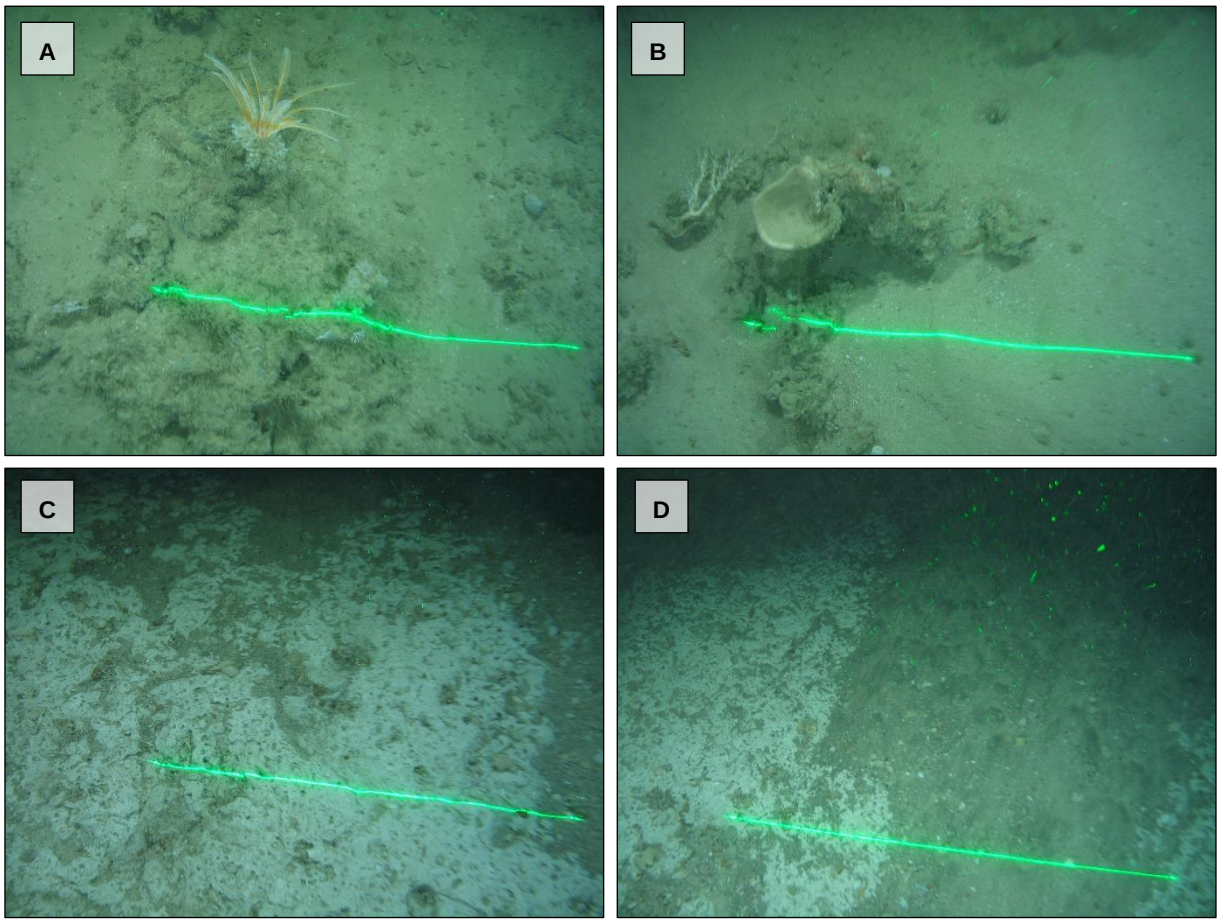


Photo A: SA1702_ENV18_42 Sand veneer over reef, crinoid (Crinoidea);
Photo B: SA1702_ENV26_93 Sand veneer over reef, sponge (Porifera);
Photo C: SA1702_ENV10_32 Sand veneer over volcanic rock, no visible fauna;
Photo D: SA1702_ENV10_35 Sand veneer over volcanic rock, no visible fauna.

Figure 4.14: Example photographs of 'Unconsolidated Sand with Hard Substrate'

4.6.7 Unconsolidated Muddy Sand

Table 4.10 summarises the classification and characteristics of this habitat.

Table 4.10: Summary Classification and Characteristics of 'Unconsolidated Muddy Sand'

Hierarchical Classification		
Level 1	**Substrate Type**	**Unconsolidated**
Level 2	Particle size	Muddy Sand
Level 3	Sediment particle size	Muddy Sand
	Sediment description	Muddy Sand (100 %)
	Profile	Flat
	Characteristic fauna	Faunal burrows
Physical Characteristics		
Depth [m]		228 m – 272 m

This habitat was only recorded at the deepest transects (ENV18, ENV20, ENV21, ENV22, ENV23, ENV24 and ENV25) surveyed along the pipeline route and was the second most common habitat observed during the survey after 'Unconsolidated Sand' (Section 4.6.5).

The high degree of turbidity limited the visibility during data acquisition along several of these transects but, where visible, the habitat comprised of muddy sand. Bioturbation in this habitat was recorded as low (1 to 2 disturbances per meter) to medium (3 to 10 disturbances per meter). The bioturbation consisted largely of faunal burrows, suggesting an abundant infaunal community as burrows increase the oxygen in the surface sediment often resulting in a greater abundance of infauna. The occasional faunal track was also observed. Epifuana was sparse in this habitat although hydroids (Hydrozoa), sponges (Porifera), hermit crabs (Paguroidea) and sea pens (Pennatulacea) were also observed in this habitat.

Example photographs of this habitat are shown in Figure 4.15.

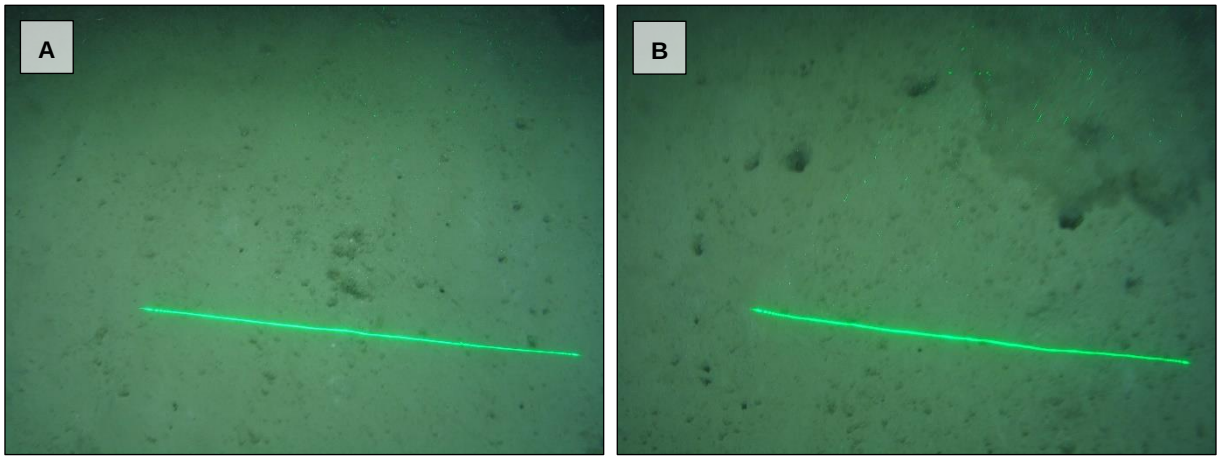


Photo A: SA1702_ENV20_73, Muddy sand, faunal burrows;
Photo B: SA1702_ENV25_27, Muddy sand, faunal burrows.

Figure 4.15: Example photographs of 'Unconsolidated Muddy Sand'

4.6.8 Unconsolidated Muddy Sand with Hard Substrate

Table 4.11 summarises the classification and characteristics of this habitat.

Table 4.11: Summary Classification and Characteristics of 'Unconsolidated Muddy Sand with Hard Substrate

Hierarchical Classification		
Level 1	**Substrate Type**	**Unconsolidated**
Level 2	Particle size	Muddy Sand
Level 3	Sediment particle size	Muddy Sand
	Sediment description	Muddy sand (76 % – 99 %) over hard substrate (1 % – 24 %)
	Profile	Flat with low reef
	Characteristic fauna	Sponges (Porifera), faunal burrows
Physical Characteristics		
Depth [m]		242 m – 269 m

This 'Unconsolidated Muddy Sand with Hard Substrate' habitat was observed at two transects, located at the bottom of the escarpments along the pipeline route (ENV20) and the alternative pipeline route (ENV25). This habitat was only recorded in the deeper water (242 m – 269 m) and was recorded alongside the 'Unconsolidated Muddy Sand' habitat described in Section 4.6.7.

The presence of hard substrate allowed the attachment of sessile epifauna. Sponges (Porifera) were characteristic of this habitat. Sea anemones (Actiniaria), sea whips (Alcyonacea), soft corals (Alcyonaria) and hydroids (Hydrozoa) were also present. However, some sessile attaching taxa that had been recorded in other areas where hard substrate had been present were not recorded in this habitat. The high levels of suspended material in the water column at this location may inhibit colonisation by other filter feeding species (e.g. soft corals and sponges), as these suspended particles may clog the filter feeding apparatus.

Example photographs of this habitat are shown in Figure 4.16.

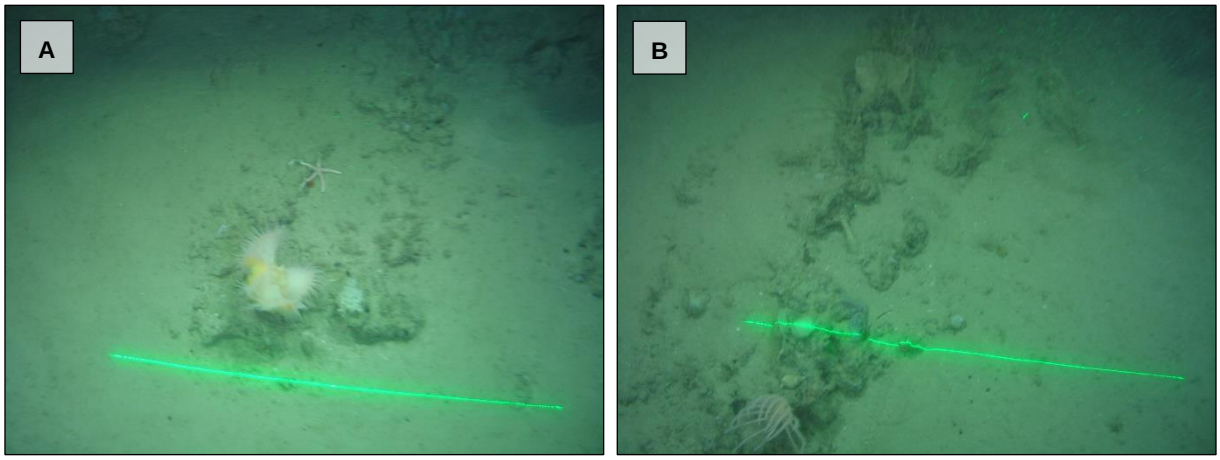


Photo A: SA1702_ENV20_13, Muddy sand with reef rubble (cobbles), starfish (Asteroidea), sea anemones (Actinaria), sponge (Porifera);
Photo B: SA1702_ENV25_9, Muddy sand with reef rubble (cobbles), soft coral (Ellisellidae), faunal burrows.

Figure 4.16: Example photographs of 'Unconsolidated Muddy Sand with Hard Substrate'

5. CONCLUSIONS

A broad range of habitat types were seen across the survey area, with eight separate habitats identified based on geomorphological structures and the sediments. Water depths ranged from 84.4 m to 262.0 m and decreased from the Crux site in the north-east of the survey area to the Prelude end of the pipeline in the south-west of the survey area. Two escarpments were evident on the video transects within the survey area: one to the north-east of Crux site and one along the pipeline route.

Areas of potential reef and mixed sediment were targeted for camera transects based on review of the sidescan sonar and bathymetry data. Sediment types observed on the camera varied across the survey area. Muddy sand was observed on the video to the south of the survey area at the Prelude end of the pipeline route, while gravelly sand with hard substrate was observed in the shallower areas of the Crux site. This was broadly consistent with the geophysical data interpretation which identified the predominant sediment type as silty sand at the Crux site with sand being the predominant sediment type along the pipeline route.

Overall epifaunal abundance was low with some habitats having little to no visible fauna. Most habitats had low faunal abundance with a few characterising taxa. Unconsolidated sediments with no hard substrate for attachment had fewer epifaunal taxa present. Sea pens (Pennatulacea), crinoids (Crinoidea) including the stalked crinoids (Isselicrinidae) and sea urchins (Echinoidea) were observed. Unconsolidated sediments had a higher level of bioturbation mainly in the form of faunal burrows, although the presence of faunal burrows depended on the sediment type and cohesiveness of the sediment.

The greatest influence on epifaunal communities was the presence of consolidated hard substrate, even in habitats where unconsolidated sediment was the dominant sediment type. Habitats containing a proportion of hard substrate for attachment had soft corals and sea whips (Alcyonacea) sea anemones (Actiniaria), hydroids (Hydrozoa) and sponges (Porifera) present. Sections of three transects (ENV02, ENV05A and ENV18), were recorded as having an abundance greater than 10 % coverage which was the threshold applied to the habitat classification applied. Sections of three transects were assigned the community classification of ‘Filter Feeders’ (ENV02, ENV05A and ENV18).

6. REFERENCES

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7. DISTRIBUTION

A copy of this report has been distributed as follows:

Shell Australia Pty Ltd

Attn: Gareth Edwards and Nick Lake : 1 x electronic copy

APPENDICES

A. LOGS

A.1 SURVEY LOGS

A.2 VIDEO/PHOTOGRAPHIC LOG

B. SEABED PHOTOGRAPHS

A. LOGS

A.1 SURVEY LOGS

GDA94, MGA94, UTM Zone 51, CM123 °East												
Date	Time [UTC]	Transect	Type	ID	Fix No.	Water Depth [m]	Proposed Location		Actual Location		Offset [m]	Notes
							Easting [m]	Northing [m]	Easting [m]	Northing [m]		
22/04/2016	05:28:06	SA1702_ENV02	Still	SA1702_ENV	108	66.9	661424.09	8571313.14	661527.17	8571429.94	155.8	
22/04/2016		SA1702_ENV02	Still	SA1702_ENV	NO FIX							
22/04/2016	05:28:31	SA1702_ENV02	Still	SA1702_ENV	109	66.6	661424.09	8571313.14	661525.11	8571428.07	153.0	
22/04/2016	05:29:31	SA1702_ENV02	Still	SA1702_ENV	110	66.1	661424.09	8571313.14	661519.69	8571423.25	145.8	
22/04/2016	05:31:03	SA1702_ENV02	Still	SA1702_ENV	111	66.5	661424.09	8571313.14	661512.10	8571414.79	134.5	
22/04/2016	05:32:15	SA1702_ENV02	Still	SA1702_ENV	112	67.4	661424.09	8571313.14	661503.82	8571406.13	122.5	
22/04/2016		SA1702_ENV02		SA1702_ENV	NO FIX							
22/04/2016	05:33:13	SA1702_ENV02	Still	SA1702_ENV	113	66.6	661424.09	8571313.14	661497.72	8571398.49	112.7	
22/04/2016	05:35:21	SA1702_ENV02	Still	SA1702_ENV	114	67.5	661424.09	8571313.14	661481.55	8571381.69	89.4	
22/04/2016	05:35:37	SA1702_ENV02	Still	SA1702_ENV	115	67.8	661424.09	8571313.14	661481.05	8571379.88	87.7	
22/04/2016	05:37:49	SA1702_ENV02	Still	SA1702_ENV	116	71.4	661424.09	8571313.14	661466.80	8571361.85	64.8	
22/04/2016	05:40:26	SA1702_ENV02	Still	SA1702_ENV	117	71.6	661424.09	8571313.14	661450.09	8571340.75	37.9	
22/04/2016	05:41:31	SA1702_ENV02	Still	SA1702_ENV	118	71.6	661424.09	8571313.14	661439.90	8571329.55	22.8	
22/04/2016	05:41:38	SA1702_ENV02	Still	SA1702_ENV	119	71.7	661424.09	8571313.14	661438.80	8571328.21	21.1	
22/04/2016	05:43:54	SA1702_ENV02	Still	SA1702_ENV	120	72.1	661424.09	8571313.14	661423.13	8571308.77	4.5	
22/04/2016	05:44:35	SA1702_ENV02	Still	NO STILL	121	73.9	661424.09	8571313.14	661418.84	8571303.42	11.0	
22/04/2016	05:45:24	SA1702_ENV02	Still	SA1702_ENV	122	75.0	661424.09	8571313.14	661412.49	8571296.20	20.5	
22/04/2016	05:46:26	SA1702_ENV02	Still	SA1702_ENV	123	80.3	661424.09	8571313.14	661404.62	8571287.10	32.5	
22/04/2016	05:46:49	SA1702_ENV02	Still	SA1702_ENV	124	82.6	661424.09	8571313.14	661401.94	8571283.80	36.8	
22/04/2016	05:47:15	SA1702_ENV02	Still	SA1702_ENV	125	83.6	661424.09	8571313.14	661398.63	8571280.44	41.4	
22/04/2016	05:48:08	SA1702_ENV02	Still	SA1702_ENV	126	86.0	661424.09	8571313.14	661392.55	8571272.89	51.1	
22/04/2016	05:48:31	SA1702_ENV02	Still	SA1702_ENV	127	86.1	661424.09	8571313.14	661389.97	8571269.69	55.2	
22/04/2016	05:49:27	SA1702_ENV02	Still	SA1702_ENV	128	86.4	661424.09	8571313.14	661383.85	8571262.12	65.0	
22/04/2016	05:49:57	SA1702_ENV02	Still	SA1702_ENV	129	88.1	661424.09	8571313.14	661379.77	8571258.13	70.6	
22/04/2016	05:50:41	SA1702_ENV02	Still	SA1702_ENV	130	87.1	661424.09	8571313.14	661375.16	8571252.73	77.7	
22/04/2016	05:51:46	SA1702_ENV02	Still	SA1702_ENV	131	88.7	661424.09	8571313.14	661368.27	8571243.88	89.0	
22/04/2016	05:52:08	SA1702_ENV02	Still	SA1702_ENV	132	89.0	661424.09	8571313.14	661366.30	8571240.70	92.7	

GDA94, MGA94, UTM Zone 51, CM123 °East												
Date	Time [UTC]	Transect	Type	ID	Fix No.	Water Depth [m]	Proposed Location		Actual Location		Offset [m]	Notes
							Easting [m]	Northing [m]	Easting [m]	Northing [m]		
22/04/2016	05:52:45	SA1702_ENV02	Still	SA1702_ENV	133	90.0	661424.09	8571313.14	661361.80	8571236.14	99.0	
22/04/2016	05:54:08	SA1702_ENV02	Still	SA1702_ENV	134	89.8	661424.09	8571313.14	661351.95	8571224.16	114.5	
22/04/2016	05:54:56	SA1702_ENV02	Still	SA1702_ENV	135	89.8	661424.09	8571313.14	661346.21	8571217.28	123.5	
22/04/2016	05:55:44	SA1702_ENV02	Still	SA1702_ENV	136	90.3	661424.09	8571313.14	661340.33	8571210.03	132.8	
22/04/2016	05:56:23	SA1702_ENV02	Still	SA1702_ENV	137	90.8	661424.09	8571313.14	661335.30	8571204.09	140.6	
22/04/2016	05:57:17	SA1702_ENV02	Still	SA1702_ENV	138	90.5	661424.09	8571313.14	661328.69	8571196.05	151.0	
22/04/2016	05:57:50	SA1702_ENV02	Still	SA1702_ENV	139	92.2	661424.09	8571313.14	661324.79	8571191.05	157.4	
22/04/2016	05:58:28	SA1702_ENV02	Still	SA1702_ENV	140	91.0	661424.09	8571313.14	661320.42	8571185.98	164.1	
22/04/2016	05:59:49	SA1702_ENV02	Still	SA1702_ENV	141	92.7	661424.09	8571313.14	661311.94	8571174.87	178.0	
22/04/2016	06:00:58	SA1702_ENV02	Still	SA1702_ENV	142	91.5	661424.09	8571313.14	661303.64	8571165.79	190.3	
22/04/2016	06:02:02	SA1702_ENV02	Still	SA1702_ENV	143	92.8	661424.09	8571313.14	661296.60	8571157.29	201.4	
22/04/2016	06:02:42	SA1702_ENV02	Still	SA1702_ENV	144	92.6	661424.09	8571313.14	661292.36	8571151.82	208.3	
22/04/2016	06:04:20	SA1702_ENV02	Still	SA1702_ENV	145	93.3	661424.09	8571313.14	661281.41	8571137.33	226.4	
22/04/2016	06:04:52	SA1702_ENV02	Still	SA1702_ENV	146	93.8	661424.09	8571313.14	661277.68	8571133.00	232.1	
22/04/2016	06:05:43	SA1702_ENV02	Still	SA1702_ENV	147	93.8	661424.09	8571313.14	661271.56	8571125.41	241.9	
22/04/2016	06:07:02	SA1702_ENV02	Still	SA1702_ENV	148	94.5	661424.09	8571313.14	661262.43	8571115.51	255.3	
22/04/2016	06:07:33	SA1702_ENV02	Still	SA1702_ENV	149	95.0	661424.09	8571313.14	661258.75	8571111.07	261.1	
22/04/2016	06:08:17	SA1702_ENV02	Still	SA1702_ENV	150	94.9	661424.09	8571313.14	661254.12	8571105.02	268.7	
22/04/2016	06:08:56	SA1702_ENV02	Still	SA1702_ENV	151	95.2	661424.09	8571313.14	661250.18	8571099.74	275.3	
22/04/2016	06:09:10	SA1702_ENV02	Still	SA1702_ENV	152	95.3	661424.09	8571313.14	661248.74	8571097.83	277.7	
22/04/2016	06:09:48	SA1702_ENV02	Still	SA1702_ENV	153	95.3	661424.09	8571313.14	661245.15	8571092.13	284.4	
22/04/2016	06:10:32	SA1702_ENV02	Still	SA1702_ENV	154	95.9	661424.09	8571313.14	661239.94	8571085.03	293.2	
22/04/2016	06:11:39	SA1702_ENV02	Still	SA1702_ENV	155	95.9	661424.09	8571313.14	661233.13	8571075.11	305.2	
22/04/2016	06:12:17	SA1702_ENV02	Still	SA1702_ENV	156	96.3	661424.09	8571313.14	661229.26	8571069.98	311.6	
22/04/2016	06:13:54	SA1702_ENV02	Still	SA1702_ENV	157	95.1	661424.09	8571313.14	661219.67	8571055.68	328.7	
22/04/2016	06:14:53	SA1702_ENV02	Still	SA1702_ENV	158	95.0	661424.09	8571313.14	661213.53	8571047.17	339.2	
22/04/2016	06:15:50	SA1702_ENV02	Still	SA1702_ENV	159	94.2	661424.09	8571313.14	661207.38	8571038.84	349.6	

GDA94, MGA94, UTM Zone 51, CM123 °East												
Date	Time [UTC]	Transect	Type	ID	Fix No.	Water Depth [m]	Proposed Location		Actual Location		Offset [m]	Notes
							Easting [m]	Northing [m]	Easting [m]	Northing [m]		
22/04/2016	11:06:15	SA1702_ENV01	Still	SA1702_ENV	201	91.0	663691.15	8570765.95	663701.98	8570780.05	17.8	
22/04/2016	11:06:35	SA1702_ENV01	Still	SA1702_ENV	202	89.0	663691.15	8570765.95	663699.00	8570776.82	13.4	
22/04/2016	11:07:19	SA1702_ENV01	Still	SA1702_ENV	203	91.0	663691.15	8570765.95	663693.65	8570768.76	3.8	
22/04/2016	11:07:57	SA1702_ENV01	Still	SA1702_ENV	204	91.0	663691.15	8570765.95	663690.37	8570762.75	3.3	
22/04/2016	11:08:39	SA1702_ENV01	Still	SA1702_ENV	205	91.0	663691.15	8570765.95	663685.94	8570755.19	12.0	
22/04/2016	11:08:47	SA1702_ENV01	Still	SA1702_ENV	206	91.0	663691.15	8570765.95	663685.25	8570754.01	13.3	
22/04/2016	11:09:35	SA1702_ENV01	Still	SA1702_ENV	207	90.0	663691.15	8570765.95	663680.64	8570747.10	21.6	
22/04/2016	11:10:26	SA1702_ENV01	Still	SA1702_ENV	208	91.0	663691.15	8570765.95	663676.51	8570740.77	29.1	
22/04/2016	11:11:24	SA1702_ENV01	Still	SA1702_ENV	209	90.0	663691.15	8570765.95	663670.77	8570733.91	38.0	
22/04/2016	11:11:56	SA1702_ENV01	Still	SA1702_ENV	210	92.0	663691.15	8570765.95	663667.68	8570729.16	43.6	
22/04/2016	11:12:14	SA1702_ENV01	Still	SA1702_ENV	211	91.0	663691.15	8570765.95	663666.45	8570727.24	45.9	
22/04/2016	11:13:09	SA1702_ENV01	Still	SA1702_ENV	212	92.0	663691.15	8570765.95	663660.33	8570717.83	57.1	
22/04/2016	11:13:41	SA1702_ENV01	Still	SA1702_ENV	213	93.0	663691.15	8570765.95	663656.38	8570713.00	63.3	
22/04/2016	11:13:56	SA1702_ENV01	Still	SA1702_ENV	214	94.0	663691.15	8570765.95	663654.77	8570710.43	66.4	
22/04/2016	11:14:41	SA1702_ENV01	Still	SA1702_ENV	215	92.0	663691.15	8570765.95	663650.59	8570702.24	75.5	
22/04/2016	11:15:07	SA1702_ENV01	Still	SA1702_ENV	216	92.0	663691.15	8570765.95	663648.82	8570697.23	80.7	
22/04/2016	11:15:56	SA1702_ENV01	Still	SA1702_ENV	217	93.0	663691.15	8570765.95	663645.20	8570690.65	88.2	
22/04/2016	11:16:56	SA1702_ENV01	Still	SA1702_ENV	218	92.0	663691.15	8570765.95	663638.02	8570679.85	101.2	
22/04/2016	11:17:48	SA1702_ENV01	Still	SA1702_ENV	219	93.0	663691.15	8570765.95	663632.13	8570671.40	111.5	
22/04/2016	11:18:17	SA1702_ENV01	Still	SA1702_ENV	220	93.0	663691.15	8570765.95	663629.56	8570667.45	116.2	
22/04/2016	11:18:32	SA1702_ENV01	Still	SA1702_ENV	221	93.0	663691.15	8570765.95	663628.33	8570665.52	118.5	
22/04/2016	11:19:11	SA1702_ENV01	Still	SA1702_ENV	222	93.0	663691.15	8570765.95	663624.71	8570659.70	125.3	
22/04/2016	11:20:17	SA1702_ENV01	Still	SA1702_ENV	223	93.0	663691.15	8570765.95	663618.02	8570650.12	137.0	
22/04/2016	11:21:19	SA1702_ENV01	Still	SA1702_ENV	224	92.0	663691.15	8570765.95	663612.22	8570640.03	148.6	
22/04/2016	11:21:56	SA1702_ENV01	Still	SA1702_ENV	225	92.0	663691.15	8570765.95	663607.94	8570634.64	155.5	
22/04/2016	11:22:39	SA1702_ENV01	Still	SA1702_ENV	226	92.0	663691.15	8570765.95	663602.24	8570627.28	164.7	
22/04/2016	11:23:25	SA1702_ENV01	Still	SA1702_ENV	227	92.0	663691.15	8570765.95	663597.17	8570619.28	174.2	

GDA94, MGA94, UTM Zone 51, CM123 °East												
Date	Time [UTC]	Transect	Type	ID	Fix No.	Water Depth [m]	Proposed Location		Actual Location		Offset [m]	Notes
							Easting [m]	Northing [m]	Easting [m]	Northing [m]		
22/04/2016	11:23:33	SA1702_ENV01	Still	SA1702_ENV	228	93.0	663691.15	8570765.95	663596.48	8570618.00	175.6	
22/04/2016	11:24:43	SA1702_ENV01	Still	SA1702_ENV	229	92.0	663691.15	8570765.95	663590.82	8570608.16	187.0	
22/04/2016	11:25:11	SA1702_ENV01	Still	SA1702_ENV	230	93.0	663691.15	8570765.95	663588.76	8570604.59	191.1	
22/04/2016	11:25:47	SA1702_ENV01	Still	SA1702_ENV	231	92.0	663691.15	8570765.95	663585.39	8570600.35	196.5	
22/04/2016	11:26:20	SA1702_ENV01	Still	SA1702_ENV	232	93.0	663691.15	8570765.95	663582.93	8570596.06	201.4	
22/04/2016	11:27:08	SA1702_ENV01	Still	SA1702_ENV	233	92.0	663691.15	8570765.95	663578.55	8570589.92	209.0	
22/04/2016	11:30:03	SA1702_ENV01	Still	SA1702_ENV	234	92.0	663691.15	8570765.95	663570.15	8570578.80	222.9	
22/04/2016	11:30:13	SA1702_ENV01	Still	SA1702_ENV	235	92.0	663691.15	8570765.95	663570.39	8570578.42	223.1	
22/04/2016	11:30:28	SA1702_ENV01	Still	SA1702_ENV	236	92.0	663691.15	8570765.95	663570.87	8570578.68	222.6	
23/04/2017	00:38:54	SA1702_ENV03	Still	NO STILL	300	166.3	657564.76	8568835.13	657488.25	8568874.61	86.1	
23/04/2017	00:44:14	SA1702_ENV03	Still	NO STILL	301	166.3	657564.76	8568835.13	657527.92	8568855.59	42.1	
23/04/2017	00:44:44	SA1702_ENV03	Still	SA1702_ENV	302	166.5	657564.76	8568835.13	657533.01	8568852.72	36.3	
23/04/2017	00:46:52	SA1702_ENV03	Still	SA1702_ENV	303	166.5	657564.76	8568835.13	657553.15	8568839.87	12.5	
23/04/2017	00:47:34	SA1702_ENV03	Still	SA1702_ENV	304	167.0	657564.76	8568835.13	657559.40	8568836.23	5.5	
23/04/2017	00:48:49	SA1702_ENV03	Still	SA1702_ENV	305	167.3	657564.76	8568835.13	657570.10	8568830.25	7.2	
23/04/2017	00:49:14	SA1702_ENV03	Still	SA1702_ENV	306	166.6	657564.76	8568835.13	657574.87	8568828.28	12.2	
23/04/2017	00:50:22	SA1702_ENV03	Still	SA1702_ENV	307	166.5	657564.76	8568835.13	657586.60	8568824.12	24.5	
23/04/2017	00:51:52	SA1702_ENV03	Still	SA1702_ENV	308	166.9	657564.76	8568835.13	657601.77	8568815.67	41.8	
23/04/2017	00:52:18	SA1702_ENV03	Still	SA1702_ENV	309	166.5	657564.76	8568835.13	657606.23	8568813.58	46.7	
23/04/2017	00:52:59	SA1702_ENV03	Still	SA1702_ENV	310	166.7	657564.76	8568835.13	657613.41	8568810.11	54.7	
23/04/2017	00:54:08	SA1702_ENV03	Still	SA1702_ENV	311	166.5	657564.76	8568835.13	657624.66	8568803.84	67.6	
23/04/2017	00:54:48	SA1702_ENV03	Still	SA1702_ENV	312	165.9	657564.76	8568835.13	657631.11	8568800.74	74.7	
23/04/2017	00:55:21	SA1702_ENV03	Still	SA1702_ENV	313	166.3	657564.76	8568835.13	657636.43	8568798.04	80.7	
23/04/2017	00:57:10	SA1702_ENV03	Still	SA1702_ENV	314	166.4	657564.76	8568835.13	657653.01	8568788.52	99.8	
23/04/2017	00:58:22	SA1702_ENV03	Still	SA1702_ENV	315	166.5	657564.76	8568835.13	657664.18	8568782.57	112.5	
23/04/2017	00:58:45	SA1702_ENV03	Still	SA1702_ENV	316	167.1	657564.76	8568835.13	657667.76	8568780.37	116.7	
23/04/2017	00:59:49	SA1702_ENV03	Still	SA1702_ENV	317	166.8	657564.76	8568835.13	657677.22	8568773.75	128.1	

GDA94, MGA94, UTM Zone 51, CM123 °East												
Date	Time [UTC]	Transect	Type	ID	Fix No.	Water Depth [m]	Proposed Location		Actual Location		Offset [m]	Notes
							Easting [m]	Northing [m]	Easting [m]	Northing [m]		
23/04/2017	01:00:34	SA1702_ENV03	Still	SA1702_ENV	318	166.6	657564.76	8568835.13	657685.26	8568769.98	137.0	
23/04/2017	01:01:06	SA1702_ENV03	Still	SA1702_ENV	319	166.8	657564.76	8568835.13	657690.68	8568767.28	143.0	
23/04/2017	01:01:18	SA1702_ENV03	Still	SA1702_ENV	320	166.9	657564.76	8568835.13	657692.54	8568766.42	145.1	
23/04/2017	01:02:03	SA1702_ENV03	Still	SA1702_ENV	321	166.3	657564.76	8568835.13	657700.16	8568762.63	153.6	
23/04/2017	01:02:32	SA1702_ENV03	Still	SA1702_ENV	322	165.9	657564.76	8568835.13	657704.87	8568759.31	159.3	
23/04/2017	01:03:16	SA1702_ENV03	Still	SA1702_ENV	323	165.3	657564.76	8568835.13	657712.16	8568755.63	167.5	
23/04/2017	01:03:34	SA1702_ENV03	Still	SA1702_ENV	324	165.9	657564.76	8568835.13	657714.68	8568754.26	170.3	
23/04/2017	01:04:19	SA1702_ENV03	Still	SA1702_ENV	325	166.6	657564.76	8568835.13	657721.68	8568751.55	177.8	
23/04/2017	01:05:05	SA1702_ENV03	Still	SA1702_ENV	326	166.7	657564.76	8568835.13	657728.40	8568747.27	185.7	
23/04/2017	01:06:14	SA1702_ENV03	Still	SA1702_ENV	327	167.3	657564.76	8568835.13	657738.56	8568741.04	197.6	
23/04/2017	01:07:08	SA1702_ENV03	Still	SA1702_ENV	328	166.2	657564.76	8568835.13	657747.35	8568736.84	207.4	
23/04/2017	01:07:50	SA1702_ENV03	Still	SA1702_ENV	329	166.8	657564.76	8568835.13	657754.70	8568733.33	215.5	
23/04/2017	01:08:02	SA1702_ENV03	Still	SA1702_ENV	330	167.2	657564.76	8568835.13	657756.18	8568732.99	217.0	
23/04/2017	01:09:03	SA1702_ENV03	Still	SA1702_ENV	331	167.3	657564.76	8568835.13	657766.88	8568727.74	228.9	
23/04/2017	01:10:00	SA1702_ENV03	Still	SA1702_ENV	332	167.0	657564.76	8568835.13	657776.28	8568722.48	239.6	
23/04/2017	01:11:00	SA1702_ENV03	Still	SA1702_ENV	333	167.5	657564.76	8568835.13	657786.11	8568717.20	250.8	
23/04/2017	01:12:18	SA1702_ENV03	Still	SA1702_ENV	334	166.9	657564.76	8568835.13	657797.59	8568708.62	265.0	
23/04/2017	01:13:09	SA1702_ENV03	Still	SA1702_ENV	335	166.8	657564.76	8568835.13	657806.00	8568704.95	274.1	
23/04/2017	01:13:52	SA1702_ENV03	Still	SA1702_ENV	336	167.5	657564.76	8568835.13	657811.81	8568701.83	280.7	
23/04/2017	03:17:53	SA1702_ENV04	Still	NO STILL	400	170.0	656182.05	8566616.90	656228.89	8566657.82	62.2	
23/04/2017	03:23:51	SA1702_ENV04	Still	SA1702_ENV	401	170.0	656182.05	8566616.90	656229.11	8566658.39	62.7	
23/04/2017	03:25:00	SA1702_ENV04	Still	SA1702_ENV	402	171.0	656182.05	8566616.90	656224.11	8566653.33	55.6	
23/04/2017	03:25:13	SA1702_ENV04	Still	SA1702_ENV	403	171.3	656182.05	8566616.90	656221.75	8566651.49	52.7	
23/04/2017	03:25:43	SA1702_ENV04	Still	NO STILL	404	170.6	656182.05	8566616.90	656215.54	8566646.98	45.0	
23/04/2017	03:25:58	SA1702_ENV04	Still	SA1702_ENV	405	170.7	656182.05	8566616.90	656212.48	8566644.71	41.2	
23/04/2017	03:26:32	SA1702_ENV04	Still	SA1702_ENV	406	170.8	656182.05	8566616.90	656205.33	8566638.86	32.0	
23/04/2017	03:27:07	SA1702_ENV04	Still	SA1702_ENV	407	171.6	656182.05	8566616.90	656198.68	8566633.34	23.4	

GDA94, MGA94, UTM Zone 51, CM123 °East												
Date	Time [UTC]	Transect	Type	ID	Fix No.	Water Depth [m]	Proposed Location		Actual Location		Offset [m]	Notes
							Easting [m]	Northing [m]	Easting [m]	Northing [m]		
23/04/2017	03:28:04	SA1702_ENV04	Still	SA1702_ENV	408	171.6	656182.05	8566616.90	656189.81	8566625.70	11.7	
23/04/2017	03:29:02	SA1702_ENV04	Still	SA1702_ENV	409	171.2	656182.05	8566616.90	656179.99	8566618.26	2.5	
23/04/2017	03:29:17	SA1702_ENV04	Still	SA1702_ENV	410	171.7	656182.05	8566616.90	656177.21	8566616.36	4.9	
23/04/2017	03:31:52	SA1702_ENV04	Still	SA1702_ENV	411	171.1	656182.05	8566616.90	656149.45	8566592.69	40.6	
23/04/2017	03:32:34	SA1702_ENV04	Still	SA1702_ENV	412	171.8	656182.05	8566616.90	656141.32	8566586.73	50.7	
23/04/2017	03:33:59	SA1702_ENV04	Still	SA1702_ENV	413	171.2	656182.05	8566616.90	656127.91	8566576.73	67.4	
23/04/2017	03:34:16	SA1702_ENV04	Still	SA1702_ENV	414	171.1	656182.05	8566616.90	656125.18	8566574.14	71.2	
23/04/2017	03:34:56	SA1702_ENV04	Still	SA1702_ENV	415	171.3	656182.05	8566616.90	656118.92	8566568.39	79.6	
23/04/2017	03:35:20	SA1702_ENV04	Still	SA1702_ENV	416	171.4	656182.05	8566616.90	656114.28	8566565.10	85.3	
23/04/2017	03:35:49	SA1702_ENV04	Still	SA1702_ENV	417	171.7	656182.05	8566616.90	656110.28	8566561.29	90.8	
23/04/2017	03:36:23	SA1702_ENV04	Still	SA1702_ENV	418	171.2	656182.05	8566616.90	656106.56	8566555.90	97.1	
23/04/2017	03:36:49	SA1702_ENV04	Still	SA1702_ENV	419	171.4	656182.05	8566616.90	656102.88	8566552.01	102.4	
23/04/2017	03:37:20	SA1702_ENV04	Still	NO STILL	420	171.9	656182.05	8566616.90	656097.95	8566547.62	109.0	
23/04/2017	03:37:59	SA1702_ENV04	Still	SA1702_ENV	421	171.3	656182.05	8566616.90	656091.53	8566542.41	117.2	
23/04/2017	03:38:49	SA1702_ENV04	Still	SA1702_ENV	422	171.0	656182.05	8566616.90	656082.73	8566536.05	128.1	
23/04/2017	03:39:15	SA1702_ENV04	Still	SA1702_ENV	423	171.4	656182.05	8566616.90	656078.76	8566531.96	133.7	
23/04/2017	04:46:43	SA1702_ENV05	Still	SA1702_ENV	501	171.0	656436.82	8565655.97	656390.80	8565627.87	53.9	
23/04/2017	04:47:26	SA1702_ENV05	Still	SA1702_ENV	502	171.0	656436.82	8565655.97	656398.17	8565632.61	45.2	
23/04/2017	04:48:04	SA1702_ENV05	Still	SA1702_ENV	503	171.9	656436.82	8565655.97	656405.47	8565637.31	36.5	
23/04/2017	04:49:43	SA1702_ENV05	Still	SA1702_ENV	504	171.8	656436.82	8565655.97	656420.96	8565647.23	18.1	
23/04/2017	04:50:13	SA1702_ENV05	Still	SA1702_ENV	505	171.3	656436.82	8565655.97	656424.78	8565649.77	13.5	
23/04/2017	04:50:40	SA1702_ENV05	Still	SA1702_ENV	506	170.8	656436.82	8565655.97	656428.35	8565652.24	9.3	
23/04/2017	04:51:17	SA1702_ENV05	Still	SA1702_ENV	507	170.8	656436.82	8565655.97	656432.94	8565654.93	4.0	
23/04/2017	04:52:09	SA1702_ENV05	Still	SA1702_ENV	508	171.7	656436.82	8565655.97	656440.36	8565660.08	5.4	
23/04/2017	04:52:57	SA1702_ENV05	Still	SA1702_ENV	509	170.3	656436.82	8565655.97	656447.56	8565665.02	14.0	
23/04/2017	04:53:42	SA1702_ENV05	Still	SA1702_ENV	510	171.0	656436.82	8565655.97	656454.93	8565669.27	22.5	
23/04/2017	04:54:49	SA1702_ENV05	Still	SA1702_ENV	511	170.5	656436.82	8565655.97	656465.30	8565676.49	35.1	

GDA94, MGA94, UTM Zone 51, CM123 °East												
Date	Time [UTC]	Transect	Type	ID	Fix No.	Water Depth [m]	Proposed Location		Actual Location		Offset [m]	Notes
							Easting [m]	Northing [m]	Easting [m]	Northing [m]		
23/04/2017	04:55:04	SA1702_ENV05	Still	SA1702_ENV	512	170.7	656436.82	8565655.97	656468.01	8565678.24	38.3	
23/04/2017	04:56:14	SA1702_ENV05	Still	SA1702_ENV	513	170.1	656436.82	8565655.97	656479.26	8565684.62	51.2	
23/04/2017	04:56:44	SA1702_ENV05	Still	SA1702_ENV	514	169.7	656436.82	8565655.97	656523.07	8565730.90	114.2	
23/04/2017	04:57:19	SA1702_ENV05	Still	SA1702_ENV	515	169.8	656436.82	8565655.97	656488.85	8565690.40	62.4	
23/04/2017	04:58:08	SA1702_ENV05	Still	SA1702_ENV	516	170.4	656436.82	8565655.97	656495.71	8565695.25	70.8	
23/04/2017	04:58:26	SA1702_ENV05	Still	SA1702_ENV	517	170.5	656436.82	8565655.97	656498.42	8565697.00	74.0	
23/04/2017	04:59:23	SA1702_ENV05	Still	SA1702_ENV	518	170.1	656436.82	8565655.97	656506.26	8565702.33	83.5	
23/04/2017	04:59:53	SA1702_ENV05	Still	SA1702_ENV	519	170.3	656436.82	8565655.97	656510.78	8565705.24	88.9	
23/04/2017	05:00:33	SA1702_ENV05	Still	SA1702_ENV	520	170.3	656436.82	8565655.97	656516.56	8565708.53	95.5	
23/04/2017	05:02:18	SA1702_ENV05	Still	SA1702_ENV	521	168.3	656436.82	8565655.97	656531.33	8565718.73	113.4	
23/04/2017	05:02:42	SA1702_ENV05	Still	SA1702_ENV	522	169.3	656436.82	8565655.97	656534.76	8565721.08	117.6	
23/04/2017	05:03:19	SA1702_ENV05	Still	SA1702_ENV	523	169.7	656436.82	8565655.97	656540.51	8565724.39	124.2	
23/04/2017	05:03:54	SA1702_ENV05	Still	SA1702_ENV	524	168.4	656436.82	8565655.97	656545.33	8565727.97	130.2	
23/04/2017	05:04:24	SA1702_ENV05	Still	SA1702_ENV	525	169.2	656436.82	8565655.97	656550.45	8565730.14	135.7	
23/04/2017	05:04:46	SA1702_ENV05	Still	SA1702_ENV	526	167.6	656436.82	8565655.97	656553.99	8565732.14	139.8	
23/04/2017	05:05:18	SA1702_ENV05	Still	NO STILL	527	167.3	656436.82	8565655.97	656558.86	8565735.82	145.8	
23/04/2017	05:05:29	SA1702_ENV05	Still	NO STILL	528	167.7	656436.82	8565655.97	656560.45	8565736.97	147.8	
23/04/2017	05:06:02	SA1702_ENV05	Still	SA1702_ENV	529	167.2	656436.82	8565655.97	656565.42	8565740.44	153.9	
23/04/2017	05:07:12	SA1702_ENV05	Still	SA1702_ENV	530	167.2	656436.82	8565655.97	656576.36	8565746.62	166.4	
23/04/2017	05:07:48	SA1702_ENV05	Still	SA1702_ENV	531	167.5	656436.82	8565655.97	656581.72	8565750.86	173.2	
23/04/2017	05:09:27	SA1702_ENV05	Still	NO STILL	532	166.7	656436.82	8565655.97	656596.90	8565761.29	191.6	
23/04/2017	05:09:45	SA1702_ENV05	Still	SA1702_ENV	533	167.1	656436.82	8565655.97	656599.38	8565763.20	194.7	
23/04/2017	05:10:41	SA1702_ENV05	Still	SA1702_ENV	534	166.5	656436.82	8565655.97	656608.35	8565769.17	205.5	
23/04/2017	05:11:04	SA1702_ENV05	Still	SA1702_ENV	535	167.5	656436.82	8565655.97	656612.10	8565771.73	210.1	
23/04/2017	11:21:51	SA1702_ENV05A	Still	SA1702_ENV	536	168.2	656436.82	8565655.97	656567.86	8565741.92	156.7	
23/04/2017	11:23:04	SA1702_ENV05A	Still	SA1702_ENV	537	167.8	656436.82	8565655.97	656581.82	8565748.54	172.0	
23/04/2017	11:23:13	SA1702_ENV05A	Still	SA1702_ENV	538	168.5	656436.82	8565655.97	656583.41	8565749.25	173.8	

GDA94, MGA94, UTM Zone 51, CM123 °East												
Date	Time [UTC]	Transect	Type	ID	Fix No.	Water Depth [m]	Proposed Location		Actual Location		Offset [m]	Notes
							Easting [m]	Northing [m]	Easting [m]	Northing [m]		
23/04/2017	11:23:26	SA1702_ENV05A	Still	SA1702_ENV	539	168.7	656436.82	8565655.97	656586.06	8565750.78	176.8	
23/04/2017	11:24:20	SA1702_ENV05A	Still	SA1702_ENV	540	168.5	656436.82	8565655.97	656595.80	8565756.76	188.2	
23/04/2017	11:24:54	SA1702_ENV05A	Still	SA1702_ENV	541	168.4	656436.82	8565655.97	656600.06	8565759.84	193.5	
23/04/2017	11:25:15	SA1702_ENV05A	Still	SA1702_ENV	542	168.4	656436.82	8565655.97	656602.36	8565761.77	196.5	
23/04/2017	11:25:23	SA1702_ENV05A	Still	SA1702_ENV	543	168.9	656436.82	8565655.97	656603.17	8565762.27	197.4	
23/04/2017	11:25:50	SA1702_ENV05A	Still	SA1702_ENV	544	168.7	656436.82	8565655.97	656606.28	8565764.27	201.1	
23/04/2017	11:25:57	SA1702_ENV05A	Still	SA1702_ENV	545	168.2	656436.82	8565655.97	656607.20	8565764.83	202.2	
23/04/2017	11:26:34	SA1702_ENV05A	Still	SA1702_ENV	546	168.7	656436.82	8565655.97	656611.87	8565768.03	207.8	
23/04/2017	11:27:11	SA1702_ENV05A	Still	SA1702_ENV	547	168.7	656436.82	8565655.97	656617.48	8565770.98	214.2	
23/04/2017	11:27:30	SA1702_ENV05A	Still	SA1702_ENV	548	168.8	656436.82	8565655.97	656620.19	8565772.80	217.4	
23/04/2017	11:28:39	SA1702_ENV05A	Still	SA1702_ENV	549	168.1	656436.82	8565655.97	656632.24	8565780.12	231.5	
23/04/2017	11:29:26	SA1702_ENV05A	Still	SA1702_ENV	550	169.0	656436.82	8565655.97	656641.48	8565785.62	242.3	
23/04/2017	11:29:52	SA1702_ENV05A	Still	SA1702_ENV	551	169.3	656436.82	8565655.97	656646.23	8565788.91	248.0	
23/04/2017	11:30:34	SA1702_ENV05A	Still	SA1702_ENV	552	170.0	656436.82	8565655.97	656653.62	8565793.42	256.7	
23/04/2017	11:30:45	SA1702_ENV05A	Still	SA1702_ENV	553	169.9	656436.82	8565655.97	656655.48	8565794.61	258.9	
23/04/2017	11:31:42	SA1702_ENV05A	Still	SA1702_ENV	554	171.0	656436.82	8565655.97	656664.97	8565800.03	269.8	
23/04/2017	11:31:50	SA1702_ENV05A	Still	SA1702_ENV	555	170.6	656436.82	8565655.97	656666.06	8565800.80	271.2	
23/04/2017	11:32:37	SA1702_ENV05A	Still	SA1702_ENV	556	171.5	656436.82	8565655.97	656671.65	8565805.52	278.4	
23/04/2017	11:32:44	SA1702_ENV05A	Still	SA1702_ENV	557	170.2	656436.82	8565655.97	656672.53	8565806.07	279.4	
23/04/2017	11:32:54	SA1702_ENV05A	Still	SA1702_ENV	558	170.4	656436.82	8565655.97	656673.76	8565806.96	281.0	
23/04/2017	11:33:29	SA1702_ENV05A	Still	SA1702_ENV	559	171.8	656436.82	8565655.97	656677.98	8565810.04	286.2	
23/04/2017	11:33:51	SA1702_ENV05A	Still	SA1702_ENV	560	171.5	656436.82	8565655.97	656681.02	8565812.16	289.9	
23/04/2017	11:34:28	SA1702_ENV05A	Still	SA1702_ENV	561	171.8	656436.82	8565655.97	656686.29	8565815.35	296.0	
23/04/2017	11:35:23	SA1702_ENV05A	Still	SA1702_ENV	562	171.9	656436.82	8565655.97	656695.28	8565820.46	306.4	
23/04/2017	11:36:01	SA1702_ENV05A	Still	SA1702_ENV	563	171.2	656436.82	8565655.97	656701.85	8565824.35	314.0	
23/04/2017	11:36:43	SA1702_ENV05A	Still	SA1702_ENV	564	171.5	656436.82	8565655.97	656708.42	8565828.13	321.6	
23/04/2017	11:37:19	SA1702_ENV05A	Still	SA1702_ENV	565	172.2	656436.82	8565655.97	656714.88	8565831.62	328.9	

GDA94, MGA94, UTM Zone 51, CM123 °East												
Date	Time [UTC]	Transect	Type	ID	Fix No.	Water Depth [m]	Proposed Location		Actual Location		Offset [m]	Notes
							Easting [m]	Northing [m]	Easting [m]	Northing [m]		
23/04/2017	11:37:57	SA1702_ENV05A	Still	SA1702_ENV	566	172.5	656436.82	8565655.97	656721.55	8565835.35	336.5	
23/04/2017	11:38:13	SA1702_ENV05A	Still	SA1702_ENV	567	171.9	656436.82	8565655.97	656724.05	8565836.91	339.5	
23/04/2017	11:39:16	SA1702_ENV05A	Still	SA1702_ENV	568	172.4	656436.82	8565655.97	656733.53	8565843.21	350.8	
24/04/2017	03:46:54	SA1702_ENV06	Vid				657811.18	8564660.75	657760.40	8564621.35	64.3	
24/04/2017	04:01:01	SA1702_ENV06	Vid				657889.94	8564727.53	657902.12	8564740.05	17.5	
24/04/2017	06:27:28	SA1702_ENV07	Vid				654237.87	8562349.02	654189.32	8562374.58	54.9	
24/04/2017	06:59:10	SA1702_ENV07	Vid				654463.56	8562215.44	654475.98	8562207.63	14.7	
24/04/2017		SA1702_ENV09	Still	SA1702_ENV	NO FIX		629648.25	8554221.82				
24/04/2017	12:08:26	SA1702_ENV09	Still	SA1702_ENV	601	198.3	629648.25	8554221.82	629706.50	8554196.05	63.7	
24/04/2017	12:08:47	SA1702_ENV09	Still	SA1702_ENV	602	198.1	629648.25	8554221.82	629702.24	8554197.24	59.3	
24/04/2017	12:09:00	SA1702_ENV09	Still	SA1702_ENV	603	198.6	629648.25	8554221.82	629700.03	8554197.44	57.2	
24/04/2017	12:09:57	SA1702_ENV09	Still	SA1702_ENV	604	198.0	629648.25	8554221.82	629689.10	8554201.47	45.6	
24/04/2017	12:10:19	SA1702_ENV09	Still	SA1702_ENV	605	197.5	629648.25	8554221.82	629685.08	8554202.92	41.4	
24/04/2017	12:11:18	SA1702_ENV09	Still	SA1702_ENV	606	197.1	629648.25	8554221.82	629675.50	8554206.61	31.2	
24/04/2017	12:12:08	SA1702_ENV09	Still	SA1702_ENV	607	197.4	629648.25	8554221.82	629667.39	8554208.55	23.3	
24/04/2017	12:12:33	SA1702_ENV09	Still	SA1702_ENV	608	199.0	629648.25	8554221.82	629662.94	8554209.55	19.1	
24/04/2017	12:42:49	SA1702_ENV09A	Still	SA1702_ENV	609	199.1	629648.25	8554221.82	629464.80	8554273.87	190.7	
24/04/2017	12:45:15	SA1702_ENV09A	Still	SA1702_ENV	610	199.4	629648.25	8554221.82	629489.96	8554264.14	163.8	
24/04/2017	12:45:32	SA1702_ENV09A	Still	NO STILL	611	197.9	629648.25	8554221.82	629492.78	8554263.19	160.9	
24/04/2017	12:46:22	SA1702_ENV09A	Still	SA1702_ENV	612	199.0	629648.25	8554221.82	629501.37	8554260.97	152.0	
24/04/2017	12:47:54	SA1702_ENV09A	Still	SA1702_ENV	613	198.9	629648.25	8554221.82	629517.08	8554255.37	135.4	
24/04/2017	12:48:43	SA1702_ENV09A	Still	SA1702_ENV	614	198.5	629648.25	8554221.82	629528.85	8554251.48	123.0	
24/04/2017	12:49:48	SA1702_ENV09A	Still	SA1702_ENV	615	198.9	629648.25	8554221.82	629543.11	8554248.52	108.5	
24/04/2017	12:50:34	SA1702_ENV09A	Still	SA1702_ENV	616	198.8	629648.25	8554221.82	629552.04	8554244.34	98.8	
24/04/2017	12:51:19	SA1702_ENV09A	Still	SA1702_ENV	618	198.5	629648.25	8554221.82	629559.94	8554241.70	90.5	
24/04/2017	12:52:07	SA1702_ENV09A	Still	SA1702_ENV	619	198.1	629648.25	8554221.82	629568.78	8554238.06	81.1	
24/04/2017	12:52:37	SA1702_ENV09A	Still	SA1702_ENV	620	197.5	629648.25	8554221.82	629574.36	8554234.78	75.0	

GDA94, MGA94, UTM Zone 51, CM123 °East												
Date	Time [UTC]	Transect	Type	ID	Fix No.	Water Depth [m]	Proposed Location		Actual Location		Offset [m]	Notes
							Easting [m]	Northing [m]	Easting [m]	Northing [m]		
24/04/2017	12:53:04	SA1702_ENV09A	Still	SA1702_ENV	621	199.0	629648.25	8554221.82	629578.84	8554233.58	70.4	
24/04/2017	12:53:12	SA1702_ENV09A	Still	SA1702_ENV	622	197.8	629648.25	8554221.82	629580.23	8554233.28	69.0	
24/04/2017	12:53:20	SA1702_ENV09A	Still	SA1702_ENV	623	198.7	629648.25	8554221.82	629581.93	8554232.84	67.2	
24/04/2017	12:54:24	SA1702_ENV09A	Still	SA1702_ENV	624	198.8	629648.25	8554221.82	629593.28	8554231.34	55.8	
24/04/2017	12:54:47	SA1702_ENV09A	Still	SA1702_ENV	625	197.5	629648.25	8554221.82	629598.38	8554229.58	50.5	
24/04/2017	12:54:53	SA1702_ENV09A	Still	SA1702_ENV	626	197.8	629648.25	8554221.82	629599.80	8554229.33	49.0	
24/04/2017	12:55:07	SA1702_ENV09A	Still	SA1702_ENV	627	198.1	629648.25	8554221.82	629602.58	8554228.52	46.2	
24/04/2017	12:55:34	SA1702_ENV09A	Still	SA1702_ENV	628	198.6	629648.25	8554221.82	629609.73	8554227.05	38.9	
24/04/2017	12:56:37	SA1702_ENV09A	Still	SA1702_ENV	629	198.4	629648.25	8554221.82	629623.50	8554223.05	24.8	
24/04/2017	12:57:44	SA1702_ENV09A	Still	SA1702_ENV	630	198.6	629648.25	8554221.82	629637.57	8554220.91	10.7	
24/04/2017	12:58:07	SA1702_ENV09A	Still	SA1702_ENV	631	198.5	629648.25	8554221.82	629641.76	8554219.78	6.8	
24/04/2017	12:58:39	SA1702_ENV09A	Still	SA1702_ENV	632	198.6	629648.25	8554221.82	629648.46	8554218.82	3.0	
24/04/2017	12:58:46	SA1702_ENV09A	Still	SA1702_ENV	633	197.8	629648.25	8554221.82	629649.97	8554218.71	3.6	
24/04/2017	12:59:16	SA1702_ENV09A	Still	SA1702_ENV	634	199.5	629648.25	8554221.82	629656.58	8554218.59	8.9	
24/04/2017	22:33:00	SA1702_ENV11	Still	SA1702_ENV	701	214.0	604623.81	8540007.26	604634.27	8540046.13	40.3	
24/04/2017	22:33:33	SA1702_ENV11	Still	SA1702_ENV	702	215.4	604623.81	8540007.26	604630.92	8540041.00	34.5	
24/04/2017	22:34:30	SA1702_ENV11	Still	SA1702_ENV	703	214.9	604623.81	8540007.26	604625.36	8540032.57	25.4	
24/04/2017	22:34:55	SA1702_ENV11	Still	SA1702_ENV	704	215.1	604623.81	8540007.26	604624.43	8540029.33	22.1	
24/04/2017	22:35:49	SA1702_ENV11	Still	SA1702_ENV	705	215.3	604623.81	8540007.26	604622.98	8540022.03	14.8	
24/04/2017	22:36:11	SA1702_ENV11	Still	SA1702_ENV	706	213.6	604623.81	8540007.26	604623.26	8540019.07	11.8	
24/04/2017	22:37:07	SA1702_ENV11	Still	SA1702_ENV	707	213.4	604623.81	8540007.26	604621.54	8540010.90	4.3	
24/04/2017	22:37:59	SA1702_ENV11	Still	SA1702_ENV	708	211.1	604623.81	8540007.26	604620.40	8540002.25	6.1	
24/04/2017	22:39:03	SA1702_ENV11	Still	SA1702_ENV	709	213.6	604623.81	8540007.26	604617.60	8539991.43	17.0	
24/04/2017	22:39:10	SA1702_ENV11	Still	SA1702_ENV	710	212.1	604623.81	8540007.26	604617.28	8539990.32	18.2	
24/04/2017	22:39:50	SA1702_ENV11	Still	SA1702_ENV	711	214.5	604623.81	8540007.26	604614.56	8539982.71	26.2	
24/04/2017	22:40:22	SA1702_ENV11	Still	SA1702_ENV	712	215.1	604623.81	8540007.26	604611.69	8539978.29	31.4	
24/04/2017	22:41:18	SA1702_ENV11	Still	SA1702_ENV	713	213.1	604623.81	8540007.26	604609.39	8539967.83	42.0	

GDA94, MGA94, UTM Zone 51, CM123 °East												
Date	Time [UTC]	Transect	Type	ID	Fix No.	Water Depth [m]	Proposed Location		Actual Location		Offset [m]	Notes
							Easting [m]	Northing [m]	Easting [m]	Northing [m]		
24/04/2017	22:41:30	SA1702_ENV11	Still	SA1702_ENV	714	212.6	604623.81	8540007.26	604609.21	8539964.78	44.9	
24/04/2017	22:42:52	SA1702_ENV11	Still	SA1702_ENV	715	213.4	604623.81	8540007.26	604604.85	8539951.34	59.1	
24/04/2017	22:43:17	SA1702_ENV11	Still	SA1702_ENV	716	212.4	604623.81	8540007.26	604603.16	8539946.93	63.8	
24/04/2017	22:44:00	SA1702_ENV11	Still	SA1702_ENV	717	212.8	604623.81	8540007.26	604599.47	8539941.01	70.6	
24/04/2017	22:44:53	SA1702_ENV11	Still	SA1702_ENV	718	211.9	604623.81	8540007.26	604595.37	8539933.58	79.0	
24/04/2017	22:45:35	SA1702_ENV11	Still	SA1702_ENV	719	212.2	604623.81	8540007.26	604592.24	8539926.48	86.7	
24/04/2017	22:46:32	SA1702_ENV11	Still	SA1702_ENV	720	214.0	604623.81	8540007.26	604590.25	8539915.33	97.9	
24/04/2017	22:47:26	SA1702_ENV11	Still	SA1702_ENV	721	213.4	604623.81	8540007.26	604586.57	8539907.29	106.7	
24/04/2017	22:48:04	SA1702_ENV11	Still	SA1702_ENV	722	213.6	604623.81	8540007.26	604583.89	8539901.98	112.6	
24/04/2017	22:49:30	SA1702_ENV11	Still	SA1702_ENV	723	214.2	604623.81	8540007.26	604577.34	8539888.24	127.8	
24/04/2017	22:49:48	SA1702_ENV11	Still	SA1702_ENV	724	214.1	604623.81	8540007.26	604575.55	8539884.65	131.8	
24/04/2017	22:50:37	SA1702_ENV11	Still	SA1702_ENV	725	214.4	604623.81	8540007.26	604572.72	8539876.80	140.1	
24/04/2017	22:50:50	SA1702_ENV11	Still	SA1702_ENV	726	214.5	604623.81	8540007.26	604572.02	8539875.12	141.9	
24/04/2017	22:51:01	SA1702_ENV11	Still	SA1702_ENV	727	214.7	604623.81	8540007.26	604571.01	8539873.46	143.8	
24/04/2017	22:51:23	SA1702_ENV11	Still	SA1702_ENV	728	214.6	604623.81	8540007.26	604570.27	8539869.47	147.8	
24/04/2017	22:51:34	SA1702_ENV11	Still	SA1702_ENV	729	214.8	604623.81	8540007.26	604569.48	8539867.88	149.6	
24/04/2017	22:51:49	SA1702_ENV11	Still	SA1702_ENV	730	215.2	604623.81	8540007.26	604569.20	8539865.30	152.1	
24/04/2017	22:52:07	SA1702_ENV11	Still	SA1702_ENV	731	214.6	604623.81	8540007.26	604568.39	8539861.62	155.8	
24/04/2017	22:52:25	SA1702_ENV11	Still	SA1702_ENV	732	214.4	604623.81	8540007.26	604567.93	8539857.98	159.4	
24/04/2017	22:53:06	SA1702_ENV11	Still	SA1702_ENV	733	214.7	604623.81	8540007.26	604565.22	8539851.82	166.1	
24/04/2017	22:53:33	SA1702_ENV11	Still	SA1702_ENV	734	213.6	604623.81	8540007.26	604563.03	8539846.94	171.5	
24/04/2017	22:54:08	SA1702_ENV11	Still	SA1702_ENV	735	214.2	604623.81	8540007.26	604560.22	8539841.35	177.7	
25/04/2017	00:49:22	SA1702_ENV12	Still	SA1702_ENV	801	204.1	602414.35	8537228.10	602452.22	8537279.87	64.1	
25/04/2017	00:50:46	SA1702_ENV12	Still	SA1702_ENV	802	204.5	602414.35	8537228.10	602446.91	8537270.51	53.5	
25/04/2017	00:51:22	SA1702_ENV12	Still	SA1702_ENV	803	203.8	602414.35	8537228.10	602442.51	8537264.49	46.0	
25/04/2017	00:52:12	SA1702_ENV12	Still	SA1702_ENV	804	204.9	602414.35	8537228.10	602436.72	8537255.86	35.7	
25/04/2017	00:53:09	SA1702_ENV12	Still	SA1702_ENV	805	204.4	602414.35	8537228.10	602431.30	8537248.19	26.3	

GDA94, MGA94, UTM Zone 51, CM123 °East												
Date	Time [UTC]	Transect	Type	ID	Fix No.	Water Depth [m]	Proposed Location		Actual Location		Offset [m]	Notes
							Easting [m]	Northing [m]	Easting [m]	Northing [m]		
25/04/2017	00:53:31	SA1702_ENV12	Still	SA1702_ENV	806	205.4	602414.35	8537228.10	602429.37	8537245.43	22.9	
25/04/2017	00:54:08	SA1702_ENV12	Still	SA1702_ENV	807	204.2	602414.35	8537228.10	602426.62	8537240.94	17.8	
25/04/2017	00:54:52	SA1702_ENV12	Still	SA1702_ENV	808	205.1	602414.35	8537228.10	602422.91	8537235.27	11.2	
25/04/2017	00:55:05	SA1702_ENV12	Still	SA1702_ENV	809	205.0	602414.35	8537228.10	602421.70	8537233.03	8.9	
25/04/2017	00:55:55	SA1702_ENV12	Still	SA1702_ENV	810	204.6	602414.35	8537228.10	602417.02	8537225.70	3.6	
25/04/2017	00:56:07	SA1702_ENV12	Still	SA1702_ENV	811	204.5	602414.35	8537228.10	602415.80	8537223.78	4.6	
25/04/2017	00:57:02	SA1702_ENV12	Still	SA1702_ENV	812	205.1	602414.35	8537228.10	602409.83	8537214.99	13.9	
25/04/2017	00:57:21	SA1702_ENV12	Still	SA1702_ENV	813	204.4	602414.35	8537228.10	602407.98	8537212.00	17.3	
25/04/2017	00:57:33	SA1702_ENV12	Still	SA1702_ENV	814	205.2	602414.35	8537228.10	602406.81	8537209.84	19.7	
25/04/2017	00:57:49	SA1702_ENV12	Still	SA1702_ENV	815	204.1	602414.35	8537228.10	602404.90	8537207.36	22.8	
25/04/2017	00:58:23	SA1702_ENV12	Still	SA1702_ENV	816	205.6	602414.35	8537228.10	602401.56	8537201.69	29.3	
25/04/2017	00:58:50	SA1702_ENV12	Still	SA1702_ENV	817	206.4	602414.35	8537228.10	602398.95	8537197.62	34.1	
25/04/2017	00:59:37	SA1702_ENV12	Still	SA1702_ENV	818	206.2	602414.35	8537228.10	602394.83	8537190.42	42.4	
25/04/2017	00:59:52	SA1702_ENV12	Still	SA1702_ENV	819	204.7	602414.35	8537228.10	602393.38	8537188.10	45.2	
25/04/2017	01:00:26	SA1702_ENV12	Still	SA1702_ENV	820	205.7	602414.35	8537228.10	602390.27	8537183.51	50.7	
25/04/2017	01:01:00	SA1702_ENV12	Still	SA1702_ENV	821	204.8	602414.35	8537228.10	602387.55	8537178.75	56.2	
25/04/2017	01:01:31	SA1702_ENV12	Still	SA1702_ENV	822	205.7	602414.35	8537228.10	602384.79	8537174.57	61.1	
25/04/2017	01:02:04	SA1702_ENV12	Still	SA1702_ENV	823	203.9	602414.35	8537228.10	602381.47	8537169.69	67.0	
25/04/2017	01:02:57	SA1702_ENV12	Still	SA1702_ENV	824	205.1	602414.35	8537228.10	602375.86	8537160.59	77.7	
25/04/2017	01:03:46	SA1702_ENV12	Still	SA1702_ENV	825	205.2	602414.35	8537228.10	602370.25	8537152.35	87.6	
25/04/2017	01:04:32	SA1702_ENV12	Still	SA1702_ENV	826	205.3	602414.35	8537228.10	602365.15	8537145.24	96.4	
25/04/2017	01:05:11	SA1702_ENV12	Still	SA1702_ENV	827	205.5	602414.35	8537228.10	602360.64	8537138.99	104.0	
25/04/2017	01:06:00	SA1702_ENV12	Still	SA1702_ENV	828	205.5	602414.35	8537228.10	602355.80	8537132.65	112.0	
25/04/2017	01:06:22	SA1702_ENV12	Still	SA1702_ENV	829	205.7	602414.35	8537228.10	602353.61	8537129.93	115.4	
25/04/2017	01:06:52	SA1702_ENV12	Still	SA1702_ENV	830	205.8	602414.35	8537228.10	602351.07	8537125.91	120.2	
25/04/2017	01:07:11	SA1702_ENV12	Still	SA1702_ENV	831	206.3	602414.35	8537228.10	602349.81	8537123.22	123.1	
25/04/2017	01:07:36	SA1702_ENV12	Still	SA1702_ENV	832	205.2	602414.35	8537228.10	602347.59	8537119.47	127.5	

GDA94, MGA94, UTM Zone 51, CM123 °East												
Date	Time [UTC]	Transect	Type	ID	Fix No.	Water Depth [m]	Proposed Location		Actual Location		Offset [m]	Notes
							Easting [m]	Northing [m]	Easting [m]	Northing [m]		
25/04/2017	01:08:23	SA1702_ENV12	Still	SA1702_ENV	833	205.8	602414.35	8537228.10	602344.02	8537112.50	135.3	
25/04/2017	01:09:07	SA1702_ENV12	Still	SA1702_ENV	834	206.7	602414.35	8537228.10	602340.02	8537105.87	143.1	
25/04/2017	01:09:48	SA1702_ENV12	Still	SA1702_ENV	835	206.4	602414.35	8537228.10	602336.42	8537099.52	150.3	
25/04/2017	01:10:22	SA1702_ENV12	Still	SA1702_ENV	836	205.2	602414.35	8537228.10	602333.30	8537094.08	156.6	
25/04/2017	01:10:55	SA1702_ENV12	Still	SA1702_ENV	837	204.3	602414.35	8537228.10	602330.03	8537088.96	162.7	
25/04/2017	01:11:43	SA1702_ENV12	Still	SA1702_ENV	838	205.4	602414.35	8537228.10	602325.68	8537081.58	171.3	
25/04/2017	01:12:31	SA1702_ENV12	Still	SA1702_ENV	839	206.0	602414.35	8537228.10	602321.35	8537073.99	180.0	
25/04/2017	01:12:39	SA1702_ENV12	Still	SA1702_ENV	840	205.8	602414.35	8537228.10	602320.53	8537072.63	181.6	
25/04/2017	01:13:39	SA1702_ENV12	Still	SA1702_ENV	841	206.4	602414.35	8537228.10	602315.51	8537063.57	191.9	
25/04/2017	01:14:23	SA1702_ENV12	Still	SA1702_ENV	842	207.4	602414.35	8537228.10	602310.48	8537055.42	201.5	
25/04/2017	01:15:02	SA1702_ENV12	Still	SA1702_ENV	843	205.8	602414.35	8537228.10	602305.96	8537048.94	209.4	
25/04/2017	01:15:30	SA1702_ENV12	Still	SA1702_ENV	844	205.9	602414.35	8537228.10	602302.47	8537044.77	214.8	
25/04/2017	01:16:15	SA1702_ENV12	Still	SA1702_ENV	845	206.1	602414.35	8537228.10	602297.79	8537038.97	222.2	
25/04/2017	01:16:48	SA1702_ENV12	Still	SA1702_ENV	846	206.1	602414.35	8537228.10	602294.48	8537034.44	227.8	
25/04/2017	01:17:38	SA1702_ENV12	Still	SA1702_ENV	847	206.2	602414.35	8537228.10	602290.36	8537027.51	235.8	
25/04/2017	01:17:50	SA1702_ENV12	Still	SA1702_ENV	848	206.6	602414.35	8537228.10	602289.28	8537025.58	238.0	
25/04/2017	01:18:35	SA1702_ENV12	Still	SA1702_ENV	849	206.3	602414.35	8537228.10	602285.08	8537018.01	246.7	
25/04/2017	04:16:25	SA1702_ENV13	Still	SA1702_ENV	901	207.7	597069.10	8533025.79	597038.42	8533093.72	74.5	
25/04/2017	04:17:10	SA1702_ENV13	Still	SA1702_ENV	902	205.5	597069.10	8533025.79	597037.92	8533086.86	68.6	
25/04/2017	04:17:56	SA1702_ENV13	Still	SA1702_ENV	903	205.4	597069.10	8533025.79	597037.62	8533079.92	62.6	
25/04/2017	04:19:27	SA1702_ENV13	Still	SA1702_ENV	904	205.8	597069.10	8533025.79	597039.49	8533069.06	52.4	
25/04/2017	04:21:07	SA1702_ENV13	Still	SA1702_ENV	905	204.7	597069.10	8533025.79	597040.37	8533054.94	40.9	
25/04/2017	04:22:00	SA1702_ENV13	Still	SA1702_ENV	906	204.5	597069.10	8533025.79	597043.16	8533044.50	32.0	
25/04/2017	04:23:39	SA1702_ENV13	Still	SA1702_ENV	907	204.5	597069.10	8533025.79	597047.05	8533025.31	22.1	
25/04/2017	04:24:46	SA1702_ENV13	Still	SA1702_ENV	908	205.4	597069.10	8533025.79	597048.49	8533014.06	23.7	
25/04/2017	04:25:42	SA1702_ENV13	Still	SA1702_ENV	909	204.3	597069.10	8533025.79	597049.10	8533004.43	29.3	
25/04/2017	04:26:19	SA1702_ENV13	Still	SA1702_ENV	910	204.2	597069.10	8533025.79	597049.96	8532998.23	33.6	

GDA94, MGA94, UTM Zone 51, CM123 °East												
Date	Time [UTC]	Transect	Type	ID	Fix No.	Water Depth [m]	Proposed Location		Actual Location		Offset [m]	Notes
							Easting [m]	Northing [m]	Easting [m]	Northing [m]		
25/04/2017	04:27:05	SA1702_ENV13	Still	SA1702_ENV	911	202.7	597069.10	8533025.79	597051.15	8532990.93	39.2	
25/04/2017	04:28:42	SA1702_ENV13	Still	SA1702_ENV	912	204.5	597069.10	8533025.79	597053.55	8532976.00	52.2	
25/04/2017	04:29:30	SA1702_ENV13	Still	SA1702_ENV	913	204.5	597069.10	8533025.79	597055.76	8532967.28	60.0	
25/04/2017	04:29:47	SA1702_ENV13	Still	SA1702_ENV	914	204.2	597069.10	8533025.79	597057.20	8532963.53	63.4	
25/04/2017	04:30:43	SA1702_ENV13	Still	SA1702_ENV	915	204.5	597069.10	8533025.79	597060.91	8532952.29	74.0	
25/04/2017	04:31:08	SA1702_ENV13	Still	SA1702_ENV	916	204.7	597069.10	8533025.79	597062.07	8532948.12	78.0	
25/04/2017	04:31:31	SA1702_ENV13	Still	SA1702_ENV	917	204.4	597069.10	8533025.79	597062.92	8532944.16	81.9	
25/04/2017	04:31:50	SA1702_ENV13	Still	SA1702_ENV	918	204.0	597069.10	8533025.79	597063.19	8532940.69	85.3	
25/04/2017	04:32:24	SA1702_ENV13	Still	SA1702_ENV	919	204.3	597069.10	8533025.79	597065.12	8532935.65	90.2	
25/04/2017	04:33:02	SA1702_ENV13	Still	SA1702_ENV	920	203.9	597069.10	8533025.79	597067.02	8532929.07	96.7	
25/04/2017	04:33:36	SA1702_ENV13	Still	SA1702_ENV	921	203.5	597069.10	8533025.79	597068.35	8532923.18	102.6	
25/04/2017	04:34:41	SA1702_ENV13	Still	SA1702_ENV	922	203.0	597069.10	8533025.79	597071.84	8532912.62	113.2	
25/04/2017	04:35:32	SA1702_ENV13	Still	SA1702_ENV	923	202.5	597069.10	8533025.79	597073.70	8532905.03	120.9	
25/04/2017	04:35:49	SA1702_ENV13	Still	SA1702_ENV	924	202.8	597069.10	8533025.79	597075.14	8532902.12	123.8	
25/04/2017	04:37:51	SA1702_ENV13	Still	SA1702_ENV	925	202.7	597069.10	8533025.79	597084.72	8532890.72	136.0	
25/04/2017	04:39:15	SA1702_ENV13	Still	SA1702_ENV	926	203.3	597069.10	8533025.79	597093.85	8532888.70	139.3	
25/04/2017	04:40:18	SA1702_ENV13	Still	SA1702_ENV	927	202.8	597069.10	8533025.79	597097.07	8532879.77	148.7	
25/04/2017	04:41:26	SA1702_ENV13	Still	SA1702_ENV	928	203.5	597069.10	8533025.79	597101.73	8532869.41	159.7	
25/04/2017	04:42:32	SA1702_ENV13	Still	SA1702_ENV	929	204.5	597069.10	8533025.79	597105.85	8532859.40	170.4	
25/04/2017	04:43:03	SA1702_ENV13	Still	SA1702_ENV	930	205.8	597069.10	8533025.79	597108.41	8532854.36	175.9	
25/04/2017	04:43:53	SA1702_ENV13	Still	SA1702_ENV	931	206.4	597069.10	8533025.79	597111.89	8532844.49	186.3	
25/04/2017	04:44:42	SA1702_ENV13	Still	SA1702_ENV	932	205.2	597069.10	8533025.79	597114.72	8532835.56	195.6	
25/04/2017	04:45:26	SA1702_ENV13	Still	SA1702_ENV	933	204.4	597069.10	8533025.79	597116.40	8532827.32	204.0	
25/04/2017	09:15:18	SA1702_ENV14	Still	SA1702_ENV	1001	209.1	585583.41	8524299.65	585599.53	8524334.59	38.5	
25/04/2017	09:16:18	SA1702_ENV14	Still	SA1702_ENV	1002	210.2	585583.41	8524299.65	585599.17	8524327.21	31.7	
25/04/2017	09:17:08	SA1702_ENV14	Still	SA1702_ENV	1003	209.5	585583.41	8524299.65	585597.04	8524322.95	27.0	
25/04/2017	09:18:22	SA1702_ENV14	Still	SA1702_ENV	1004	210.2	585583.41	8524299.65	585591.51	8524318.09	20.1	

GDA94, MGA94, UTM Zone 51, CM123 °East												
Date	Time [UTC]	Transect	Type	ID	Fix No.	Water Depth [m]	Proposed Location		Actual Location		Offset [m]	Notes
							Easting [m]	Northing [m]	Easting [m]	Northing [m]		
25/04/2017	09:18:38	SA1702_ENV14	Still	SA1702_ENV	1005	208.8	585583.41	8524299.65	585591.06	8524316.62	18.6	
25/04/2017	09:19:51	SA1702_ENV14	Still	SA1702_ENV	1006	209.7	585583.41	8524299.65	585587.22	8524306.87	8.2	
25/04/2017	09:20:21	SA1702_ENV14	Still	SA1702_ENV	1007	209.3	585583.41	8524299.65	585585.07	8524302.97	3.7	
25/04/2017	09:21:00	SA1702_ENV14	Still	SA1702_ENV	1008	210.3	585583.41	8524299.65	585582.97	8524297.51	2.2	
25/04/2017	09:22:14	SA1702_ENV14	Still	SA1702_ENV	1009	210.0	585583.41	8524299.65	585579.24	8524289.21	11.2	
25/04/2017	09:22:52	SA1702_ENV14	Still	SA1702_ENV	1010	211.2	585583.41	8524299.65	585577.71	8524282.94	17.7	
25/04/2017	09:23:06	SA1702_ENV14	Still	SA1702_ENV	1011	211.6	585583.41	8524299.65	585576.68	8524281.35	19.5	
25/04/2017	09:23:16	SA1702_ENV14	Still	SA1702_ENV	1012	211.4	585583.41	8524299.65	585576.28	8524279.80	21.1	
25/04/2017	09:23:36	SA1702_ENV14	Still	SA1702_ENV	1013	212.1	585583.41	8524299.65	585576.02	8524276.03	24.7	
25/04/2017	09:23:46	SA1702_ENV14	Still	SA1702_ENV	1014	211.5	585583.41	8524299.65	585575.24	8524274.48	26.5	
25/04/2017	09:24:08	SA1702_ENV14	Still	SA1702_ENV	1015	212.1	585583.41	8524299.65	585574.51	8524270.64	30.3	
25/04/2017	09:24:30	SA1702_ENV14	Still	SA1702_ENV	1016	210.8	585583.41	8524299.65	585574.57	8524267.28	33.6	
25/04/2017	09:25:02	SA1702_ENV14	Still	SA1702_ENV	1017	208.7	585583.41	8524299.65	585574.46	8524260.18	40.5	
25/04/2017	09:26:00	SA1702_ENV14	Still	SA1702_ENV	1018	208.9	585583.41	8524299.65	585571.71	8524249.86	51.2	
25/04/2017	09:27:22	SA1702_ENV14	Still	SA1702_ENV	1019	209.7	585583.41	8524299.65	585569.44	8524237.37	63.8	
25/04/2017	09:29:31	SA1702_ENV14	Still	SA1702_ENV	1020	211.2	585583.41	8524299.65	585566.35	8524220.99	80.5	
25/04/2017	09:30:22	SA1702_ENV14	Still	SA1702_ENV	1021	212.7	585583.41	8524299.65	585563.97	8524214.21	87.6	
25/04/2017	09:31:17	SA1702_ENV14	Still	SA1702_ENV	1022	210.1	585583.41	8524299.65	585562.39	8524203.71	98.2	
25/04/2017	09:31:41	SA1702_ENV14	Still	SA1702_ENV	1023	209.3	585583.41	8524299.65	585561.50	8524198.68	103.3	
25/04/2017	09:32:16	SA1702_ENV14	Still	SA1702_ENV	1024	209.1	585583.41	8524299.65	585559.87	8524191.67	110.5	
25/04/2017	09:33:07	SA1702_ENV14	Still	SA1702_ENV	1025	210.1	585583.41	8524299.65	585557.11	8524182.87	119.7	
25/04/2017	09:33:30	SA1702_ENV14	Still	SA1702_ENV	1026	210.0	585583.41	8524299.65	585555.78	8524178.85	123.9	
25/04/2017	09:34:06	SA1702_ENV14	Still	SA1702_ENV	1027	210.8	585583.41	8524299.65	585554.14	8524173.29	129.7	
25/04/2017	09:34:45	SA1702_ENV14	Still	SA1702_ENV	1028	209.7	585583.41	8524299.65	585552.44	8524166.81	136.4	
25/04/2017	13:10:05	SA1702_ENV15	Still	SA1702_ENV	1101	210.5	579249.33	8519395.76	579251.97	8519441.41	45.7	
25/04/2017	13:11:06	SA1702_ENV15	Still	SA1702_ENV	1102	211.3	579249.33	8519395.76	579254.29	8519429.56	34.2	
25/04/2017	13:11:43	SA1702_ENV15	Still	SA1702_ENV	1103	212.5	579249.33	8519395.76	579254.50	8519423.18	27.9	

GDA94, MGA94, UTM Zone 51, CM123 °East												
Date	Time [UTC]	Transect	Type	ID	Fix No.	Water Depth [m]	Proposed Location		Actual Location		Offset [m]	Notes
							Easting [m]	Northing [m]	Easting [m]	Northing [m]		
25/04/2017	13:12:28	SA1702_ENV15	Still	SA1702_ENV	1104	211.7	579249.33	8519395.76	579253.21	8519416.15	20.7	
25/04/2017	13:12:41	SA1702_ENV15	Still	SA1702_ENV	1105	211.5	579249.33	8519395.76	579253.29	8519413.97	18.6	
25/04/2017	13:12:54	SA1702_ENV15	Still	SA1702_ENV	1106	210.4	579249.33	8519395.76	579252.74	8519411.87	16.5	
25/04/2017	13:13:29	SA1702_ENV15	Still	SA1702_ENV	1107	210.9	579249.33	8519395.76	579252.95	8519408.92	13.6	
25/04/2017	13:14:01	SA1702_ENV15	Still	SA1702_ENV	1108	212.7	579249.33	8519395.76	579253.57	8519406.36	11.4	
25/04/2017	13:14:35	SA1702_ENV15	Still	SA1702_ENV	1109	212.6	579249.33	8519395.76	579253.89	8519400.28	6.4	
25/04/2017	13:14:41	SA1702_ENV15	Still	SA1702_ENV	1110	210.8	579249.33	8519395.76	579253.79	8519399.09	5.6	
25/04/2017	13:14:52	SA1702_ENV15	Still	SA1702_ENV	1111	211.3	579249.33	8519395.76	579253.69	8519397.05	4.5	
25/04/2017	13:15:02	SA1702_ENV15	Still	SA1702_ENV	1112	211.5	579249.33	8519395.76	579253.66	8519395.81	4.3	
25/04/2017	13:15:14	SA1702_ENV15	Still	SA1702_ENV	1113	211.7	579249.33	8519395.76	579253.70	8519393.53	4.9	
25/04/2017	13:15:24	SA1702_ENV15	Still	SA1702_ENV	1114	211.8	579249.33	8519395.76	579254.16	8519391.78	6.3	
25/04/2017	13:15:40	SA1702_ENV15	Still	SA1702_ENV	1115	211.5	579249.33	8519395.76	579255.06	8519388.96	8.9	
25/04/2017	13:15:57	SA1702_ENV15	Still	SA1702_ENV	1116	211.3	579249.33	8519395.76	579255.84	8519385.69	12.0	
25/04/2017	13:16:06	SA1702_ENV15	Still	SA1702_ENV	1117	212.7	579249.33	8519395.76	579256.43	8519383.62	14.1	
25/04/2017	13:16:22	SA1702_ENV15	Still	SA1702_ENV	1118	212.4	579249.33	8519395.76	579257.07	8519380.39	17.2	
25/04/2017	13:17:18	SA1702_ENV15	Still	SA1702_ENV	1119	213.8	579249.33	8519395.76	579258.64	8519372.87	24.7	
25/04/2017	13:18:01	SA1702_ENV15	Still	SA1702_ENV	1120	214.4	579249.33	8519395.76	579257.99	8519365.96	31.0	
25/04/2017	13:18:14	SA1702_ENV15	Still	SA1702_ENV	1121	214.5	579249.33	8519395.76	579258.68	8519363.65	33.4	
25/04/2017	13:19:18	SA1702_ENV15	Still	SA1702_ENV	1122	211.0	579249.33	8519395.76	579261.46	8519353.77	43.7	
25/04/2017	13:20:36	SA1702_ENV15	Still	SA1702_ENV	1123	211.2	579249.33	8519395.76	579267.36	8519336.85	61.6	
25/04/2017	13:21:11	SA1702_ENV15	Still	SA1702_ENV	1124	211.4	579249.33	8519395.76	579270.29	8519330.08	68.9	
25/04/2017	13:21:54	SA1702_ENV15	Still	SA1702_ENV	1125	210.7	579249.33	8519395.76	579272.66	8519321.29	78.0	
25/04/2017	13:22:38	SA1702_ENV15	Still	SA1702_ENV	1126	210.9	579249.33	8519395.76	579276.99	8519311.13	89.0	
25/04/2017	13:23:53	SA1702_ENV15	Still	SA1702_ENV	1127	211.5	579249.33	8519395.76	579283.40	8519293.87	107.4	
25/04/2017	13:24:40	SA1702_ENV15	Still	SA1702_ENV	1128	211.1	579249.33	8519395.76	579286.61	8519281.20	120.5	
25/04/2017	13:25:12	SA1702_ENV15	Still	SA1702_ENV	1129	210.5	579249.33	8519395.76	579289.55	8519274.71	127.6	
25/04/2017	13:25:54	SA1702_ENV15	Still	SA1702_ENV	1130	211.7	579249.33	8519395.76	579292.46	8519268.08	134.8	

GDA94, MGA94, UTM Zone 51, CM123 °East												
Date	Time [UTC]	Transect	Type	ID	Fix No.	Water Depth [m]	Proposed Location		Actual Location		Offset [m]	Notes
							Easting [m]	Northing [m]	Easting [m]	Northing [m]		
25/04/2017	13:26:30	SA1702_ENV15	Still	SA1702_ENV	1131	212.1	579249.33	8519395.76	579293.80	8519259.13	143.7	
25/04/2017	13:26:59	SA1702_ENV15	Still	SA1702_ENV	1132	211.5	579249.33	8519395.76	579296.69	8519252.95	150.5	
25/04/2017	13:28:41	SA1702_ENV15	Still	SA1702_ENV	1133	211.8	579249.33	8519395.76	579304.08	8519251.37	154.4	
25/04/2017	13:29:41	SA1702_ENV15	Still	SA1702_ENV	1134	211.0	579249.33	8519395.76	579305.40	8519246.14	159.8	
25/04/2017	13:30:24	SA1702_ENV15	Still	SA1702_ENV	1135	211.6	579249.33	8519395.76	579308.41	8519237.63	168.8	
25/04/2017	13:30:48	SA1702_ENV15	Still	SA1702_ENV	1136	211.5	579249.33	8519395.76	579310.70	8519231.72	175.1	
26/04/2017	00:44:04	SA1702_ENV18	Still	SA1702_ENV	1201	227.6	559546.59	8500658.78	559575.263	8500695.911	46.9	
26/04/2017	00:44:38	SA1702_ENV18	Still	SA1702_ENV	1202	228.3	559546.59	8500658.78	559572.408	8500692.719	42.6	
26/04/2017	00:45:32	SA1702_ENV18	Still	SA1702_ENV	1203	228.0	559546.59	8500658.78	559567.835	8500689.915	37.7	
26/04/2017	00:45:44	SA1702_ENV18	Still	SA1702_ENV	1204	227.7	559546.59	8500658.78	559567.06	8500689.007	36.5	
26/04/2017	00:46:18	SA1702_ENV18	Still	SA1702_ENV	1205	228.4	559546.59	8500658.78	559564.457	8500685.978	32.5	
26/04/2017	00:46:50	SA1702_ENV18	Still	SA1702_ENV	1206	228.0	559546.59	8500658.78	559562.221	8500683.414	29.2	
26/04/2017	00:47:14	SA1702_ENV18	Still	SA1702_ENV	1207	228.5	559546.59	8500658.78	559560.569	8500681.364	26.6	
26/04/2017	00:47:48	SA1702_ENV18	Still	SA1702_ENV	1208	227.8	559546.59	8500658.78	559558.216	8500678.717	23.1	
26/04/2017	00:48:00	SA1702_ENV18	Still	SA1702_ENV	1209	227.6	559546.59	8500658.78	559557.486	8500678.005	22.1	
26/04/2017	00:48:17	SA1702_ENV18	Still	SA1702_ENV	1210	228.8	559546.59	8500658.78	559556.17	8500676.885	20.5	
26/04/2017	00:48:35	SA1702_ENV18	Still	NO STILL	1211	227.6	559546.59	8500658.78	559554.742	8500675.992	19.0	
26/04/2017	00:48:55	SA1702_ENV18	Still	SA1702_ENV	1212	228.3	559546.59	8500658.78	559552.647	8500674.704	17.0	
26/04/2017	00:49:22	SA1702_ENV18	Still	SA1702_ENV	1213	228.1	559546.59	8500658.78	559550.232	8500672.513	14.2	
26/04/2017	00:50:04	SA1702_ENV18	Still	SA1702_ENV	1214	227.8	559546.59	8500658.78	559546.313	8500668.752	10.0	
26/04/2017	00:51:29	SA1702_ENV18	Still	SA1702_ENV	1215	228.3	559546.59	8500658.78	559539.551	8500661.366	7.5	
26/04/2017	00:52:46	SA1702_ENV18	Still	SA1702_ENV	1216	228.2	559546.59	8500658.78	559533.96	8500654.219	13.4	
26/04/2017	00:52:57	SA1702_ENV18	Still	SA1702_ENV	1217	228.0	559546.59	8500658.78	559533.022	8500653.287	14.6	
26/04/2017	00:53:29	SA1702_ENV18	Still	SA1702_ENV	1218	228.5	559546.59	8500658.78	559529.721	8500650.622	18.7	
26/04/2017	00:53:42	SA1702_ENV18	Still	SA1702_ENV	1219	228.2	559546.59	8500658.78	559528.315	8500649.01	20.7	
26/04/2017	00:54:24	SA1702_ENV18	Still	SA1702_ENV	1220	227.6	559546.59	8500658.78	559523.847	8500645.674	26.2	
26/04/2017	00:55:29	SA1702_ENV18	Still	SA1702_ENV	1221	228.0	559546.59	8500658.78	559517.536	8500640.147	34.5	

GDA94, MGA94, UTM Zone 51, CM123 °East												
Date	Time [UTC]	Transect	Type	ID	Fix No.	Water Depth [m]	Proposed Location		Actual Location		Offset [m]	Notes
							Easting [m]	Northing [m]	Easting [m]	Northing [m]		
26/04/2017	00:56:21	SA1702_ENV18	Still	SA1702_ENV	1222	226.5	559546.59	8500658.78	559511.888	8500635.191	42.0	
26/04/2017	00:56:36	SA1702_ENV18	Still	SA1702_ENV	1223	226.9	559546.59	8500658.78	559510.398	8500634.02	43.8	
26/04/2017	00:57:05	SA1702_ENV18	Still	SA1702_ENV	1224	227.2	559546.59	8500658.78	559507.409	8500630.735	48.2	
26/04/2017	00:57:28	SA1702_ENV18	Still	SA1702_ENV	1225	227.2	559546.59	8500658.78	559505.409	8500628.686	51.0	
26/04/2017	00:58:42	SA1702_ENV18	Still	SA1702_ENV	1226	226.2	559546.59	8500658.78	559496.412	8500620.797	62.9	
26/04/2017	00:59:05	SA1702_ENV18	Still	SA1702_ENV	1227	225.7	559546.59	8500658.78	559493.154	8500618.538	66.9	
26/04/2017	00:59:16	SA1702_ENV18	Still	SA1702_ENV	1228	225.1	559546.59	8500658.78	559491.865	8500617.827	68.3	
26/04/2017	00:59:26	SA1702_ENV18	Still	SA1702_ENV	1229	225.0	559546.59	8500658.78	559490.718	8500616.529	70.0	
26/04/2017	00:59:39	SA1702_ENV18	Still	SA1702_ENV	1230	224.2	559546.59	8500658.78	559489.22	8500615.157	72.1	
26/04/2017	00:59:49	SA1702_ENV18	Still	SA1702_ENV	1231	223.9	559546.59	8500658.78	559487.765	8500613.955	74.0	
26/04/2017	01:00:00	SA1702_ENV18	Still	SA1702_ENV	1232	223.4	559546.59	8500658.78	559486.099	8500612.707	76.0	
26/04/2017	01:00:16	SA1702_ENV18	Still	SA1702_ENV	1233	223.3	559546.59	8500658.78	559484.048	8500611.189	78.6	
26/04/2017	01:00:44	SA1702_ENV18	Still	SA1702_ENV	1234	222.9	559546.59	8500658.78	559480.844	8500609.247	82.3	
26/04/2017	01:00:44	SA1702_ENV18	Still	NO STILL	1235	222.9	559546.59	8500658.78	559480.844	8500609.247	82.3	
26/04/2017	01:01:00	SA1702_ENV18	Still	SA1702_ENV	1236	222.8	559546.59	8500658.78	559478.485	8500609.021	84.3	
26/04/2017	01:01:37	SA1702_ENV18	Still	SA1702_ENV	1237	222.0	559546.59	8500658.78	559473.778	8500607.365	89.1	
26/04/2017	01:02:03	SA1702_ENV18	Still	SA1702_ENV	1238	222.7	559546.59	8500658.78	559471.01	8500604.772	92.9	
26/04/2017	01:03:18	SA1702_ENV18	Still	SA1702_ENV	1239	222.7	559546.59	8500658.78	559462.644	8500597.835	103.7	
26/04/2017	01:03:47	SA1702_ENV18	Still	SA1702_ENV	1240	223.3	559546.59	8500658.78	559459.567	8500595.606	107.5	
26/04/2017	01:04:43	SA1702_ENV18	Still	SA1702_ENV	1241	224.0	559546.59	8500658.78	559453.761	8500591.335	114.7	
26/04/2017	01:04:52	SA1702_ENV18	Still	SA1702_ENV	1242	223.5	559546.59	8500658.78	559452.849	8500590.757	115.8	
26/04/2017	01:05:25	SA1702_ENV18	Still	SA1702_ENV	1243	224.7	559546.59	8500658.78	559448.637	8500587.534	121.1	
26/04/2017	01:05:51	SA1702_ENV18	Still	SA1702_ENV	1244	225.6	559546.59	8500658.78	559445.482	8500585.496	124.9	
26/04/2017	01:06:56	SA1702_ENV18	Still	SA1702_ENV	1245	226.2	559546.59	8500658.78	559438.28	8500581.51	133.0	
26/04/2017	01:07:43	SA1702_ENV18	Still	SA1702_ENV	1246	226.2	559546.59	8500658.78	559470.843	8500538.776	141.9	
26/04/2017	01:07:58	SA1702_ENV18	Still	SA1702_ENV	1247	226.3	559546.59	8500658.78	559431.729	8500577.952	140.4	
26/04/2017	01:08:40	SA1702_ENV18	Still	SA1702_ENV	1248	227.1	559546.59	8500658.78	559427.261	8500575.282	145.6	

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Date	Time [UTC]	Transect	Type	ID	Fix No.	Water Depth [m]	Proposed Location		Actual Location		Offset [m]	Notes
							Easting [m]	Northing [m]	Easting [m]	Northing [m]		
26/04/2017	01:09:13	SA1702_ENV18	Still	SA1702_ENV	1249	227.7	559546.59	8500658.78	559423.605	8500573.015	149.9	
26/04/2017	01:09:39	SA1702_ENV18	Still	SA1702_ENV	1250	227.8	559546.59	8500658.78	559420.813	8500570.905	153.4	
26/04/2017	01:10:21	SA1702_ENV18	Still	SA1702_ENV	1251	228.6	559546.59	8500658.78	559415.909	8500567.545	159.4	
26/04/2017	01:11:20	SA1702_ENV18	Still	SA1702_ENV	1252	229.0	559546.59	8500658.78	559409.648	8500562.984	167.1	
26/04/2017	01:11:58	SA1702_ENV18	Still	SA1702_ENV	1253	228.3	559546.59	8500658.78	559405.606	8500559.908	172.2	
26/04/2017	01:12:42	SA1702_ENV18	Still	SA1702_ENV	1254	228.9	559546.59	8500658.78	559400.567	8500555.209	179.0	
26/04/2017	02:11:19	SA1702_ENV19	Still	SA1702_ENV	1301	235.9	558524.61	8499087.33	558592.51	8499070.52	70.0	
26/04/2017	02:12:27	SA1702_ENV19	Still	SA1702_ENV	1302	235.5	558524.61	8499087.33	558589.07	8499070.69	66.6	
26/04/2017	02:13:29	SA1702_ENV19	Still	SA1702_ENV	1303	237.0	558524.61	8499087.33	558579.83	8499072.97	57.1	
26/04/2017	02:13:52	SA1702_ENV19	Still	SA1702_ENV	1304	236.4	558524.61	8499087.33	558575.75	8499074.41	52.7	
26/04/2017	02:14:45	SA1702_ENV19	Still	SA1702_ENV	1305	236.8	558524.61	8499087.33	558566.51	8499076.76	43.2	
26/04/2017	02:15:44	SA1702_ENV19	Still	SA1702_ENV	1306	237.4	558524.61	8499087.33	558554.86	8499080.13	31.1	
26/04/2017	02:16:16	SA1702_ENV19	Still	SA1702_ENV	1307	238.0	558524.61	8499087.33	558548.86	8499081.83	24.9	
26/04/2017	02:16:44	SA1702_ENV19	Still	SA1702_ENV	1308	237.6	558524.61	8499087.33	558543.92	8499083.29	19.7	
26/04/2017	02:17:23	SA1702_ENV19	Still	SA1702_ENV	1309	237.5	558524.61	8499087.33	558535.85	8499085.65	11.4	
26/04/2017	02:18:32	SA1702_ENV19	Still	SA1702_ENV	1310	237.8	558524.61	8499087.33	558520.89	8499089.45	4.3	
26/04/2017	02:19:29	SA1702_ENV19	Still	SA1702_ENV	1311	238.6	558524.61	8499087.33	558508.04	8499092.42	17.3	
26/04/2017	02:20:31	SA1702_ENV19	Still	SA1702_ENV	1312	237.7	558524.61	8499087.33	558494.01	8499096.24	31.9	
26/04/2017	02:20:47	SA1702_ENV19	Still	SA1702_ENV	1313	237.7	558524.61	8499087.33	558490.65	8499096.89	35.3	
26/04/2017	02:21:17	SA1702_ENV19	Still	SA1702_ENV	1314	237.5	558524.61	8499087.33	558484.01	8499098.12	42.0	
26/04/2017	02:21:28	SA1702_ENV19	Still	SA1702_ENV	1315	236.6	558524.61	8499087.33	558481.38	8499098.88	44.7	
26/04/2017	02:21:59	SA1702_ENV19	Still	SA1702_ENV	1316	234.4	558524.61	8499087.33	558474.29	8499101.07	52.2	
26/04/2017	02:22:10	SA1702_ENV19	Still	SA1702_ENV	1317	233.8	558524.61	8499087.33	558471.79	8499101.94	54.8	
26/04/2017	02:22:31	SA1702_ENV19	Still	SA1702_ENV	1318	233.3	558524.61	8499087.33	558467.27	8499102.82	59.4	
26/04/2017	02:22:57	SA1702_ENV19	Still	SA1702_ENV	1319	231.6	558524.61	8499087.33	558462.01	8499104.41	64.9	
26/04/2017	02:23:09	SA1702_ENV19	Still	SA1702_ENV	1320	230.3	558524.61	8499087.33	558459.54	8499104.72	67.4	
26/04/2017	02:23:41	SA1702_ENV19	Still	NO STILL	1321	230.0	558524.61	8499087.33	558454.29	8499107.27	73.1	

GDA94, MGA94, UTM Zone 51, CM123 °East												
Date	Time [UTC]	Transect	Type	ID	Fix No.	Water Depth [m]	Proposed Location		Actual Location		Offset [m]	Notes
							Easting [m]	Northing [m]	Easting [m]	Northing [m]		
26/04/2017	02:24:32	SA1702_ENV19	Still	SA1702_ENV	1322	229.3	558524.61	8499087.33	558443.54	8499109.41	84.0	
26/04/2017	02:24:43	SA1702_ENV19	Still	SA1702_ENV	1323	231.2	558524.61	8499087.33	558440.82	8499110.06	86.8	
26/04/2017	02:24:53	SA1702_ENV19	Still	SA1702_ENV	1324	232.3	558524.61	8499087.33	558438.49	8499110.40	89.2	
26/04/2017	02:25:09	SA1702_ENV19	Still	SA1702_ENV	1325	234.7	558524.61	8499087.33	558434.26	8499111.44	93.5	
26/04/2017	02:25:30	SA1702_ENV19	Still	SA1702_ENV	1326	237.8	558524.61	8499087.33	558428.97	8499112.57	98.9	
26/04/2017	02:25:47	SA1702_ENV19	Still	SA1702_ENV	1327	239.2	558524.61	8499087.33	558424.44	8499113.50	103.5	
26/04/2017	02:26:13	SA1702_ENV19	Still	SA1702_ENV	1328	239.5	558524.61	8499087.33	558417.55	8499115.22	110.6	
26/04/2017	02:26:43	SA1702_ENV19	Still	SA1702_ENV	1329	240.0	558524.61	8499087.33	558409.91	8499116.74	118.4	
26/04/2017	02:26:58	SA1702_ENV19	Still	SA1702_ENV	1330	240.7	558524.61	8499087.33	558406.50	8499117.46	121.9	
26/04/2017	02:27:21	SA1702_ENV19	Still	SA1702_ENV	1331	241.2	558524.61	8499087.33	558401.56	8499118.72	127.0	
26/04/2017	02:27:48	SA1702_ENV19	Still	SA1702_ENV	1332	241.0	558524.61	8499087.33	558395.72	8499120.35	133.0	
26/04/2017	02:28:10	SA1702_ENV19	Still	SA1702_ENV	1333	241.5	558524.61	8499087.33	558390.25	8499121.79	138.7	
26/04/2017	02:28:22	SA1702_ENV19	Still	SA1702_ENV	1334	241.1	558524.61	8499087.33	558387.85	8499122.49	141.2	
26/04/2017	02:28:52	SA1702_ENV19	Still	SA1702_ENV	1335	240.6	558524.61	8499087.33	558380.96	8499124.34	148.3	
26/04/2017	02:29:12	SA1702_ENV19	Still	SA1702_ENV	1336	241.8	558524.61	8499087.33	558376.37	8499125.73	153.1	
26/04/2017	02:29:37	SA1702_ENV19	Still	SA1702_ENV	1337	242.0	558524.61	8499087.33	558370.66	8499127.16	159.0	
26/04/2017	02:30:18	SA1702_ENV19	Still	SA1702_ENV	1338	242.0	558524.61	8499087.33	558361.06	8499129.48	168.9	
26/04/2017	02:30:43	SA1702_ENV19	Still	SA1702_ENV	1339	242.1	558524.61	8499087.33	558354.94	8499131.18	175.2	
26/04/2017	02:31:06	SA1702_ENV19	Still	SA1702_ENV	1340	242.9	558524.61	8499087.33	558351.12	8499132.20	179.2	
26/04/2017	02:31:17	SA1702_ENV19	Still	SA1702_ENV	1341	242.3	558524.61	8499087.33	558348.46	8499132.61	181.9	
26/04/2017	02:32:09	SA1702_ENV19	Still	SA1702_ENV	1342	242.0	558524.61	8499087.33	558335.98	8499135.30	194.6	
26/04/2017	02:32:40	SA1702_ENV19	Still	SA1702_ENV	1343	242.8	558524.61	8499087.33	558327.66	8499137.23	203.2	
26/04/2017	02:33:13	SA1702_ENV19	Still	SA1702_ENV	1344	242.7	558524.61	8499087.33	558319.67	8499139.30	211.4	
26/04/2017	02:33:53	SA1702_ENV19	Still	NO STILL	1345	242.8	558524.61	8499087.33	558309.96	8499141.70	221.4	
26/04/2017	02:34:27	SA1702_ENV19	Still	SA1702_ENV	1346	243.5	558524.61	8499087.33	558301.96	8499143.68	229.7	
26/04/2017	02:34:54	SA1702_ENV19	Still	SA1702_ENV	1347	242.0	558524.61	8499087.33	558296.07	8499145.29	235.8	
26/04/2017	02:35:08	SA1702_ENV19	Still	SA1702_ENV	1348	240.8	558524.61	8499087.33	558292.64	8499146.12	239.3	

GDA94, MGA94, UTM Zone 51, CM123 °East												
Date	Time [UTC]	Transect	Type	ID	Fix No.	Water Depth [m]	Proposed Location		Actual Location		Offset [m]	Notes
							Easting [m]	Northing [m]	Easting [m]	Northing [m]		
26/04/2017	02:35:29	SA1702_ENV19	Still	SA1702_ENV	1349	241.1	558524.61	8499087.33	558288.25	8499147.46	243.9	
26/04/2017	02:36:45	SA1702_ENV19	Still	SA1702_ENV	1350	240.2	558524.61	8499087.33	558270.16	8499152.04	262.6	
26/04/2017	02:37:32	SA1702_ENV19	Still	SA1702_ENV	1351	242.1	558524.61	8499087.33	558259.63	8499154.94	273.5	
26/04/2017	02:38:20	SA1702_ENV19	Still	SA1702_ENV	1352	240.8	558524.61	8499087.33	558249.25	8499157.46	284.1	
26/04/2017	02:38:38	SA1702_ENV19	Still	SA1702_ENV	1353	240.7	558524.61	8499087.33	558245.43	8499158.60	288.1	
26/04/2017	02:38:56	SA1702_ENV19	Still	SA1702_ENV	1354	239.1	558524.61	8499087.33	558241.59	8499160.11	292.2	
26/04/2017	02:39:20	SA1702_ENV19	Still	NO STILL	1355	239.5	558524.61	8499087.33	558237.27	8499160.96	296.6	
26/04/2017	02:39:53	SA1702_ENV19	Still	NO STILL	1356	240.6	558524.61	8499087.33	558229.86	8499162.79	304.3	
26/04/2017	02:40:01	SA1702_ENV19	Still	NO STILL	1357	240.7	558524.61	8499087.33	558229.18	8499162.98	305.0	
26/04/2017	02:40:41	SA1702_ENV19	Still	SA1702_ENV	1358	241.4	558524.61	8499087.33	558219.72	8499165.25	314.7	
26/04/2017	02:41:07	SA1702_ENV19	Still	SA1702_ENV	1359	241.9	558524.61	8499087.33	558213.52	8499166.80	321.1	
26/04/2017	02:41:28	SA1702_ENV19	Still	SA1702_ENV	1360	242.0	558524.61	8499087.33	558208.40	8499167.73	326.3	
26/04/2017	02:42:02	SA1702_ENV19	Still	SA1702_ENV	1361	242.1	558524.61	8499087.33	558200.06	8499169.47	334.8	
26/04/2017	06:32:24	SA1702_ENV20	Still	SA1702_ENV	1401	248.1	556578.81	8498053.76	556523.66	8498100.90	72.6	
26/04/2017	06:33:15	SA1702_ENV20	Still	SA1702_ENV	1402	248.2	556578.81	8498053.76	556528.21	8498096.72	66.4	
26/04/2017	06:34:51	SA1702_ENV20	Still	SA1702_ENV	1403	247.6	556578.81	8498053.76	556537.35	8498086.83	53.0	
26/04/2017	06:35:18	SA1702_ENV20	Still	SA1702_ENV	1404	248.7	556578.81	8498053.76	556539.76	8498084.14	49.5	
26/04/2017	06:37:39	SA1702_ENV20	Still	SA1702_ENV	1405	248.3	556578.81	8498053.76	556556.25	8498068.17	26.8	
26/04/2017	06:38:16	SA1702_ENV20	Still	SA1702_ENV	1406	249.2	556578.81	8498053.76	556561.27	8498063.87	20.2	
26/04/2017	06:39:34	SA1702_ENV20	Still	SA1702_ENV	1407	248.5	556578.81	8498053.76	556571.57	8498053.90	7.2	
26/04/2017	06:40:23	SA1702_ENV20	Still	SA1702_ENV	1408	248.7	556578.81	8498053.76	556578.41	8498048.64	5.1	
26/04/2017	06:40:44	SA1702_ENV20	Still	SA1702_ENV	1409	249.0	556578.81	8498053.76	556581.41	8498046.31	7.9	
26/04/2017	06:41:29	SA1702_ENV20	Still	SA1702_ENV	1410	248.9	556578.81	8498053.76	556587.13	8498040.90	15.3	
26/04/2017	06:42:03	SA1702_ENV20	Still	SA1702_ENV	1411	248.6	556578.81	8498053.76	556591.57	8498037.04	21.0	
26/04/2017	06:42:44	SA1702_ENV20	Still	SA1702_ENV	1412	247.9	556578.81	8498053.76	556596.99	8498031.79	28.5	
26/04/2017	06:42:54	SA1702_ENV20	Still	SA1702_ENV	1413	248.3	556578.81	8498053.76	556598.35	8498030.72	30.2	
26/04/2017	06:43:14	SA1702_ENV20	Still	SA1702_ENV	1414	247.8	556578.81	8498053.76	556600.97	8498028.21	33.8	

GDA94, MGA94, UTM Zone 51, CM123 °East												
Date	Time [UTC]	Transect	Type	ID	Fix No.	Water Depth [m]	Proposed Location		Actual Location		Offset [m]	Notes
							Easting [m]	Northing [m]	Easting [m]	Northing [m]		
26/04/2017	06:44:01	SA1702_ENV20	Still	SA1702_ENV	1415	247.1	556578.81	8498053.76	556607.40	8498022.76	42.2	
26/04/2017	06:44:14	SA1702_ENV20	Still	SA1702_ENV	1416	248.1	556578.81	8498053.76	556609.04	8498021.22	44.4	
26/04/2017	06:44:25	SA1702_ENV20	Still	SA1702_ENV	1417	248.5	556578.81	8498053.76	556610.51	8498020.10	46.2	
26/04/2017	06:44:59	SA1702_ENV20	Still	SA1702_ENV	1418	247.3	556578.81	8498053.76	556616.48	8498016.86	52.7	
26/04/2017	06:45:32	SA1702_ENV20	Still	SA1702_ENV	1419	247.4	556578.81	8498053.76	556620.95	8498015.46	57.0	
26/04/2017	06:45:55	SA1702_ENV20	Still	SA1702_ENV	1420	247.7	556578.81	8498053.76	556623.67	8498014.35	59.7	
26/04/2017	06:46:38	SA1702_ENV20	Still	SA1702_ENV	1421	247.7	556578.81	8498053.76	556630.16	8498010.89	66.9	
26/04/2017	06:46:58	SA1702_ENV20	Still	SA1702_ENV	1422	247.6	556578.81	8498053.76	556633.58	8498008.66	70.9	
26/04/2017	06:47:13	SA1702_ENV20	Still	SA1702_ENV	1423	245.4	556578.81	8498053.76	556635.56	8498007.42	73.3	
26/04/2017	06:47:45	SA1702_ENV20	Still	SA1702_ENV	1424	247.2	556578.81	8498053.76	556639.45	8498004.12	78.4	
26/04/2017	06:48:10	SA1702_ENV20	Still	SA1702_ENV	1425	247.7	556578.81	8498053.76	556642.19	8498001.67	82.0	
26/04/2017	06:48:22	SA1702_ENV20	Still	SA1702_ENV	1426	246.9	556578.81	8498053.76	556643.23	8498000.62	83.5	
26/04/2017	06:49:02	SA1702_ENV20	Still	SA1702_ENV	1427	246.5	556578.81	8498053.76	556647.25	8497998.35	88.1	
26/04/2017	06:49:47	SA1702_ENV20	Still	SA1702_ENV	1428	247.8	556578.81	8498053.76	556651.62	8497996.25	92.8	
26/04/2017	06:50:25	SA1702_ENV20	Still	SA1702_ENV	1429	246.5	556578.81	8498053.76	556655.88	8497992.89	98.2	
26/04/2017	06:51:18	SA1702_ENV20	Still	SA1702_ENV	1430	246.5	556578.81	8498053.76	556662.47	8497988.21	106.3	
26/04/2017	06:52:04	SA1702_ENV20	Still	SA1702_ENV	1431	246.1	556578.81	8498053.76	556668.47	8497983.36	114.0	
26/04/2017	06:52:30	SA1702_ENV20	Still	SA1702_ENV	1432	245.6	556578.81	8498053.76	556671.77	8497980.23	118.5	
26/04/2017	06:53:04	SA1702_ENV20	Still	SA1702_ENV	1433	245.7	556578.81	8498053.76	556676.75	8497975.39	125.4	
26/04/2017	06:53:32	SA1702_ENV20	Still	SA1702_ENV	1434	244.6	556578.81	8498053.76	556680.45	8497971.59	130.7	
26/04/2017	06:53:55	SA1702_ENV20	Still	SA1702_ENV	1435	244.1	556578.81	8498053.76	556684.07	8497968.62	135.4	
26/04/2017	06:54:20	SA1702_ENV20	Still	SA1702_ENV	1436	244.0	556578.81	8498053.76	556687.55	8497965.11	140.3	
26/04/2017	06:55:03	SA1702_ENV20	Still	SA1702_ENV	1437	243.1	556578.81	8498053.76	556693.58	8497959.29	148.6	
26/04/2017	06:55:18	SA1702_ENV20	Still	SA1702_ENV	1438	243.1	556578.81	8498053.76	556695.11	8497957.29	151.1	
26/04/2017	06:55:47	SA1702_ENV20	Still	SA1702_ENV	1439	242.4	556578.81	8498053.76	556698.92	8497952.91	156.8	
26/04/2017	06:55:57	SA1702_ENV20	Still	SA1702_ENV	1440	242.6	556578.81	8498053.76	556700.63	8497951.63	159.0	
26/04/2017	06:56:22	SA1702_ENV20	Still	SA1702_ENV	1441	242.5	556578.81	8498053.76	556703.86	8497948.12	163.7	

GDA94, MGA94, UTM Zone 51, CM123 °East												
Date	Time [UTC]	Transect	Type	ID	Fix No.	Water Depth [m]	Proposed Location		Actual Location		Offset [m]	Notes
							Easting [m]	Northing [m]	Easting [m]	Northing [m]		
26/04/2017	06:56:29	SA1702_ENV20	Still	SA1702_ENV	1442	242.3	556578.81	8498053.76	556705.07	8497947.08	165.3	
26/04/2017	06:56:56	SA1702_ENV20	Still	SA1702_ENV	1443	243.1	556578.81	8498053.76	556708.81	8497943.51	170.5	
26/04/2017	06:57:20	SA1702_ENV20	Still	SA1702_ENV	1444	243.0	556578.81	8498053.76	556711.96	8497940.40	174.9	
26/04/2017	06:57:56	SA1702_ENV20	Still	SA1702_ENV	1445	242.9	556578.81	8498053.76	556717.28	8497935.84	181.9	
26/04/2017	06:58:07	SA1702_ENV20	Still	SA1702_ENV	1446	242.5	556578.81	8498053.76	556718.62	8497934.19	184.0	
26/04/2017	06:58:23	SA1702_ENV20	Still	SA1702_ENV	1447	242.7	556578.81	8498053.76	556721.22	8497931.69	187.6	
26/04/2017	06:59:22	SA1702_ENV20	Still	SA1702_ENV	1448	242.2	556578.81	8498053.76	556729.70	8497924.44	198.7	
26/04/2017	06:59:29	SA1702_ENV20	Still	SA1702_ENV	1449	242.6	556578.81	8498053.76	556730.79	8497923.22	200.3	
26/04/2017	07:00:03	SA1702_ENV20	Still	SA1702_ENV	1450	241.9	556578.81	8498053.76	556735.88	8497918.93	207.0	
26/04/2017	07:00:21	SA1702_ENV20	Still	SA1702_ENV	1451	242.5	556578.81	8498053.76	556738.53	8497916.23	210.8	
26/04/2017	07:00:37	SA1702_ENV20	Still	SA1702_ENV	1452	242.8	556578.81	8498053.76	556740.69	8497914.41	213.6	
26/04/2017	07:01:20	SA1702_ENV20	Still	SA1702_ENV	1453	241.9	556578.81	8498053.76	556747.15	8497908.56	222.3	
26/04/2017	07:01:42	SA1702_ENV20	Still	SA1702_ENV	1454	242.2	556578.81	8498053.76	556750.56	8497905.58	226.8	
26/04/2017	07:02:04	SA1702_ENV20	Still	SA1702_ENV	1455	242.2	556578.81	8498053.76	556753.56	8497902.68	231.0	
26/04/2017	07:02:32	SA1702_ENV20	Still	SA1702_ENV	1456	241.9	556578.81	8498053.76	556757.06	8497898.47	236.4	
26/04/2017	07:03:06	SA1702_ENV20	Still	SA1702_ENV	1457	242.6	556578.81	8498053.76	556762.06	8497893.23	243.6	
26/04/2017	07:03:17	SA1702_ENV20	Still	SA1702_ENV	1458	243.0	556578.81	8498053.76	556763.39	8497891.75	245.6	
26/04/2017	07:03:52	SA1702_ENV20	Still	SA1702_ENV	1459	242.3	556578.81	8498053.76	556768.04	8497886.68	252.4	
26/04/2017	07:04:46	SA1702_ENV20	Still	SA1702_ENV	1460	243.3	556578.81	8498053.76	556776.25	8497877.80	264.5	
26/04/2017	07:04:52	SA1702_ENV20	Still	SA1702_ENV	1461	242.7	556578.81	8498053.76	556777.32	8497876.18	266.3	
26/04/2017	07:05:26	SA1702_ENV20	Still	SA1702_ENV	1462	243.8	556578.81	8498053.76	556782.83	8497871.44	273.6	
26/04/2017	07:05:52	SA1702_ENV20	Still	SA1702_ENV	1463	243.9	556578.81	8498053.76	556786.60	8497867.58	279.0	
26/04/2017	07:06:14	SA1702_ENV20	Still	SA1702_ENV	1464	244.4	556578.81	8498053.76	556789.95	8497864.46	283.6	
26/04/2017	07:06:53	SA1702_ENV20	Still	SA1702_ENV	1465	245.3	556578.81	8498053.76	556795.52	8497858.79	291.5	
26/04/2017	07:07:21	SA1702_ENV20	Still	SA1702_ENV	1466	245.2	556578.81	8498053.76	556800.06	8497854.48	297.8	
26/04/2017	07:08:10	SA1702_ENV20	Still	SA1702_ENV	1467	245.8	556578.81	8498053.76	556807.76	8497846.81	308.6	
26/04/2017	07:08:32	SA1702_ENV20	Still	SA1702_ENV	1468	245.3	556578.81	8498053.76	556811.52	8497843.03	313.9	

GDA94, MGA94, UTM Zone 51, CM123 °East												
Date	Time [UTC]	Transect	Type	ID	Fix No.	Water Depth [m]	Proposed Location		Actual Location		Offset [m]	Notes
							Easting [m]	Northing [m]	Easting [m]	Northing [m]		
26/04/2017	07:09:20	SA1702_ENV20	Still	SA1702_ENV	1469	245.9	556578.81	8498053.76	556819.40	8497835.39	324.9	
26/04/2017	07:10:05	SA1702_ENV20	Still	SA1702_ENV	1470	245.6	556578.81	8498053.76	556827.10	8497828.13	335.5	
26/04/2017	07:10:57	SA1702_ENV20	Still	SA1702_ENV	1471	245.7	556578.81	8498053.76	556835.94	8497820.09	347.4	
26/04/2017	07:11:31	SA1702_ENV20	Still	SA1702_ENV	1472	246.6	556578.81	8498053.76	556841.47	8497814.66	355.2	
26/04/2017	07:12:15	SA1702_ENV20	Still	SA1702_ENV	1473	246.7	556578.81	8498053.76	556848.95	8497807.48	365.6	
26/04/2017	07:13:01	SA1702_ENV20	Still	SA1702_ENV	1474	246.4	556578.81	8498053.76	556857.27	8497800.03	376.7	
26/04/2017	07:13:45	SA1702_ENV20	Still	SA1702_ENV	1475	246.7	556578.81	8498053.76	556864.56	8497792.80	387.0	
26/04/2017	07:14:03	SA1702_ENV20	Still	SA1702_ENV	1476	246.5	556578.81	8498053.76	556866.82	8497790.24	390.4	
26/04/2017	07:14:42	SA1702_ENV20	Still	SA1702_ENV	1477	246.6	556578.81	8498053.76	556873.32	8497782.90	400.1	
26/04/2017	07:15:40	SA1702_ENV20	Still	SA1702_ENV	1478	246.4	556578.81	8498053.76	556882.76	8497773.30	413.6	
26/04/2017	07:16:07	SA1702_ENV20	Still	SA1702_ENV	1479	246.6	556578.81	8498053.76	556886.77	8497768.26	419.9	
26/04/2017	07:16:46	SA1702_ENV20	Still	SA1702_ENV	1480	246.7	556578.81	8498053.76	556892.70	8497761.36	429.0	
26/04/2017	07:17:34	SA1702_ENV20	Still	SA1702_ENV	1481	246.7	556578.81	8498053.76	556899.73	8497752.45	440.2	
26/04/2017	07:17:54	SA1702_ENV20	Still	SA1702_ENV	1482	246.2	556578.81	8498053.76	556902.00	8497748.94	444.3	
26/04/2017	12:55:24	SA1702_ENV26	Still	SA1702_ENV	1501	220.9	559072.19	8491572.02	559082.55	8491595.24	25.4	
26/04/2017	12:55:40	SA1702_ENV26	Still	SA1702_ENV	1502	220.5	559072.19	8491572.02	559082.22	8491594.27	24.4	
26/04/2017	12:56:24	SA1702_ENV26	Still	SA1702_ENV	1503	220.6	559072.19	8491572.02	559081.54	8491590.24	20.5	
26/04/2017	12:56:49	SA1702_ENV26	Still	SA1702_ENV	1504	221.0	559072.19	8491572.02	559080.46	8491586.99	17.1	
26/04/2017	12:57:56	SA1702_ENV26	Still	SA1702_ENV	1505	221.5	559072.19	8491572.02	559078.46	8491575.87	7.4	
26/04/2017	12:58:49	SA1702_ENV26	Still	SA1702_ENV	1506	220.9	559072.19	8491572.02	559074.59	8491570.24	3.0	
26/04/2017	12:59:12	SA1702_ENV26	Still	SA1702_ENV	1507	220.8	559072.19	8491572.02	559073.15	8491568.66	3.5	
26/04/2017	12:59:31	SA1702_ENV26	Still	SA1702_ENV	1508	221.2	559072.19	8491572.02	559071.71	8491567.34	4.7	
26/04/2017	13:01:14	SA1702_ENV26	Still	SA1702_ENV	1509	221.2	559072.19	8491572.02	559063.26	8491558.13	16.5	
26/04/2017	13:01:59	SA1702_ENV26	Still	SA1702_ENV	1510	221.8	559072.19	8491572.02	559059.23	8491554.80	21.5	
26/04/2017	13:02:30	SA1702_ENV26	Still	SA1702_ENV	1511	222.2	559072.19	8491572.02	559055.82	8491551.69	26.1	
26/04/2017	13:03:49	SA1702_ENV26	Still	SA1702_ENV	1512	221.8	559072.19	8491572.02	559045.71	8491545.84	37.2	
26/04/2017	13:04:16	SA1702_ENV26	Still	SA1702_ENV	1513	221.2	559072.19	8491572.02	559042.98	8491544.00	40.5	

GDA94, MGA94, UTM Zone 51, CM123 °East												
Date	Time [UTC]	Transect	Type	ID	Fix No.	Water Depth [m]	Proposed Location		Actual Location		Offset [m]	Notes
							Easting [m]	Northing [m]	Easting [m]	Northing [m]		
26/04/2017	13:05:00	SA1702_ENV26	Still	SA1702_ENV	1514	221.8	559072.19	8491572.02	559039.21	8491541.78	44.7	
26/04/2017	13:05:47	SA1702_ENV26	Still	SA1702_ENV	1515	221.7	559072.19	8491572.02	559034.31	8491542.21	48.2	
26/04/2017	13:06:46	SA1702_ENV26	Still	SA1702_ENV	1516	221.4	559072.19	8491572.02	559030.68	8491541.84	51.3	
26/04/2017	13:07:32	SA1702_ENV26	Still	SA1702_ENV	1517	222.3	559072.19	8491572.02	559025.31	8491542.07	55.6	
26/04/2017	13:08:31	SA1702_ENV26	Still	SA1702_ENV	1518	222.9	559072.19	8491572.02	559020.70	8491542.42	59.4	
26/04/2017	13:09:02	SA1702_ENV26	Still	SA1702_ENV	1519	222.4	559072.19	8491572.02	559019.26	8491545.01	59.4	
26/04/2017	13:10:15	SA1702_ENV26	Still	SA1702_ENV	1520	224.9	559072.19	8491572.02	559014.05	8491544.95	64.1	
26/04/2017	13:10:52	SA1702_ENV26	Still	SA1702_ENV	1521	225.4	559072.19	8491572.02	559011.24	8491544.71	66.8	
26/04/2017	13:11:20	SA1702_ENV26	Still	SA1702_ENV	1522	227.3	559072.19	8491572.02	559008.89	8491543.53	69.4	
26/04/2017	13:12:11	SA1702_ENV26	Still	NO STILL	1523	229.0	559072.19	8491572.02	559004.90	8491541.54	73.9	
26/04/2017	13:13:21	SA1702_ENV26	Still	SA1702_ENV	1524	230.2	559072.19	8491572.02	558999.19	8491538.51	80.3	
26/04/2017	13:13:38	SA1702_ENV26	Still	SA1702_ENV	1525	230.4	559072.19	8491572.02	558997.25	8491537.30	82.6	
26/04/2017	13:14:07	SA1702_ENV26	Still	SA1702_ENV	1526	230.8	559072.19	8491572.02	558994.30	8491536.00	85.8	
26/04/2017	13:14:48	SA1702_ENV26	Still	SA1702_ENV	1527	232.1	559072.19	8491572.02	558990.36	8491534.47	90.0	
26/04/2017	13:15:29	SA1702_ENV26	Still	SA1702_ENV	1528	231.0	559072.19	8491572.02	558987.20	8491532.53	93.7	
26/04/2017	13:15:39	SA1702_ENV26	Still	SA1702_ENV	1529	234.7	559072.19	8491572.02	558986.05	8491533.29	94.4	
26/04/2017	13:16:01	SA1702_ENV26	Still	SA1702_ENV	1530	235.6	559072.19	8491572.02	558985.05	8491530.69	96.4	
26/04/2017	13:16:50	SA1702_ENV26	Still	SA1702_ENV	1531	237.2	559072.19	8491572.02	558980.85	8491526.20	102.2	
26/04/2017	13:17:40	SA1702_ENV26	Still	SA1702_ENV	1532	240.1	559072.19	8491572.02	558975.74	8491523.53	107.9	
26/04/2017	13:18:10	SA1702_ENV26	Still	SA1702_ENV	1533	241.2	559072.19	8491572.02	558972.20	8491520.81	112.3	
26/04/2017	13:18:59	SA1702_ENV26	Still	SA1702_ENV	1534	243.1	559072.19	8491572.02	558966.99	8491516.42	119.0	
26/04/2017	13:19:34	SA1702_ENV26	Still	SA1702_ENV	1535	244.5	559072.19	8491572.02	558964.74	8491513.81	122.2	
26/04/2017	13:20:15	SA1702_ENV26	Still	SA1702_ENV	1536	244.0	559072.19	8491572.02	558964.18	8491492.91	133.9	
26/04/2017	13:20:38	SA1702_ENV26	Still	SA1702_ENV	1537	245.6	559072.19	8491572.02	558959.00	8491508.57	129.8	
26/04/2017	13:20:58	SA1702_ENV26	Still	SA1702_ENV	1538	245.1	559072.19	8491572.02	558958.03	8491506.53	131.6	
26/04/2017	13:22:41	SA1702_ENV26	Still	SA1702_ENV	1539	247.1	559072.19	8491572.02	558951.00	8491500.43	140.8	
26/04/2017	13:23:25	SA1702_ENV26	Still	SA1702_ENV	1540	247.8	559072.19	8491572.02	558948.45	8491498.61	143.9	

GDA94, MGA94, UTM Zone 51, CM123 °East												
Date	Time [UTC]	Transect	Type	ID	Fix No.	Water Depth [m]	Proposed Location		Actual Location		Offset [m]	Notes
							Easting [m]	Northing [m]	Easting [m]	Northing [m]		
26/04/2017	13:23:36	SA1702_ENV26	Still	SA1702_ENV	1541	248.3	559072.19	8491572.02	558947.51	8491498.42	144.8	
26/04/2017	13:24:26	SA1702_ENV26	Still	SA1702_ENV	1542	248.9	559072.19	8491572.02	558965.94	8491467.63	149.0	
26/04/2017	13:25:11	SA1702_ENV26	Still	SA1702_ENV	1543	249.2	559072.19	8491572.02	558941.66	8491494.41	151.9	
26/04/2017	13:26:12	SA1702_ENV26	Still	NO STILL	1544	250.2	559072.19	8491572.02	558937.84	8491490.91	156.9	
26/04/2017	13:26:35	SA1702_ENV26	Still	SA1702_ENV	1545	252.0	559072.19	8491572.02	558936.24	8491489.25	159.2	
26/04/2017	13:27:24	SA1702_ENV26	Still	SA1702_ENV	1546	253.3	559072.19	8491572.02	558931.09	8491486.98	164.7	
26/04/2017	13:27:49	SA1702_ENV26	Still	SA1702_ENV	1547	254.4	559072.19	8491572.02	558928.44	8491486.16	167.4	
26/04/2017	13:28:32	SA1702_ENV26	Still	SA1702_ENV	1548	255.2	559072.19	8491572.02	558923.94	8491485.62	171.6	
26/04/2017	13:29:37	SA1702_ENV26	Still	SA1702_ENV	1549	255.6	559072.19	8491572.02	558916.79	8491485.67	177.8	
26/04/2017	13:29:57	SA1702_ENV26	Still	SA1702_ENV	1550	255.8	559072.19	8491572.02	558914.34	8491485.18	180.2	
26/04/2017	13:30:19	SA1702_ENV26	Still	SA1702_ENV	1551	256.7	559072.19	8491572.02	558912.28	8491485.03	182.0	
26/04/2017	13:30:57	SA1702_ENV26	Still	SA1702_ENV	1552	256.2	559072.19	8491572.02	558907.54	8491484.29	186.6	
26/04/2017	13:31:41	SA1702_ENV26	Still	SA1702_ENV	1553	256.5	559072.19	8491572.02	558903.04	8491483.49	190.9	
26/04/2017	13:32:35	SA1702_ENV26	Still	SA1702_ENV	1554	256.1	559072.19	8491572.02	558898.87	8491484.12	194.3	
26/04/2017	13:33:11	SA1702_ENV26	Still	SA1702_ENV	1555	256.6	559072.19	8491572.02	558895.52	8491481.63	198.4	
26/04/2017	13:33:31	SA1702_ENV26	Still	SA1702_ENV	1556	255.4	559072.19	8491572.02	558893.36	8491480.27	201.0	
26/04/2017	13:33:54	SA1702_ENV26	Still	SA1702_ENV	1557	255.8	559072.19	8491572.02	558891.89	8491479.13	202.8	
26/04/2017	13:35:23	SA1702_ENV26	Still	SA1702_ENV	1558	255.7	559072.19	8491572.02	558884.25	8491475.29	211.4	
26/04/2017	13:35:33	SA1702_ENV26	Still	SA1702_ENV	1559	257.1	559072.19	8491572.02	558882.95	8491474.35	213.0	
26/04/2017	13:35:42	SA1702_ENV26	Still	SA1702_ENV	1560	255.7	559072.19	8491572.02	558882.34	8491473.98	213.7	
26/04/2017	13:35:50	SA1702_ENV26	Still	SA1702_ENV	1561	255.6	559072.19	8491572.02	558881.05	8491473.39	215.1	
26/04/2017	13:36:21	SA1702_ENV26	Still	SA1702_ENV	1562	255.8	559072.19	8491572.02	558878.87	8491472.65	217.4	
26/04/2017	13:36:50	SA1702_ENV26	Still	SA1702_ENV	1563	255.6	559072.19	8491572.02	558875.29	8491471.71	221.0	
26/04/2017	13:36:58	SA1702_ENV26	Still	SA1702_ENV	1564	254.3	559072.19	8491572.02	558874.72	8491471.23	221.7	
26/04/2017	13:37:47	SA1702_ENV26	Still	SA1702_ENV	1565	254.2	559072.19	8491572.02	558869.16	8491467.14	228.5	
26/04/2017	13:38:03	SA1702_ENV26	Still	SA1702_ENV	1566	254.8	559072.19	8491572.02	558867.68	8491465.45	230.6	
26/04/2017	13:38:25	SA1702_ENV26	Still	SA1702_ENV	1567	254.9	559072.19	8491572.02	558864.95	8491463.45	234.0	

GDA94, MGA94, UTM Zone 51, CM123 °East												
Date	Time [UTC]	Transect	Type	ID	Fix No.	Water Depth [m]	Proposed Location		Actual Location		Offset [m]	Notes
							Easting [m]	Northing [m]	Easting [m]	Northing [m]		
26/04/2017	13:39:30	SA1702_ENV26	Still	SA1702_ENV	1568	254.5	559072.19	8491572.02	558858.90	8491458.01	241.8	
26/04/2017	13:40:11	SA1702_ENV26	Still	SA1702_ENV	1569	254.8	559072.19	8491572.02	558854.87	8491454.28	247.2	
26/04/2017	13:41:05	SA1702_ENV26	Still	SA1702_ENV	1570	252.8	559072.19	8491572.02	558861.30	8491459.13	239.2	
26/04/2017	13:41:44	SA1702_ENV26	Still	SA1702_ENV	1571	252.8	559072.19	8491572.02	558844.69	8491445.93	260.1	
26/04/2017	13:42:08	SA1702_ENV26	Still	SA1702_ENV	1572	253.1	559072.19	8491572.02	558841.53	8491444.27	263.7	
26/04/2017	13:42:35	SA1702_ENV26	Still	SA1702_ENV	1573	253.4	559072.19	8491572.02	558838.56	8491442.98	266.9	
26/04/2017	13:43:23	SA1702_ENV26	Still	SA1702_ENV	1574	254.1	559072.19	8491572.02	558832.58	8491439.81	273.7	
26/04/2017	13:43:34	SA1702_ENV26	Still	SA1702_ENV	1575	254.1	559072.19	8491572.02	558831.43	8491439.01	275.1	
26/04/2017	13:44:36	SA1702_ENV26	Still	SA1702_ENV	1576	253.6	559072.19	8491572.02	558822.21	8491435.12	285.0	
26/04/2017	13:44:50	SA1702_ENV26	Still	SA1702_ENV	1577	253.7	559072.19	8491572.02	558819.43	8491433.93	288.0	
26/04/2017	13:44:55	SA1702_ENV26	Still	SA1702_ENV	1578	253.2	559072.19	8491572.02	558819.11	8491433.52	288.5	
26/04/2017	13:45:32	SA1702_ENV26	Still	NO STILL	1579	253.1	559072.19	8491572.02	558813.95	8491431.57	294.0	
26/04/2017	13:46:07	SA1702_ENV26	Still	SA1702_ENV	1580	253.1	559072.19	8491572.02	558808.75	8491428.75	299.9	
26/04/2017	13:46:18	SA1702_ENV26	Still	SA1702_ENV	1581	252.8	559072.19	8491572.02	558807.61	8491428.17	301.2	
26/04/2017	13:47:19	SA1702_ENV26	Still	SA1702_ENV	1582	250.8	559072.19	8491572.02	558801.62	8491407.52	316.6	
26/04/2017	13:47:52	SA1702_ENV26	Still	SA1702_ENV	1583	250.1	559072.19	8491572.02	558792.40	8491421.22	317.8	
26/04/2017	13:48:53	SA1702_ENV26	Still	NO STILL	1584	248.1	559072.19	8491572.02	558783.00	8491413.59	329.7	
26/04/2017	13:49:42	SA1702_ENV26	Still	SA1702_ENV	1585	246.6	559072.19	8491572.02	558775.26	8491409.04	338.7	
26/04/2017	13:50:31	SA1702_ENV26	Still	SA1702_ENV	1586	246.4	559072.19	8491572.02	558767.17	8491405.23	347.6	
26/04/2017	13:51:34	SA1702_ENV26	Still	SA1702_ENV	1587	247.3	559072.19	8491572.02	558758.90	8491400.50	357.2	
26/04/2017	13:52:09	SA1702_ENV26	Still	SA1702_ENV	1588	248.2	559072.19	8491572.02	558752.79	8491397.04	364.2	
26/04/2017	13:52:18	SA1702_ENV26	Still	SA1702_ENV	1589	248.7	559072.19	8491572.02	558751.37	8491395.93	366.0	
26/04/2017	13:52:59	SA1702_ENV26	Still	SA1702_ENV	1590	247.8	559072.19	8491572.02	558743.10	8491391.81	375.2	
26/04/2017	13:53:32	SA1702_ENV26	Still	SA1702_ENV	1591	246.6	559072.19	8491572.02	558737.48	8491389.57	381.2	
26/04/2017	13:54:07	SA1702_ENV26	Still	SA1702_ENV	1592	244.4	559072.19	8491572.02	558731.80	8491387.60	387.1	
26/04/2017	13:54:29	SA1702_ENV26	Still	SA1702_ENV	1593	244.7	559072.19	8491572.02	558728.33	8491386.61	390.7	
26/04/2017	13:54:55	SA1702_ENV26	Still	SA1702_ENV	1594	243.8	559072.19	8491572.02	558724.30	8491384.31	395.3	

GDA94, MGA94, UTM Zone 51, CM123 °East												
Date	Time [UTC]	Transect	Type	ID	Fix No.	Water Depth [m]	Proposed Location		Actual Location		Offset [m]	Notes
							Easting [m]	Northing [m]	Easting [m]	Northing [m]		
26/04/2017	13:56:06	SA1702_ENV26	Still	SA1702_ENV	1595	243.9	559072.19	8491572.02	558715.43	8491374.93	407.6	
26/04/2017	13:56:20	SA1702_ENV26	Still	SA1702_ENV	1596	244.2	559072.19	8491572.02	558713.47	8491373.16	410.1	
26/04/2017	13:56:31	SA1702_ENV26	Still	SA1702_ENV	1597	244.7	559072.19	8491572.02	558711.78	8491372.03	412.2	
26/04/2017	13:57:10	SA1702_ENV26	Still	SA1702_ENV	1598	244.1	559072.19	8491572.02	558706.20	8491368.83	418.6	
26/04/2017	13:57:26	SA1702_ENV26	Still	SA1702_ENV	1599	244.1	559072.19	8491572.02	558704.11	8491367.73	421.0	
26/04/2017	14:54:46	SA1702_ENV25	Still	SA1702_ENV	1601	265.7	557379.21	8490677.78	557442.14	8490717.79	74.6	
26/04/2017	14:55:56	SA1702_ENV25	Still	SA1702_ENV	1602	266.1	557379.21	8490677.78	557440.26	8490708.33	68.3	
26/04/2017	14:56:12	SA1702_ENV25	Still	SA1702_ENV	1603	265.5	557379.21	8490677.78	557439.27	8490706.97	66.8	
26/04/2017	14:57:27	SA1702_ENV25	Still	SA1702_ENV	1604	266.5	557379.21	8490677.78	557431.35	8490704.19	58.4	
26/04/2017	14:57:47	SA1702_ENV25	Still	SA1702_ENV	1605	262.7	557379.21	8490677.78	557428.82	8490702.96	55.6	
26/04/2017	14:57:57	SA1702_ENV25	Still	SA1702_ENV	1606	266.3	557379.21	8490677.78	557427.50	8490702.01	54.0	
26/04/2017	14:59:21	SA1702_ENV25	Still	SA1702_ENV	1607	266.7	557379.21	8490677.78	557417.03	8490691.72	40.3	
26/04/2017	14:59:32	SA1702_ENV25	Still	SA1702_ENV	1608	266.1	557379.21	8490677.78	557415.44	8490690.22	38.3	
26/04/2017	15:00:01	SA1702_ENV25	Still	SA1702_ENV	1609	266.5	557379.21	8490677.78	557411.09	8490687.16	33.2	
26/04/2017	15:00:58	SA1702_ENV25	Still	SA1702_ENV	1610	266.6	557379.21	8490677.78	557403.54	8490682.75	24.8	
26/04/2017	15:01:06	SA1702_ENV25	Still	SA1702_ENV	1611	266.2	557379.21	8490677.78	557401.96	8490681.99	23.1	
26/04/2017	15:01:14	SA1702_ENV25	Still	SA1702_ENV	1612	266.1	557379.21	8490677.78	557400.87	8490681.52	22.0	
26/04/2017	15:01:59	SA1702_ENV25	Still	SA1702_ENV	1613	266.1	557379.21	8490677.78	557392.68	8490678.99	13.5	
26/04/2017	15:03:03	SA1702_ENV25	Still	SA1702_ENV	1614	266.5	557379.21	8490677.78	557380.94	8490676.35	2.2	
26/04/2017	15:03:46	SA1702_ENV25	Still	SA1702_ENV	1615	266.6	557379.21	8490677.78	557371.67	8490674.02	8.4	
26/04/2017	15:04:27	SA1702_ENV25	Still	SA1702_ENV	1616	267.6	557379.21	8490677.78	557362.89	8490670.45	17.9	
26/04/2017	15:05:39	SA1702_ENV25	Still	SA1702_ENV	1617	267.4	557379.21	8490677.78	557348.84	8490662.09	34.2	
26/04/2017	15:06:10	SA1702_ENV25	Still	SA1702_ENV	1618	267.9	557379.21	8490677.78	557343.05	8490658.36	41.0	
26/04/2017	15:06:47	SA1702_ENV25	Still	SA1702_ENV	1619	268.8	557379.21	8490677.78	557336.59	8490654.33	48.6	
26/04/2017	15:07:37	SA1702_ENV25	Still	SA1702_ENV	1620	269.7	557379.21	8490677.78	557329.05	8490647.86	58.4	
26/04/2017	15:08:33	SA1702_ENV25	Still	SA1702_ENV	1621	270.8	557379.21	8490677.78	557320.01	8490641.17	69.6	
26/04/2017	15:09:34	SA1702_ENV25	Still	SA1702_ENV	1622	272.0	557379.21	8490677.78	557310.28	8490635.76	80.7	

GDA94, MGA94, UTM Zone 51, CM123 °East												
Date	Time [UTC]	Transect	Type	ID	Fix No.	Water Depth [m]	Proposed Location		Actual Location		Offset [m]	Notes
							Easting [m]	Northing [m]	Easting [m]	Northing [m]		
26/04/2017	15:10:26	SA1702_ENV25	Still	SA1702_ENV	1623	272.3	557379.21	8490677.78	557300.92	8490630.13	91.6	
26/04/2017	15:11:18	SA1702_ENV25	Still	SA1702_ENV	1624	272.7	557379.21	8490677.78	557294.07	8490624.05	100.7	
26/04/2017	15:11:48	SA1702_ENV25	Still	SA1702_ENV	1625	271.9	557379.21	8490677.78	557292.17	8490619.88	104.5	
26/04/2017	15:11:58	SA1702_ENV25	Still	SA1702_ENV	1626	271.9	557379.21	8490677.78	557291.57	8490618.28	105.9	
26/04/2017	15:12:11	SA1702_ENV25	Still	SA1702_ENV	1627	272.8	557379.21	8490677.78	557290.84	8490616.12	107.8	
26/04/2017	15:12:58	SA1702_ENV25	Still	SA1702_ENV	1628	272.3	557379.21	8490677.78	557288.87	8490607.65	114.4	
26/04/2017	15:13:20	SA1702_ENV25	Still	SA1702_ENV	1629	272.9	557379.21	8490677.78	557287.22	8490605.27	117.1	
26/04/2017	15:13:55	SA1702_ENV25	Still	SA1702_ENV	1630	271.5	557379.21	8490677.78	557283.21	8490600.02	123.5	
26/04/2017	19:23:33	SA1702_ENV21	Still	SA1702_ENV	1701	269.9	551906.91	8492893.77	551829.53	8492890.30	77.5	
26/04/2017	19:24:19	SA1702_ENV21	Still	SA1702_ENV	1702	269.4	551906.91	8492893.77	551832.75	8492890.16	74.2	
26/04/2017	19:24:42	SA1702_ENV21	Still	SA1702_ENV	1703	270.8	551906.91	8492893.77	551834.99	8492890.33	72.0	
26/04/2017	19:26:18	SA1702_ENV21	Still	SA1702_ENV	1704	269.9	551906.91	8492893.77	551845.82	8492890.37	61.2	
26/04/2017	19:27:35	SA1702_ENV21	Still	SA1702_ENV	1705	270.0	551906.91	8492893.77	551856.29	8492889.81	50.8	
26/04/2017	19:28:20	SA1702_ENV21	Still	SA1702_ENV	1706	270.6	551906.91	8492893.77	551863.85	8492890.81	43.2	
26/04/2017	19:28:44	SA1702_ENV21	Still	SA1702_ENV	1707	270.0	551906.91	8492893.77	551868.18	8492891.03	38.8	
26/04/2017	19:29:01	SA1702_ENV21	Still	SA1702_ENV	1708	269.5	551906.91	8492893.77	551871.46	8492891.11	35.5	
26/04/2017	19:29:53	SA1702_ENV21	Still	SA1702_ENV	1709	270.5	551906.91	8492893.77	551880.54	8492891.10	26.5	
26/04/2017	19:30:22	SA1702_ENV21	Still	SA1702_ENV	1710	270.5	551906.91	8492893.77	551886.32	8492891.29	20.7	
26/04/2017	19:30:41	SA1702_ENV21	Still	SA1702_ENV	1711	270.6	551906.91	8492893.77	551890.18	8492891.55	16.9	
26/04/2017	19:31:26	SA1702_ENV21	Still	SA1702_ENV	1712	270.8	551906.91	8492893.77	551898.87	8492891.54	8.3	
26/04/2017	19:31:40	SA1702_ENV21	Still	SA1702_ENV	1713	270.6	551906.91	8492893.77	551901.77	8492891.32	5.7	
26/04/2017	19:32:29	SA1702_ENV21	Still	SA1702_ENV	1714	270.2	551906.91	8492893.77	551910.81	8492890.25	5.3	
26/04/2017	19:33:22	SA1702_ENV21	Still	SA1702_ENV	1715	270.4	551906.91	8492893.77	551921.30	8492889.80	14.9	
26/04/2017	19:33:50	SA1702_ENV21	Still	SA1702_ENV	1716	270.0	551906.91	8492893.77	551926.77	8492889.67	20.3	
26/04/2017	19:34:22	SA1702_ENV21	Still	SA1702_ENV	1717	271.0	551906.91	8492893.77	551932.59	8492889.46	26.0	
26/04/2017	19:35:34	SA1702_ENV21	Still	SA1702_ENV	1718	270.3	551906.91	8492893.77	551946.59	8492889.42	39.9	
26/04/2017	19:35:45	SA1702_ENV21	Still	SA1702_ENV	1719	270.4	551906.91	8492893.77	551948.96	8492889.53	42.3	

GDA94, MGA94, UTM Zone 51, CM123 °East												
Date	Time [UTC]	Transect	Type	ID	Fix No.	Water Depth [m]	Proposed Location		Actual Location		Offset [m]	Notes
							Easting [m]	Northing [m]	Easting [m]	Northing [m]		
26/04/2017	19:36:29	SA1702_ENV21	Still	SA1702_ENV	1720	270.8	551906.91	8492893.77	551957.55	8492889.79	50.8	
26/04/2017	19:37:26	SA1702_ENV21	Still	SA1702_ENV	1721	270.2	551906.91	8492893.77	551969.25	8492889.49	62.5	
26/04/2017	19:37:50	SA1702_ENV21	Still	SA1702_ENV	1722	270.0	551906.91	8492893.77	551974.61	8492889.38	67.8	
26/04/2017	19:38:57	SA1702_ENV21	Still	SA1702_ENV	1723	270.7	551906.91	8492893.77	551988.04	8492888.45	81.3	
26/04/2017	19:39:34	SA1702_ENV21	Still	SA1702_ENV	1724	270.8	551906.91	8492893.77	551995.93	8492888.58	89.2	
26/04/2017	19:40:06	SA1702_ENV21	Still	SA1702_ENV	1725	270.8	551906.91	8492893.77	552002.66	8492888.51	95.9	
26/04/2017	19:40:35	SA1702_ENV21	Still	SA1702_ENV	1726	271.0	551906.91	8492893.77	552008.18	8492888.00	101.4	
26/04/2017	19:40:56	SA1702_ENV21	Still	SA1702_ENV	1727	270.9	551906.91	8492893.77	552012.49	8492887.98	105.7	
26/04/2017	19:41:31	SA1702_ENV21	Still	SA1702_ENV	1728	270.5	551906.91	8492893.77	552018.91	8492888.15	112.1	
27/04/2017	00:48:58	SA1702_ENV22	Still	SA1702_ENV	1801	265.2	546438.14	8487540.79	546512.93	8487480.74	95.9	
27/04/2017	00:49:46	SA1702_ENV22	Still	SA1702_ENV	1802	266.5	546438.14	8487540.79	546513.28	8487482.89	94.9	
27/04/2017	00:50:53	SA1702_ENV22	Still	SA1702_ENV	1803	266.3	546438.14	8487540.79	546508.17	8487486.94	88.3	
27/04/2017	00:52:15	SA1702_ENV22	Still	SA1702_ENV	1804	266.0	546438.14	8487540.79	546498.12	8487494.86	75.5	
27/04/2017	00:52:30	SA1702_ENV22	Still	SA1702_ENV	1805	265.8	546438.14	8487540.79	546496.42	8487496.40	73.3	
27/04/2017	00:52:35	SA1702_ENV22	Still	NO STILL	1806	267.0	546438.14	8487540.79	546496.31	8487496.58	73.1	
27/04/2017	00:53:28	SA1702_ENV22	Still	SA1702_ENV	1807	267.0	546438.14	8487540.79	546492.02	8487500.89	67.0	
27/04/2017	00:54:10	SA1702_ENV22	Still	SA1702_ENV	1808	266.4	546438.14	8487540.79	546487.69	8487505.11	61.1	
27/04/2017	00:54:28	SA1702_ENV22	Still	SA1702_ENV	1809	266.9	546438.14	8487540.79	546485.99	8487507.00	58.6	
27/04/2017	00:56:09	SA1702_ENV22	Still	SA1702_ENV	1810	266.7	546438.14	8487540.79	546475.86	8487516.81	44.7	
27/04/2017	00:57:04	SA1702_ENV22	Still	SA1702_ENV	1811	266.0	546438.14	8487540.79	546469.93	8487520.91	37.5	
27/04/2017	00:59:11	SA1702_ENV22	Still	SA1702_ENV	1812	266.0	546438.14	8487540.79	546453.10	8487529.71	18.6	
27/04/2017	00:59:27	SA1702_ENV22	Still	SA1702_ENV	1813	265.9	546438.14	8487540.79	546450.78	8487531.06	15.9	
27/04/2017	01:01:23	SA1702_ENV22	Still	SA1702_ENV	1814	265.8	546438.14	8487540.79	546432.89	8487542.82	5.6	
27/04/2017	01:01:29	SA1702_ENV22	Still	SA1702_ENV	1815	266.4	546438.14	8487540.79	546432.14	8487543.63	6.6	
27/04/2017	01:02:01	SA1702_ENV22	Still	SA1702_ENV	1816	266.5	546438.14	8487540.79	546427.03	8487547.53	13.0	
27/04/2017	01:02:14	SA1702_ENV22	Still	SA1702_ENV	1817	266.7	546438.14	8487540.79	546425.15	8487549.38	15.6	
27/04/2017	01:03:03	SA1702_ENV22	Still	SA1702_ENV	1818	266.5	546438.14	8487540.79	546419.52	8487554.65	23.2	

GDA94, MGA94, UTM Zone 51, CM123 °East												
Date	Time [UTC]	Transect	Type	ID	Fix No.	Water Depth [m]	Proposed Location		Actual Location		Offset [m]	Notes
							Easting [m]	Northing [m]	Easting [m]	Northing [m]		
27/04/2017	01:03:13	SA1702_ENV22	Still	SA1702_ENV	1819	266.3	546438.14	8487540.79	546418.28	8487555.72	24.8	
27/04/2017	01:03:30	SA1702_ENV22	Still	SA1702_ENV	1820	265.5	546438.14	8487540.79	546415.91	8487557.71	27.9	
27/04/2017	01:03:41	SA1702_ENV22	Still	SA1702_ENV	1821	266.7	546438.14	8487540.79	546414.12	8487558.98	30.1	
27/04/2017	01:03:51	SA1702_ENV22	Still	SA1702_ENV	1822	266.7	546438.14	8487540.79	546412.69	8487560.38	32.1	
27/04/2017	01:04:08	SA1702_ENV22	Still	SA1702_ENV	1823	266.5	546438.14	8487540.79	546410.51	8487562.85	35.4	
27/04/2017	01:04:56	SA1702_ENV22	Still	SA1702_ENV	1824	266.8	546438.14	8487540.79	546403.65	8487569.08	44.6	
27/04/2017	01:05:54	SA1702_ENV22	Still	SA1702_ENV	1825	266.6	546438.14	8487540.79	546395.39	8487575.37	55.0	
27/04/2017	01:06:07	SA1702_ENV22	Still	SA1702_ENV	1826	266.5	546438.14	8487540.79	546393.82	8487576.90	57.2	
27/04/2017	01:06:51	SA1702_ENV22	Still	SA1702_ENV	1827	266.4	546438.14	8487540.79	546387.82	8487582.43	65.3	
27/04/2017	01:07:53	SA1702_ENV22	Still	SA1702_ENV	1828	267.3	546438.14	8487540.79	546377.68	8487590.64	78.4	
27/04/2017	01:08:03	SA1702_ENV22	Still	SA1702_ENV	1829	267.2	546438.14	8487540.79	546376.10	8487591.81	80.3	
27/04/2017	01:08:30	SA1702_ENV22	Still	SA1702_ENV	1830	266.8	546438.14	8487540.79	546372.36	8487595.02	85.3	
27/04/2017	01:09:20	SA1702_ENV22	Still	SA1702_ENV	1831	266.4	546438.14	8487540.79	546365.81	8487600.30	93.7	
27/04/2017	01:09:55	SA1702_ENV22	Still	SA1702_ENV	1832	267.2	546438.14	8487540.79	546360.70	8487604.43	100.2	
27/04/2017	01:10:23	SA1702_ENV22	Still	SA1702_ENV	1833	266.2	546438.14	8487540.79	546357.06	8487607.85	105.2	
27/04/2017	01:10:45	SA1702_ENV22	Still	SA1702_ENV	1834	267.5	546438.14	8487540.79	546353.44	8487610.93	110.0	
27/04/2017	01:11:11	SA1702_ENV22	Still	SA1702_ENV	1835	267.4	546438.14	8487540.79	546349.57	8487614.42	115.2	
27/04/2017	01:11:38	SA1702_ENV22	Still	SA1702_ENV	1836	267.2	546438.14	8487540.79	546345.18	8487617.66	120.6	
27/04/2017	01:11:54	SA1702_ENV22	Still	SA1702_ENV	1837	266.7	546438.14	8487540.79	546342.91	8487619.40	123.5	
27/04/2017	01:12:18	SA1702_ENV22	Still	SA1702_ENV	1838	266.2	546438.14	8487540.79	546339.24	8487622.57	128.3	
27/04/2017	01:12:32	SA1702_ENV22	Still	SA1702_ENV	1839	266.8	546438.14	8487540.79	546336.89	8487624.20	131.2	
27/04/2017	01:12:48	SA1702_ENV22	Still	SA1702_ENV	1840	266.8	546438.14	8487540.79	546334.67	8487626.10	134.1	
27/04/2017	01:13:05	SA1702_ENV22	Still	SA1702_ENV	1841	266.4	546438.14	8487540.79	546332.48	8487628.05	137.0	
27/04/2017	01:14:13	SA1702_ENV22	Still	SA1702_ENV	1842	267.1	546438.14	8487540.79	546323.73	8487636.11	148.9	
27/04/2017	01:14:32	SA1702_ENV22	Still	SA1702_ENV	1843	267.0	546438.14	8487540.79	546321.19	8487638.25	152.2	
27/04/2017	01:15:06	SA1702_ENV22	Still	SA1702_ENV	1844	267.2	546438.14	8487540.79	546316.14	8487642.88	159.1	
27/04/2017	01:15:53	SA1702_ENV22	Still	SA1702_ENV	1845	267.2	546438.14	8487540.79	546310.57	8487648.11	166.7	

GDA94, MGA94, UTM Zone 51, CM123 °East												
Date	Time [UTC]	Transect	Type	ID	Fix No.	Water Depth [m]	Proposed Location		Actual Location		Offset [m]	Notes
							Easting [m]	Northing [m]	Easting [m]	Northing [m]		
27/04/2017	02:40:30	SA1702_ENV24	Still	SA1702_ENV	1901	261.3	549157.34	8484632.54	549100.29	8484646.15	58.7	
27/04/2017	02:41:13	SA1702_ENV24	Still	SA1702_ENV	1902	261.5	549157.34	8484632.54	549103.51	8484645.58	55.4	
27/04/2017	02:41:33	SA1702_ENV24	Still	SA1702_ENV	1903	261.4	549157.34	8484632.54	549105.90	8484644.60	52.8	
27/04/2017	02:42:09	SA1702_ENV24	Still	SA1702_ENV	1904	262.4	549157.34	8484632.54	549112.34	8484643.70	46.4	
27/04/2017	02:43:01	SA1702_ENV24	Still	SA1702_ENV	1905	261.8	549157.34	8484632.54	549124.64	8484641.45	33.9	
27/04/2017	02:43:33	SA1702_ENV24	Still	SA1702_ENV	1906	262.0	549157.34	8484632.54	549130.88	8484638.88	27.2	
27/04/2017	02:43:38	SA1702_ENV24	Still	SA1702_ENV	1907	261.8	549157.34	8484632.54	549131.87	8484638.51	26.2	
27/04/2017	02:44:25	SA1702_ENV24	Still	SA1702_ENV	1908	262.0	549157.34	8484632.54	549138.30	8484636.35	19.4	
27/04/2017	02:44:37	SA1702_ENV24	Still	SA1702_ENV	1909	262.0	549157.34	8484632.54	549139.54	8484636.23	18.2	
27/04/2017	02:44:59	SA1702_ENV24	Still	SA1702_ENV	1910	261.9	549157.34	8484632.54	549141.38	8484636.31	16.4	
27/04/2017	02:46:43	SA1702_ENV24	Still	SA1702_ENV	1911	262.0	549157.34	8484632.54	549150.68	8484635.25	7.2	
27/04/2017	02:46:54	SA1702_ENV24	Still	SA1702_ENV	1912	262.2	549157.34	8484632.54	549152.82	8484634.87	5.1	
27/04/2017	02:47:35	SA1702_ENV24	Still	SA1702_ENV	1913	261.5	549157.34	8484632.54	549160.82	8484633.27	3.5	
27/04/2017	02:48:14	SA1702_ENV24	Still	SA1702_ENV	1914	261.3	549157.34	8484632.54	549170.04	8484631.33	12.8	
27/04/2017	02:48:43	SA1702_ENV24	Still	SA1702_ENV	1915	261.5	549157.34	8484632.54	549176.85	8484629.63	19.7	
27/04/2017	02:49:05	SA1702_ENV24	Still	SA1702_ENV	1916	262.3	549157.34	8484632.54	549182.30	8484628.59	25.3	
27/04/2017	02:49:44	SA1702_ENV24	Still	SA1702_ENV	1917	262.1	549157.34	8484632.54	549191.19	8484627.02	34.3	
27/04/2017	02:50:29	SA1702_ENV24	Still	SA1702_ENV	1918	261.8	549157.34	8484632.54	549199.84	8484623.94	43.4	
27/04/2017	02:51:01	SA1702_ENV24	Still	SA1702_ENV	1919	261.9	549157.34	8484632.54	549204.49	8484621.97	48.3	
27/04/2017	02:51:11	SA1702_ENV24	Still	SA1702_ENV	1920	261.2	549157.34	8484632.54	549205.73	8484621.47	49.6	
27/04/2017	02:51:59	SA1702_ENV24	Still	NO STILL	1921	262.5	549157.34	8484632.54	549211.45	8484620.32	55.5	
27/04/2017	02:53:18	SA1702_ENV24	Still	SA1702_ENV	1922	261.8	549157.34	8484632.54	549224.27	8484617.38	68.6	
27/04/2017	02:54:05	SA1702_ENV24	Still	SA1702_ENV	1923	261.7	549157.34	8484632.54	549230.60	8484614.80	75.4	
27/04/2017	02:54:44	SA1702_ENV24	Still	SA1702_ENV	1924	261.0	549157.34	8484632.54	549236.67	8484613.57	81.6	
27/04/2017	02:55:56	SA1702_ENV24	Still	SA1702_ENV	1925	261.1	549157.34	8484632.54	549249.19	8484610.92	94.4	
27/04/2017	02:56:30	SA1702_ENV24	Still	SA1702_ENV	1926	261.3	549157.34	8484632.54	549256.61	8484609.41	101.9	
27/04/2017	02:56:57	SA1702_ENV24	Still	SA1702_ENV	1927	261.6	549157.34	8484632.54	549262.08	8484608.15	107.5	

GDA94, MGA94, UTM Zone 51, CM123 °East												
Date	Time [UTC]	Transect	Type	ID	Fix No.	Water Depth [m]	Proposed Location		Actual Location		Offset [m]	Notes
							Easting [m]	Northing [m]	Easting [m]	Northing [m]		
27/04/2017	02:57:17	SA1702_ENV24	Still	SA1702_ENV	1928	261.9	549157.34	8484632.54	549266.15	8484607.47	111.7	
27/04/2017	02:57:47	SA1702_ENV24	Still	SA1702_ENV	1929	261.6	549157.34	8484632.54	549272.30	8484605.99	118.0	
27/04/2017	02:58:00	SA1702_ENV24	Still	SA1702_ENV	1930	261.7	549157.34	8484632.54	549274.91	8484605.29	120.7	
27/04/2017	02:58:08	SA1702_ENV24	Still	SA1702_ENV	1931	261.8	549157.34	8484632.54	549276.63	8484604.79	122.5	
27/04/2017	02:58:39	SA1702_ENV24	Still	SA1702_ENV	1932	261.4	549157.34	8484632.54	549282.15	8484602.69	128.3	
27/04/2017	02:58:57	SA1702_ENV24	Still	SA1702_ENV	1933	261.4	549157.34	8484632.54	549285.58	8484601.67	131.9	
27/04/2017	09:02:18	SA1702_ENV23	Still	SA1702_ENV	2001	257.6	539807.25	8481170.65	539753.84	8481136.11	63.6	
27/04/2017	09:02:33	SA1702_ENV23	Still	SA1702_ENV	2002	257.1	539807.25	8481170.65	539755.33	8481137.46	61.6	
27/04/2017	09:03:23	SA1702_ENV23	Still	SA1702_ENV	2003	257.3	539807.25	8481170.65	539761.04	8481141.09	54.9	
27/04/2017	09:03:54	SA1702_ENV23	Still	SA1702_ENV	2004	257.1	539807.25	8481170.65	539764.22	8481143.37	51.0	
27/04/2017	09:04:02	SA1702_ENV23	Still	SA1702_ENV	2005	257.4	539807.25	8481170.65	539765.05	8481144.06	49.9	
27/04/2017	09:04:23	SA1702_ENV23	Still	SA1702_ENV	2006	257.8	539807.25	8481170.65	539767.24	8481145.72	47.1	
27/04/2017	09:04:38	SA1702_ENV23	Still	SA1702_ENV	2007	257.0	539807.25	8481170.65	539768.58	8481146.85	45.4	
27/04/2017	09:05:11	SA1702_ENV23	Still	NO STILL	2008	257.3	539807.25	8481170.65	539768.58	8481146.85	45.4	
27/04/2017	09:08:11	SA1702_ENV23	Still	SA1702_ENV	2009	256.8	539807.25	8481170.65	539795.84	8481163.49	13.5	
27/04/2017	09:08:51	SA1702_ENV23	Still	SA1702_ENV	2010	257.2	539807.25	8481170.65	539800.19	8481164.33	9.5	
27/04/2017	09:09:46	SA1702_ENV23	Still	SA1702_ENV	2011	257.3	539807.25	8481170.65	539806.22	8481167.11	3.7	
27/04/2017	09:10:23	SA1702_ENV23	Still	SA1702_ENV	2012	257.4	539807.25	8481170.65	539810.25	8481170.85	3.0	
27/04/2017	09:10:49	SA1702_ENV23	Still	SA1702_ENV	2013	257.4	539807.25	8481170.65	539812.87	8481173.34	6.2	
27/04/2017	09:11:01	SA1702_ENV23	Still	SA1702_ENV	2014	257.2	539807.25	8481170.65	539814.52	8481174.72	8.3	
27/04/2017	09:11:35	SA1702_ENV23	Still	SA1702_ENV	2015	256.5	539807.25	8481170.65	539819.51	8481178.32	14.5	
27/04/2017	09:11:43	SA1702_ENV23	Still	SA1702_ENV	2016	257.9	539807.25	8481170.65	539820.88	8481179.24	16.1	
27/04/2017	09:12:26	SA1702_ENV23	Still	SA1702_ENV	2017	256.8	539807.25	8481170.65	539827.09	8481183.83	23.8	
27/04/2017	09:13:06	SA1702_ENV23	Still	SA1702_ENV	2018	256.4	539807.25	8481170.65	539831.74	8481188.00	30.0	
27/04/2017	09:13:51	SA1702_ENV23	Still	SA1702_ENV	2019	256.3	539807.25	8481170.65	539838.24	8481192.85	38.1	
27/04/2017	09:14:03	SA1702_ENV23	Still	SA1702_ENV	2020	255.9	539807.25	8481170.65	539839.35	8481194.14	39.8	
27/04/2017	09:14:54	SA1702_ENV23	Still	SA1702_ENV	2021	255.3	539807.25	8481170.65	539845.02	8481201.86	49.0	

GDA94, MGA94, UTM Zone 51, CM123 °East												
Date	Time [UTC]	Transect	Type	ID	Fix No.	Water Depth [m]	Proposed Location		Actual Location		Offset [m]	Notes
							Easting [m]	Northing [m]	Easting [m]	Northing [m]		
27/04/2017	09:15:02	SA1702_ENV23	Still	SA1702_ENV	2022	255.4	539807.25	8481170.65	539845.91	8481202.94	50.4	
27/04/2017	09:15:30	SA1702_ENV23	Still	SA1702_ENV	2023	255.4	539807.25	8481170.65	539848.81	8481206.76	55.1	
27/04/2017	09:15:55	SA1702_ENV23	Still	SA1702_ENV	2024	255.9	539807.25	8481170.65	539851.98	8481210.04	59.6	
27/04/2017	09:16:04	SA1702_ENV23	Still	SA1702_ENV	2025	255.6	539807.25	8481170.65	539853.02	8481211.32	61.2	
27/04/2017	09:16:33	SA1702_ENV23	Still	SA1702_ENV	2026	255.1	539807.25	8481170.65	539856.41	8481215.50	66.5	
27/04/2017	09:16:57	SA1702_ENV23	Still	SA1702_ENV	2027	255.8	539807.25	8481170.65	539858.70	8481218.21	70.1	
27/04/2017	09:17:52	SA1702_ENV23	Still	SA1702_ENV	2028	255.8	539807.25	8481170.65	539865.29	8481223.96	78.8	
27/04/2017	09:18:50	SA1702_ENV23	Still	SA1702_ENV	2029	256.6	539807.25	8481170.65	539872.47	8481231.31	89.1	
27/04/2017	09:19:20	SA1702_ENV23	Still	SA1702_ENV	2030	256.6	539807.25	8481170.65	539875.85	8481234.76	93.9	
27/04/2017	09:19:46	SA1702_ENV23	Still	SA1702_ENV	2031	257.1	539807.25	8481170.65	539878.86	8481237.98	98.3	
27/04/2017	09:20:34	SA1702_ENV23	Still	SA1702_ENV	2032	256.8	539807.25	8481170.65	539885.73	8481243.28	106.9	
27/04/2017	09:21:02	SA1702_ENV23	Still	SA1702_ENV	2033	257.1	539807.25	8481170.65	539889.86	8481246.23	112.0	
27/04/2017	09:21:18	SA1702_ENV23	Still	SA1702_ENV	2034	257.1	539807.25	8481170.65	539892.07	8481247.33	114.3	
27/04/2017	09:21:48	SA1702_ENV23	Still	SA1702_ENV	2035	257.2	539807.25	8481170.65	539895.98	8481250.28	119.2	
27/04/2017	09:22:12	SA1702_ENV23	Still	SA1702_ENV	2036	257.4	539807.25	8481170.65	539898.96	8481252.58	123.0	
27/04/2017	09:22:30	SA1702_ENV23	Still	SA1702_ENV	2037	257.3	539807.25	8481170.65	539900.81	8481254.14	125.4	
30/04/2017	14:32:16	SA1702_ENV29	Still	SA1702_ENV	2101	165.0	661390.26	8566820.76	661323.45	8566816.04	67.0	
30/04/2017	14:32:20	SA1702_ENV29	Still	SA1702_ENV	2102	165.1	661390.26	8566820.76	661323.46	8566816.05	67.0	
30/04/2017	14:32:27	SA1702_ENV29	Still	SA1702_ENV	2103	164.8	661390.26	8566820.76	661323.50	8566816.20	66.9	
30/04/2017	14:32:57	SA1702_ENV29	Still	SA1702_ENV	2104	164.5	661390.26	8566820.76	661323.78	8566817.17	66.6	
30/04/2017	14:33:18	SA1702_ENV29	Still	SA1702_ENV	2105	164.7	661390.26	8566820.76	661324.88	8566817.93	65.4	
30/04/2017	14:34:49	SA1702_ENV29	Still	SA1702_ENV	2106	164.4	661390.26	8566820.76	661335.89	8566818.92	54.4	
30/04/2017	14:36:22	SA1702_ENV29	Still	SA1702_ENV	2107	164.5	661390.26	8566820.76	661351.64	8566819.78	38.6	
30/04/2017	14:36:41	SA1702_ENV29	Still	SA1702_ENV	2108	164.4	661390.26	8566820.76	661355.16	8566820.65	35.1	
30/04/2017	14:37:20	SA1702_ENV29	Still	SA1702_ENV	2109	164.4	661390.26	8566820.76	661363.63	8566820.68	26.6	
30/04/2017	14:37:51	SA1702_ENV29	Still	SA1702_ENV	2110	164.9	661390.26	8566820.76	661370.66	8566820.64	19.6	
30/04/2017	20:56:40	SA1702_ENV08	Still	SA1702_ENV	2201	180.1	656192.87	8559557.34	656141.77	8559588.03	59.6	

GDA94, MGA94, UTM Zone 51, CM123 °East												
Date	Time [UTC]	Transect	Type	ID	Fix No.	Water Depth [m]	Proposed Location		Actual Location		Offset [m]	Notes
							Easting [m]	Northing [m]	Easting [m]	Northing [m]		
30/04/2017	20:57:26	SA1702_ENV08	Still	SA1702_ENV	2202	180.0	656192.87	8559557.34	656144.63	8559587.79	57.0	
30/04/2017	20:58:03	SA1702_ENV08	Still	SA1702_ENV	2203	180.5	656192.87	8559557.34	656150.85	8559587.17	51.5	
30/04/2017	20:58:30	SA1702_ENV08	Still	SA1702_ENV	2204	180.1	656192.87	8559557.34	656155.36	8559585.77	47.1	
30/04/2017	20:58:38	SA1702_ENV08	Still	SA1702_ENV	2205	180.8	656192.87	8559557.34	656156.24	8559585.16	46.0	
30/04/2017	20:59:34	SA1702_ENV08	Still	SA1702_ENV	2206	179.7	656192.87	8559557.34	656163.22	8559579.76	37.2	
30/04/2017	21:01:04	SA1702_ENV08	Still	SA1702_ENV	2207	180.6	656192.87	8559557.34	656175.11	8559569.69	21.6	
30/04/2017	21:01:54	SA1702_ENV08	Still	SA1702_ENV	2208	179.9	656192.87	8559557.34	656181.84	8559564.47	13.1	
30/04/2017	21:02:28	SA1702_ENV08	Still	SA1702_ENV	2209	179.5	656192.87	8559557.34	656187.18	8559560.85	6.7	
30/04/2017	21:04:34	SA1702_ENV08	Still	SA1702_ENV	2210	179.4	656192.87	8559557.34	656200.04	8559552.38	8.7	
30/04/2017	21:04:47	SA1702_ENV08	Still	SA1702_ENV	2211	179.6	656192.87	8559557.34	656202.00	8559551.92	10.6	
30/04/2017	21:05:19	SA1702_ENV08	Still	SA1702_ENV	2212	179.3	656192.87	8559557.34	656206.92	8559550.80	15.5	
30/04/2017	21:05:44	SA1702_ENV08	Still	SA1702_ENV	2213	179.7	656192.87	8559557.34	656211.32	8559549.45	20.1	
30/04/2017	21:05:50	SA1702_ENV08	Still	SA1702_ENV	2214	179.5	656192.87	8559557.34	656211.96	8559549.34	20.7	
30/04/2017	21:05:55	SA1702_ENV08	Still	NO STILL	2215	180.3	656192.87	8559557.34	656212.66	8559549.15	21.4	
30/04/2017	21:07:46	SA1702_ENV08	Still	SA1702_ENV	2216	179.9	656192.87	8559557.34	656230.40	8559541.80	40.6	
30/04/2017	21:08:34	SA1702_ENV08	Still	SA1702_ENV	2217	180.0	656192.87	8559557.34	656238.58	8559537.68	49.8	
30/04/2017	21:09:02	SA1702_ENV08	Still	SA1702_ENV	2218	179.4	656192.87	8559557.34	656243.22	8559534.52	55.3	
30/04/2017	21:09:13	SA1702_ENV08	Still	SA1702_ENV	2219	179.8	656192.87	8559557.34	656244.99	8559533.15	57.5	
30/04/2017	21:10:32	SA1702_ENV08	Still	SA1702_ENV	2220	179.8	656192.87	8559557.34	656257.67	8559525.35	72.3	
30/04/2017	21:11:26	SA1702_ENV08	Still	SA1702_ENV	2221	179.6	656192.87	8559557.34	656265.72	8559519.65	82.0	
30/04/2017	21:11:50	SA1702_ENV08	Still	SA1702_ENV	2222	179.4	656192.87	8559557.34	656269.10	8559516.81	86.3	
30/04/2017	21:12:05	SA1702_ENV08	Still	SA1702_ENV	2223	179.5	656192.87	8559557.34	656271.25	8559515.25	89.0	
30/04/2017	21:12:25	SA1702_ENV08	Still	SA1702_ENV	2224	179.6	656192.87	8559557.34	656274.06	8559513.49	92.3	
30/04/2017	21:13:03	SA1702_ENV08	Still	SA1702_ENV	2225	179.3	656192.87	8559557.34	656279.98	8559509.09	99.6	
30/04/2017	21:13:28	SA1702_ENV08	Still	SA1702_ENV	2226	179.1	656192.87	8559557.34	656283.96	8559506.73	104.2	
30/04/2017	21:13:58	SA1702_ENV08	Still	SA1702_ENV	2227	179.8	656192.87	8559557.34	656288.03	8559503.30	109.4	
30/04/2017	21:14:27	SA1702_ENV08	Still	SA1702_ENV	2228	179.2	656192.87	8559557.34	656292.05	8559500.67	114.2	

GDA94, MGA94, UTM Zone 51, CM123 °East												
Date	Time [UTC]	Transect	Type	ID	Fix No.	Water Depth [m]	Proposed Location		Actual Location		Offset [m]	Notes
							Easting [m]	Northing [m]	Easting [m]	Northing [m]		
30/04/2017	21:15:09	SA1702_ENV08	Still	SA1702_ENV	2229	180.0	656192.87	8559557.34	656297.45	8559496.00	121.2	
01/05/2017	01:41:40	SA1702_ENV10	Still	SA1702_ENV	2301	209.0	618604.16	8548495.23	618683.31	8548453.19	89.6	
01/05/2017	01:42:42	SA1702_ENV10	Still	SA1702_ENV	2302	209.8	618604.16	8548495.23	618683.01	8548449.17	91.3	
01/05/2017	01:46:41	SA1702_ENV10	Still	SA1702_ENV	2303	209.3	618604.16	8548495.23	618663.95	8548456.38	71.3	
01/05/2017	01:48:04	SA1702_ENV10	Still	SA1702_ENV	2304	211.0	618604.16	8548495.23	618648.22	8548469.12	51.2	
01/05/2017	01:48:50	SA1702_ENV10	Still	SA1702_ENV	2305	210.1	618604.16	8548495.23	618639.44	8548476.50	39.9	
01/05/2017	01:49:31	SA1702_ENV10	Still	SA1702_ENV	2306	209.6	618604.16	8548495.23	618632.06	8548482.61	30.6	
01/05/2017	01:49:35	SA1702_ENV10	Still	SA1702_ENV	2307	209.7	618604.16	8548495.23	618631.22	8548483.00	29.7	
01/05/2017	01:49:38	SA1702_ENV10	Still	NO STILL	2308	209.7	618604.16	8548495.23	618630.75	8548483.70	29.0	
01/05/2017	01:50:19	SA1702_ENV10	Still	SA1702_ENV	2309	210.4	618604.16	8548495.23	618623.05	8548488.64	20.0	
01/05/2017	01:51:10	SA1702_ENV10	Still	SA1702_ENV	2310	209.9	618604.16	8548495.23	618613.54	8548494.61	9.4	
01/05/2017	01:52:05	SA1702_ENV10	Still	SA1702_ENV	2311	209.4	618604.16	8548495.23	618601.95	8548498.38	3.8	
01/05/2017	01:52:41	SA1702_ENV10	Still	SA1702_ENV	2312	210.6	618604.16	8548495.23	618594.15	8548501.68	11.9	
01/05/2017	01:53:06	SA1702_ENV10	Still	SA1702_ENV	2313	210.3	618604.16	8548495.23	618590.15	8548502.32	15.7	
01/05/2017	01:53:45	SA1702_ENV10	Still	SA1702_ENV	2314	210.5	618604.16	8548495.23	618583.90	8548501.62	21.2	
01/05/2017	01:55:05	SA1702_ENV10	Still	SA1702_ENV	2315	209.4	618604.16	8548495.23	618570.61	8548496.42	33.6	
01/05/2017	01:55:37	SA1702_ENV10	Still	SA1702_ENV	2316	209.6	618604.16	8548495.23	618563.37	8548495.89	40.8	
01/05/2017	01:56:06	SA1702_ENV10	Still	SA1702_ENV	2317	209.8	618604.16	8548495.23	618555.81	8548494.13	48.4	
01/05/2017	01:56:29	SA1702_ENV10	Still	SA1702_ENV	2318	210.6	618604.16	8548495.23	618550.04	8548493.73	54.1	
01/05/2017	01:57:00	SA1702_ENV10	Still	SA1702_ENV	2319	209.9	618604.16	8548495.23	618541.85	8548492.39	62.4	
01/05/2017	01:57:57	SA1702_ENV10	Still	SA1702_ENV	2320	210.2	618604.16	8548495.23	618523.30	8548494.06	80.9	
01/05/2017	01:58:04	SA1702_ENV10	Still	SA1702_ENV	2321	211.0	618604.16	8548495.23	618521.61	8548493.37	82.6	
01/05/2017	01:58:41	SA1702_ENV10	Still	SA1702_ENV	2322	211.0	618604.16	8548495.23	618509.84	8548494.50	94.3	
01/05/2017	01:58:53	SA1702_ENV10	Still	SA1702_ENV	2323	210.5	618604.16	8548495.23	618504.83	8548496.31	99.3	
01/05/2017	01:59:46	SA1702_ENV10	Still	SA1702_ENV	2324	210.2	618604.16	8548495.23	618488.25	8548501.03	116.1	
01/05/2017	02:00:19	SA1702_ENV10	Still	SA1702_ENV	2325	210.2	618604.16	8548495.23	618478.53	8548502.39	125.8	
01/05/2017	02:00:39	SA1702_ENV10	Still	SA1702_ENV	2326	210.1	618604.16	8548495.23	618473.00	8548502.92	131.4	

GDA94, MGA94, UTM Zone 51, CM123 °East												
Date	Time [UTC]	Transect	Type	ID	Fix No.	Water Depth [m]	Proposed Location		Actual Location		Offset [m]	Notes
							Easting [m]	Northing [m]	Easting [m]	Northing [m]		
01/05/2017	02:00:56	SA1702_ENV10	Still	SA1702_ENV	2327	210.7	618604.16	8548495.23	618467.35	8548503.95	137.1	
01/05/2017	02:01:07	SA1702_ENV10	Still	SA1702_ENV	2328	210.7	618604.16	8548495.23	618464.38	8548504.31	140.1	
01/05/2017	02:01:36	SA1702_ENV10	Still	SA1702_ENV	2329	210.7	618604.16	8548495.23	618455.47	8548506.01	149.1	
01/05/2017	02:01:54	SA1702_ENV10	Still	SA1702_ENV	2330	210.8	618604.16	8548495.23	618450.83	8548506.59	153.8	
01/05/2017	02:02:21	SA1702_ENV10	Still	SA1702_ENV	2331	210.3	618604.16	8548495.23	618444.18	8548506.70	160.4	
01/05/2017	02:02:43	SA1702_ENV10	Still	NO STILL	2332	210.3	618604.16	8548495.23	618438.29	8548506.75	166.3	
01/05/2017	02:03:03	SA1702_ENV10	Still	SA1702_ENV	2333	210.0	618604.16	8548495.23	618433.20	8548506.01	171.3	
01/05/2017	02:03:33	SA1702_ENV10	Still	SA1702_ENV	2334	210.6	618604.16	8548495.23	618425.19	8548506.09	179.3	
01/05/2017	02:03:47	SA1702_ENV10	Still	SA1702_ENV	2335	210.8	618604.16	8548495.23	618421.71	8548505.85	182.8	
01/05/2017	02:04:05	SA1702_ENV10	Still	SA1702_ENV	2336	211.2	618604.16	8548495.23	618416.68	8548505.49	187.8	
01/05/2017	02:04:14	SA1702_ENV10	Still	SA1702_ENV	2337	211.1	618604.16	8548495.23	618414.16	8548506.14	190.3	
01/05/2017	02:04:21	SA1702_ENV10	Still	SA1702_ENV	2338	210.8	618604.16	8548495.23	618412.54	8548506.30	191.9	
01/05/2017	02:04:35	SA1702_ENV10	Still	SA1702_ENV	2339	211.3	618604.16	8548495.23	618407.98	8548506.54	196.5	
01/05/2017	02:04:50	SA1702_ENV10	Still	SA1702_ENV	2340	211.6	618604.16	8548495.23	618402.88	8548507.47	201.7	
01/05/2017	02:05:01	SA1702_ENV10	Still	SA1702_ENV	2341	211.6	618604.16	8548495.23	618399.86	8548508.09	204.7	
01/05/2017	02:05:29	SA1702_ENV10	Still	SA1702_ENV	2342	210.4	618604.16	8548495.23	618392.59	8548508.28	212.0	
01/05/2017	07:42:25	SA1702_ENV16	Still	SA1702_ENV	2401	171.6	572916.72	8513079.05	572969.77	8513096.64	55.9	
01/05/2017	07:43:00	SA1702_ENV16	Still	SA1702_ENV	2402	172.2	572916.72	8513079.05	572968.18	8513091.77	53.0	
01/05/2017	07:43:14	SA1702_ENV16	Still	SA1702_ENV	2403	172.6	572916.72	8513079.05	572967.86	8513090.59	52.4	
01/05/2017	07:44:41	SA1702_ENV16	Still	SA1702_ENV	2404	171.6	572916.72	8513079.05	572960.81	8513084.27	44.4	
01/05/2017	07:45:00	SA1702_ENV16	Still	NO STILL	2405	171.2	572916.72	8513079.05	572957.91	8513083.05	41.4	
01/05/2017	07:45:58	SA1702_ENV16	Still	SA1702_ENV	2406	170.8	572916.72	8513079.05	572951.46	8513080.97	34.8	
01/05/2017	07:47:20	SA1702_ENV16	Still	SA1702_ENV	2407	171.6	572916.72	8513079.05	572940.84	8513078.40	24.1	
01/05/2017	07:47:57	SA1702_ENV16	Still	SA1702_ENV	2408	172.4	572916.72	8513079.05	572934.01	8513077.60	17.4	
01/05/2017	07:48:30	SA1702_ENV16	Still	SA1702_ENV	2409	171.5	572916.72	8513079.05	572927.73	8513077.44	11.1	
01/05/2017	07:49:04	SA1702_ENV16	Still	NO STILL	2410	170.8	572916.72	8513079.05	572922.40	8513078.47	5.7	
01/05/2017	07:50:16	SA1702_ENV16	Still	SA1702_ENV	2411	171.1	572916.72	8513079.05	572908.79	8513079.51	7.9	

GDA94, MGA94, UTM Zone 51, CM123 °East												
Date	Time [UTC]	Transect	Type	ID	Fix No.	Water Depth [m]	Proposed Location		Actual Location		Offset [m]	Notes
							Easting [m]	Northing [m]	Easting [m]	Northing [m]		
01/05/2017	07:50:54	SA1702_ENV16	Still	SA1702_ENV	2412	170.9	572916.72	8513079.05	572900.12	8513079.59	16.6	
01/05/2017	07:50:59	SA1702_ENV16	Still	SA1702_ENV	2413	172.0	572916.72	8513079.05	572898.66	8513079.78	18.1	
01/05/2017	07:51:29	SA1702_ENV16	Still	SA1702_ENV	2414	170.6	572916.72	8513079.05	572891.47	8513080.13	25.3	
01/05/2017	07:52:29	SA1702_ENV16	Still	SA1702_ENV	2415	170.8	572916.72	8513079.05	572877.64	8513081.73	39.2	
01/05/2017	07:52:56	SA1702_ENV16	Still	SA1702_ENV	2416	171.2	572916.72	8513079.05	572872.18	8513082.63	44.7	
01/05/2017	07:53:10	SA1702_ENV16	Still	SA1702_ENV	2417	171.0	572916.72	8513079.05	572869.95	8513083.09	46.9	
01/05/2017	07:53:55	SA1702_ENV16	Still	SA1702_ENV	2418	170.9	572916.72	8513079.05	572863.09	8513084.66	53.9	
01/05/2017	07:54:27	SA1702_ENV16	Still	SA1702_ENV	2419	171.7	572916.72	8513079.05	572857.41	8513084.99	59.6	
01/05/2017	07:54:44	SA1702_ENV16	Still	SA1702_ENV	2420	171.2	572916.72	8513079.05	572854.85	8513085.53	62.2	
01/05/2017	07:55:32	SA1702_ENV16	Still	SA1702_ENV	2421	171.3	572916.72	8513079.05	572846.40	8513085.30	70.6	
01/05/2017	07:55:58	SA1702_ENV16	Still	SA1702_ENV	2422	171.5	572916.72	8513079.05	572841.08	8513084.04	75.8	
01/05/2017	07:56:02	SA1702_ENV16	Still	SA1702_ENV	2423	171.9	572916.72	8513079.05	572840.15	8513083.96	76.7	
01/05/2017	07:56:12	SA1702_ENV16	Still	NO STILL	2424	170.9	572916.72	8513079.05	572838.26	8513083.62	78.6	
01/05/2017	07:57:09	SA1702_ENV16	Still	SA1702_ENV	2425	171.7	572916.72	8513079.05	572823.82	8513079.35	92.9	
01/05/2017	07:57:51	SA1702_ENV16	Still	SA1702_ENV	2426	171.9	572916.72	8513079.05	572813.29	8513078.33	103.4	
01/05/2017	07:58:10	SA1702_ENV16	Still	SA1702_ENV	2427	171.6	572916.72	8513079.05	572808.28	8513077.48	108.5	
01/05/2017	07:58:21	SA1702_ENV16	Still	NO STILL	2428	171.9	572916.72	8513079.05	572805.81	8513077.88	110.9	
01/05/2017	07:58:48	SA1702_ENV16	Still	SA1702_ENV	2429	171.7	572916.72	8513079.05	572800.23	8513078.02	116.5	

A.2 VIDEO/PHOTOGRAPHIC LOG

GDA94, MGA94, UTM Zone 51, CM123 °East									
Date	Transect	Video File	Time [UTC]	Video Coordinates		Length [m]	Still Nos.	Sediment Description	Fauna/Bioturbation/Debris
				Easting [m]	Northing [m]				
22/04/2017	SA1702_ENV02	20170422052614_1	05:26:13	661531.53	8571433.04	16	3	Reef with gravelly sand veneer	Sea whip (Alcyonacea), fan coral (Alcyonacea), branching coral (Alcyonacea), hydroids (Hydrozoa), sea anemones (Actiniaria)
			05:28:49	661519.01	8571422.76				
22/04/2017	SA1702_ENV02	20170422052614_1	05:28:49	661519.01	8571422.76	10	1	Sand	Burrows, hydroids (Hydrozoa)
			05:30:07	661512.76	8571415.31				
22/04/2017	SA1702_ENV02	20170422052614_1	05:30:07	661512.76	8571415.31	140	10	Reef with gravelly sand veneer	Sea whip (Alcyonacea), fan coral (Alcyonacea), hydroids (Hydrozoa), branching coral (Alcyonacea), sponges (Porifera), barrel sponges (Porifera), sea cucumber, fish, cryptic coral
			05:43:08	661422.80	8571308.30				
22/04/2017	SA1702_ENV02	20170422052614_1	05:43:08	661422.80	8571308.30	149	17	Reef with sand veneer	Sea whip (Alcyonacea), fan coral (Alcyonacea), hydroids (Hydrozoa), branching coral (Alcyonacea), sponges (Porifera), fish, dead coral
			05:56:42	661326.94	8571193.89				
22/04/2017	SA1702_ENV02	20170422052614_2	05:56:42	661326.94	8571193.89	101	10	Reef with sand veneer	Fish, fan coral (Alcyonacea), branching coral (Alcyonacea), hydroids (Hydrozoa), sea whip (Alcyonacea), dead coral
			06:06:07	661262.88	8571115.98				
22/04/2017	SA1702_ENV02	20170422052614_2	06:06:07	661262.88	8571115.98	20	2	Sand	Burrows, hydroids (Hydrozoa)
			06:08:04	661250.56	8571100.11				
22/04/2017	SA1702_ENV02	20170422052614_2	06:08:04	661250.56	8571100.11	8	1	Reef boulders with sand veneer	Hydroids (Hydrozoa), branching coral (Alcyonacea), fan coral (Alcyonacea), fish
			06:08:49	661246.25	8571093.52				
22/04/2017	SA1702_ENV02	20170422052614_2	06:08:49	661246.25	8571093.52	74	9	Sand forming ripples	Burrows, hydroids (Hydrozoa), faunal tracks
			06:15:39	661202.72	8571033.20				
22/04/2017	SA1702_ENV01	20170424034654	11:05:22	663708.71	8570789.01	49	6	Gravelly sand	Soft coral (Alcyonaria), sea cucumber (Holothuridae), hydroids (Hydrozoa), fish, flat fish
			11:09:28	663681.20	8570747.95				
22/04/2017	SA1702_ENV01	20170424034654	11:09:28	663681.20	8570747.95	25	5	Reef with gravelly sand veneer	Fish, hydroids (Hydrozoa)
			11:12:14	663666.45	8570727.24				
22/04/2017	SA1702_ENV01	20170424034654	11:12:14	663666.45	8570727.24	177	25	Gravelly sand	Soft coral (Alcyonaria), hydroids (Hydrozoa), sea cucumber? (Holothuridae), fish, sea pen
			11:30:37	663570.85	8570578.62				

GDA94, MGA94, UTM Zone 51, CM123 °East									
Date	Transect	Video File	Time [UTC]	Video Coordinates		Length [m]	Still Nos.	Sediment Description	Fauna/Bioturbation/Debris
				Easting [m]	Northing [m]				
									(Pennatulacea), burrows, sea urchin (Echinoidea), sea whip (Alcyonacea), burrows, sea anemones (Actiniaria)
23/04/2017	SA1702_ENV03	20170423004121_1	00:41:21	657509.58	8568862.76	321	32	Sand forming ripples	Burrows, sea pen (Pennatulacea), sea urchin (Echinoidea), hydroids (Hydrozoa)
			01:11:49	657793.18	8568711.71				
23/04/2017	SA1702_ENV03	20170423004121_2	01:11:50	657793.50	8568711.42	24	3	Sand forming ripples	Burrows
			01:14:11	657814.66	8568700.43				
23/04/2017	SA1702_ENV04	20170423032326	03:23:25	656229.20	8566668.33	204	21	Sand forming ripples	Sea anemones (Actiniaria), tubular glass sponges (Porifera), burrows, stalked crinoid (Isselicrinidae), sea urchin (Echinoidea), fish, hydroids (Hydrozoa)
			03:39:24	656078.04	8566531.18				
23/04/2017	SA1702_ENV05	20170423044616	04:46:16	656387.08	8565625.02	178	22	Gravelly sand	burrows, sea anemones (Actiniaria), hydroids (Hydrozoa), tubular glass sponges (Porifera), soft coral (Alcyonaria), sea whip (Alcyonacea)
			05:02:51	656536.53	8565722.02				
23/04/2017	SA1702_ENV05	20170423044616	05:02:51	656536.53	8565722.02	99	10	Reef covered by gravelly sand veneer	Soft coral (Alcyonaria), sponges (Porifera), hydroids (Hydrozoa), stalked crinoids (Isselicrinidae), fish, burrows, laminar sponge (Porifera), sea urchin (Echinoidea)
			05:11:51	656619.49	8565775.63				
23/04/2017	SA1702_ENV05A	20170423112046	11:20:46	656566.11	8565740.66	40	6	Gravelly sand	Stalked crinoids (Isselicrinidae), hydroids (Hydrozoa), sea urchin, fish, sponge (Porifera), soft coral (Nephtheidae), bryozoan, burrows
			11:25:00	656600.83	8565760.34				
23/04/2017	SA1702_ENV05A	20170423112046	11:25:00	656600.83	8565760.34	68	12	Outcropping of hard substrate	Stalked crinoids (Isselicrinidae), hydroids (Hydrozoa), sea urchin (Echinoidea), fish, sponge, branching coral (Alcyonacea), bryozoan, burrows, tubular sponges (Porifera), sea whips (Alcyonacea)
			11:31:01	656658.56	8565796.47				
23/04/2017	SA1702_ENV05A	20170423112046	11:31:01	656658.56	8565796.47	90	15	Gravelly sand	Burrows, sponge, branching coral (Alcyonacea), sea anemone (Actiniaria), hydroids (Hydrozoa), crinoids (Crinoidea), sea urchins (Echinoidea)
			11:39:25	656735.03	8565844.19				
24/04/2017	SA1702_ENV06	20170423034654	03:46:54	657760.40	8564621.35	185	10*	Sand	

GDA94, MGA94, UTM Zone 51, CM123 °East									
Date	Transect	Video File	Time [UTC]	Video Coordinates		Length [m]	Still Nos.	Sediment Description	Fauna/Bioturbation/Debris
				Easting [m]	Northing [m]				
			04:01:01	657902.12	8564740.05				sea anemones (Actiniaria), burrows, fish, hydroids (Hydrozoa), tubular glass sponge (Porifera), sea urchin (Echinoidea)
24/04/2017	SA1702_ENV07	20170424062728_1	06:27:28	654189.3	8562374.6	320	13*	Sand forming ripples	Burrows, hermit crab (Paguroidea), sea potato (Echinoidea), fish, sea urchin (Echinoidea)
			06:58:06	654465.85	8562213.90				
24/04/2017	SA1702_ENV07	20170424062728_2	06:58:06	654465.85	8562213.90	12	3*	Sand forming ripples	Burrows
			06:59:10	654475.98	8562207.63				
24/04/2017	SA1702_ENV09	20170424120541	12:05:40	629714.45	8554194.01	63	9	Gravelly sand	Fish, sea anemones (Actiniaria)
			12:13:30	629653.94	8554211.67				
24/04/2017	SA1702_ENV09A	20170424124209	12:42:08	629457.86	8554276.82	148	14	Gravelly sand	Fish, burrows
			12:54:43	629598.00	8554229.66				
24/04/2017	SA1702_ENV09A	20170424124209	12:54:43	629598.00	8554229.66	5	3	Reef rubble with gravelly sand veneer	Stalked crinoids (Isselicrinidae), sponges (Porifera), hydroids (Hydrozoa), fish
			12:55:04	629602.41	8554228.59				
24/04/2017	SA1702_ENV09A	20170424124209	12:55:04	629602.41	8554228.59	62	7	Gravelly sand	Fish, burrows
			12:59:43	629663.36	8554219.02				
24/04/2017	SA1702_ENV11	20170424223209	22:32:08	604638.61	8540051.69	36	6	Sandy gravel	Fish
			22:36:12	604623.92	8540018.48				
24/04/2017	SA1702_ENV11	20170424223209	22:36:12	604623.92	8540018.48	22	2	Gravelly sand forming ripples	Fish
			22:38:29	604619.19	8539996.51				
24/04/2017	SA1702_ENV11	20170424223209	22:38:29	604619.19	8539996.51	27	4	Sandy gravel	No visible fauna
			22:41:00	604609.38	8539971.82				
24/04/2017	SA1702_ENV11	20170424223209	22:41:00	604609.38	8539971.82	28	4	Sand forming ripples	No visible fauna
			22:43:35	604601.34	8539944.58				
24/04/2017	SA1702_ENV11	20170424223209	22:43:35	604601.34	8539944.58	70	8	Gravelly sand	No visible fauna
			22:50:16	604573.48	8539880.46				
24/04/2017	SA1702_ENV11	20170424223209	22:50:16	604573.48	8539880.46	43	11	Reef with sand veneer	Sea pen (Pennatulacea), crinoid (Crinoidea), sponge (Porifera)
			22:54:15	604559.80	8539839.63				

GDA94, MGA94, UTM Zone 51, CM123 °East									
Date	Transect	Video File	Time [UTC]	Video Coordinates		Length [m]	Still Nos.	Sediment Description	Fauna/Bioturbation/Debris
				Easting [m]	Northing [m]				
25/04/2017	SA1702_ENV12	20170425004905	00:49:04	602451.71	8537279.04	312	49	Reef with sand veneer	Stalked crinoid (Isselicrinidae), sponge (Porifera), starfish (Asteroidea), sea anemone (Actiniaria), branched coral (Alcyonacea), crinoids (Crinoidea), sea urchins (Echinoidea), burrows
			01:18:43	602283.90	8537016.35				
25/04/2017	SA1702_ENV13	20170425041526	04:15:25	597039.12	8533100.50	287	33	Sand forming ripples, shell fragments	Burrows, fish
			04:45:39	597117.33	8532824.13				
25/04/2017	SA1702_ENV14	20170425041526	09:14:57	585598.47	8524336.86	56	9	Sand	fish, burrows, faunal tracks
			09:22:41	585577.81	8524284.77				
25/04/2017	SA1702_ENV14	20170425041526	09:22:41	585577.81	8524284.77	14	5	Depression, reef rubble with sand veneer	No visible fauna
			09:24:02	585574.56	8524271.51				
25/04/2017	SA1702_ENV14	20170425041526	09:24:02	585574.56	8524271.51	111	14	Sand	Sea urchin (Echinoidea), fish, burrows,
			09:35:06	585551.40	8524163.03				
25/04/2017	SA1702_ENV15	20170425130924	13:09:23	579254.05	8519450.22	34	3	Sand	Burrows, fish
			13:12:24	579253.35	8519416.68				
25/04/2017	SA1702_ENV15	20170425130924	13:12:24	579253.35	8519416.68	53	17	Depression, reef rubble with gravelly sand veneer	Sea whip (Alcyonacea), hydroids (Hydrozoa), fish, sponge (Porifera), stalked crinoid (Isselicrinidae), burrows,
			13:18:13	579258.68	8519363.65				
25/04/2017	SA1702_ENV15	20170425130924	13:18:13	579258.68	8519363.65	149	16	Sand	Burrows, sea pen? (Pennatulacea), fish
			13:31:12	579313.23	8519224.71				
26/04/2017	SA1702_ENV18	20170426004247	00:42:47	559581.08	8500701.19	23	5	Muddy sand	Burrows, branching coral (Alcyonacea), fish
			00:46:20	559564.19	8500685.63				
26/04/2017	SA1702_ENV18	20170426004247	00:46:20	559564.19	8500685.63	23	6	Reef rubble with sand veneer	Sponge, crinoid (Crinoidea), sea anemone (Actiniaria), Soft coral (Alcyonaria), fish
			00:49:53	559547.20	8500669.63				
26/04/2017	SA1702_ENV18	20170426004247	00:49:53	559547.20	8500669.63	74	13	Sand	Burrows, sand dollar (Echinoidea), fish
			00:58:58	559493.79	8500619.12				
26/04/2017	SA1702_ENV18	20170426004247	00:58:58	559493.79	8500619.12	60	17	Reef outcropping	Crinoids (Crinoidea), soft coral (Alcyonaria), sea anemones (Actiniaria), branching coral (Alcyonacea), sea pen
			01:05:58	559444.49	8500584.63				

GDA94, MGA94, UTM Zone 51, CM123 °East									
Date	Transect	Video File	Time [UTC]	Video Coordinates		Length [m]	Still Nos.	Sediment Description	Fauna/Bioturbation/Debris
				Easting [m]	Northing [m]				
									(Pennatulacea), stalked crinoid (Isselicrinidae), fan coral (Alcyonacea), squat lobsters (Anomura), fish, sea urchin (Echinoidea)
26/04/2017	SA1702_ENV18	20170426004247	01:05:58	559444.49	8500584.63	55	10	Reef rubble with sand veneer	Fish, burrows, soft coral (Alcyonaria), stalked crinoid (Isselicrinidae), bryozoan
			01:12:52	559399.17	8500553.92				
26/04/2017	SA1702_ENV19	20170426021026_1	02:10:25	558593.31	8499068.71	111	13	Reef rubble with sand veneer	Fan worms (Sabellidae), burrows, soft coral (Alcyonaria), crinoid (Crinoidea), branching coral (Alcyonacea), sponge (Porifera), sea pen (Pennatulacea), bryozoan, starfish (Asteroidea)
			02:21:08	558485.98	8499097.89				
26/04/2017	SA1702_ENV19	20170426021026_1	02:21:08	558485.98	8499097.89	60	12	Reef with sand veneer, high relief	Burrows, soft coral (Alcyonaria), fan coral (Alcyonacea), sponge (Porifera), sea anemone (Actiniaria), branching coral (Alcyonacea),
			02:25:33	558427.98	8499112.97				
26/04/2017	SA1702_ENV19	20170426021026_1	02:25:33	558427.98	8499112.97	135	19	Reef with sand veneer	Soft coral (Alcyonaria), sponges (Porifera), sea urchin (Echinoidea), fan coral (Alcyonacea), fan worms (Sabellidae), sea pen (Pennatulacea), acorn worm casing (Enteropneusta), sea anemone (Actiniaria), faunal tracks, burrows
			02:34:49	558296.46	8499145.13				
26/04/2017	SA1702_ENV19	20170426021026_1	02:34:49	558296.46	8499145.13	67	8	Reef with sand veneer, medium relief	Sponges (Porifera), sea urchin (Echinoidea), branching coral (Alcyonacea), burrows, crab (Decapoda)
			02:39:42	558231.89	8499162.33				
26/04/2017	SA1702_ENV19	20170426021026_1	02:39:42	558231.89	8499162.33	18	1	Sand	Burrows, hermit crab (Paguroidae), sea anemone (Actiniaria)
			02:41:00	558214.84	8499166.55				
26/04/2017	SA1702_ENV19	20170426021026_2	02:41:01	558214.62	8499166.58	17	3	Reef with sand veneer	Burrows, sea anemone (Actiniaria)
			02:42:14	558197.58	8499170.16				
26/04/2017	SA1702_ENV20	20170426063102_1	06:31:02	556518.21	8498104.46	45	4	Muddy sand forming ripples	Burrows, sea urchin (Echinoidea), faunal tracks, hydroids (Hydrozoa)
			06:36:54	556550.93	8498073.26				
26/04/2017	SA1702_ENV20	20170426063102_1	06:36:54	556550.93	8498073.26	64	8	Muddy sand	Burrows, sea pen (Pennatulacea)
			06:42:51	556598.25	8498030.83				

GDA94, MGA94, UTM Zone 51, CM123 °East									
Date	Transect	Video File	Time [UTC]	Video Coordinates		Length [m]	Still Nos.	Sediment Description	Fauna/Bioturbation/Debris
				Easting [m]	Northing [m]				
26/04/2017	SA1702_ENV20	20170426063102_1	06:42:51	556598.25	8498030.83	193	40	Reef rubble with veneer of muddy sand	Laminar sponge (Porifera), soft coral (Alcyonaria), sea anemone (Actiniaria), burrows, hydroids (Hydrozoa), sea whip (Alcyonacea), sponge (Porifera), stalked crinoid (Isselicrinidae), sea cucumber (Holothuridae), starfish (Asteroidea)
			07:01:19	556747.26	8497908.49				
26/04/2017	SA1702_ENV20	20170426063102_2	07:01:20	556747.26	8497908.49	73	13	Reef rubble with veneer of muddy sand	Sponge (Porifera), branching coral (Alcyonacea), starfish (Asteroidea), laminar sponge (Porifera), burrows
			07:07:05	556797.92	8497856.37				
26/04/2017	SA1702_ENV20	20170426063102_2	07:07:05	556797.92	8497856.37	155	17	Muddy sand	Burrows, fan worm (Sabellidae), sponge (Porifera)
			07:18:18	556905.36	8497744.97				
26/04/2017	SA1702_ENV26	20170426125427_1	12:54:27	559082.60	8491595.79	172	41	Reef with veneer of sand	Sponge (Porifera), hydroids (Hydrozoa), sea anemones (Actiniaria), branching coral (Alcyonacea), tubular sponges (Porifera), sea whip (Alcyonacea), crab (Decapoda), burrows, soft coral (Alcyonaria), crinoids (Crinoidea)
			13:24:50	558942.68	8491495.02				
26/04/2017	SA1702_ENV26	20170426125427_2	13:24:51	558942.76	8491494.65	176	39	Reef with veneer of sand	Sponge (Porifera), starfish (Asteroidea), burrows, fish, sea anemone (Actiniaria), foliose sponge (Porifera), crinoids (Crinoidea), sea snail (Trochidae), squat lobster (Decapoda), lobster (Decapoda), starfish (Asteroidea)
			13:48:36	558785.33	8491415.74				
26/04/2017	SA1702_ENV26	20170426125427_2	13:48:36	558785.33	8491415.74	30	2	Sand forming sand ripples	Hydroids (Hydrozoa), burrows
			13:51:30	558759.19	8491400.81				
26/04/2017	SA1702_ENV26	20170426125427_2	13:51:30	558759.19	8491400.81	29	6	Gravelly sand	Hydroids (Hydrozoa), burrows, crinoids (Crinoidea)
			13:53:59	558732.86	8491388.15				
26/04/2017	SA1702_ENV26	20170426125427_2	13:53:59	558732.86	8491388.15	16	3	Reef with veneer of sand	Sponges (Porifera), sea anemone (Actiniaria), basket star (Phrynophiurida)
			13:55:30	558719.54	8491378.94				
26/04/2017	SA1702_ENV26	20170426125427_3	13:55:30	558719.54	8491378.94	22	5	Reef with veneer of sand	Sea pens (Pennatulacea), burrows, sea cucumber (Holothuridae), sponge (laminar) (Porifera), hydroids (Hydrozoa), soft coral (Alcyonaria),
			13:57:47	558701.54	8491365.67				

GDA94, MGA94, UTM Zone 51, CM123 °East									
Date	Transect	Video File	Time [UTC]	Video Coordinates		Length [m]	Still Nos.	Sediment Description	Fauna/Bioturbation/Debris
				Easting [m]	Northing [m]				
26/04/2017	SA1702_ENV25	20170426145238	14:52:38	557436.38	8490735.70	48	8	Muddy sand	Burrows, hydroids (Hydrozoa), fish, hermit crab (Paguroidea), sea pen (Pennatulacea)
			14:59:19	557417.03	8490691.71				
26/04/2017	SA1702_ENV25	20170426145238	14:59:19	557417.03	8490691.71	96	11	Reef rubble with sand veneer	Soft coral (Alcyonaria), hydroids (Hydrozoa), fish, sponges (Porifera), burrows, sea urchins (Echinoidea), crinoid (Crinoidea)
			15:07:22	557330.77	8490649.12				
26/04/2017	SA1702_ENV25	20170426145238	15:07:22	557330.77	8490649.12	75	11	Muddy sand	Burrows, fish
			15:14:31	557278.17	8490595.75				
26/04/2017	SA1702_ENV21	20170426192216	19:22:16	551827.71	8492890.98	194	28	Muddy sand	Fish, sea anemone (Actiniaria), sea pens (Pennatulacea), ray (Torpediniformes), hermit crab (Paguroidea)
			19:41:41	552021.36	8492888.26				
27/04/2017	SA1702_ENV22	20170427004806	00:48:05	546512.10	8487478.14	225	36	Muddy sand	Burrows, fish
			01:12:13	546339.73	8487622.17				
27/04/2017	SA1702_ENV22	20170427004806	01:12:13	546339.73	8487622.17	40	8	Reef rubble with muddy sand veneer	Soft coral (Alcyonaria), stalked crinoid (Isselicrinidae)
			01:15:59	546309.53	8487649.05				
27/04/2017	SA1702_ENV24	20170427023955	02:39:54	549099.63	8484644.79	196	32	Muddy sand	Burrows, fish, sea urchin (Echinoidea), hydroids (Hydrozoa),
			02:59:21	549290.68	8484600.66				
27/04/2017	SA1702_ENV23	20170427090124	09:01:24	539749.30	8481133.38	196	36	Muddy sand	Burrows, sea urchin (Echinoidea)
			09:22:39	539902.12	8481255.46				
30/04/2017	SA1702_ENV29	20170430143123	14:31:23	661324.94	8566814.76	49	10	Transect aborted due to visibility - footage recorded to show conditions	
			14:38:02	661373.54	8566820.59				
30/04/2017	SA1702_ENV08	20170430205550	20:55:50	656141.51	8559588.55	183	28	Sand, occasional cobble	Fish, sea anemone (Actiniaria), soft coral (Alcyonaria), sea urchins (Echinoidea), hydroids (Hydrozoa), stalked crinoids (Isselicrinidae)
			21:15:14	656298.64	8559495.57				
01/05/2017	SA1702_ENV10	20170501013944	01:39:44	618673.46	8548464.64	12	2	Sand	No visible fauna
			01:46:05	618668.63	8548453.50				
01/05/2017	SA1702_ENV10	20170501013944	01:46:05	618668.63	8548453.50	161	19	Hard substrate (possibly volcanic) with sand veneer forming small sand ripples	No visible fauna
			01:58:31	618512.53	8548493.93				

GDA94, MGA94, UTM Zone 51, CM123 °East									
Date	Transect	Video File	Time [UTC]	Video Coordinates		Length [m]	Still Nos.	Sediment Description	Fauna/Bioturbation/Debris
				Easting [m]	Northing [m]				
01/05/2017	SA1702_ENV10	20170501013944	01:58:31	618512.53	8548493.93	127	19	Hard substrate (possibly volcanic) with sand veneer forming medium sand ripples	No visible fauna
			02:05:49	618386.56	8548508.30				
01/05/2017	SA1702_ENV16	20170501074207	07:42:07	572970.58	8513099.97	173	25	Sand	Starfish (Asteroidea)
			07:58:51	572799.07	8513078.15				

GDA94, MGA94, UTM Zone 51, CM123 °East											
Date	Transect	Video File	Time [UTC]	Classification		Substrate Type	Substrate Composition	Reef Particle Size	Reef Profile	Sediment Particle Size	Sediment Profile	Bioturbation
				Community Type	Habitat Type							
22/04/2017	SA1702_ENV02	20170422052614_1	05:26:13 05:28:49	No macrobiota	Mixed reef	Unconsolidated	Reef 25-49%	Rock (unbroken)	Low	Gravelly sand	Flat	None
22/04/2017	SA1702_ENV02	20170422052614_1	05:28:49 05:30:07	No macrobiota	Soft bottom benthos; sediment	Unconsolidated	Sediment 100%	n/a	n/a	Sand	Flat	None
22/04/2017	SA1702_ENV02	20170422052614_1	05:30:07 05:43:08	Filter feeders	Filter-feeders: reef	Consolidated	Reef 51-75%	Rock (unbroken)	Medium	Gravelly sand	Flat	None
22/04/2017	SA1702_ENV02	20170422052614_1	05:43:08 05:56:42	No macrobiota	Mixed reef	Consolidated	Reef 51-75%	Rock (unbroken)	Medium	Sand	Flat	None
22/04/2017	SA1702_ENV02	20170422052614_2	05:56:42 06:06:07	No macrobiota	Mixed reef	Consolidated	Reef 51-75%	Rock (unbroken)	Medium	Sand	Flat	None
22/04/2017	SA1702_ENV02	20170422052614_2	06:06:07 06:08:04	Burrowing macrofauna	Soft bottom benthos; sediment	Unconsolidated	Sediment 100%	n/a	n/a	Sand	Flat	Medium
22/04/2017	SA1702_ENV02	20170422052614_2	06:08:04 06:08:49	No macrobiota	Mixed reef	Consolidated	Reef 51-75%	Boulder	Low	Sand	Flat	None
22/04/2017	SA1702_ENV02	20170422052614_2	06:08:49 06:15:39	No macrobiota	Soft bottom benthos; sediment	Unconsolidated	Sediment 100%	n/a	n/a	Sand	small ripples	None
22/04/2017	SA1702_ENV01	20170424034654	11:05:22 11:09:28	No macrobiota	Soft bottom benthos; sediment	Unconsolidated	Sediment 100%	n/a	n/a	Gravelly sand	Flat	None
22/04/2017	SA1702_ENV01	20170424034654	11:09:28 11:12:14	No macrobiota	Mixed reef	Consolidated	Reef 51-75%	Rock (unbroken) with boulders	Low	Gravelly sand	Flat	None
22/04/2017	SA1702_ENV01	20170424034654	11:12:14 11:30:37	Burrowing macrofauna	Soft bottom benthos; sediment	Unconsolidated	Sediment 100%	n/a	n/a	Gravelly sand	Flat	Low
23/04/2017	SA1702_ENV03	20170423004121_1	00:41:21 01:11:49	Burrowing macrofauna	Soft bottom benthos; sediment	Unconsolidated	Sediment 100%	n/a	n/a	Sand	small ripples	Low
23/04/2017	SA1702_ENV03	20170423004121_2	01:11:50 01:14:11	Burrowing macrofauna	Soft bottom benthos; sediment	Unconsolidated	Sediment 100%	n/a	n/a	Sand	small ripples	Low

GDA94, MGA94, UTM Zone 51, CM123 °East												
Date	Transect	Video File	Time [UTC]	Classification		Substrate Type	Substrate Composition	Reef Particle Size	Reef Profile	Sediment Particle Size	Sediment Profile	Bioturbation
				Community Type	Habitat Type							
23/04/2017	SA1702_ENV04	20170423032326	03:23:25	Burrowing macrofauna	Soft bottom benthos; sediment	Unconsolidated	Sediment 100%	n/a	n/a	Sand	small ripples	Low
			03:39:24									
23/04/2017	SA1702_ENV05	20170423044616	04:46:16	Burrowing macrofauna	Soft bottom benthos; sediment	Unconsolidated	Sediment 100%	n/a	n/a	Gravelly sand	small ripples	Medium
			05:02:51									
23/04/2017	SA1702_ENV05	20170423044616	05:02:51	Burrowing macrofauna	Mixed reef	Unconsolidated	Reef 1-24%	Cobbles	Low	Sand	Flat	Medium
			05:11:51									
23/04/2017	SA1702_ENV05A	20170423112046	11:20:46	Burrowing macrofauna	Mixed reef	Unconsolidated	Reef 1-24%	Cobbles	Low	Sand	Flat	Medium
			11:25:00									
23/04/2017	SA1702_ENV05A	20170423112046	11:25:00	Filter feeders	Filter-feeders: reef	Consolidated	Reef 51-75%	Rock (unbroken) with cobbles	Low	Sand	Flat	None
			11:31:01									
23/04/2017	SA1702_ENV05A	20170423112046	11:31:01	Burrowing macrofauna	Soft bottom benthos; sediment	Unconsolidated	Sediment 100%	n/a	n/a	Gravelly Sand	Flat	Medium
			11:39:25									
24/04/2017	SA1702_ENV06	20170423034654	03:46:54	Burrowing macrofauna	Soft bottom benthos; sediment	Unconsolidated	Sediment 100%	n/a	n/a	Sand	Flat	Medium
			04:01:01									
24/04/2017	SA1702_ENV07	20170424062728_1	06:27:28	Burrowing macrofauna	Soft bottom benthos; sediment	Unconsolidated	Sediment 100%	n/a	n/a	Sand	small ripples	Low
			06:58:06									
24/04/2017	SA1702_ENV07	20170424062728_2	06:58:06	Burrowing macrofauna	Soft bottom benthos; sediment	Unconsolidated	Sediment 100%	n/a	n/a	Sand	small ripples	Low
			06:59:10									
24/04/2017	SA1702_ENV09	20170424120541	12:05:40	No macrobiota	Soft bottom benthos; sediment	Unconsolidated	Sediment 100%	n/a	n/a	Gravelly sand	Flat	None
			12:13:30									
24/04/2017	SA1702_ENV09A	20170424124209	12:42:08	No macrobiota	Soft bottom benthos; sediment	Unconsolidated	Sediment 100%	n/a	n/a	Gravelly sand	Flat	None
			12:54:43									
24/04/2017	SA1702_ENV09A	20170424124209	12:54:43	No macrobiota	Mixed reef	Unconsolidated	Reef 25-49%	Cobbles	Low	Gravelly sand	Flat	None
			12:55:04									
24/04/2017	SA1702_ENV09A	20170424124209	12:55:04	Burrowing macrofauna	Soft bottom benthos; sediment	Unconsolidated	Sediment 100%	n/a	n/a	Gravelly sand	Flat	Low
			12:59:43									
24/04/2017	SA1702_ENV11	20170424223209	22:32:08			Unconsolidated	Sediment 100%	n/a	n/a		Flat	None

GDA94, MGA94, UTM Zone 51, CM123 °East												
Date	Transect	Video File	Time [UTC]	Classification		Substrate Type	Substrate Composition	Reef Particle Size	Reef Profile	Sediment Particle Size	Sediment Profile	Bioturbation
				Community Type	Habitat Type							
			22:36:12	No macrobiota	Soft bottom benthos; sediment					Sandy Gravel		
24/04/2017	SA1702_ENV11	20170424223209	22:36:12	No macrobiota	Soft bottom benthos; sediment	Unconsolidated	Sediment 100%	n/a	n/a	Gravelly sand	small ripples	None
			22:38:29									
24/04/2017	SA1702_ENV11	20170424223209	22:38:29	No macrobiota	Soft bottom benthos; sediment	Unconsolidated	Sediment 100%	n/a	n/a	Sandy Gravel	Flat	None
			22:41:00									
24/04/2017	SA1702_ENV11	20170424223209	22:41:00	No macrobiota	Soft bottom benthos; sediment	Unconsolidated	Sediment 100%	n/a	n/a	Sand	small ripples	None
			22:43:35									
24/04/2017	SA1702_ENV11	20170424223209	22:43:35	No macrobiota	Soft bottom benthos; sediment	Unconsolidated	Sediment 100%	n/a	n/a	Gravelly sand	Flat	None
			22:50:16									
24/04/2017	SA1702_ENV11	20170424223209	22:50:16	No macrobiota	Mixed reef	Consolidated	Reef 51-75%	Rock (unbroken)	Low	Sand	Flat	None
			22:54:15									
25/04/2017	SA1702_ENV12	20170425004905	00:49:04	No macrobiota	Mixed reef	Consolidated	Reef 51-75%	Rock (unbroken)	Low	Sand	Flat	None
			01:18:43									
25/04/2017	SA1702_ENV13	20170425041526	04:15:25	No macrobiota	Soft bottom benthos; sediment	Unconsolidated	Sediment 100%	n/a	n/a	Sand	Medium ripples	None
			04:45:39									
25/04/2017	SA1702_ENV14	20170425041526	09:14:57	No macrobiota	Soft bottom benthos; sediment	Unconsolidated	Sediment 100%	n/a	n/a	Sand	small ripples	None
			09:22:41									
25/04/2017	SA1702_ENV14	20170425041526	09:22:41	No macrobiota	Mixed reef	Unconsolidated	Reef 1-24%	Cobbles	Low	Sand	Flat	None
			09:24:02									
25/04/2017	SA1702_ENV14	20170425041526	09:24:02	No macrobiota	Soft bottom benthos; sediment	Unconsolidated	Sediment 100%	n/a	n/a	Sand	small ripples	None
			09:35:06									
25/04/2017	SA1702_ENV15	20170425130924	13:09:23	No macrobiota	Soft bottom benthos; sediment	Unconsolidated	Sediment 100%	n/a	n/a	Sand	Flat	None
			13:12:24									
25/04/2017	SA1702_ENV15	20170425130924	13:12:24	No macrobiota	Mixed reef	Unconsolidated	Reef 1-24%	Cobbles	Low	Gravelly sand	Flat	None
			13:18:13									
25/04/2017	SA1702_ENV15	20170425130924	13:18:13			Unconsolidated	Sediment 100%	n/a	n/a	Sand	small ripples	None

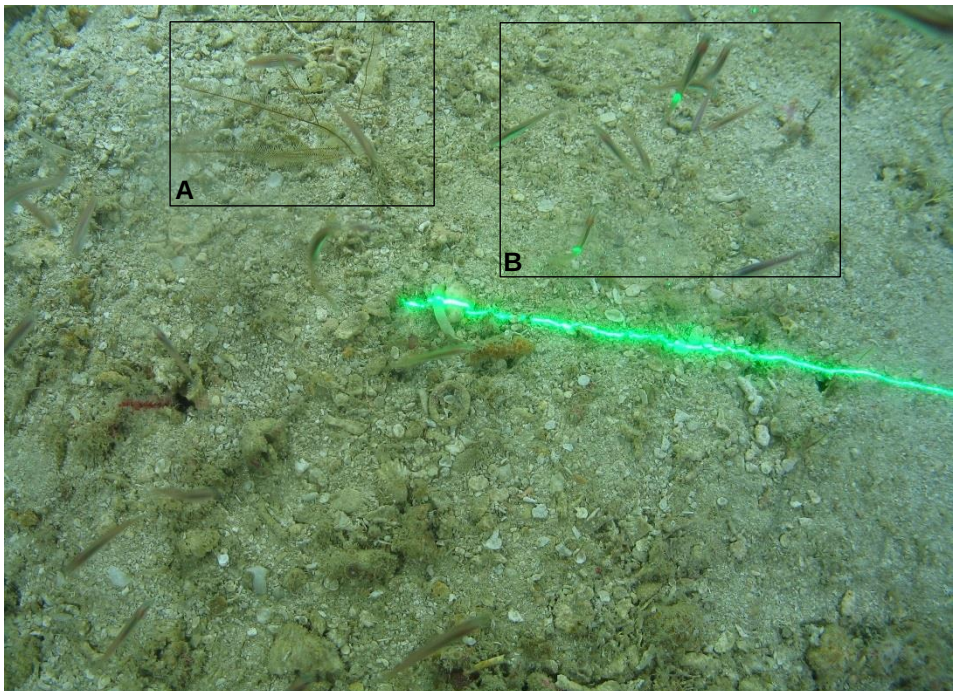
GDA94, MGA94, UTM Zone 51, CM123 °East												
Date	Transect	Video File	Time [UTC]	Classification		Substrate Type	Substrate Composition	Reef Particle Size	Reef Profile	Sediment Particle Size	Sediment Profile	Bioturbation
				Community Type	Habitat Type							
			13:31:12	No macrobiota	Soft bottom benthos; sediment							
26/04/2017	SA1702_ENV18	20170426004247	00:42:47	Burrowing macrofauna	Soft bottom benthos; sediment	Unconsolidated	Sediment 100%	n/a	n/a	Muddy sand	Flat	Low
			00:46:20									
26/04/2017	SA1702_ENV18	20170426004247	00:46:20	No macrobiota	Mixed reef	Unconsolidated	Reef 1-24%	Cobble	Low	Sand	Flat	None
			00:49:53									
26/04/2017	SA1702_ENV18	20170426004247	00:49:53	Burrowing macrofauna	Soft bottom benthos; sediment	Unconsolidated	Sediment 100%	n/a	n/a	Sand	Flat	Low
			00:58:58									
26/04/2017	SA1702_ENV18	20170426004247	00:58:58	Filter feeders	Filter-feeders: reef	Consolidated	Reef 75-99%	Rock (unbroken)	Medium	Sand	Flat	None
			01:05:58									
26/04/2017	SA1702_ENV18	20170426004247	01:05:58	Burrowing macrofauna	Mixed reef	Unconsolidated	Reef 25-49%	Rock (unbroken) with cobbles	Low	Sand	Flat	Low
			01:12:52									
26/04/2017	SA1702_ENV19	20170426021026_1	02:10:25	No macrobiota	Mixed reef	Unconsolidated	Reef 25-49%	Cobble	Low	Sand	Flat	None
			02:21:08									
26/04/2017	SA1702_ENV19	20170426021026_1	02:21:08	No macrobiota	Mixed reef	Consolidated	Reef 75-99%	Rock (unbroken)	High	Sand	Flat	None
			02:25:33									
26/04/2017	SA1702_ENV19	20170426021026_1	02:25:33	No macrobiota	Mixed reef	Unconsolidated	Reef 25-49%	Rock (unbroken)	Low	Sand	Flat	None
			02:34:49									
26/04/2017	SA1702_ENV19	20170426021026_1	02:34:49	No macrobiota	Mixed reef	Consolidated	Reef 75-99%	Rock (unbroken)	Medium	Sand	Flat	None
			02:39:42									
26/04/2017	SA1702_ENV19	20170426021026_1	02:39:42	Burrowing macrofauna	Soft bottom benthos; sediment	Unconsolidated	n	n/a	Low	Sand	Flat	Low
			02:41:00									
26/04/2017	SA1702_ENV19	20170426021026_2	02:41:01	Burrowing macrofauna	Soft bottom benthos; sediment	Unconsolidated	n	n/a	Low	Sand	Flat	Low
			02:42:14									
26/04/2017	SA1702_ENV20	20170426063102_1	06:31:02	Burrowing macrofauna	Soft bottom benthos; sediment	Unconsolidated	n	n/a	Low	Muddy sand	Flat	Low
			06:36:54									
26/04/2017	SA1702_ENV20	20170426063102_1	06:36:54			Unconsolidated	n	n/a	Low	Muddy sand	Flat	Medium

GDA94, MGA94, UTM Zone 51, CM123 °East												
Date	Transect	Video File	Time [UTC]	Classification		Substrate Type	Substrate Composition	Reef Particle Size	Reef Profile	Sediment Particle Size	Sediment Profile	Bioturbation
				Community Type	Habitat Type							
			06:42:51	Burrowing macrofauna	Soft bottom benthos; sediment							
26/04/2017	SA1702_ENV20	20170426063102_1	06:42:51 07:01:19	Burrowing macrofauna	Mixed reef	Unconsolidated	Reef 1-24%	Cobble	Low	Muddy sand	Flat	Low
26/04/2017	SA1702_ENV20	20170426063102_2	07:01:20 07:07:05	Burrowing macrofauna	Mixed reef	Unconsolidated	Reef 1-24%	Cobble	Low	Muddy sand	Flat	Low
26/04/2017	SA1702_ENV20	20170426063102_2	07:07:05 07:18:18	Burrowing macrofauna	Soft bottom benthos; sediment	Unconsolidated	n	n/a	Low	Muddy sand	Flat	Medium
26/04/2017	SA1702_ENV26	20170426125427_1	12:54:27 13:24:50	No macrobiota	Mixed reef	Unconsolidated	Reef 25-49%	Rock (unbroken) with cobbles	Low	Sand	Flat	None
26/04/2017	SA1702_ENV26	20170426125427_2	13:24:51 13:48:36	No macrobiota	Mixed reef	Unconsolidated	Reef 25-49%	Rock (unbroken) with cobbles	Low	Sand	Flat	None
26/04/2017	SA1702_ENV26	20170426125427_2	13:48:36 13:51:30	No macrobiota	Soft bottom benthos; sediment	Unconsolidated	Sediment 100%	n/a	n/a	Sand	small ripples	None
26/04/2017	SA1702_ENV26	20170426125427_2	13:51:30 13:53:59	No macrobiota	Soft bottom benthos; sediment	Unconsolidated	Sediment 100%	n/a	n/a	Gravelly sand	Flat	None
26/04/2017	SA1702_ENV26	20170426125427_2	13:53:59 13:55:30	No macrobiota	Soft bottom benthos; sediment	Unconsolidated	Reef 1-24%	Cobble	Low	Sand	Flat	None
26/04/2017	SA1702_ENV26	20170426125427_3	13:55:30 13:57:47	Burrowing macrofauna	Soft bottom benthos; sediment	Unconsolidated	Reef 1-24%	Cobble	Low	Sand	Flat	Low
26/04/2017	SA1702_ENV25	20170426145238	14:52:38 14:59:19	Burrowing macrofauna	Soft bottom benthos; sediment	Unconsolidated	Sediment 100%	n/a	n/a	Muddy sand	Flat	Low
26/04/2017	SA1702_ENV25	20170426145238	14:59:19 15:07:22	Burrowing macrofauna	Mixed reef	Unconsolidated	Reef 1-24%	Cobble	Low	Muddy sand	Flat	Low
26/04/2017	SA1702_ENV25	20170426145238	15:07:22 15:14:31	Burrowing macrofauna	Soft bottom benthos; sediment	Unconsolidated	Sediment 100%	n/a	n/a	Muddy sand	Flat	Medium
26/04/2017	SA1702_ENV21	20170426192216	19:22:16			Unconsolidated	Sediment 100%	n/a	n/a	Muddy sand	Flat	Medium

GDA94, MGA94, UTM Zone 51, CM123 °East												
Date	Transect	Video File	Time [UTC]	Classification		Substrate Type	Substrate Composition	Reef Particle Size	Reef Profile	Sediment Particle Size	Sediment Profile	Bioturbation
				Community Type	Habitat Type							
			19:41:41	Burrowing macrofauna	Soft bottom benthos; sediment							
27/04/2017	SA1702_ENV22	20170427004806	00:48:05	Burrowing macrofauna	Soft bottom benthos; sediment	Unconsolidated	Sediment 100%	n/a	n/a	Muddy sand	Flat	Medium
			01:12:13									
27/04/2017	SA1702_ENV22	20170427004806	01:12:13	Burrowing macrofauna	Soft bottom benthos; sediment	Unconsolidated	Sediment 100%	n/a	n/a	Muddy sand	Flat	Medium
			01:15:59									
27/04/2017	SA1702_ENV24	20170427023955	02:39:54	Burrowing macrofauna	Soft bottom benthos; sediment	Unconsolidated	Sediment 100%	n/a	n/a	Muddy sand	Flat	Medium
			02:59:21									
27/04/2017	SA1702_ENV23	20170427090124	09:01:24	Burrowing macrofauna	Soft bottom benthos; sediment	Unconsolidated	Sediment 100%	n/a	n/a	Muddy sand	Flat	Medium
			09:22:39									
30/04/2017	SA1702_ENV29	20170430143123	14:31:23	-	-	-	-	-	-	-	-	-
			14:38:02									
30/04/2017	SA1702_ENV08	20170430205550	20:55:50	No macrobiota	Soft bottom benthos; sediment	Unconsolidated	Sediment 100%	n/a	n/a	Sand	Flat	None
			21:15:14									
01/05/2017	SA1702_ENV10	20170501013944	01:39:44	No macrobiota	Soft bottom benthos; sediment	Unconsolidated	Sediment 100%	n/a	n/a	Sand	Flat	None
			01:46:05									
01/05/2017	SA1702_ENV10	20170501013944	01:46:05	No macrobiota	Hard substrate non-reef	Unconsolidated	Hard substrate 25-49%	Rock (unbroken)	Low	Sand	small ripples	None
			01:58:31									
01/05/2017	SA1702_ENV10	20170501013944	01:58:31	No macrobiota	Hard substrate non-reef	Unconsolidated	Hard substrate 25-49%	Rock (unbroken)	Low	Sand	Medium ripples	None
			02:05:49									
01/05/2017	SA1702_ENV16	20170501074207	07:42:07	No macrobiota	Soft bottom benthos; sediment	Unconsolidated	Sediment 100%	n/a	n/a	Sand	Flat	None
			07:58:51									

B. SEABED PHOTOGRAPHS

SA1702_ENV01

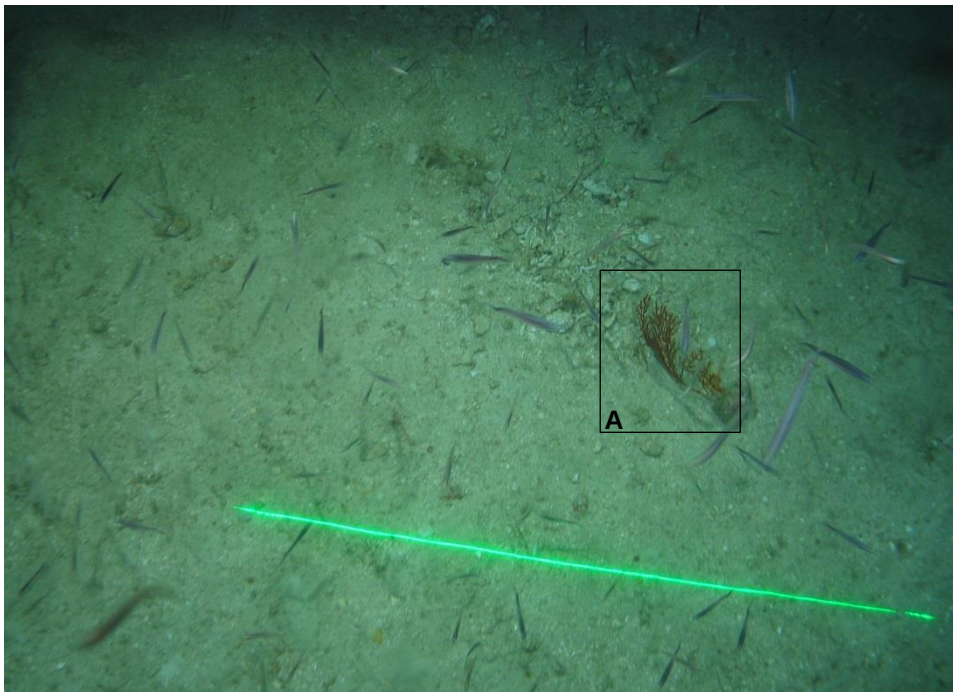


Photograph:
SA1702_ENV01_22

Easting: 663624.71 mE
Northing: 8570659.70 mN
Depth: 93 m

Sediment Type:
Gravelly sand

Fauna:
A: Hydroids (Hydrozoa)
B: Unidentified fish



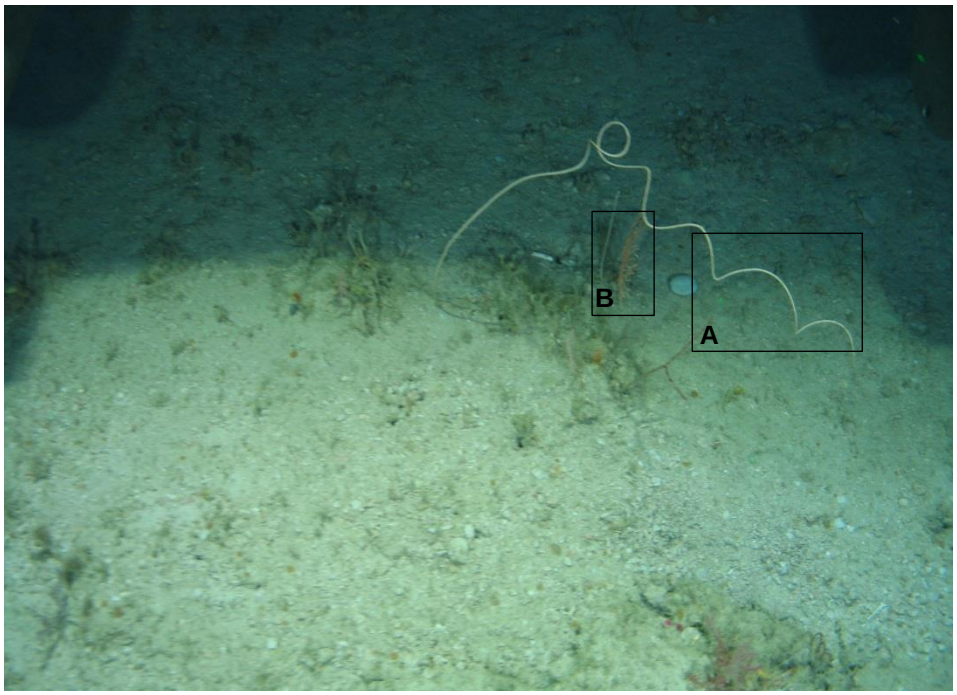
Photograph:
SA1702_ENV01_10

Easting: 663667.683 mE
Northing: 8570729.16 mN
Depth: 92 m

Sediment Type:
Reef rubble with sand veneer

Fauna:
A: Sea fan (Alcyonacea)
Unidentified fish

SA1702_ENV02

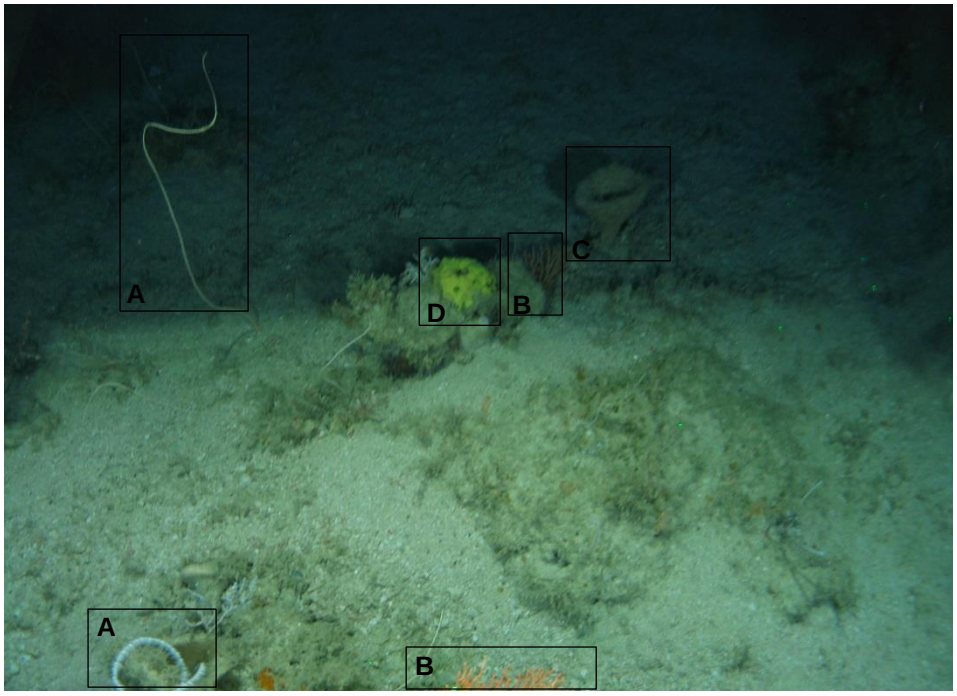


Photograph:
SA1702_ENV02_6

Easting: 661503.82 mE
Northing: 8571406.13 mN
Depth: 67.42m

Sediment Type:
Reef rubble with sand veneer

Fauna:
A: Sea Whip (Alcyonacea)
B: Hydroids (Hydrozoa)



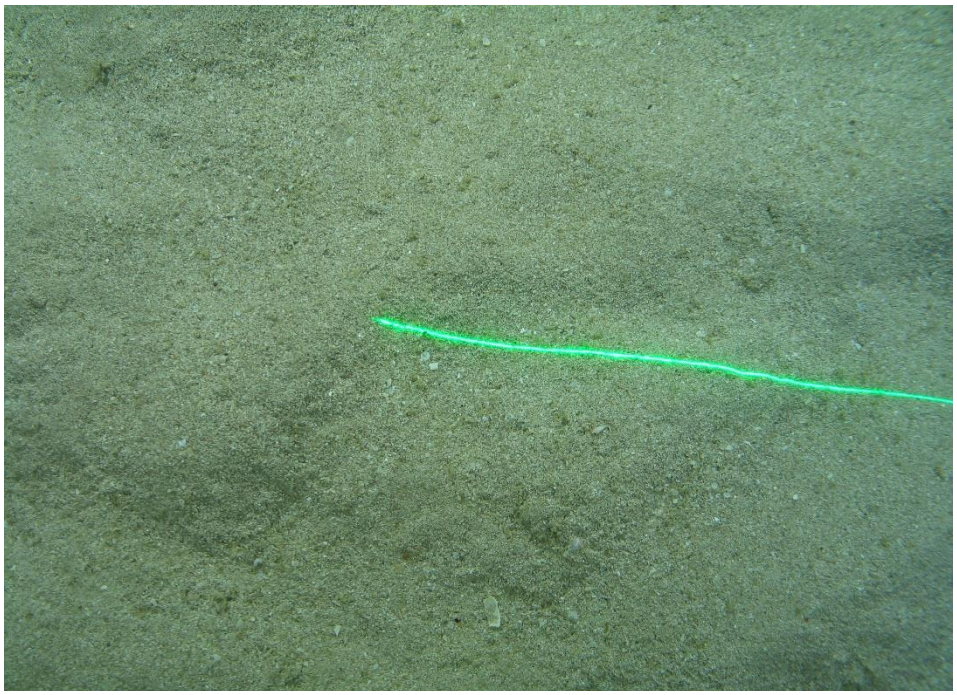
Photograph:
SA1702_ENV02_12

Easting: 661450.09 mE
Northing: 8571340.75 mN
Depth: 71.61 m

Sediment Type:
Reef with sand veneer

Fauna:
A: Sea Whip (Alcyonacea)
B: Sea Fan (Alcyonacea)
C: Barrel Sponge (Porifera)
D: Encrusting sponge (Porifera)
Hydroids (Hydrozoa)

SA1702_ENV03

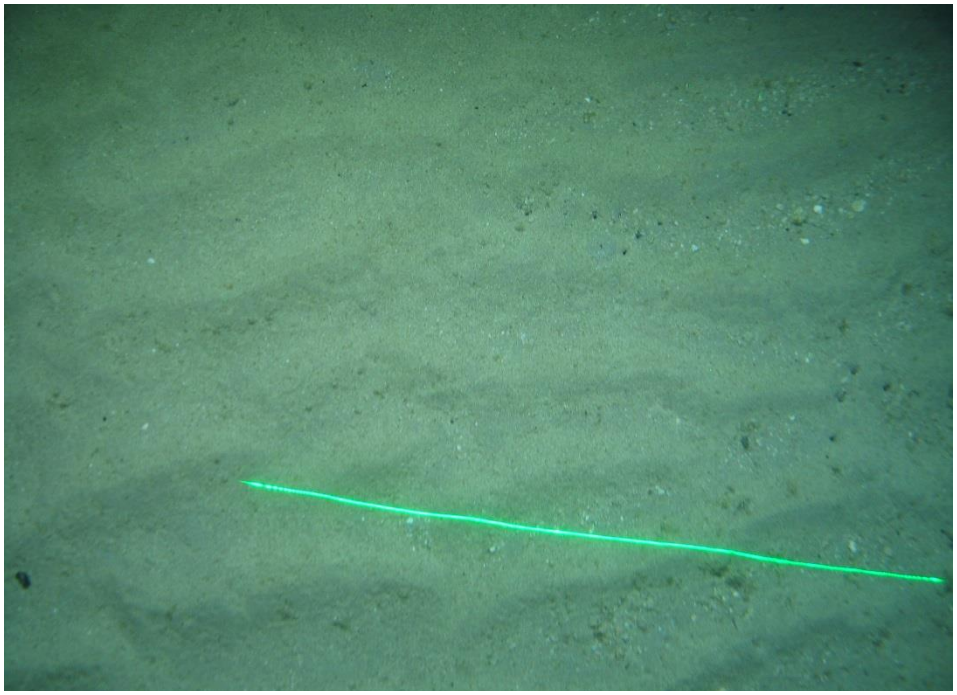


Photograph:
SA1702_ENV03_19

Easting: 657692.54 mE
Northing: 8568766.42 mN
Depth: 166.9 m

Sediment Type:
Rippled sand

Fauna:
No visible fauna



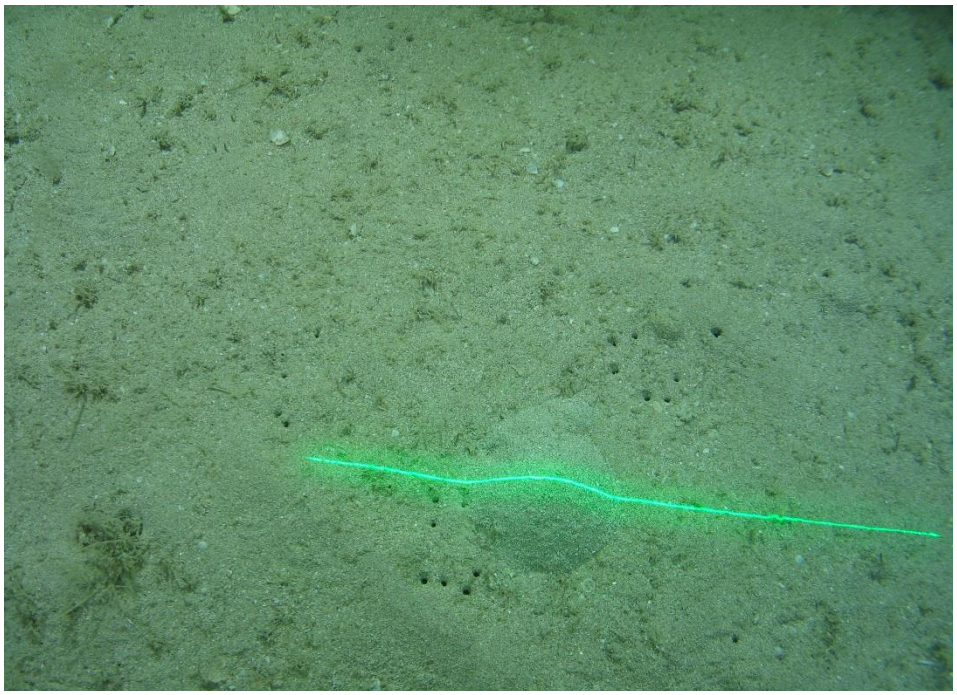
Photograph:
SA1702_ENV03_23

Easting: 657714.68 mE
Northing: 8568754.26 mN
Depth: 165.9 m

Sediment Type:
Rippled sand

Fauna:
Faunal burrows

SA1702_ENV04

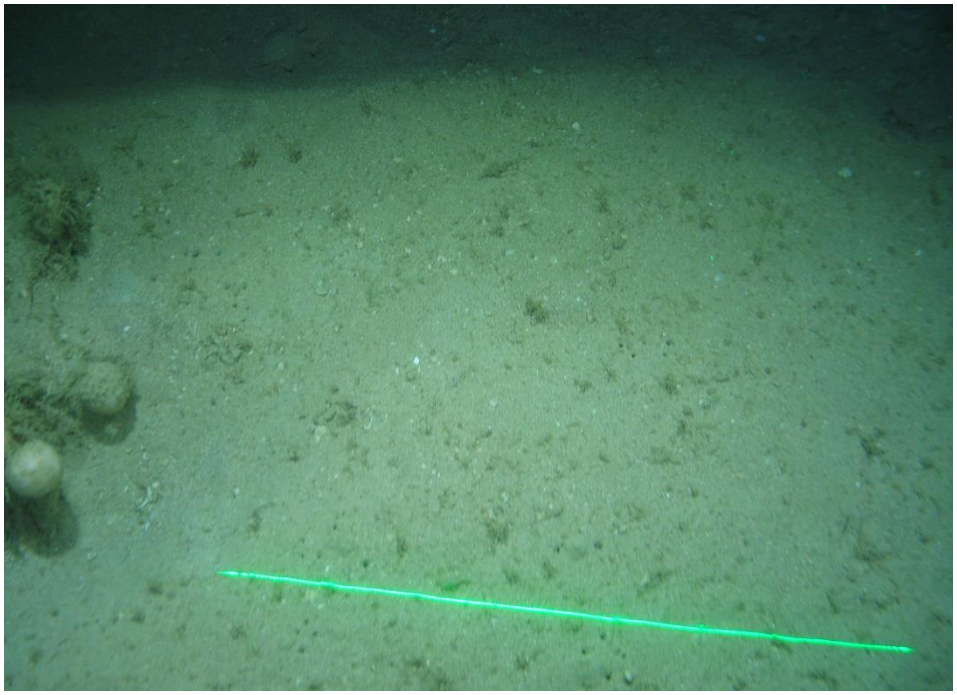


Photograph:
SA1702_ENV04_07

Easting: 656189.81 mE
Northing: 8566625.70 mN
Depth: 171.6 m

Sediment Type:
Sand

Fauna:
Faunal burrows
Hydroids (Hydrozoa)



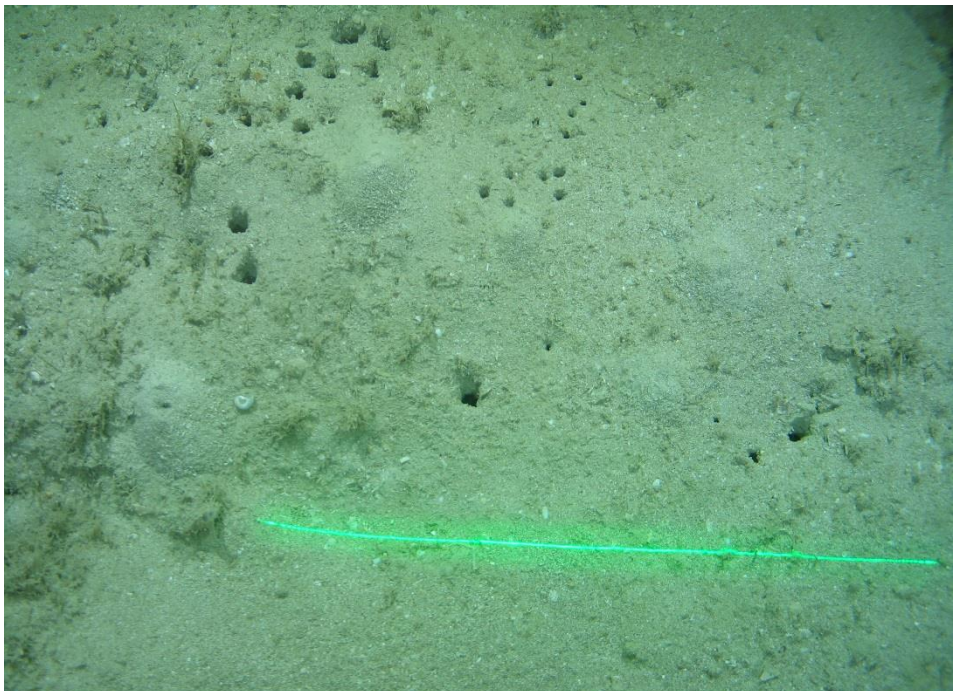
Photograph:
SA1702_ENV04_16

Easting: 656110.28 mE
Northing: 8566561.29 mN
Depth: 171.7 m

Sediment Type:
Sand

Fauna:
A: Sponges (Porifera)
B: Hydroids (Hydrozoa)

SA1702_ENV05

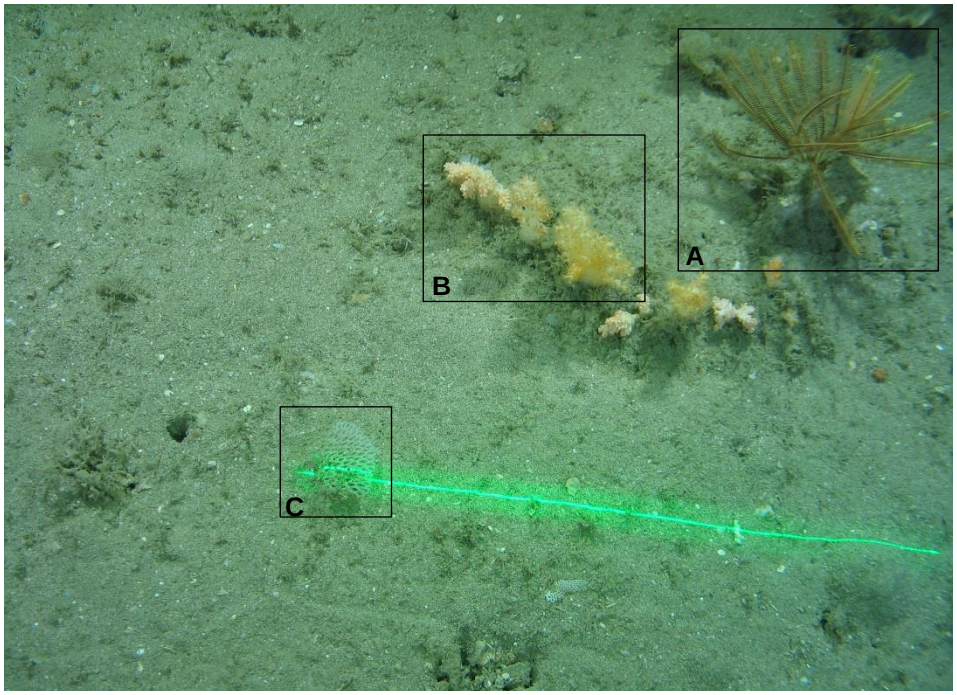


Photograph:
SA1702_ENV05_06

Easting: 656424.78 mE
Northing: 8565649.77 mN
Depth: 171.3 m

Sediment Type:
Gravelly sand

Fauna:
Faunal burrows
Hydroids (Hydrozoa)



Photograph:
SA1702_ENV05A_40

Easting: 656603.17 mE
Northing: 8565762.27 mN
Depth: 168.9 m

Sediment Type:
Reef rubble with veneer of gravelly sand

Fauna:
A: Crinoid (Crinoidea)
B: Soft Coral (Alcyonaria)
C: Bryozoa

SA1702_ENV06



Photograph:
SA1702_ENV06_05
(Screen grab from video)

Easting: 657811.87 mE
Northing: 8564667.23 mN
Depth: 172.8 m

Sediment Type:
Sand

Fauna:
Tubular glass sponge (Porifera)



Photograph:
SA1702_ENV06_06
(Screen grab from video)

Easting: 657818.11 mE
Northing: 8564672.98 mN
Depth: 172.4 m

Sediment Type:
Sand

Fauna:
Faunal burrows

SA1702_ENV07



Photograph:
SA1702_ENV05_06
(Screen grab from video)

Easting: 656424.78 mE
Northing: 8565649.77 mN
Depth: 171.3 m

Sediment Type:
Sand

Fauna:
Faunal burrows



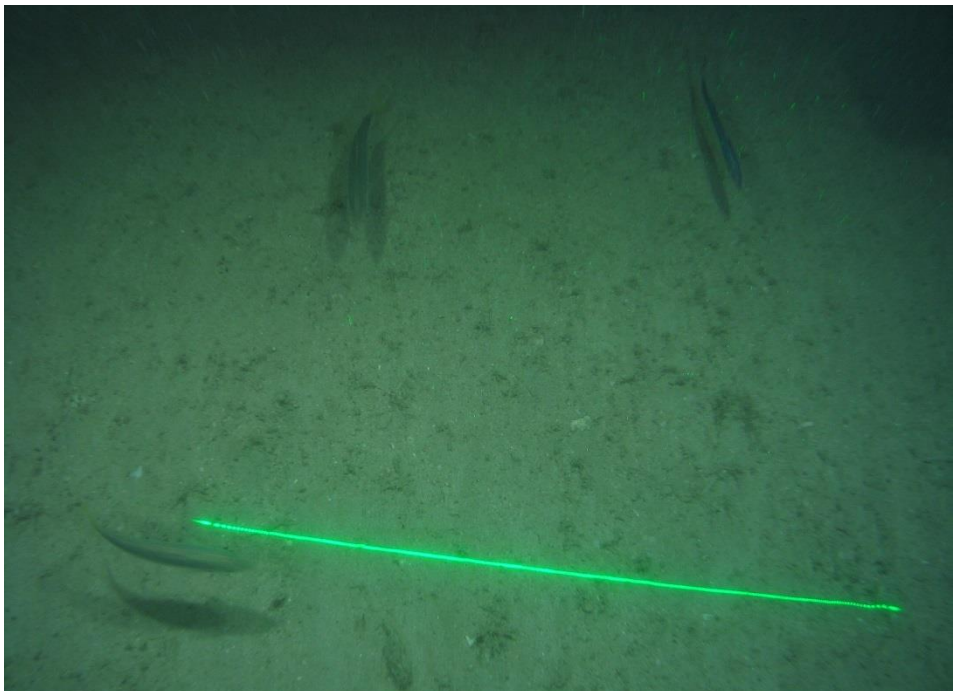
Photograph:
SA1702_ENV05A_40
(Screen grab from video)

Easting: 656603.17 mE
Northing: 8565762.27 mN
Depth: 168.9 m

Sediment Type:
Sand forming ripples

Fauna:
A: Sea Urchin (Echinoidea)

SA1702_ENV08

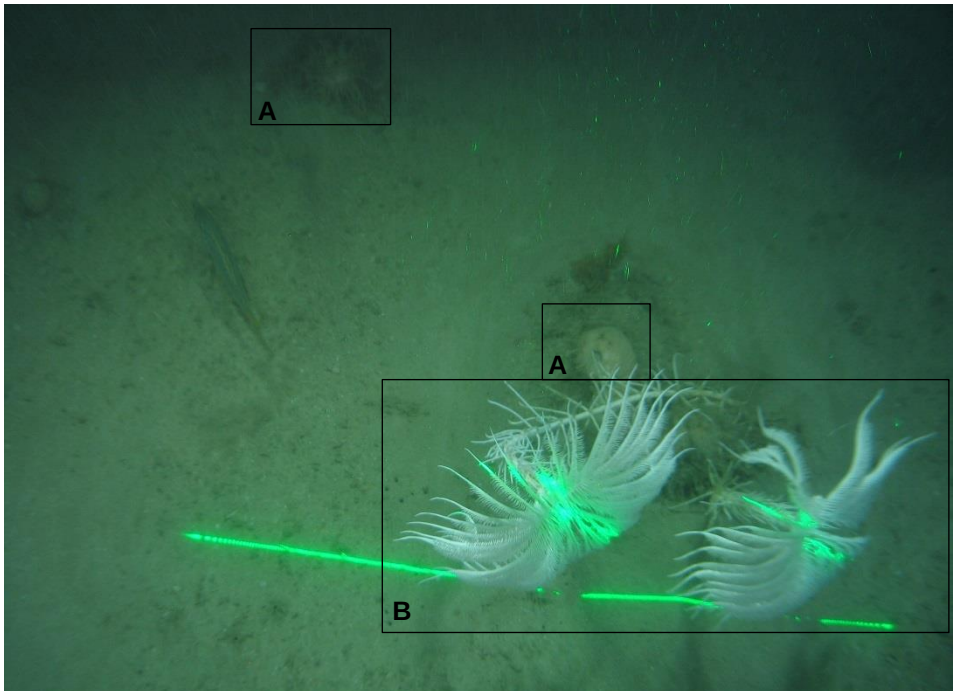


Photograph:
SA1702_ENV08_19

Easting: 656257.67mE
Northing: 8559525.35 mN
Depth: 179.8 m

Sediment Type:
Sand

Fauna:
Unidentified fish



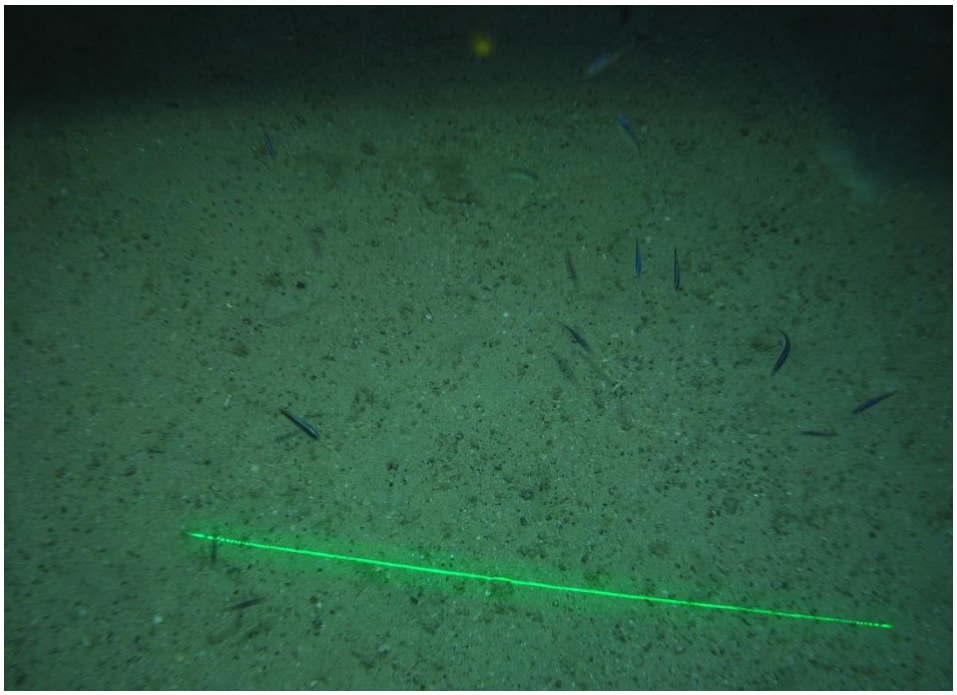
Photograph:
SA1702_ENV08_26

Easting: 656288.03 mE
Northing: 8568741.04 mN
Depth: 167.3 m

Sediment Type:
Sand

Fauna:
A: Sea anemone (Actiniaria)
B: Stalked crinoid (Isselicrinoidea)
Unidentified fish

SA1702_ENV09

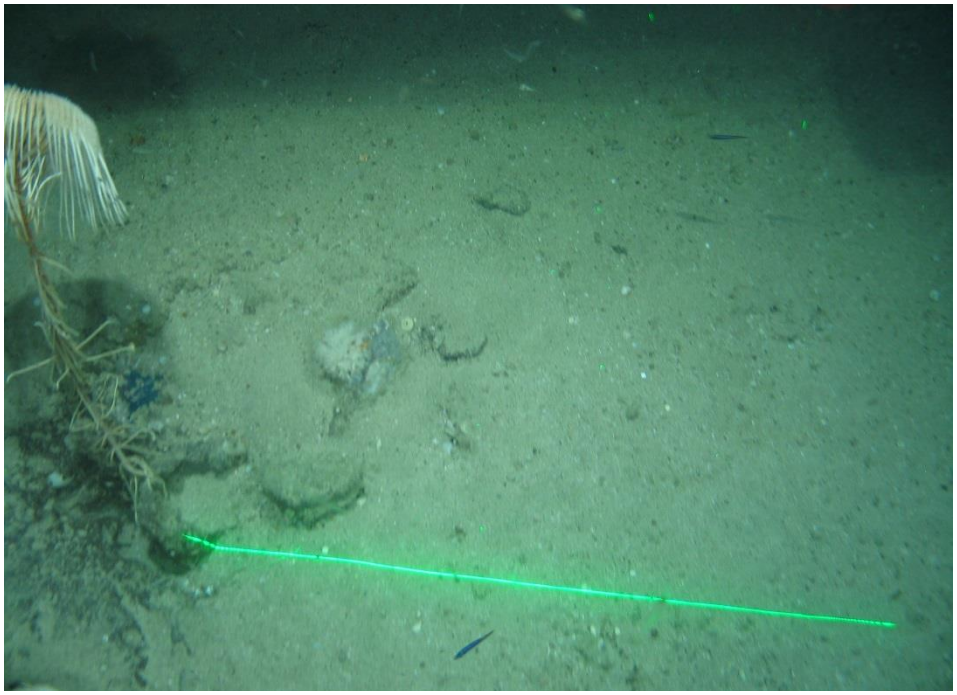


Photograph:
SA1702_ENV09A_15

Easting: 629543.11 mE
Northing: 8554248.52 mN
Depth: 198.9 m

Sediment Type:
Gravelly sand

Fauna:
Unidentified fish



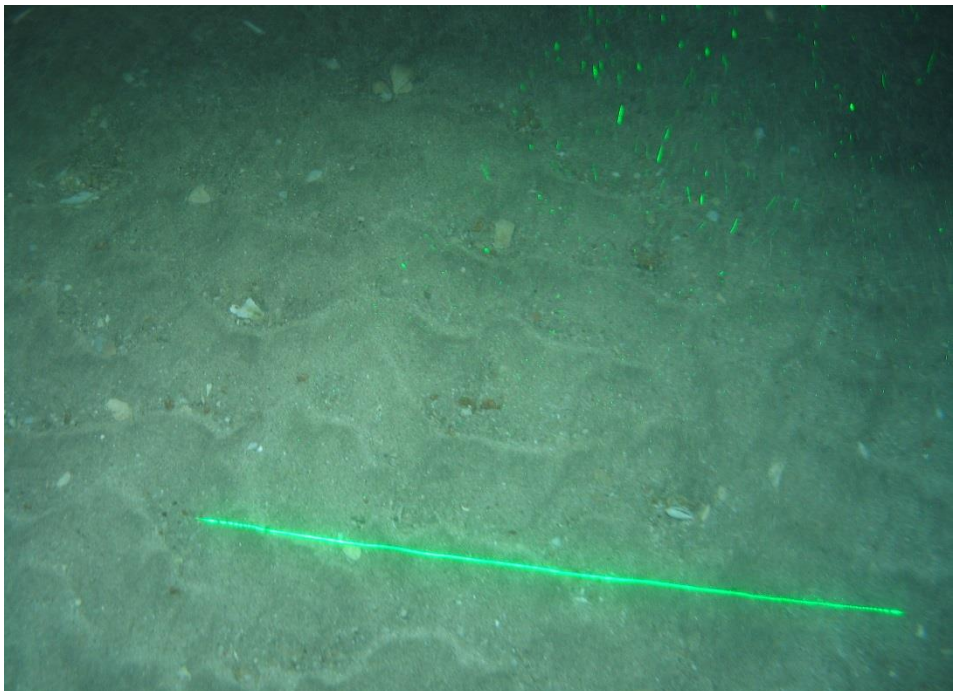
Photograph:
SA1702_ENV09A_24

Easting: 629598.38 mE
Northing: 8554229.58 mN
Depth: 197.5 m

Sediment Type:
Reef rubble with gravelly sand veneer

Fauna:
A: Stalked crinoid (Isselicrinoidea)
Unidentified fish

SA1702_ENV10

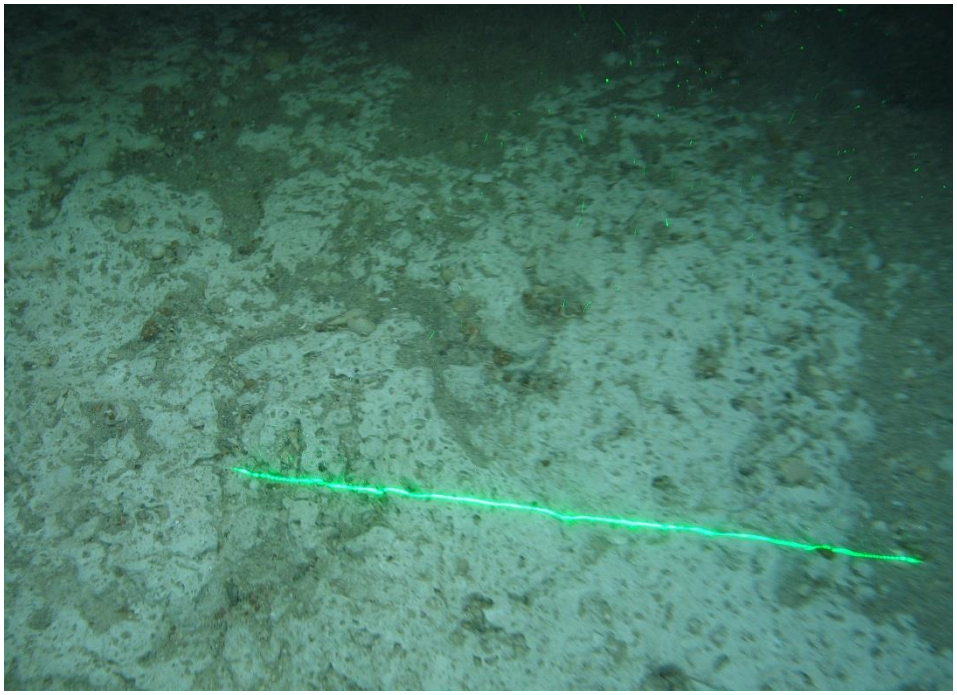


Photograph:
SA1702_ENV10_10

Easting: 618601.95 mE
Northing: 8548498.38 mN
Depth: 209.4 m

Sediment Type:
Sand forming ripples

Fauna:
No visible fauna



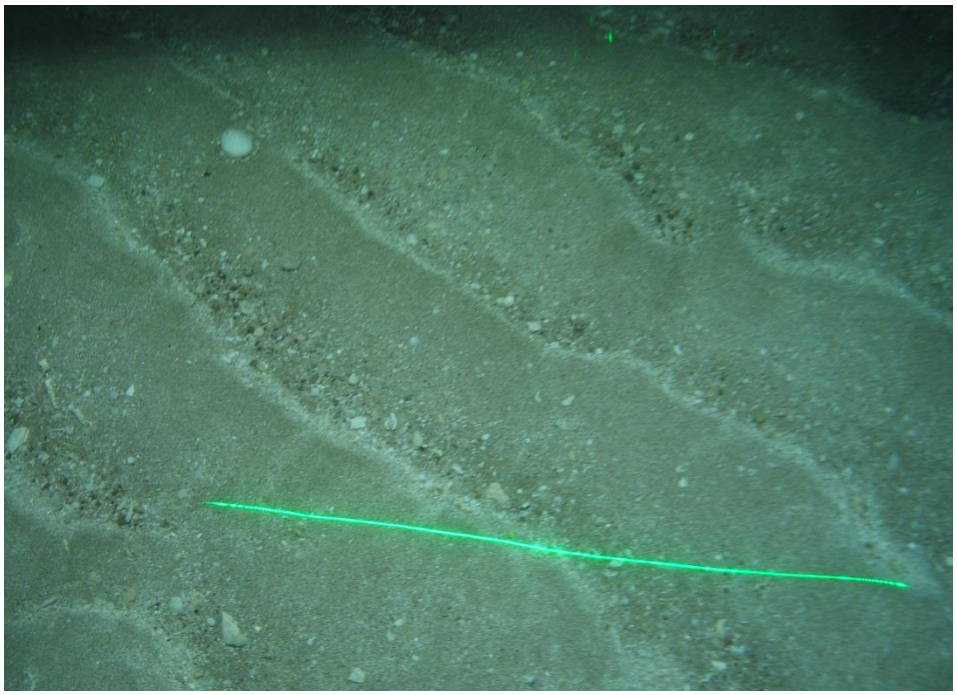
Photograph:
SA1702_ENV10_32

Easting: 618425.19 mE
Northing: 8548506.09 mN
Depth: 210.6 m

Sediment Type:
Hard substrate (volcanic rock) with sand veneer

Fauna:
No visible fauna

SA1702_ENV11

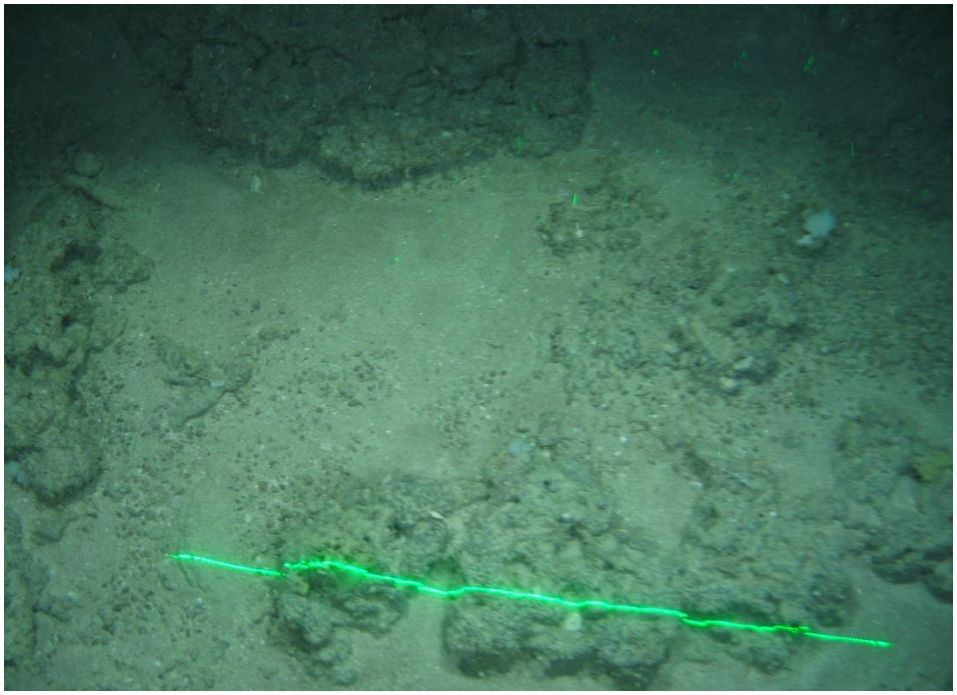


Photograph:
SA1702_ENV11_15

Easting: 618563.37 mE
Northing: 8548495.89 mN
Depth: 209.6 m

Sediment Type:
Rippled sand with some shell fragments

Fauna:
No visible fauna



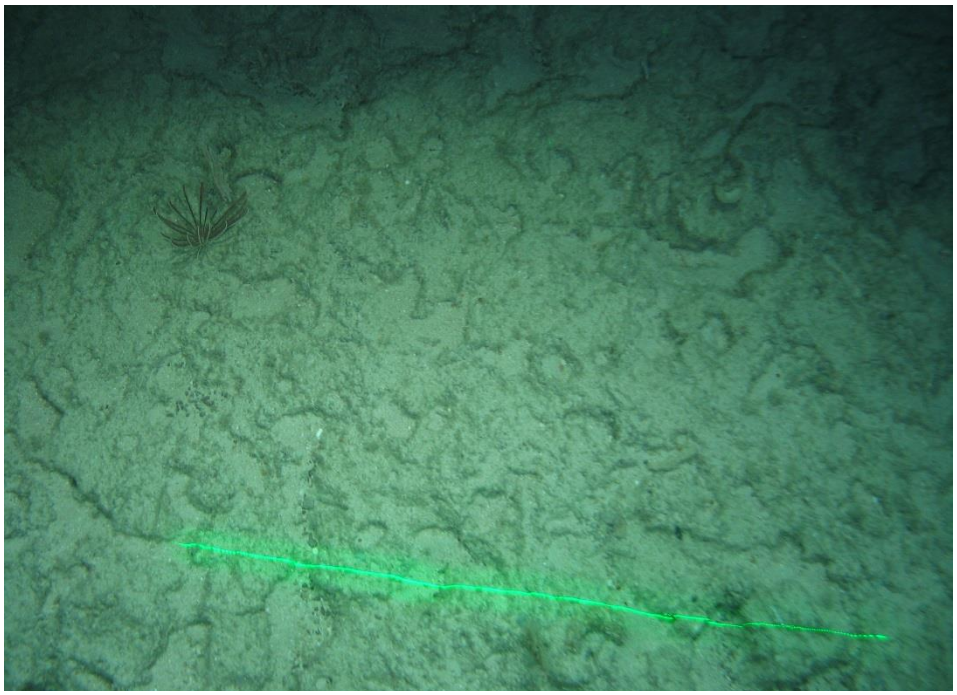
Photograph:
SA1702_ENV11_33

Easting: 618421.71 mE
Northing: 8548505.85 mN
Depth: 210.8 m

Sediment Type:
Reef rubble with sand veneer

Fauna:
No visible fauna

SA1702_ENV12

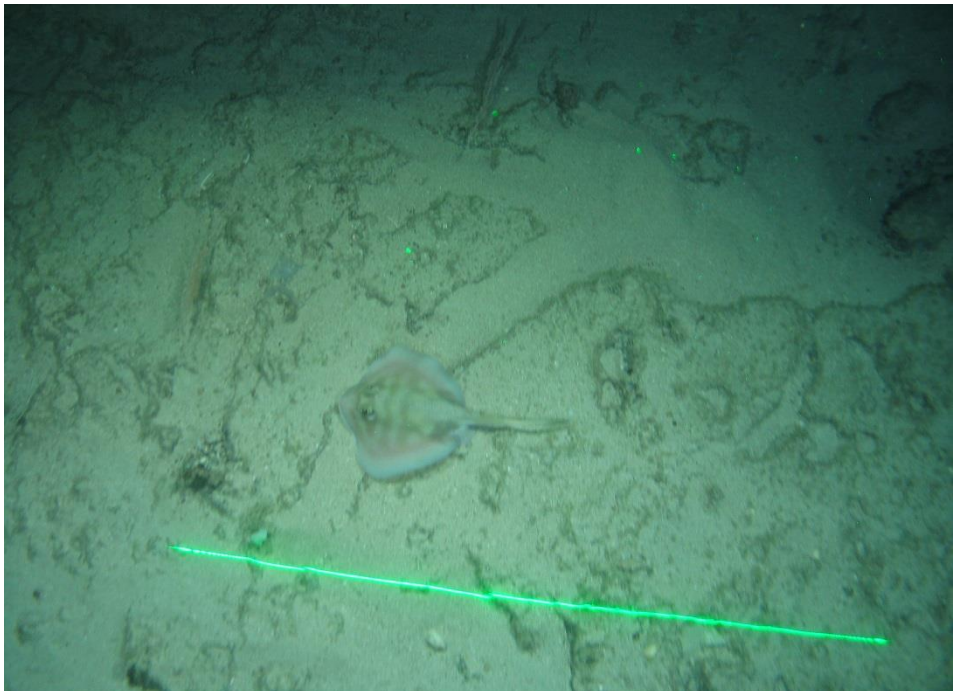


Photograph:
SA1702_ENV12_06

Easting: 618563.37 mE
Northing: 8537245.43 mN
Depth: 205.4 m

Sediment Type:
Reef rubble with sand veneer

Fauna:
Crinoid (Crinoidea)



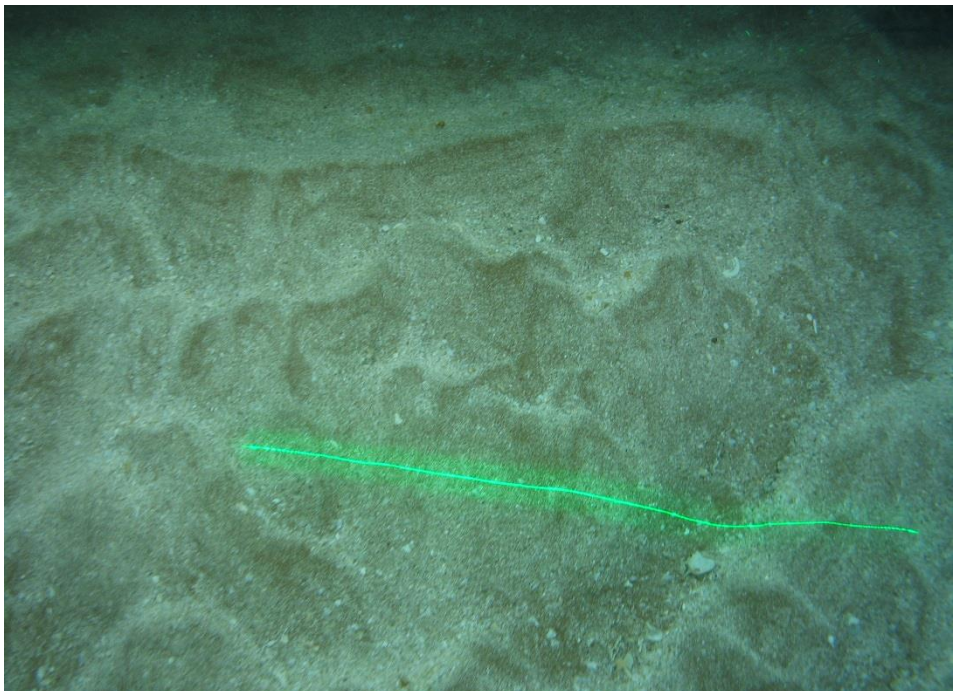
Photograph:
SA1702_ENV12_35

Easting: 602336.42 mE
Northing: 8537099.52 mN
Depth: 206.4 m

Sediment Type:
Reef rubble with sand veneer

Fauna:
A: Sea fan (Alcyonacea)
B: Ray (Batoidea)

SA1702_ENV13

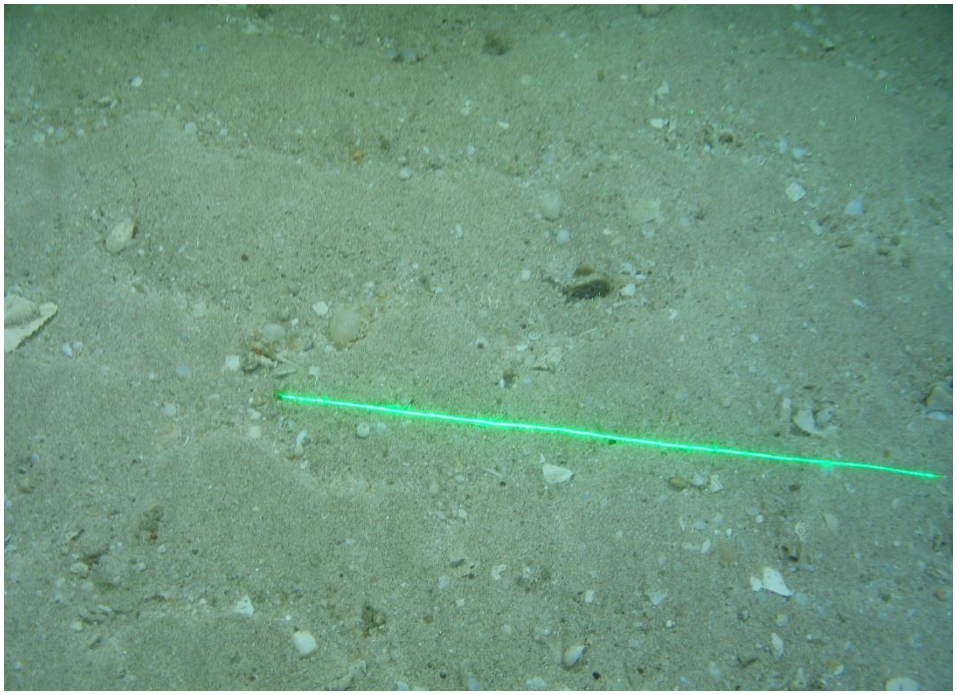


Photograph:
SA1702_ENV13_03

Easting: 597037.62 mE
Northing: 8533079.92 mN
Depth: 205.4 m

Sediment Type:
Sand forming ripples

Fauna:
No visible fauna



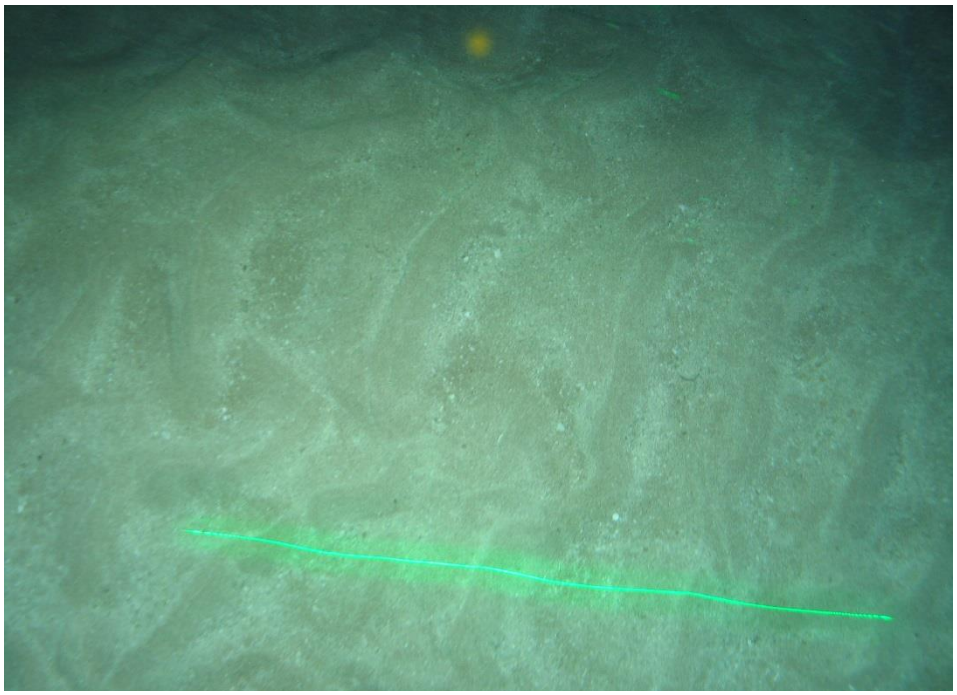
Photograph:
SA1702_ENV13_31

Easting: 597111.89 mE
Northing: 8532844.49 mN
Depth: 206.4 m

Sediment Type:
Sand forming ripples with shell fragments

Fauna:
No visible fauna

SA1702_ENV14

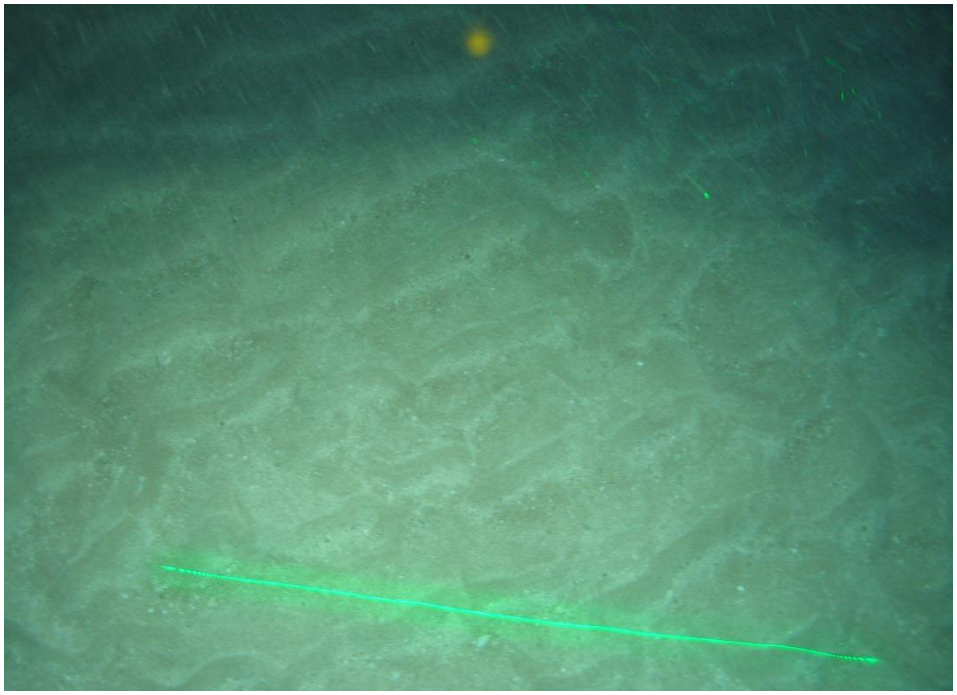


Photograph:
SA1702_ENV14_02

Easting: 585599.17 mE
Northing: 8524327.21 mN
Depth: 210.2 m

Sediment Type:
Sand forming ripples

Fauna:
No visible fauna



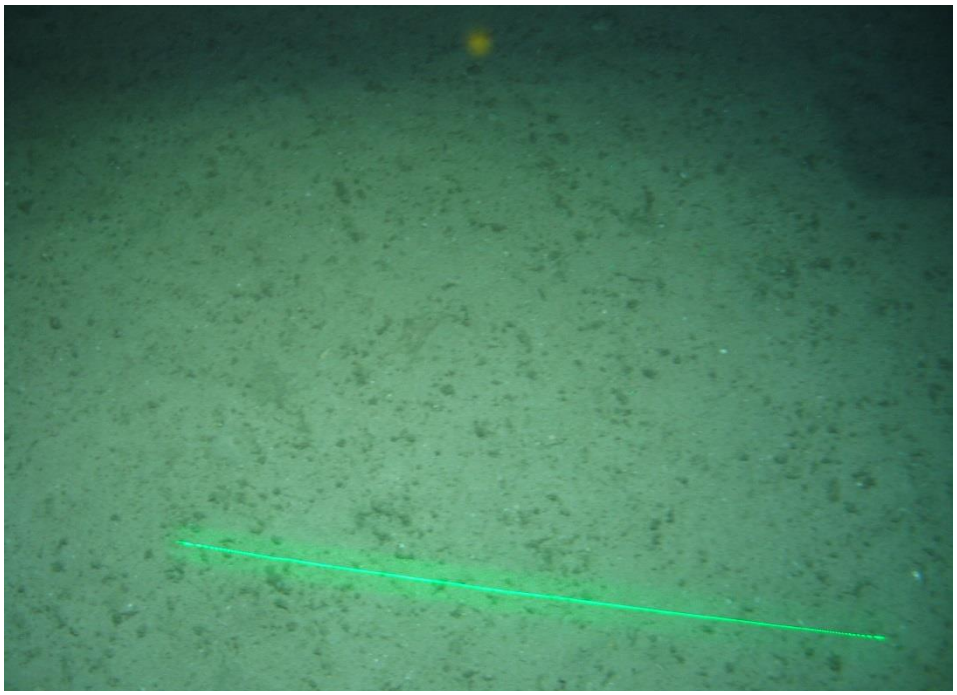
Photograph:
SA1702_ENV14_03

Easting: 585597.04 mE
Northing: 8524322.95 mN
Depth: 210.2 m

Sediment Type:
Sand forming ripples

Fauna:
No visible fauna

SA1702_ENV15

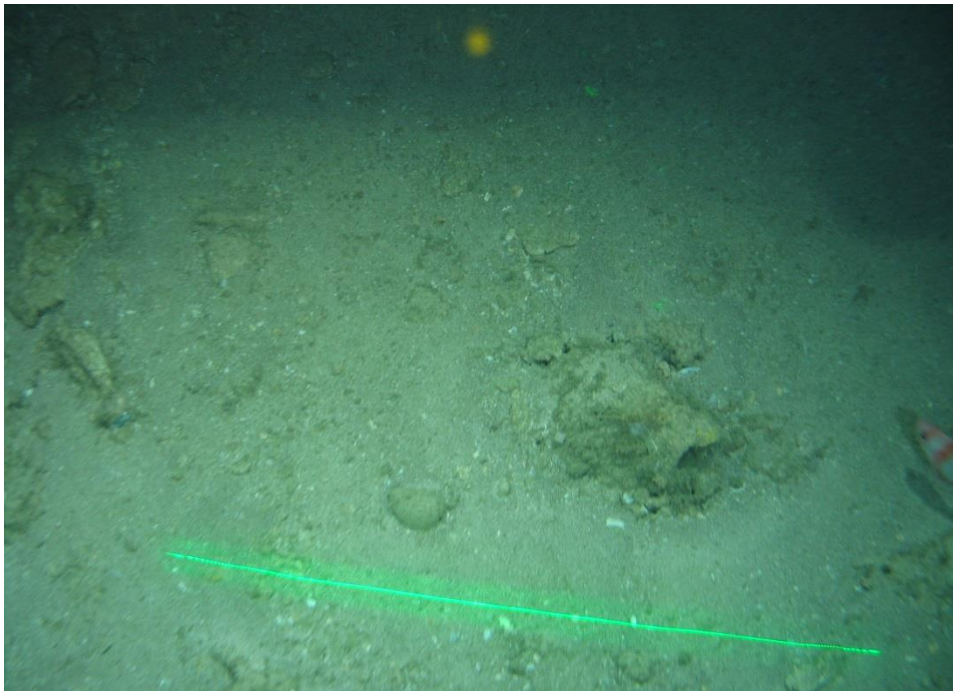


Photograph:
SA1702_ENV15_03

Easting: 579254.50 mE
Northing:8519423.18 mN
Depth: 212.5 m

Sediment Type:
Gravelly sand

Fauna:
No visible fauna



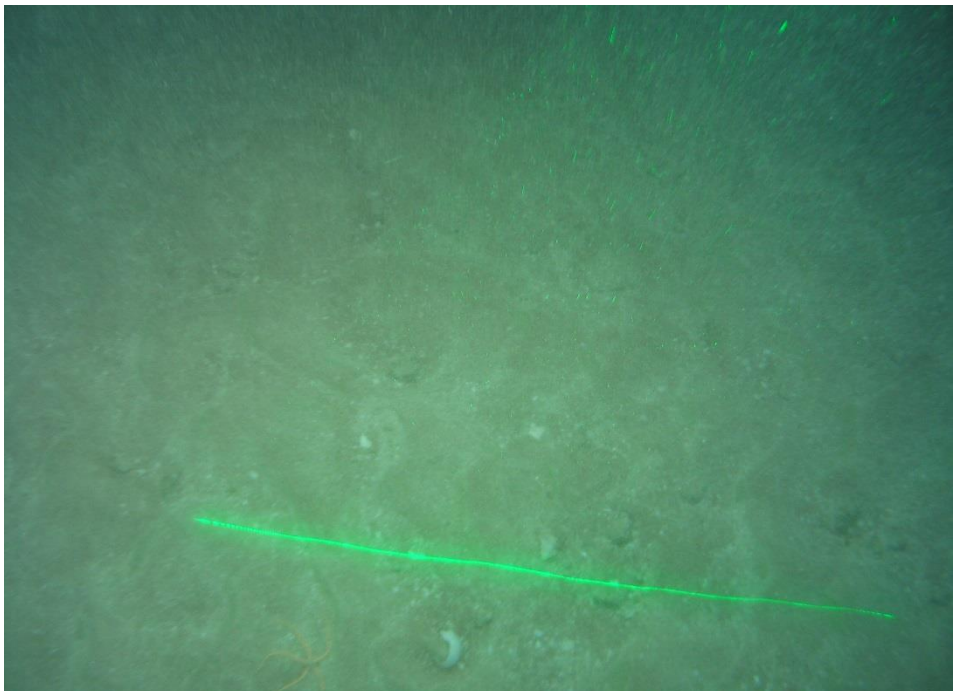
Photograph:
SA1702_ENV15_14

Easting: 579254.16 mE
Northing: 8519391.78 mN
Depth: 211.8 m

Sediment Type:
Reef rubble with gravelly sand veneer

Fauna:
Saddle Grouper (*Cephalopholis sexmaculata*)

SA1702_ENV16

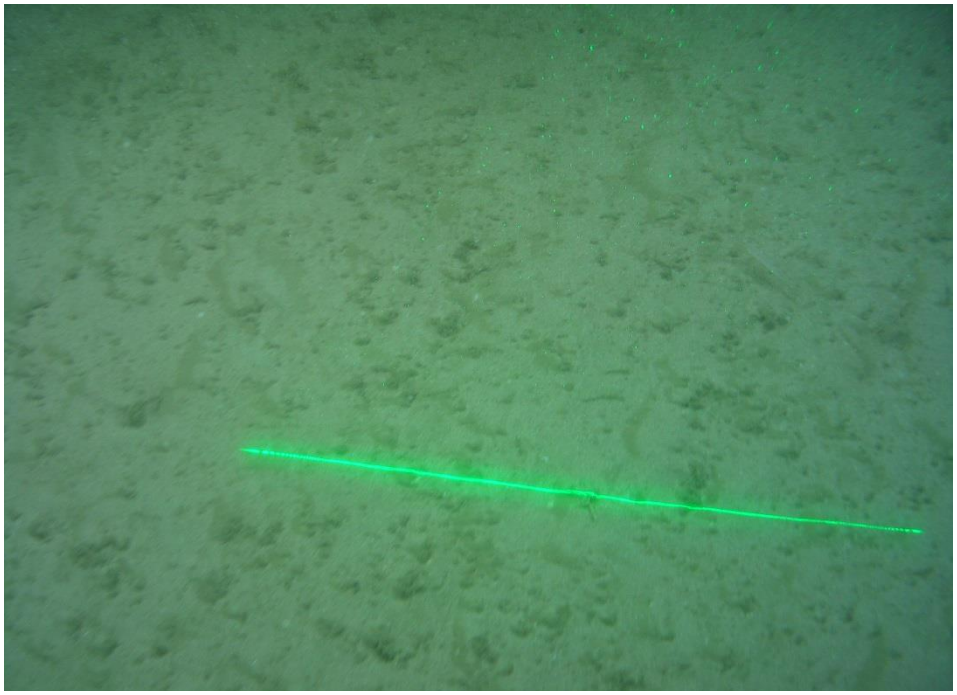


Photograph:
SA1702_ENV16_14

Easting: 572872.18 mE
Northing: 8513082.63 mN
Depth: -171.25 m

Sediment Type:
Sand forming ripples

Fauna:
No visible fauna



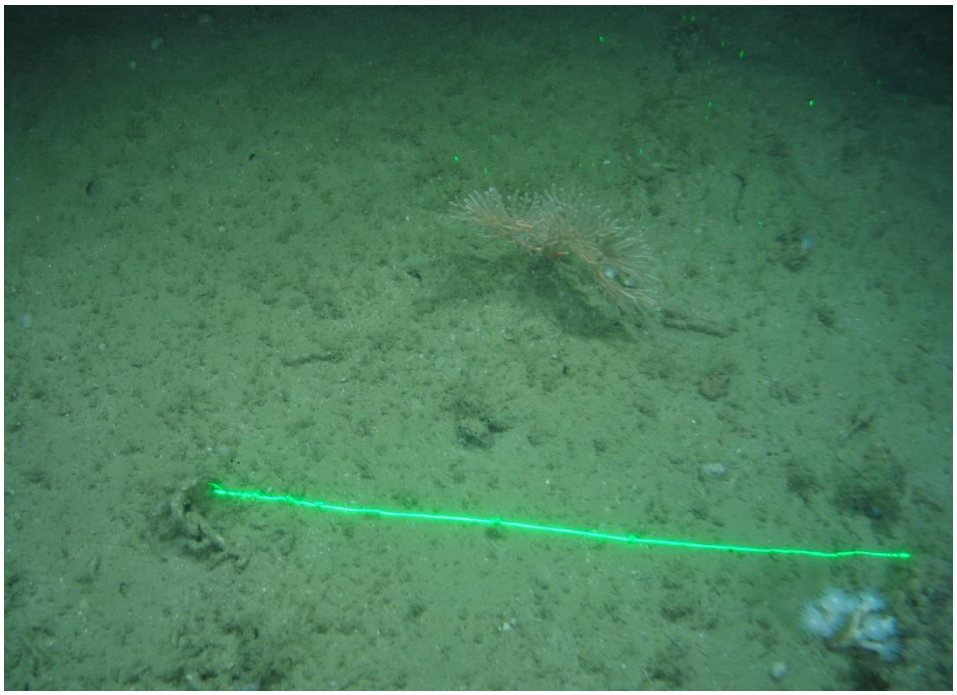
Photograph:
SA1702_ENV16_20

Easting: 572841.08 mE
Northing: 8513084.04 mN
Depth: -171.55 m

Sediment Type:
Sand

Fauna:
Hydroids (Hydrozoa)

SA1702_ENV18

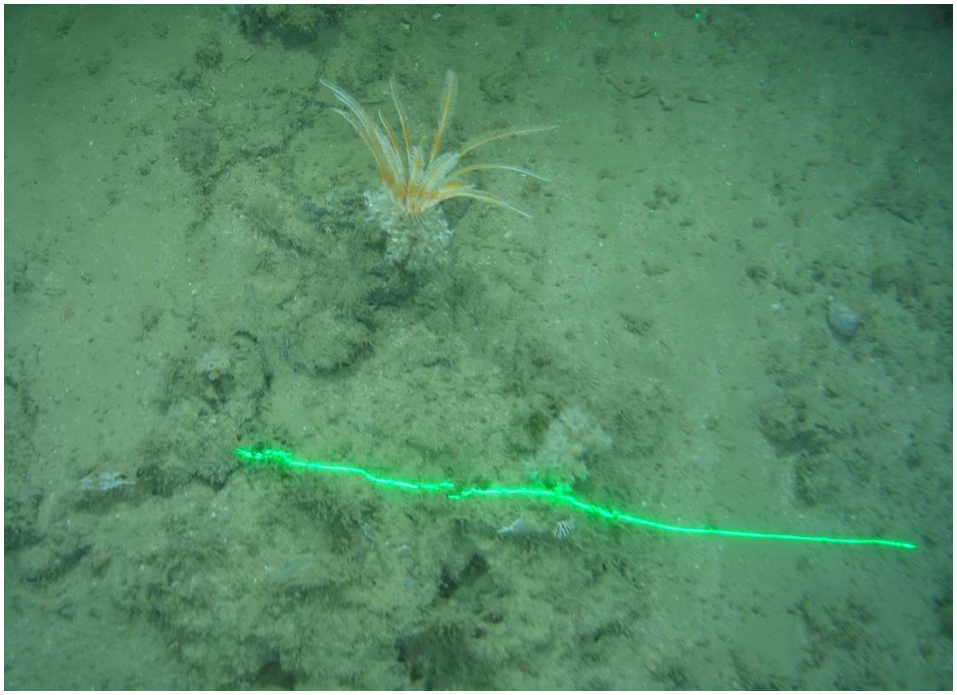


Photograph:
SA1702_ENV18_33

Easting: 559480.844 mE
Northing: 8500609.25 mN
Depth: 222.9 m

Sediment Type:
Reef with sand veneer

Fauna:
A: Sea fan (Alcyonacea)
B: Soft coral (Alcyonaria)
Hydroids (Hydrozoa)



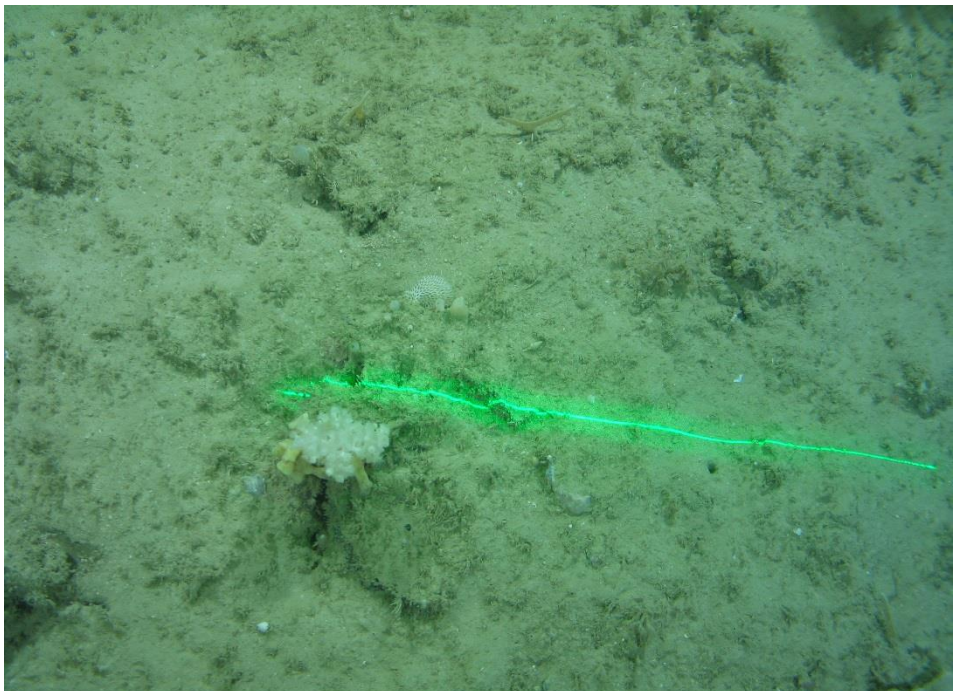
Photograph:
SA1702_ENV18_42

Easting: 559445.482 mE
Northing: 8500585.50 mN
Depth: 225.6 m

Sediment Type:
Reef rubble with sand veneer

Fauna:
Crinoid (Crinoidea)

SA1702_ENV19

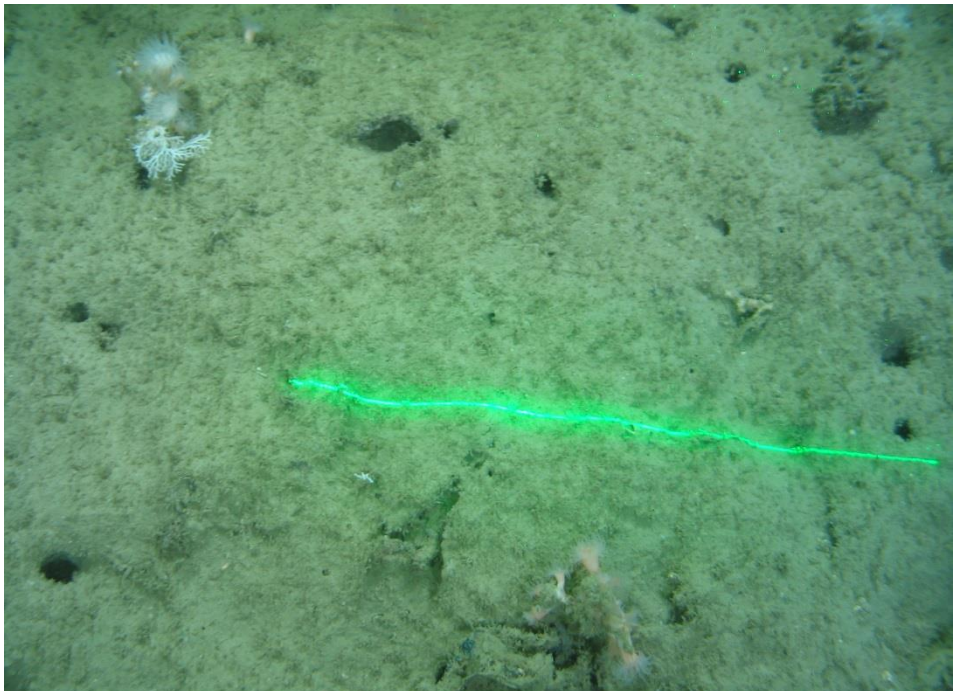


Photograph:
SA1702_ENV19_07

Easting: 558548.86 mE
Northing: 8499081.83 mN
Depth: 238 m

Sediment Type:
Reef rubble with sand veneer

Fauna:
Soft coral (Alcyonaria)
Bryozoa
Hydroids (Hydrozoa)



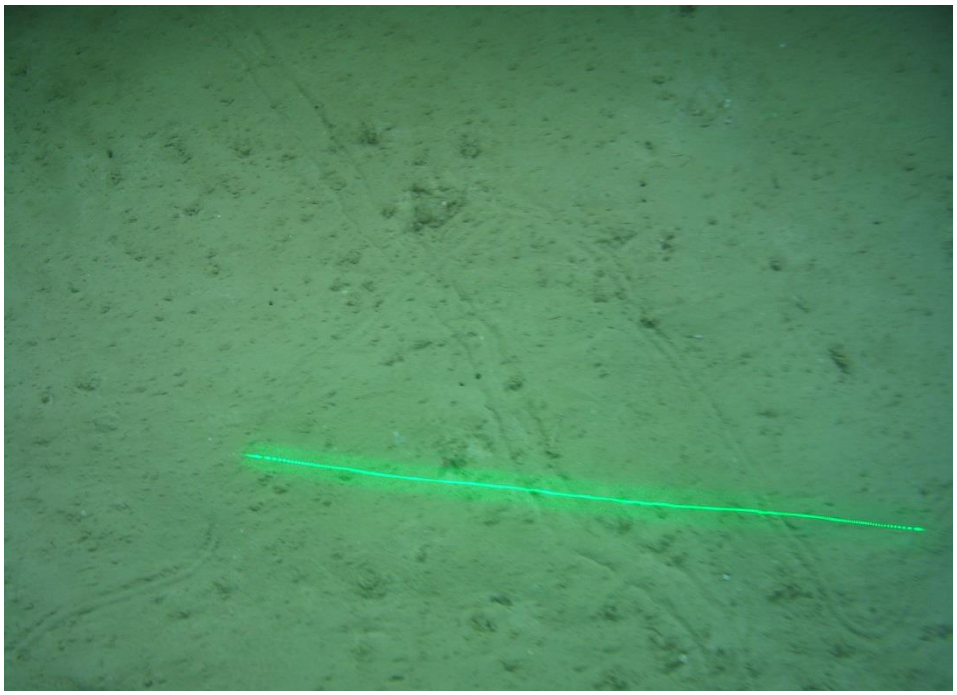
Photograph:
SA1702_ENV19_18

Easting: 558467.27 mE
Northing: 8499102.82 mN
Depth: 233.3 m

Sediment Type:
Reef rubble with sand veneer

Fauna:
Soft coral (Alcyonaria)
Bryozoa
Faunal burrows

SA1702_ENV20

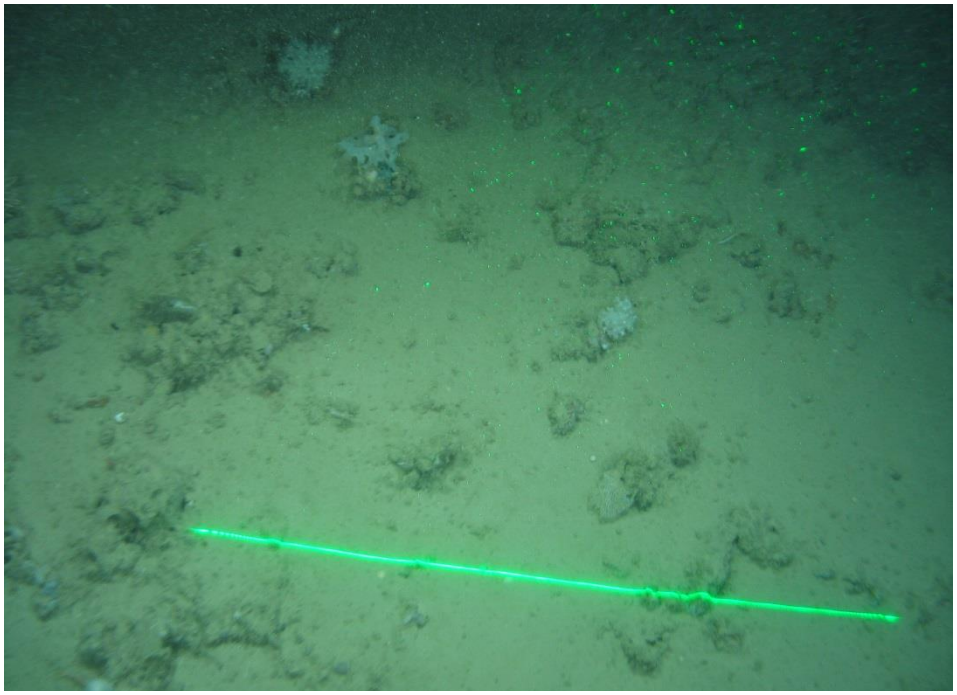


Photograph:
SA1702_ENV20_06

Easting: 556561.27 mE
Northing: 8498063.87 mN
Depth: 249.2 m

Sediment Type:
Muddy sand

Fauna:
Faunal tracks
Faunal burrows



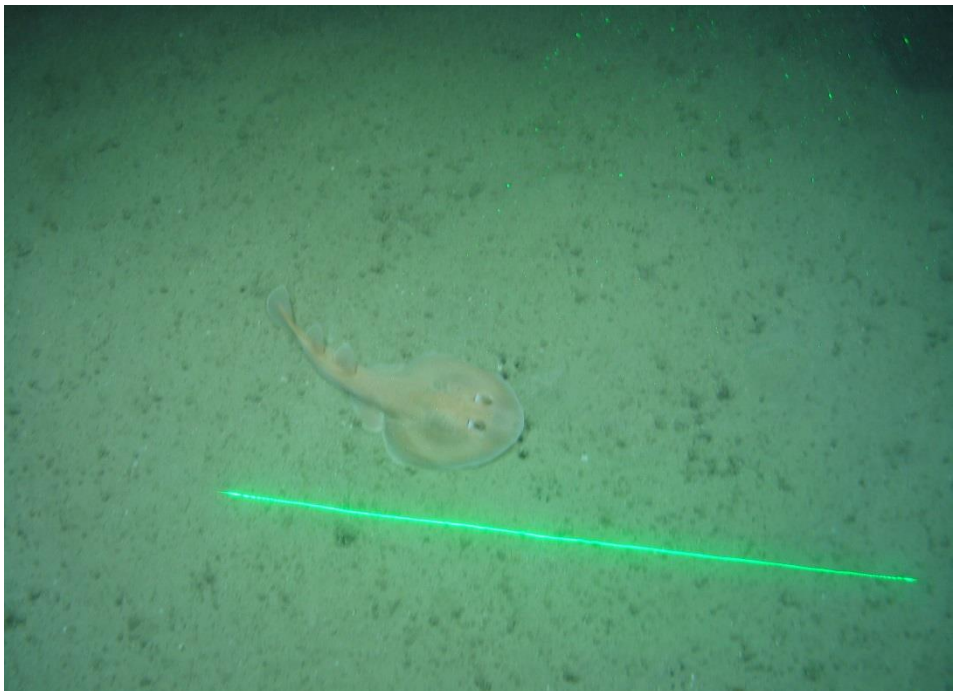
Photograph:
SA1702_ENV20_43

Easting: 556708.81 mE
Northing: 8497943.51 mN
Depth: 243.1 m

Sediment Type:
Reef rubble with muddy sand veneer

Fauna:
Sponges (Porifera)
Hydroids (Hydrozoa)

SA1702_ENV21

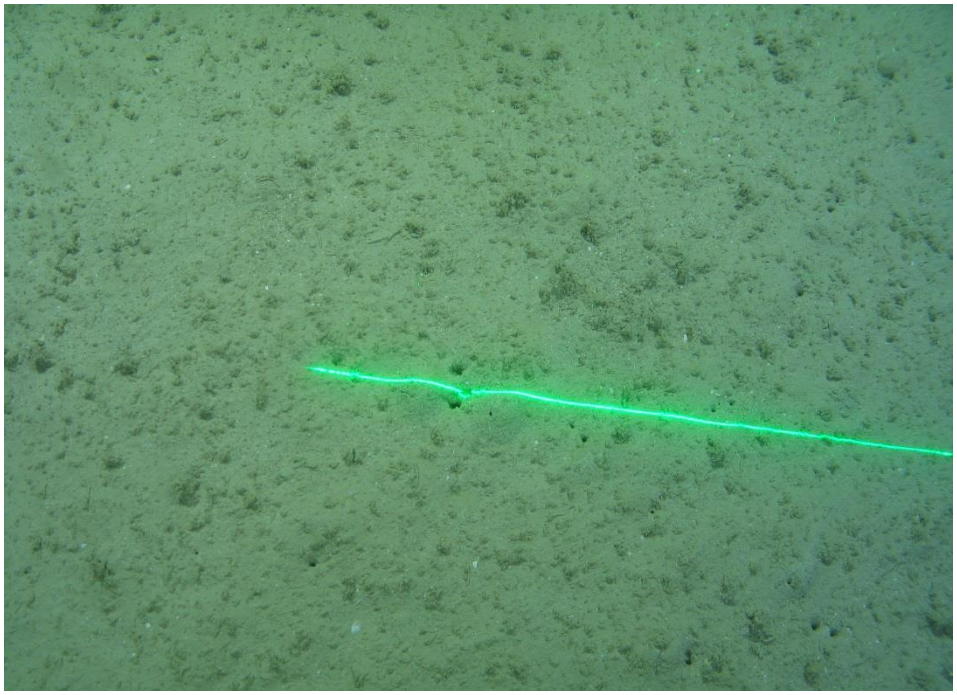


Photograph:
SA1702_ENV21_13

Easting: 551901.77 mE
Northing: 8492891.32 mN
Depth: 270.6 m

Sediment Type:
Muddy sand

Fauna:
Ray (Torpediniformes)



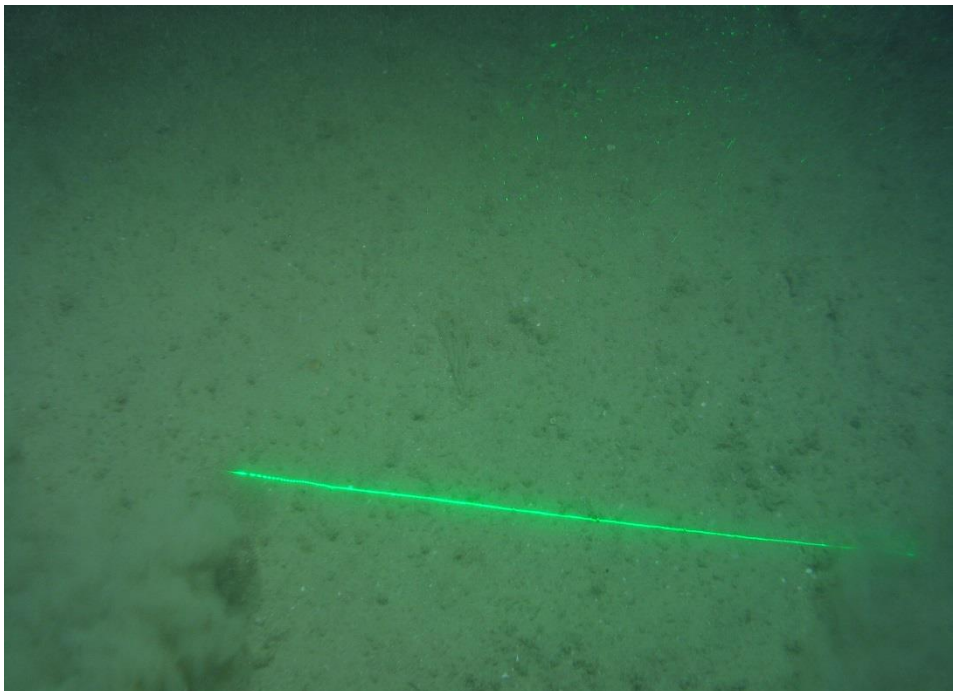
Photograph:
SA1702_ENV21_17

Easting: 551932.59 mE
Northing: 8492889.46 mN
Depth: 271 m

Sediment Type:
Muddy sand

Fauna:
Faunal burrows
Hydroids (Hydrozoa)

SA1702_ENV22

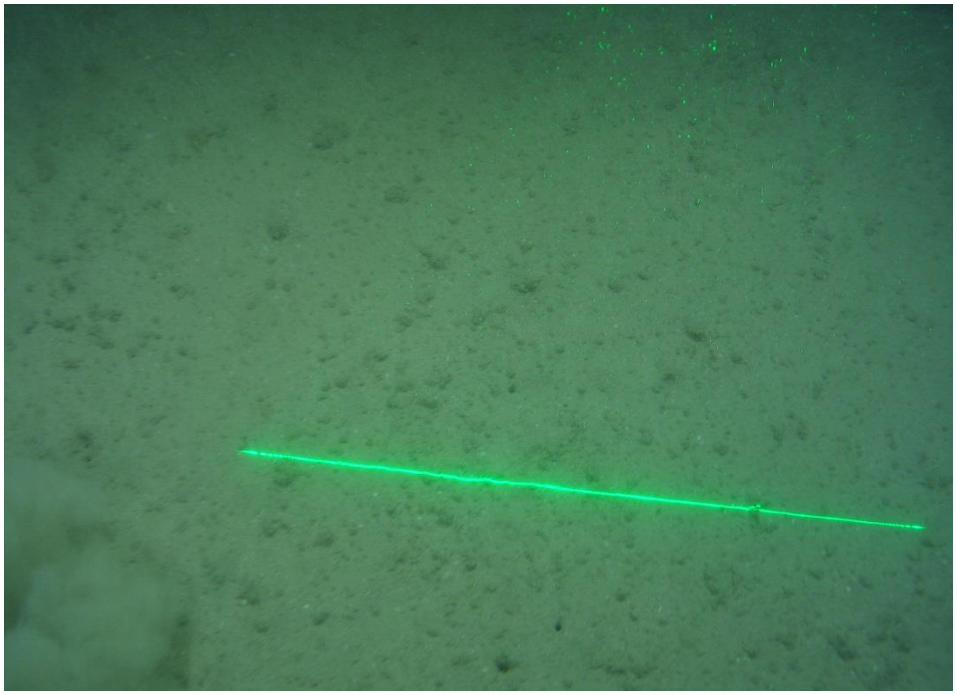


Photograph:
SA1702_ENV22_21

Easting: 546412.69 mE
Northing: 8487560.38 mN
Depth: 266.7 m

Sediment Type:
Muddy sand

Fauna:
No visible fauna



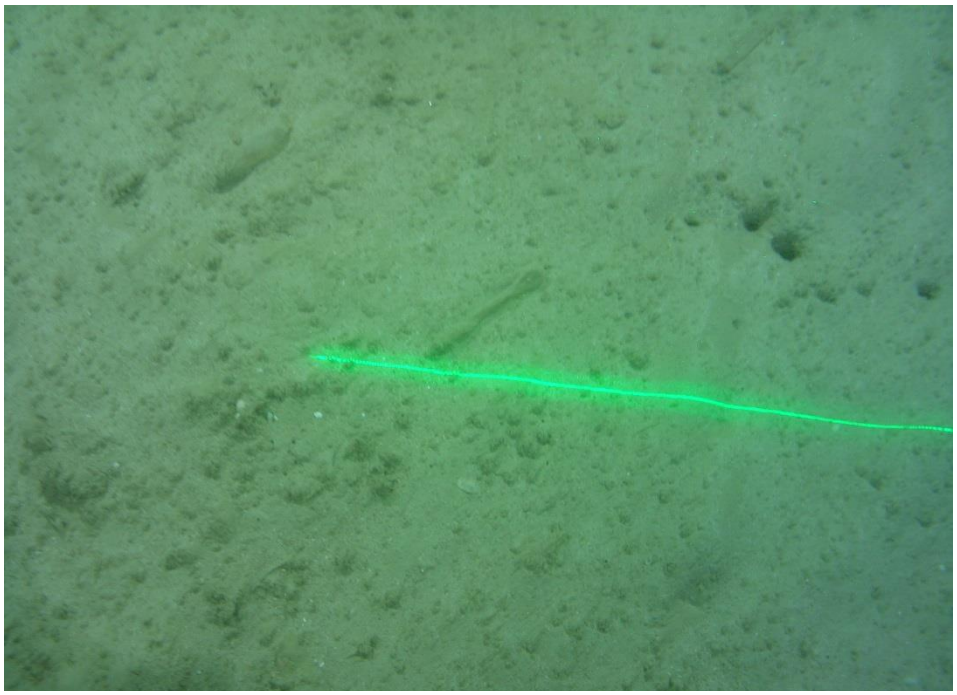
Photograph:
SA1702_ENV22_28

Easting: 546376.10 mE
Northing: 8487591.81 mN
Depth: 267.2 m

Sediment Type:
Muddy sand

Fauna:
No visible fauna

SA1702_ENV23

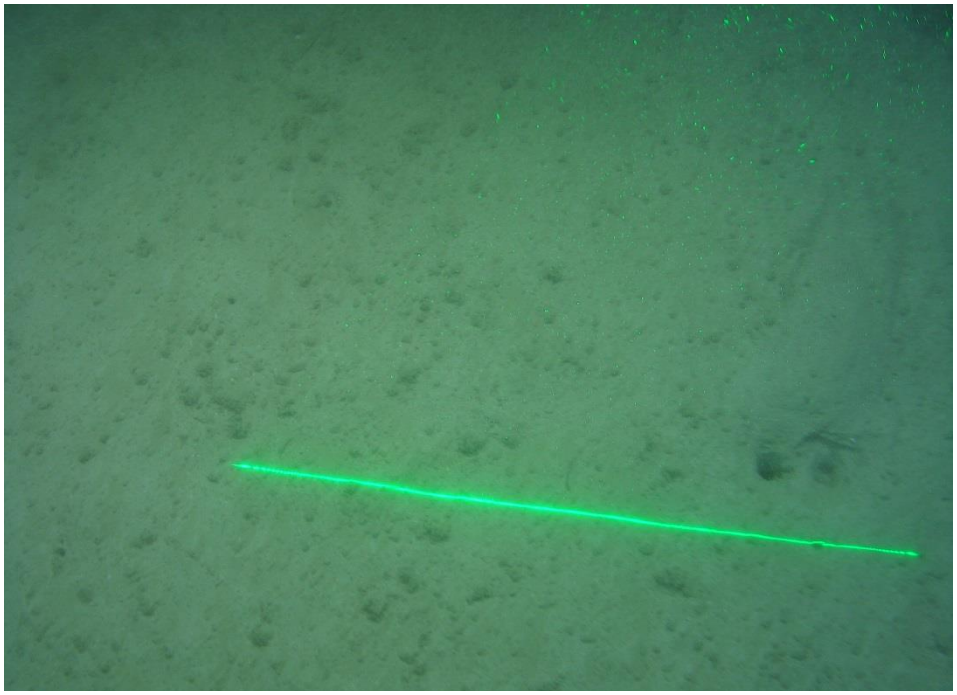


Photograph:
SA1702_ENV23_06

Easting: 539767.24 mE
Northing: 8481145.72 mN
Depth: 257.8 m

Sediment Type:
Muddy sand

Fauna:
Faunal burrows



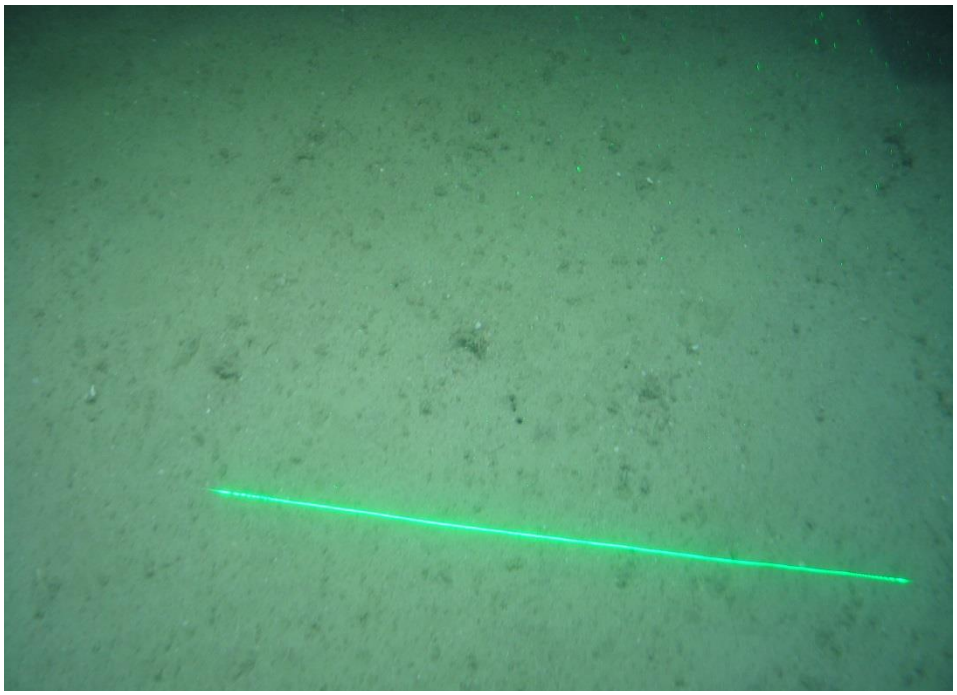
Photograph:
SA1702_ENV23_35

Easting: 539898.96 mE
Northing: 8481252.58 mN
Depth: 257.4 m

Sediment Type:
Muddy sand

Fauna:
Faunal burrows

SA1702_ENV24

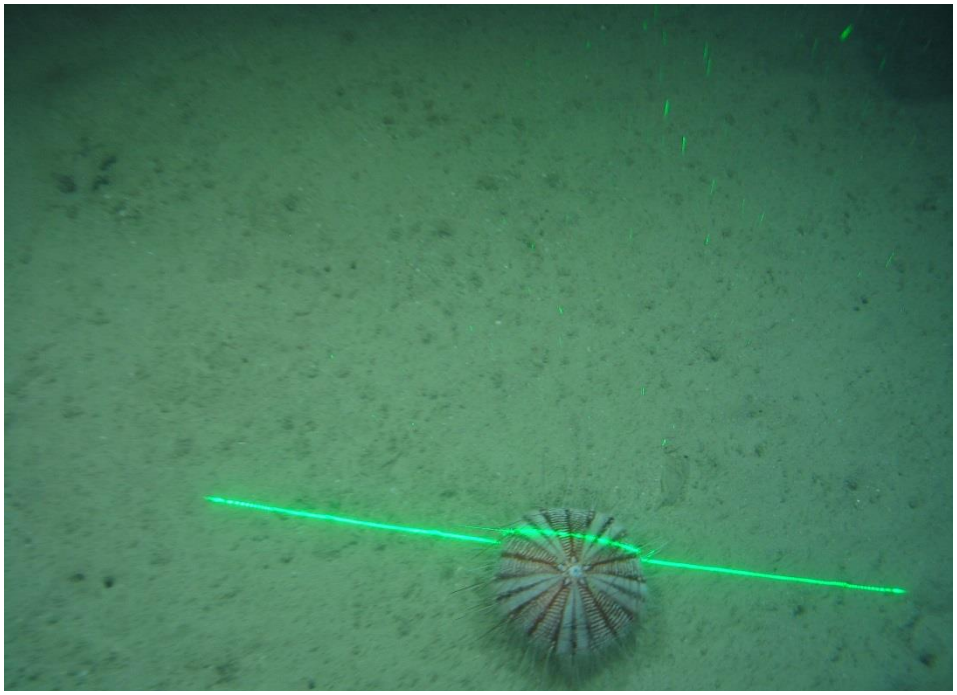


Photograph:
SA1702_ENV24_27

Easting: 549266.15 mE
Northing: 8484607.47 mN
Depth: 261.9 m

Sediment Type:
Muddy sand

Fauna:
Faunal burrows



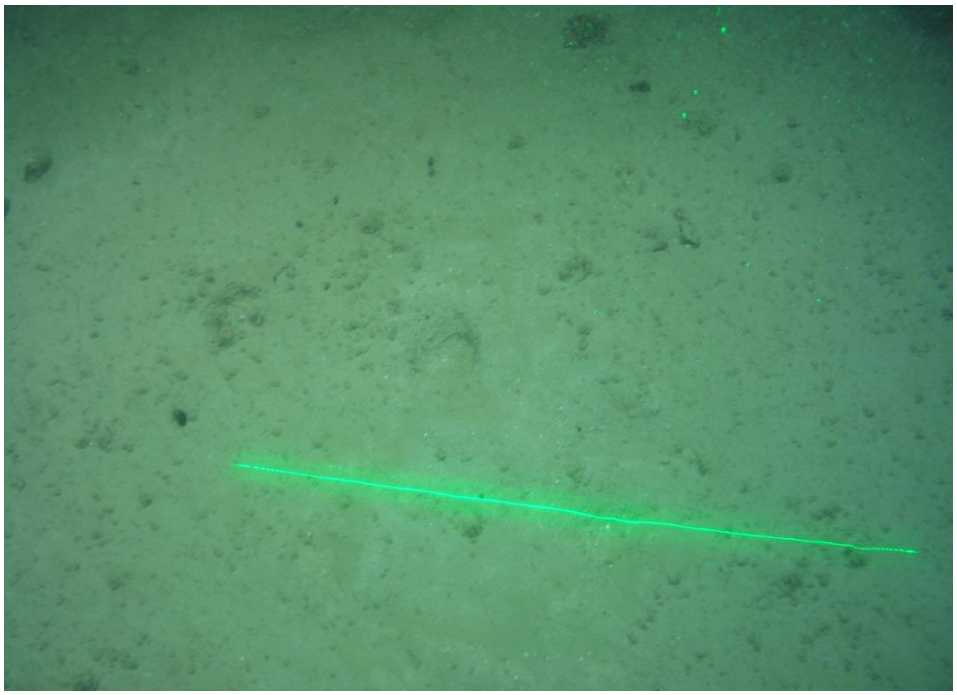
Photograph:
SA1702_ENV24_32

Easting: 549285.58 mE
Northing: 8484601.67 mN
Depth: 261.4 m

Sediment Type:
Muddy sand

Fauna:
Sea urchin (Echinoidea)
Faunal burrows

SA1702_ENV25

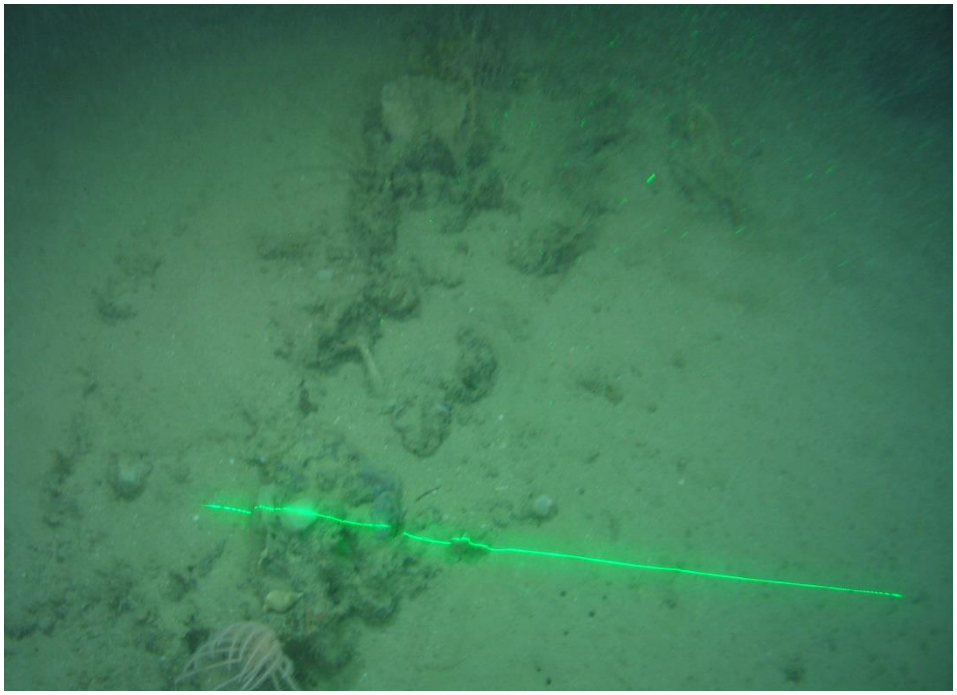


Photograph:
SA1702_ENV25_02

Easting: 557440.26 mE
Northing: 8490708.33 mN
Depth: 266.1 m

Sediment Type:
Muddy Sand

Fauna:
Faunal burrows



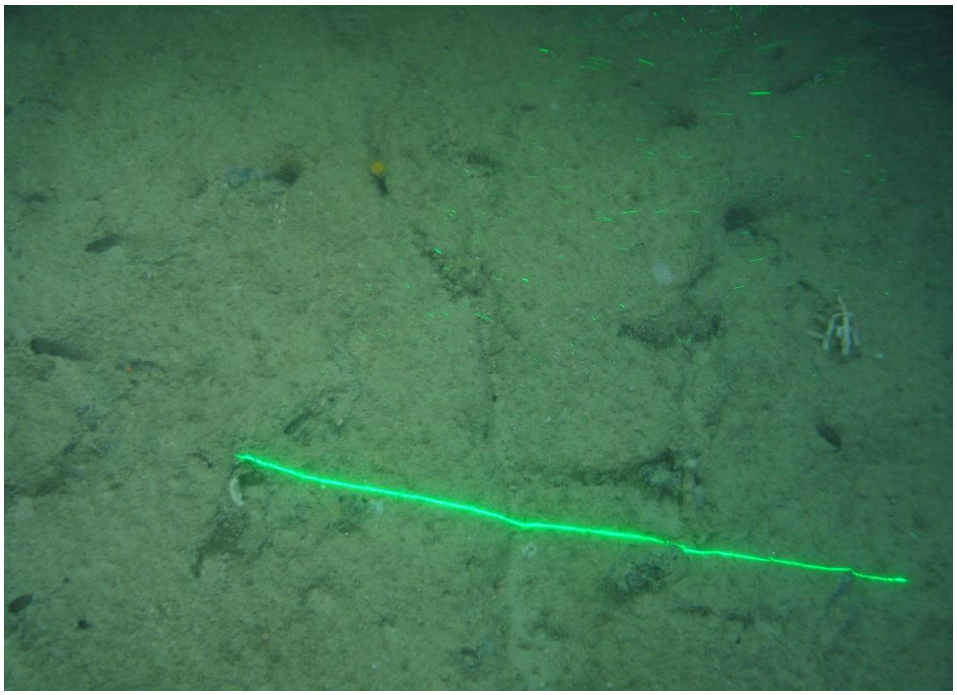
Photograph:
SA1702_ENV25_09

Easting: 557411.09 mE
Northing: 8490687.16 mN
Depth: 266.5 m

Sediment Type:
Reef rubble with muddy sand veneer

Fauna:
Sponge (Porifera)
Hydroids (Hydrozoa)
Soft coral (Alcyonaria)

SA1702_ENV26

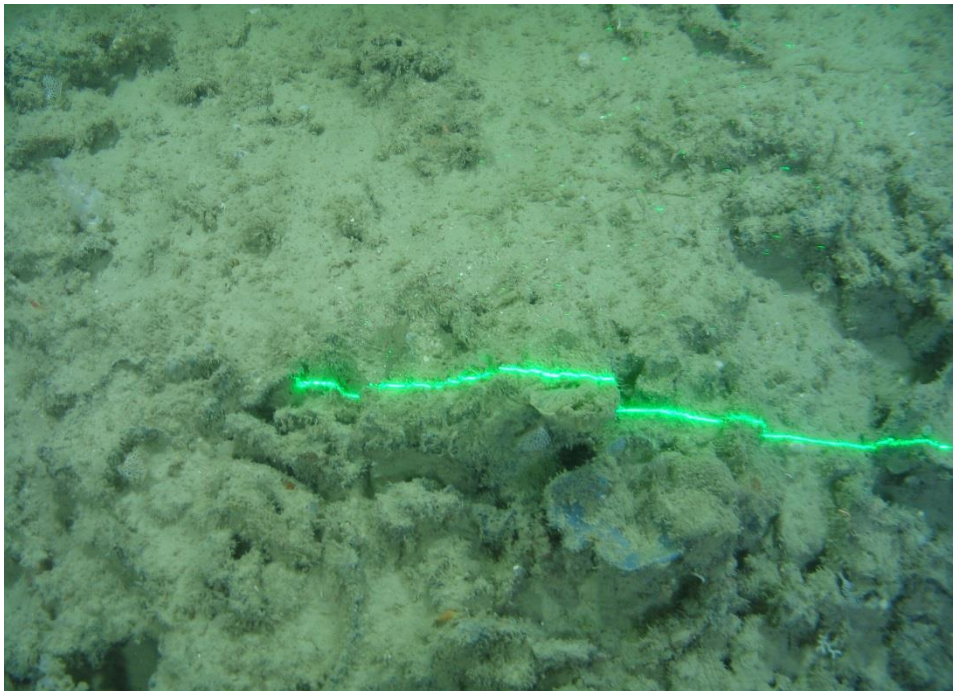


Photograph:
SA1702_ENV26_42

Easting: 558941.66 mE
Northing: 8491494.41 mN
Depth: 249.2 m

Sediment Type:
Reef with sand veneer

Fauna:
Sponges (Porifera)
Soft coral (Alcyonaria)



Photograph:
SA1702_ENV26_60

Easting: 558878.87 mE
Northing: 8491472.65 mN
Depth: 255.8 m

Sediment Type:
Reef with sand veneer

Fauna:
Sponges (Porifera)
Soft coral (Alcyonaria)
Hydroids (Hydrozoa)
Bryozoa

Appendix D: Drill Cuttings and Drilling Muds Dispersion Modelling Study (RPS 2018a)

REPORT

Shell Crux Project

Sediment Dispersion Modelling of Drill Cuttings and Fluids Discharges

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Approval for Issue

Name	Signature	Date
Sasha Zigic		12/07/2018

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1 Introduction

1.1 Background

RPS has been commissioned by CDM Smith Australia Pty Ltd (CDM Smith), on behalf of Shell Australia Pty Ltd (Shell), to undertake a sediment dispersion modelling study of discharged cuttings and fluids during drilling of the development wells within the Crux field (Table 1.1 and Figure 1.1). The Crux field is located in the northern Browse Basin in offshore Commonwealth marine waters, approximately 190 km offshore north-west Australia and 620 km north-north-east of Broome.

The principal aim of the study was to calculate the fate of discharged drill cuttings and unrecoverable drilling muds, quantify the likely area of coverage and levels of suspended sediments and bottom deposition (thickness and accumulated load), and assess the risk to sensitive receptors of contact from cuttings and muds discharged during the operation.

During the Crux drilling campaign, Shell intends to drill five wells all from one drill centre (one location), with each well currently proposed to be drilled as five intervals using conventional drilling techniques. Based on the current well design and information from previous drilling campaigns undertaken by Shell for Prelude and the Auriga-1 well, the Crux drilling programme is expected to result in the discharge of an estimated 891 m^3 of cuttings and 247 m^3 of mud solids over 33.5 days per well. In total, 167.5 days will be required to drill all five wells.

The potential area that may be influenced by the discharge of drill cuttings and drilling fluids was assessed on both a monthly and annualised basis.

Table 1.1 Location of the proposed Crux Development Well used as the release site for the drill cuttings and drilling fluids dispersion modelling assessment.

Release Site	Latitude (°S)	Longitude (°E)	Water Depth (m)
Crux Development Well	12° 57’ 52.46”	124° 26’ 33.21”	170

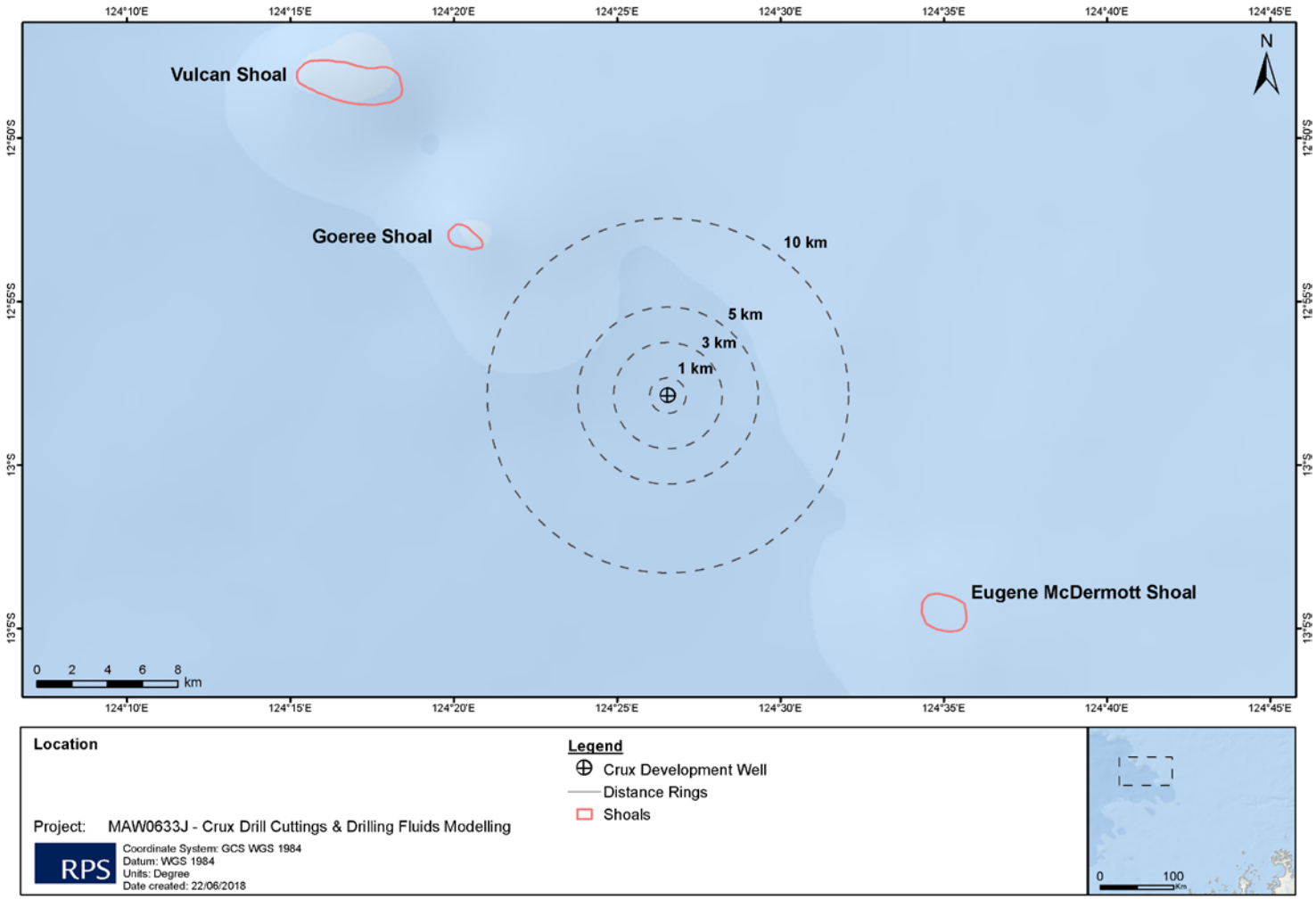


Figure 1.1 Location of the proposed Crux Development Well relative to the nearest submerged shoals.

1.2 Modelling Scope

The scope of the modelling included the following components:

1. Collation of a suitable three-dimensional, spatially-varying current data set surrounding the proposed Crux Development Well location for a ten-year (2008-2017) hindcast period. The current data set included the combined influence of drift and tidal currents, and was suitably long as to be indicative of interannual variability in ocean currents. The current data set was validated against the metocean data collected in the Crux development area.
2. Collation of seasonally-varying vertical water density profiles at the Crux development area for use as input to the sediment dispersion model.
3. Summary of the drilling plan as discrete discharge characteristics representing each stage of the drilling programme for input to the sediment dispersion model.
4. Establishment of a sediment dispersion model to repeatedly simulate all stages of the drilling programme under different sample conditions, with each sample represented by a time sequence of current flow commencing on the first day of each calendar month within the ten-year hindcast of currents (i.e. 120 simulations from January 2008 to December 2017).
5. Analysis of the results of all simulations to map the distribution and thicknesses of discharged drill cuttings and drilling muds in the water column and on the sea floor.

2 Regional Ocean Currents

2.1 Overview

The area of interest for this study is typified by strong tidal flows over the shallower regions, particularly along the inshore region of the Kimberley Coast. However, the offshore regions with water depths exceeding 100-200 m experience significant large-scale drift currents. These drift currents can be relatively strong (1-2 knots) and complex, manifesting as a series of eddies, meandering currents and connecting flows. These offshore drift currents also tend to persist longer (days to weeks) than tidal current flows (hours between reversals) and thus will have greater influence upon the net trajectory of sediment plumes over time scales exceeding a few hours.

Wind shear on the water surface also generates local-scale currents that can persist for extended periods (hours to days) and result in long trajectories. Hence, the current-induced transport of plumes can be variably affected by combinations of tidal, wind-induced and density-induced drift currents. Depending on their local influence, it is important to consider all these potential advective mechanisms to rigorously understand patterns of potential transport from a given discharge location.

To appropriately allow for temporal and spatial variation in the current field, dispersion modelling requires the current speed and direction over a spatial grid covering the potential migration zone of plumes. Estimates of the net currents were derived by combining predictions of the drift currents, available from a mesoscale ocean model, with estimates of the tidal currents generated by an RPS model set up for the study area. These estimates are considered representative of the oceanographic currents that influence the Crux development area. Shell has also collected 12 months of metocean data in the Crux development area, with this data being used to validate the hydrodynamic model used in this modelling study. Refer to Section 2.4 for further discussion of the tidal and current model validation.

A composite modelled ocean current data product was derived by combining predictions of mesoscale circulation currents, available at daily resolution from global ocean models, with predictions of the hourly tidal currents generated by the RPS HYDROMAP model. By combining a drift current model with a tidal model, the influences of inter-annual and seasonal drift patterns, and the more regular variations in tide, were included.

2.2 Mesoscale Circulation

Large-scale and mesoscale ocean circulation (also referred to as drift currents) will be the dominant driver of long-term (> several days) transport of effluent plumes. Mesoscale ocean processes are generally defined as having horizontal spatial scales of 10-500 km, and periods of 10-200 days, and processes with scales greater than this are referred to as large-scale. The major persistent large-scale and mesoscale surface currents off Western Australia are presented in Figure 2.1. They are characterised as follows:

- **Buoyancy driven circulation**. The main buoyancy-driven feature in the region is the Indonesian Throughflow (ITF) which conducts warm water from the equator into the Indian Ocean. Buoyancy gradients across the continental shelf due to differential heating and cooling and/or surface runoff may also drive three-dimensional circulation patterns.
- **Wind (Ekman) driven circulation**. The Australian North West Shelf has an annual wind cycle (easterly winds during winter, south-westerly winds during summer) which drives seasonal variability in surface circulation patterns.
- **Eddies and jets**. These non-linear features evolve from the large-scale and mesoscale flow field interacting with the bathymetry. These are random features and it is generally hard to predict their exact timing and location.



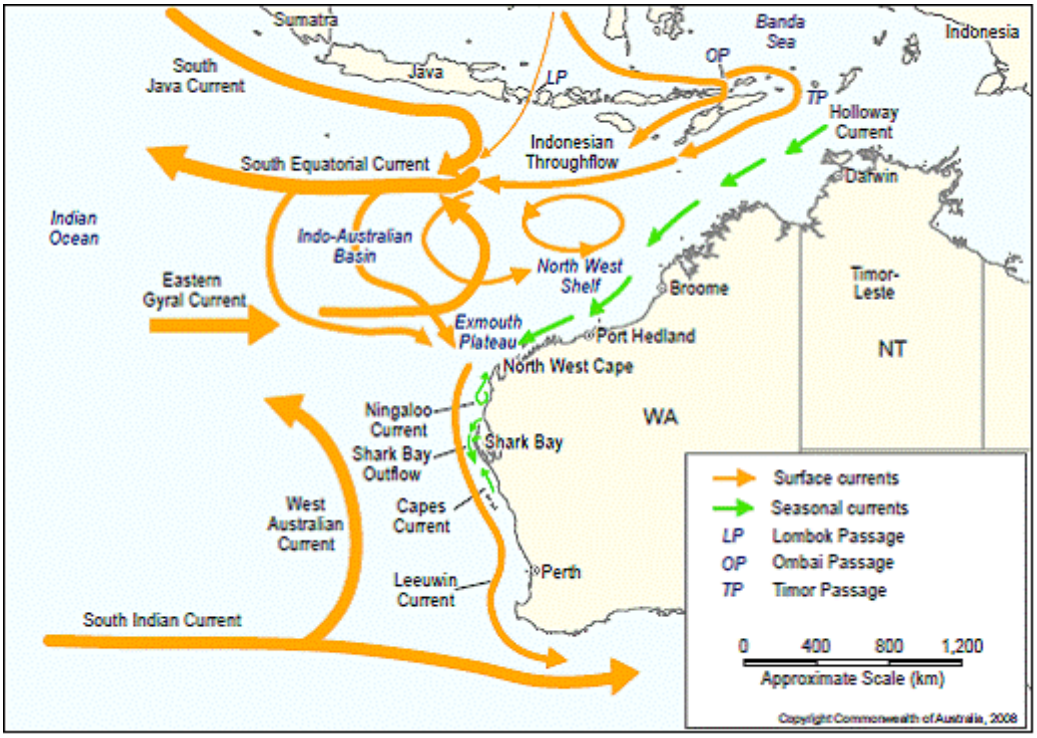


Figure 2.1 A map of the major currents off the West Australian coast (DEWHA, 2008).

2.2.1 Description of Mesoscale Model: HYCOM

Representation of the drift currents was available from the output of the global circulation model the Hybrid Coordinate Ocean Model (HYCOM; Bleck, 2002; Chassignet *et al.*, 2007, 2009), created by the National Ocean Partnership Program (NOPP), as part of the US Global Ocean Data Assimilation Experiment (GODAE). The HYCOM model is a three-dimensional model that assimilates ocean observations of sea surface temperature, sea surface salinity and surface height, obtained by satellite observations, along with atmospheric forcing conditions from atmospheric models to predict drift currents generated by such forces as wind shear, density and sea height variations and the rotation of the earth.

The HYCOM model is configured to combine the three vertical coordinate types currently in use in ocean models: depth (*z*-levels), density (isopycnal layers), and terrain-following (σ-levels). HYCOM uses isopycnal layers in the open, stratified ocean, but uses the layered continuity equation to make a dynamically smooth transition to a terrain-following coordinate in shallow coastal regions, and to *z*-level coordinates in the mixed layer and/or unstratified seas. Thus, this hybrid coordinate system allows for the extension of the geographic range of applicability to shallow coastal seas and unstratified parts of the world ocean. It maintains the significant advantages of an isopycnal model in stratified regions while allowing more vertical resolution near the surface and in shallow coastal areas, hence providing a better representation of the upper ocean physics. The model has global coverage with a horizontal resolution of $1/12^{th}$ of a degree (approximately 7 km at mid-latitudes) and a temporal resolution of one day.

A hindcast data set of HYCOM currents was obtained for a ten-year period spanning 2008 to 2017 (inclusive).

2.3 Tidal Currents

2.3.1 Description of Tidal Model: HYDROMAP

As the HYCOM model does not include tidal forcing, and because the data is only available at a daily frequency, a tidal model was developed for the study region using RPS' three-dimensional hydrodynamic model, HYDROMAP.

The model formulations and output (current speed, direction and sea level) of this model have been validated through field measurements around the world for more than 25 years (Isaji & Spaulding, 1984, 1986; Isaji *et al.*, 2001; Zigic *et al.*, 2003). HYDROMAP current data has also been widely used as input to forecasts and hindcasts of oil spill migrations in Australian waters. This modelling system forms part of the National Marine Oil Spill Contingency Plan for the Australian Maritime Safety Authority (AMSA) (AMSA, 2002).

HYDROMAP simulates the flow of ocean currents within a model region due to forcing by astronomical tides, wind stress and bottom friction. The model employs a sophisticated dynamically nested-gridding strategy, supporting up to six levels of spatial resolution within a single domain. This allows for higher resolution of currents within areas of greater bathymetric and coastline complexity, or of particular interest to a study.

The numerical solution methodology of HYDROMAP follows that of Davies (1977a, 1977b) with further developments for model efficiency by Owen (1980) and Gordon (1982). A more detailed presentation of the model can be found in Isaji & Spaulding (1984).

2.3.2 Tidal Grid Setup

A HYDROMAP model was established over a domain that extended approximately 3,300 km east-west by 3,100 km north-south over the eastern Indian Ocean. The grid extends beyond Eucla in the south and beyond Bathurst Island in the north (Figure 2.2).

Four layers of sub-gridding were applied to provide variable resolution throughout the domain. The resolution at the primary level was 15 km. The finer levels were defined by subdividing these cells into 4, 16 and 64 cells, resulting in resolutions of 7.5 km, 3.75 km and 1.88 km. The finer grids were allocated in a step-wise fashion to areas where higher resolution of circulation patterns was required to resolve flows through channels, around shorelines or over more complex bathymetry. Approximately 98,600 cells were used to define the region.

Bathymetric data used to define the three-dimensional shape of the study domain was extracted from the CMAP electronic chart database and supplemented where necessary with manual digitisation of chart data supplied by the Australian Hydrographic Office. Depths in the domain ranged from shallow intertidal areas through to approximately 7,200 m.

2.3.3 Tidal Boundary Conditions

Ocean boundary data for the HYDROMAP model was obtained from the TOPEX/Poseidon global tidal database (TPXO7.2) of satellite-measured altimetry data, which provided estimates of tidal amplitudes and phases for the eight dominant tidal constituents (designated as K_2, S_2, M_2, N_2, K_1, P_1, O_1 and Q_1) at a horizontal scale of approximately 0.25°. Using the tidal data, sea surface heights are firstly calculated along the open boundaries at each time step in the model.

The TOPEX/Poseidon satellite data is produced, and quality controlled by the US National Atmospheric and Space Agency (NASA). The satellites, equipped with two highly accurate altimeters capable of taking sea level measurements accurate to less than ±5 cm, measured oceanic surface elevations (and the resultant tides) for over 13 years (1992–2005). In total, these satellites carried out more than 62,000 orbits of the planet. The TOPEX/Poseidon tidal data has been widely used amongst the oceanographic community, being the subject of more than 2,100 research publications (e.g. Andersen, 1995; Ludicone *et al.*, 1998; Matsumoto *et al.*, 2000;

Kostianoy *et al.*, 2003; Yaremchuk & Tangdong, 2004; Qiu & Chen, 2010). As such, the TOPEX/Poseidon tidal data is considered suitably accurate for this study.

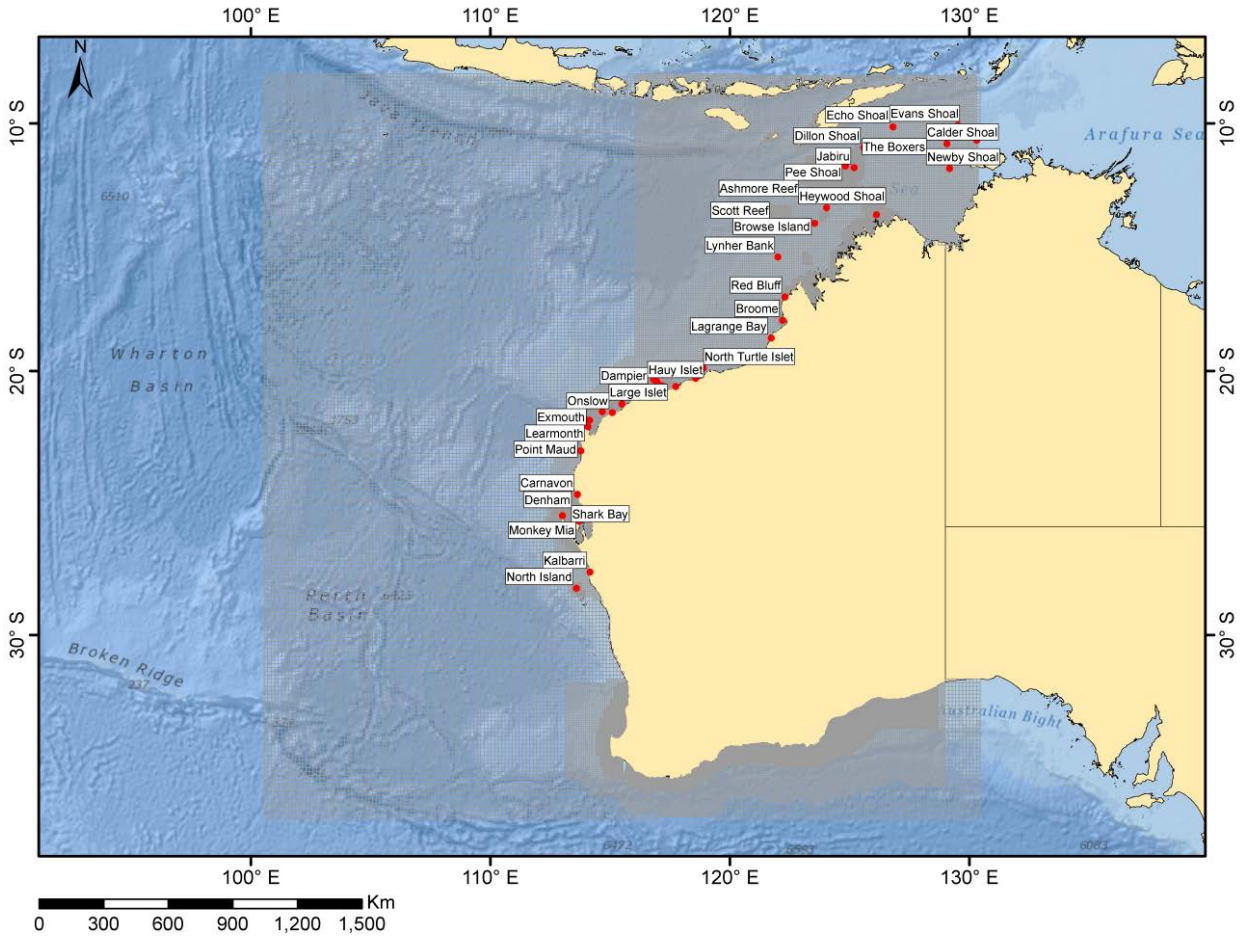


Figure 2.2 Hydrodynamic model grid (grey wire mesh) used to generate the tidal currents, showing the full domain in context with the continental land mass and the locations available for tidal comparisons (red labelled dots). Higher-resolution areas are indicated by the denser mesh zones.

2.4 Tidal and Current Model Validation

The suitability of the modelled tidal and drift current data products was evaluated by comparing the predicted currents to those measured at the Crux development area. The following sections describe the sources of both the modelled and measured data, the comparison methodology, and the outcomes of the comparisons for both the tidal and drift current components.

2.4.1 Data Sources

A tidal model was developed for the study region using RPS' three-dimensional hydrodynamic model, HYDROMAP. HYDROMAP simulates the flow of ocean currents within a model region due to forcing by astronomical tides, wind stress and bottom friction. This model is described in Section 2.3.

A mesoscale ocean current data sets was selected for the study: HYCOM (Hybrid Coordinate Ocean Model) Consortium's global ocean model, HYCOM. This model is described in Section 0.

A data set of measured currents was collected by RPS at the Crux development area between April 2016 and May 2017 (RPS, 2017). This data set includes a series of point current measurements made at six depths through the water column using CM04 current meters mounted on a floating mooring. The measurement depths are approximately 20 m, 70 m, 110 m, 150 m, 165 m and 167 m below the water surface. The temporal resolution of the data is 1 minute. The raw data was quality-controlled by RPS and only data identified as high-quality was used for comparison to model data. For the measurements at a 20 m water depth, there is approximately a 7-week gap in the data between early September and late October 2016.

2.4.2 Model Validation Skills

2.4.2.1 Overview

The mesoscale and tidal current models were validated through quantitative and visual comparisons of measured and modelled data.

2.4.2.2 Statistics

A quantitative analysis of a model's skill at replicating the environmental conditions was conducted using the Index of Agreement (IOA), presented in Willmott (1981), and the Mean Absolute Error (MAE), discussed in Willmott (1982) and Willmott & Matsuura (2005). Other traditional error estimates, such as the correlation coefficient and the root mean square error (RMSE) are problematic and prone to ambiguities and bias (Willmott & Matsuura, 2005; Willmott, 1982). Consequently, they are not reported in isolation here.

The MAE is simply the average of the absolute values of the differences between the observed and modelled values. MAE is a more natural measure of average error (Willmott & Matsuura, 2005) and more readily understood. The IOA is determined using the following formula:

$$\mathrm{IOA} = 1 - \frac{\sum |X_{\mathrm{model}} - X_{\mathrm{obs}}|^2}{\sum \left(|X_{\mathrm{model}} - \overline{X_{\mathrm{obs}}}| + |X_{\mathrm{obs}} - \overline{X_{\mathrm{obs}}}| \right)^2}$$

In this equation, X represents the variable being compared and $\bar{X}$ represents the mean of that variable over time.

A perfect agreement can be said to exist between the model and field observations if the IOA gives a measure of one, and complete disagreement will produce an IOA measure of zero (Wilmott, 1981). Although it is difficult to find guidelines for what values of the IOA might represent a good agreement, Willmott *et al.* (1985) suggests that values meaningfully larger than 0.5 represent good model performance. Clearly, the higher the IOA and the lower the MAE, the better the model performance.

An important point to note regarding both, and in fact most, measures of model performance, is that slight phase differences in the series can result in a seemingly poor statistical comparison, particularly in rapidly changing series such as tidal direction or water elevation where the tidal range is large. It is therefore always important to consider both the statistics and the visual representation of the comparison (Willmott *et al.*, 1985). Statistical comparison of current direction can be misleading; skill measures of direction can become biased where the directional fluctuations are near 0-360°. Therefore, we have based the quantitative assessment on the U and V current components and not magnitude and direction.

2.4.2.3 Time Series

In addition to bulk statistical measures, model performance for the measurement period was assessed visually with the aid of scatterplots and rose plots. The scatterplots show the correlation between the x- and y-components of the measured and modelled data. The rose plots show the frequency of current direction by sector, and magnitude by colour, to allow comparison of current direction between modelled and measured data.

The model performance was also evaluated against time series plots of water level, U (east-west) velocity component, V (north/south) velocity component, current speed and current direction data. This approach is valuable because statistical measures of model skill can heavily penalise errors in phase (i.e. time lags) even when the dynamics of flow are broadly reproduced.

2.4.3 Tidal Elevation Validation

For verification of the tidal elevation predictions, the model output was compared against independent predictions of tides using the XTide database (Flater, 1998). The XTide database contains harmonic tidal constituents derived from measured water level data at locations around the world. Of more than 80 tidal stations within the HYDROMAP model domain, 18 sites near the Crux development area were used for comparison.

Time series comparisons were completed for a six-month period from January to June 2010. The statistics are summarised in Table 2.1, and indicate excellent model performance in this region. Water level time series for these locations are shown in Figure 2.3, Figure 2.4 and Figure 2.5 for a one-month period (March 2010). All comparisons show that the model produces a very good match to the known tidal behaviour for a wide range of tidal amplitudes and clearly represents the varying diurnal and semi-diurnal nature of the tidal signal.

For the purposes of understanding the limitations in accuracy of the tidal predictions, the RMSE and MAE in Table 2.1 should be noted. On average, the model predictions are within 0.1-0.3 m of XTide predictions based on known constituent data at any point in time. Often the error is mostly attributable to errors of phase in the tidal signal, with the magnitude of the tidal rise and fall over each tide well represented. However, in the application of the data predictions to operational circumstances, the potential errors should be considered.

The model skill was further evaluated through a comparison of the predicted and observed tidal constituents, derived from an analysis of model-predicted time-series at each location. A scatter plot of the observed and modelled amplitude (top) and phase (bottom) of the five dominant tidal constituents (S_2, M_2, N_2, K_1 and O_1) is presented in Figure 2.6. The red line on each plot shows the 1:1 line, which would indicate a perfect match between the modelled and observed data. Note that the data is generally closely aligned to the 1:1 line demonstrating the high quality of the model performance.

Table 2.1 Statistical comparison of predicted surface elevation data from HYDROMAP and XTide at 18 locations in the tidal model domain (January to July 2010).

Tide Station	Longitude (°E)	Latitude (°S)	IOA	CC	MAE (m)	RMSE (m)
Ashmore Reef	123.02	12.22	0.99	0.99	0.14	0.18
Browse Island	123.55	14.10	0.97	0.97	0.36	0.45
Calder Shoal	129.07	10.85	0.97	0.97	0.17	0.21
Cape Legendre	116.83	20.35	0.99	0.99	0.12	0.14
Dillon Shoal	125.60	11.00	0.97	0.95	0.18	0.22
Echo Shoal	126.82	10.15	0.97	0.94	0.17	0.21
Evans Shoal	129.53	10.08	0.98	0.98	0.11	0.14
Goodrich Bank	130.32	10.70	0.99	0.97	0.13	0.16
Heywood Shoal	124.05	13.47	0.98	0.96	0.27	0.33
Jabiru	125.20	11.83	097	0.95	0.22	0.27
Loxton Shoal	128.72	09.60	0.99	0.98	0.10	0.13
Lynedoch Bank	130.82	10.03	0.98	0.98	0.12	0.15
Lynher Bank	122.02	15.47	0.98	0.97	0.26	0.31
Newby Shoal	129.18	11.87	0.98	0.96	0.23	0.27
Pee Shoal	124.83	11.77	0.97	0.94	0.23	0.27
Scott Reef	121.80	14.05	0.99	0.98	0.16	0.19
The Boxers	128.35	11.45	0.97	0.96	0.16	0.20
Troughton Island	126.13	13.75	0.97	0.95	0.27	0.33

Notes: *IOA Index of Agreement – values close to 1 represent a high level of agreement.*
CC Correlation Coefficient – values close to 1 represent very good correlation.
MAE Mean Absolute Error – the lower the value, the smaller the error.
RMSE Root Mean Square Error – the lower the value, the smaller the error.

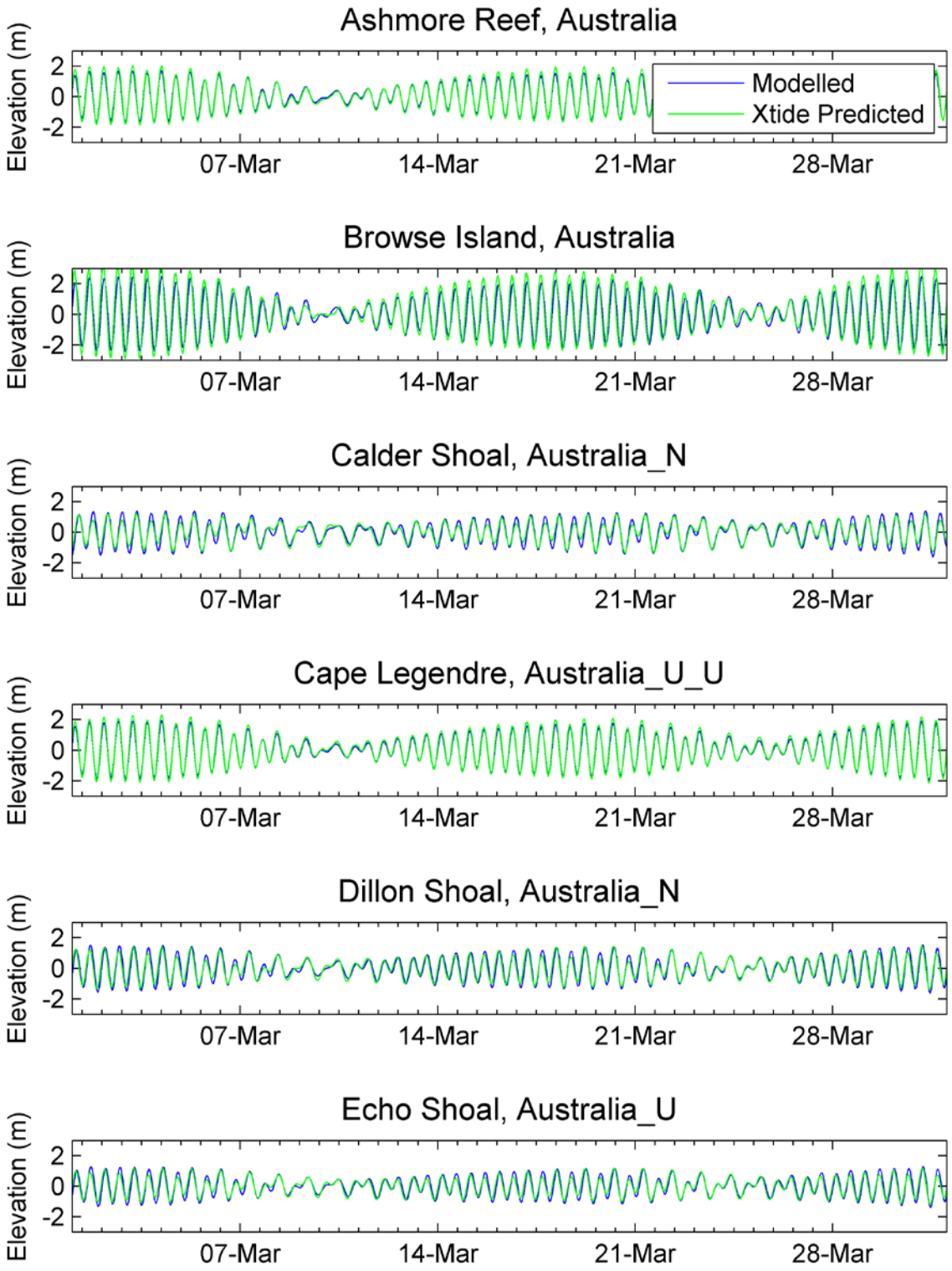


Figure 2.3 Time series comparisons between predicted surface elevation data from HYDROMAP (blue line) and XTide (green line) at six locations in the tidal model domain (March 2010).

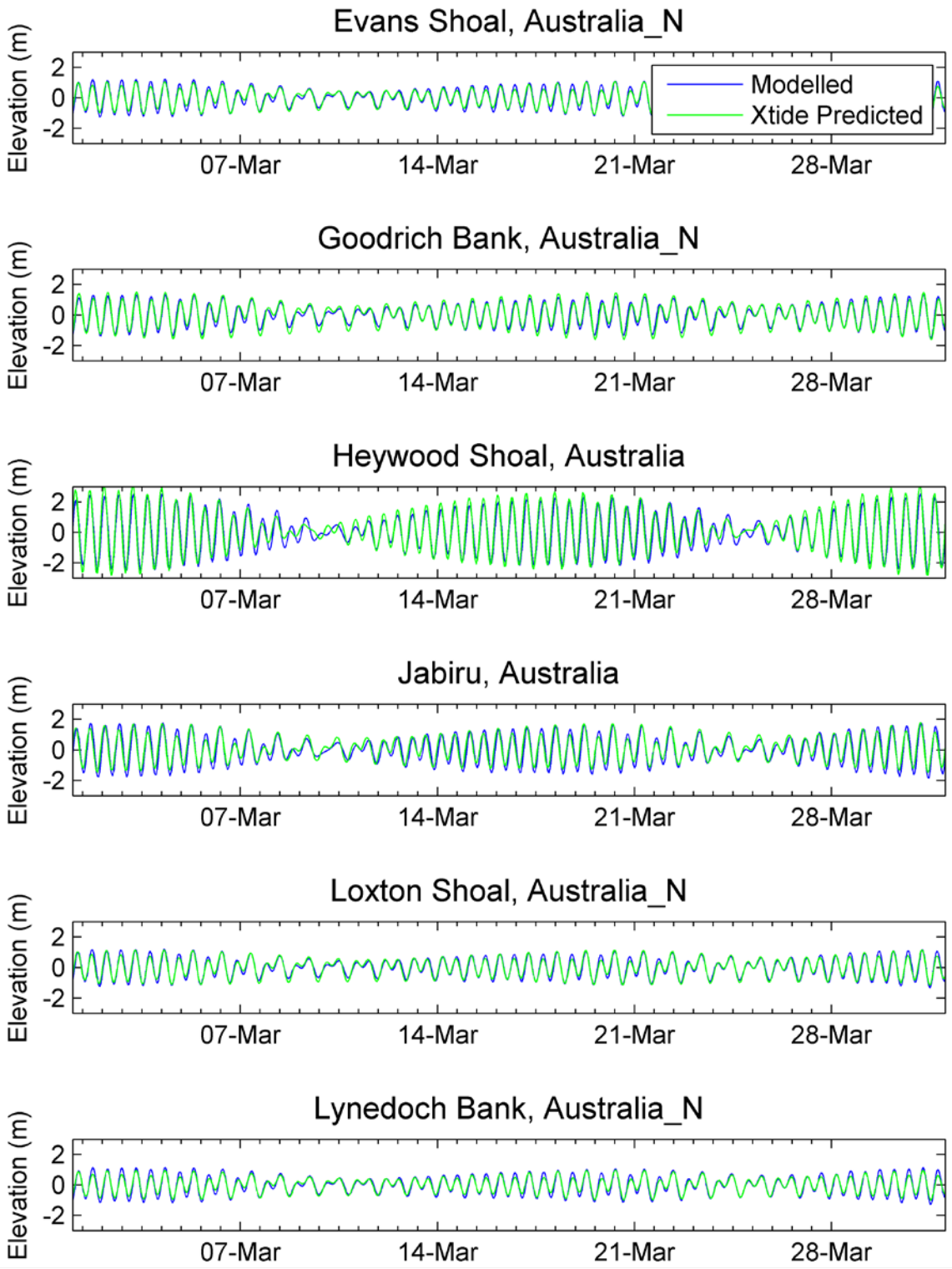


Figure 2.4 Time series comparisons between predicted surface elevation data from HYDROMAP (blue line) and XTide (green line) at six locations in the tidal model domain (March 2010).

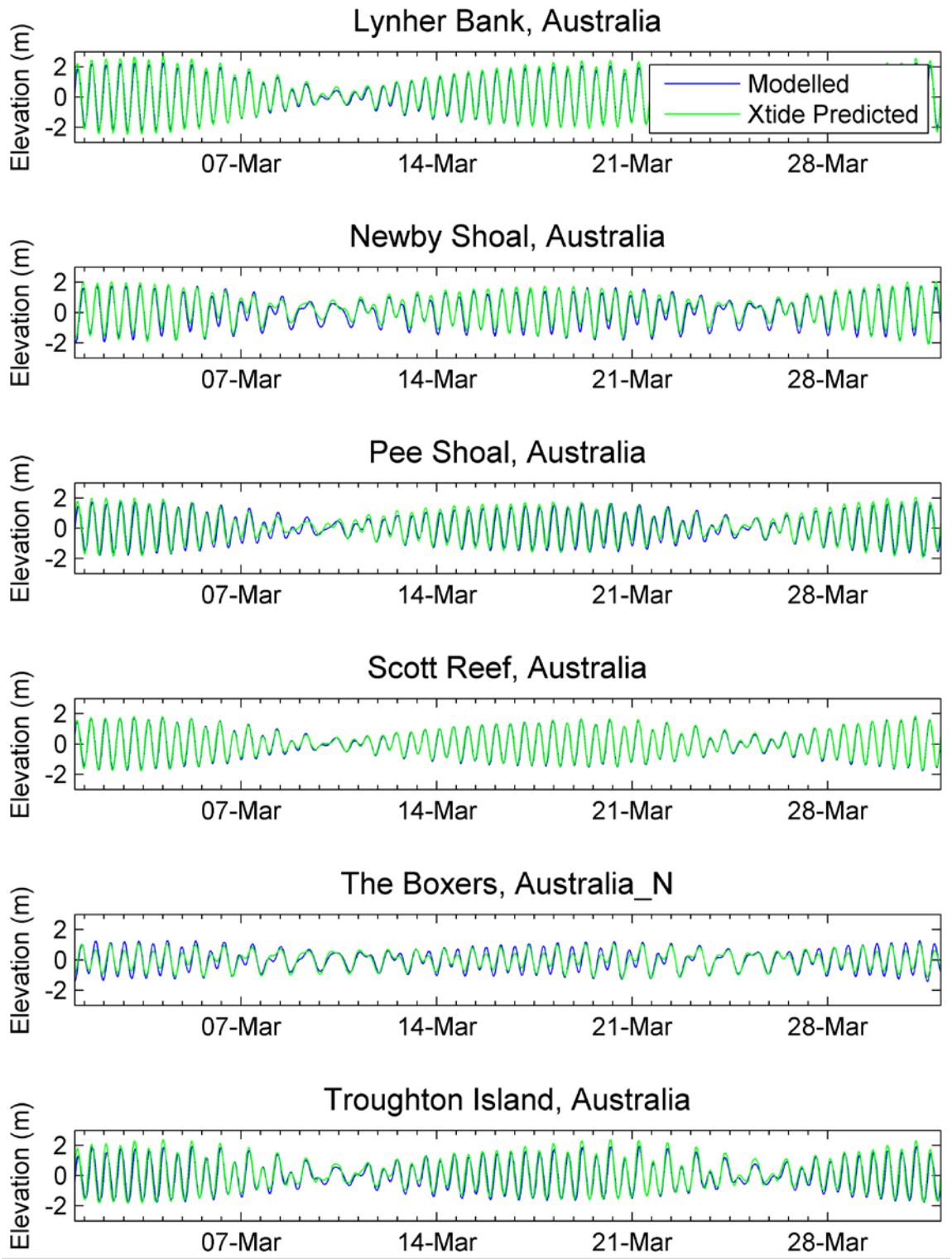


Figure 2.5 Time series comparisons between predicted surface elevation data from HYDROMAP (blue line) and XTide (green line) at six locations in the tidal model domain (March 2010).

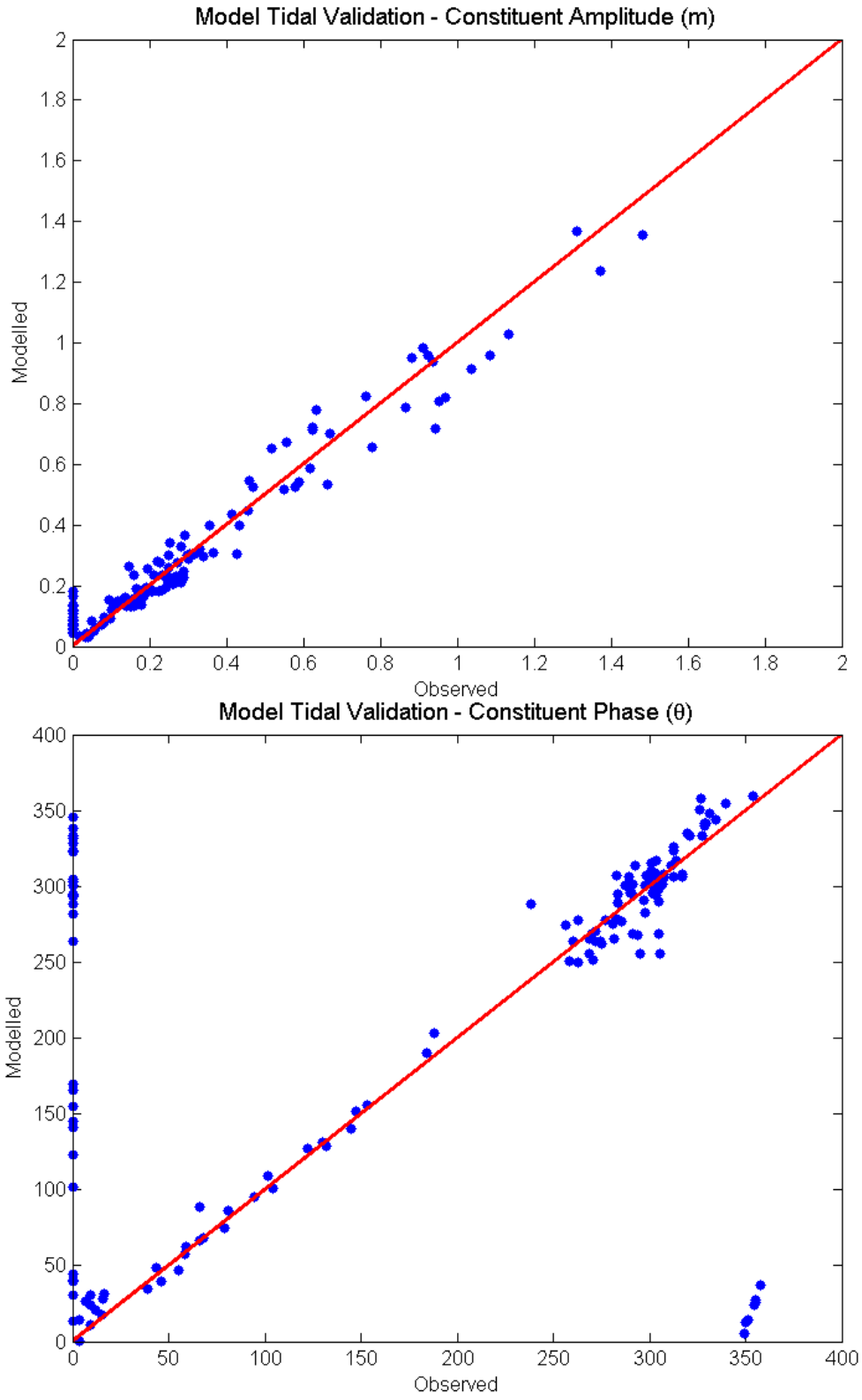


Figure 2.6 Comparisons between predicted tidal constituent amplitudes (top) and phases (bottom) from HYDROMAP and XTide at all stations in the tidal model domain. The red line indicates a 1:1 correlation between the respective data sets.

2.4.4 Composite Current Data Set Validation: HYDROMAP + HYCOM

A composite modelled ocean current data product was derived by combining predictions of mesoscale circulation currents, available at daily resolution from the HYCOM ocean model, with predictions of the hourly tidal currents generated by the RPS HYDROMAP model.

To verify the modelled current predictions, the composite model outputs at the Crux development area were compared against the unfiltered site-specific current measurements. The model results were validated through both quantitative and visual comparisons between measured and modelled data at each depth where both data sets were available.

Time series comparison of composite model outputs and measured current magnitude, direction, and U/V velocity components at water depths of 20 m, 70 m and 110 m are presented in Figure 2.7, Figure 2.8 and Figure 2.9, respectively, for one month during winter (June 2016) and summer (December 2016). The time series comparisons reveal that the composite model offers a good match with the measured U/V velocity components at all water depths in both winter and summer, with the magnitudes and timings of the peaks and troughs matching well.

The IOA and MAE values derived from comparisons of the U/V velocity components at water depths of 20 m, 70 m and 110 m over the full measurement period are presented in Table 2.2. The IOA for each velocity component is high at all water depths, reflecting the good match in the magnitudes and timings of the peaks and troughs in the composite model data and measured data. The MAE for the U/V velocity components is relatively low at approximately 0.1 m/s for all water depths, indicating that the magnitude and range of the velocity components match well; however, a slight overprediction of the current magnitude is evident at times.

To compare directionality, roses for the composite model outputs and measured currents at 20 m, 70 m and 110 m water depths over the full measurement period are shown in Figure 2.9. The roses show that the composite model current direction is a good match with the measured direction. A shift in the dominant current direction from a north/south alignment in the measured data set to a northwest/southeast alignment in the composite model data set is evident at the 20 m water depth, and to a lesser extent also at the 70 m water depth. However, the range and variability in the measured current direction is captured by the composite model data, which matches best with the measured data at the water depth of 110 m.

Based on the validation performance, the composite model data set is a good model of standard conditions at the Crux development area and will adequately resolve local and regional circulation patterns. As such, the model is considered suitable for use in the numerical modelling studies conducted as part of the Crux project.

Table 2.2 Statistical comparison of predicted (HYDROMAP+HYCOM) and observed current speeds along orthogonal component axes at the Crux development area (2016-2017).

Skill Measure	Index of Agreement (IOA)			Mean Absolute Error (MAE) (m/s)		
Depth (m)	20	70	110	20	70	110
U Component	0.72	0.75	0.76	0.11	0.11	0.11
V Component	0.82	0.80	0.78	0.11	0.10	0.10

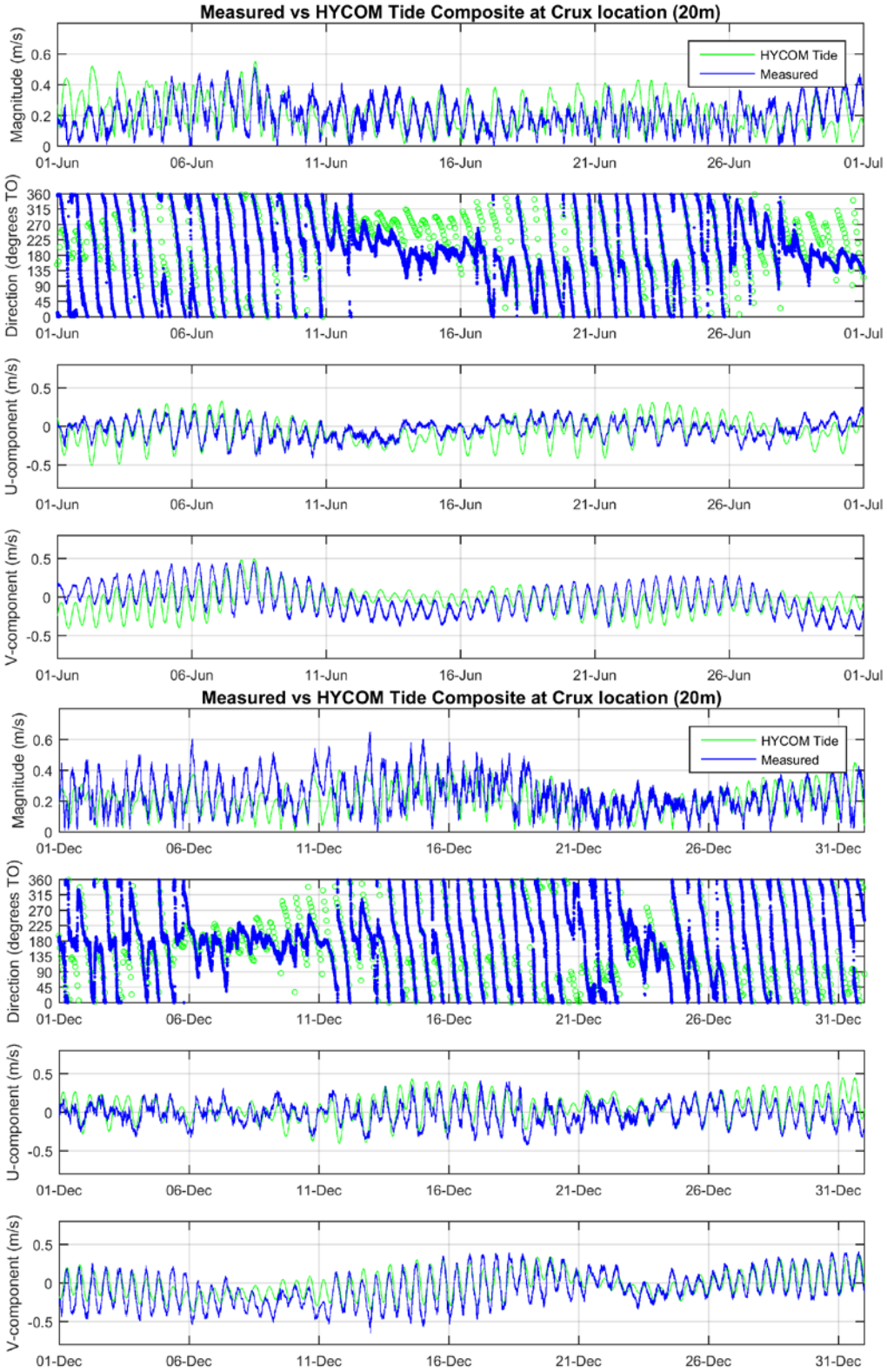


Figure 2.7 Time series comparisons between predicted (HYDROMAP+HYCOM, green line) and measured (blue line) current data at the Crux development area at a depth of approximately 20 m for June 2016 (top panel) and December 2016 (bottom panel).

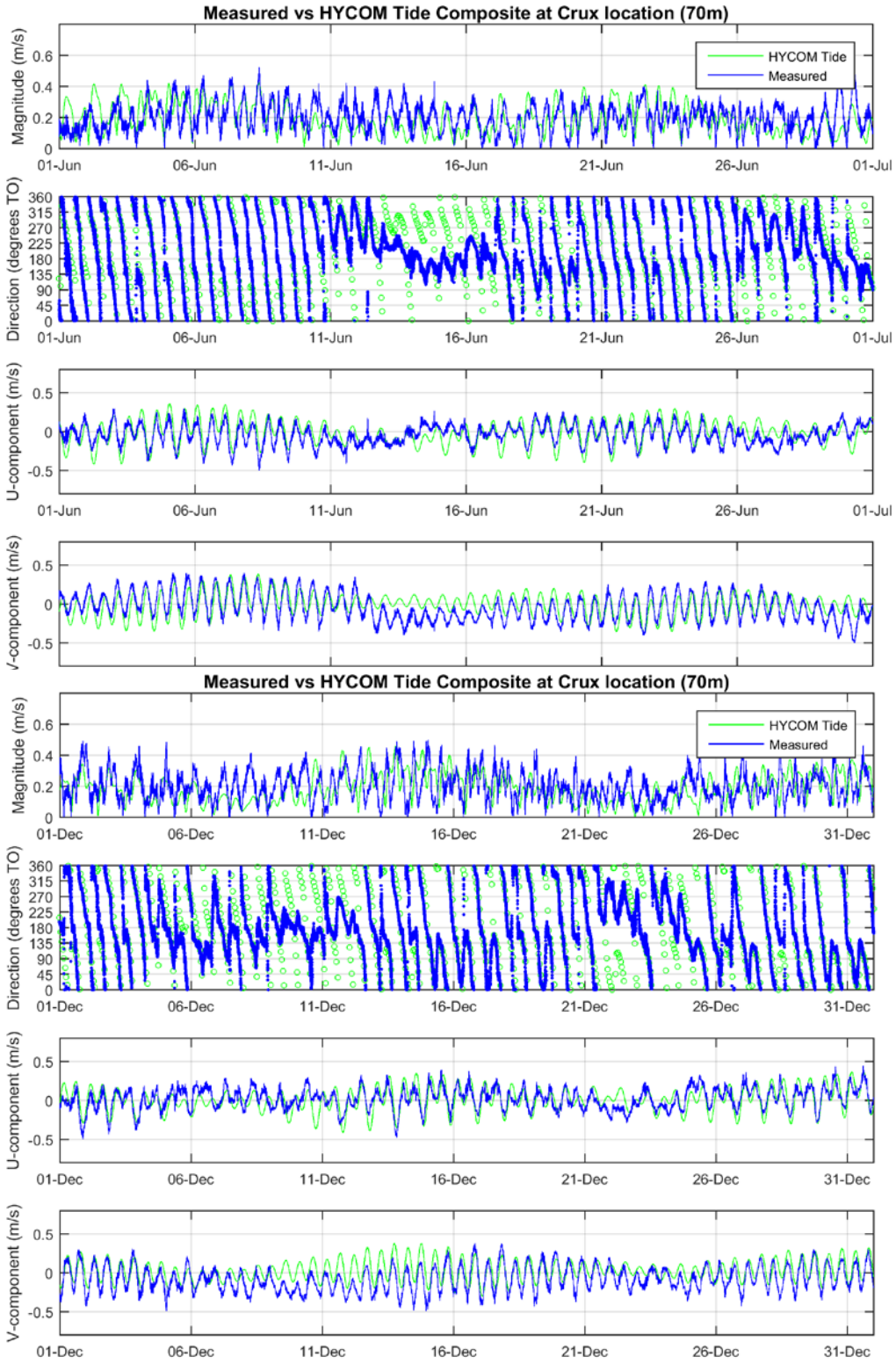


Figure 2.8 Time series comparisons between predicted (HYDROMAP+HYCOM, green line) and measured (blue line) current data at the Crux development area at a depth of approximately 70 m for June 2016 (top panel) and December 2016 (bottom panel).

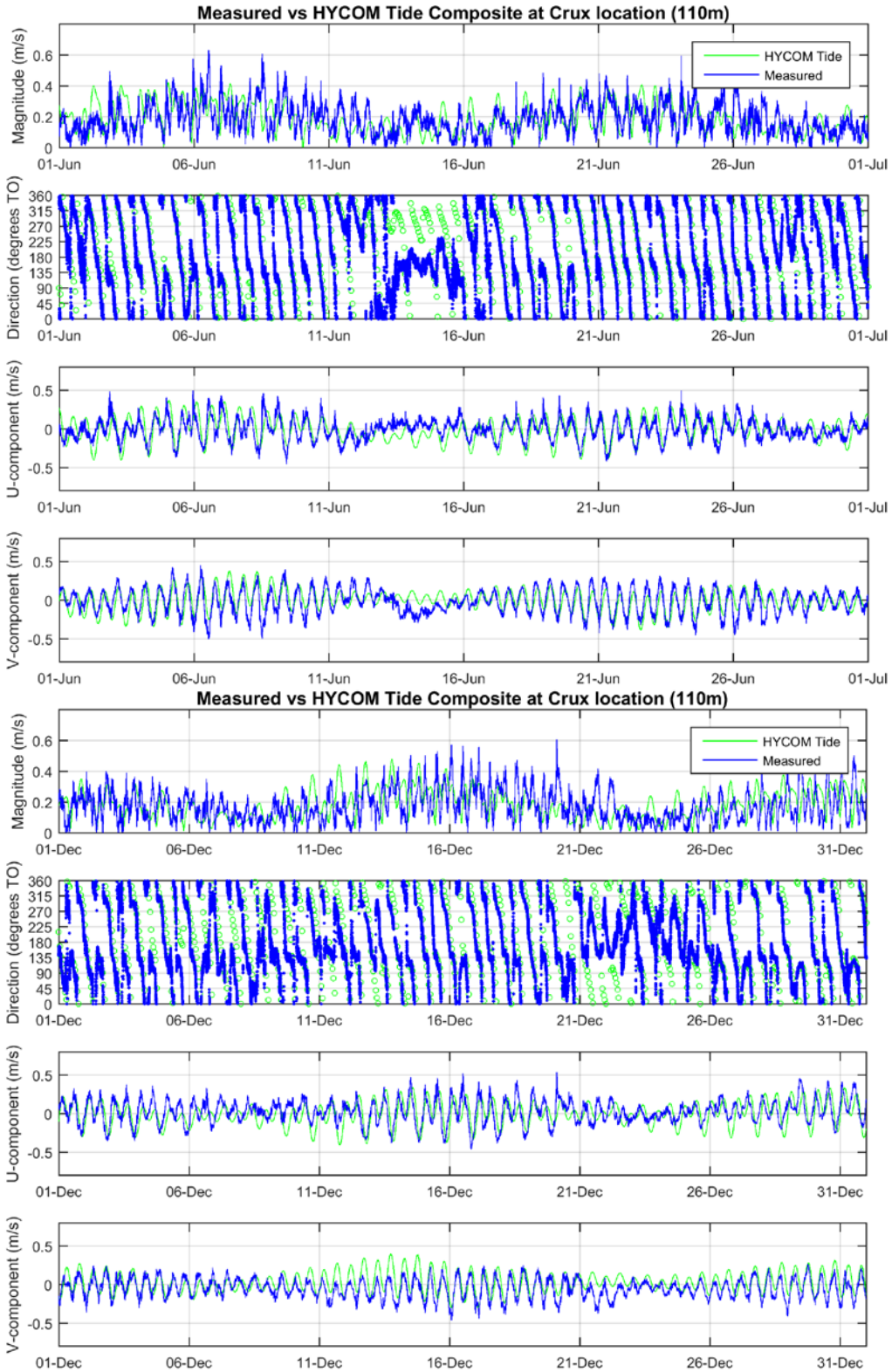


Figure 2.9 Time series comparisons between predicted (HYDROMAP+HYCOM, green line) and measured (blue line) current data at the Crux development area at a depth of approximately 110 m for June 2016 (top panel) and December 2016 (bottom panel).

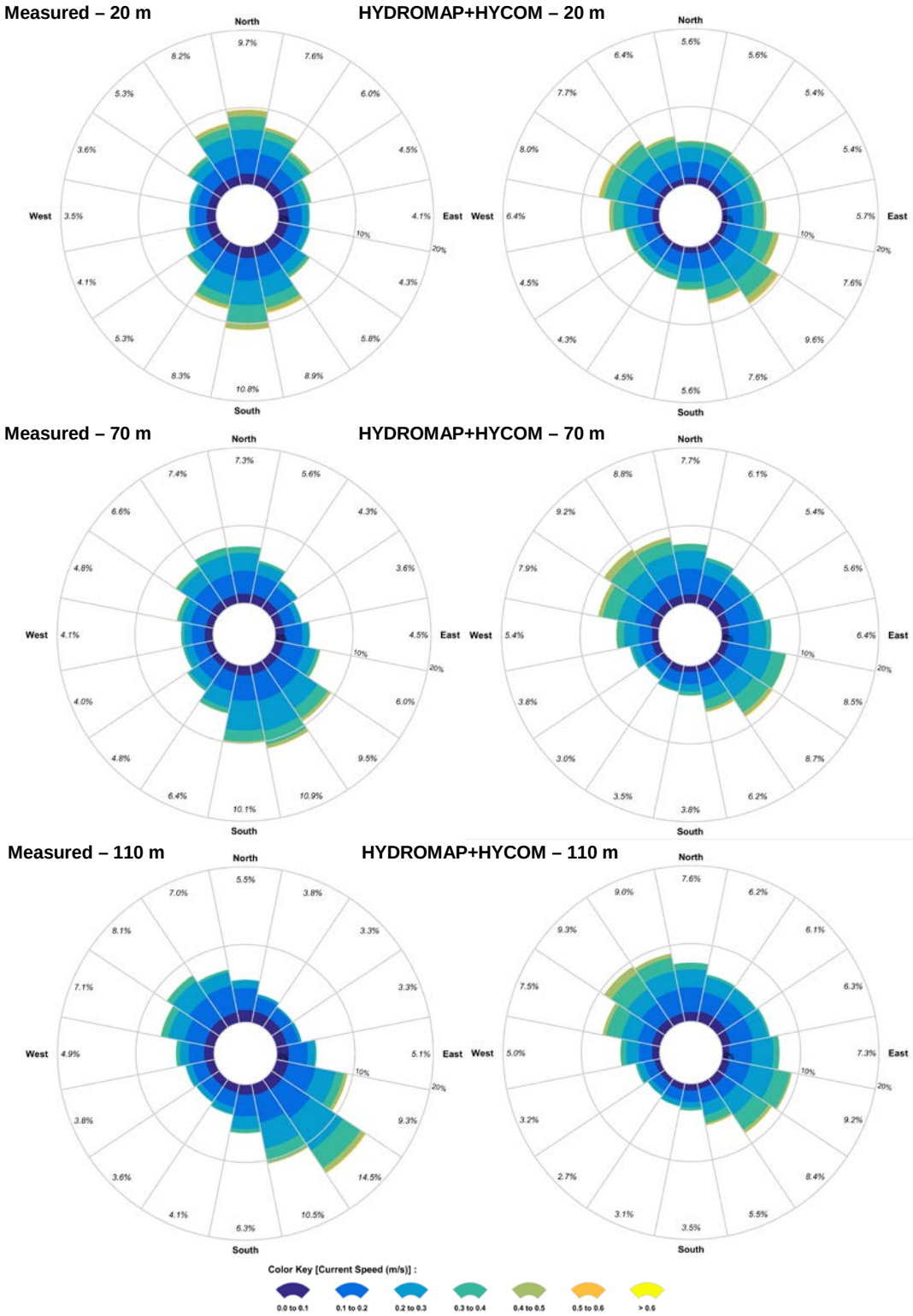


Figure 2.10 Comparative distributions for measured (left column) and predicted (HYDROMAP+HYCOM, right column) current data at the Crux development area (2016-2017) at depths of approximately 20 m (top row), 70 m (middle row) and 110 m (bottom row). The colour key shows the current magnitude, the compass direction provides the direction towards which the current is flowing, and the size of the wedge gives the percentage of the record.

2.5 Currents at Crux Development Well

Table 2.3 displays the monthly average and maximum near-surface and near-seabed current speeds calculated from the combination of HYCOM ocean currents and HYDROMAP tidal currents near the Crux Development Well location. Figure 2.11 and Figure 2.12 show the monthly near-surface and near-seabed current roses, respectively.

The data shows that the current speeds vary between seasons. In general, during summer (December to February) both near-surface and near-seabed currents are strongest (maximum near-surface speed of 1.51 m/s in January and maximum near-seabed speed of 0.60 m/s in December).

Table 2.3 Monthly average and maximum near-surface and near-seabed current speeds (2008-2017, inclusive) derived from the combined HYCOM and HYDROMAP databases near to the Crux Development Well location.

Month	Near-Surface Current Speed		Near-Seabed Current Speed	
	Average (m/s)	Maximum (m/s)	Average (m/s)	Maximum (m/s)
January	0.28	1.51	0.19	0.53
February	0.27	0.86	0.21	0.57
March	0.25	0.71	0.22	0.52
April	0.24	0.82	0.21	0.57
May	0.23	0.68	0.20	0.58
June	0.23	0.67	0.19	0.55
July	0.22	0.77	0.20	0.50
August	0.23	0.67	0.21	0.50
September	0.23	0.60	0.21	0.50
October	0.23	0.61	0.21	0.52
November	0.22	0.65	0.19	0.53
December	0.24	0.70	0.19	0.60
Maximum	**0.28**	**1.51**	**0.22**	**0.60**
Minimum	**0.22**	**0.60**	**0.19**	**0.50**

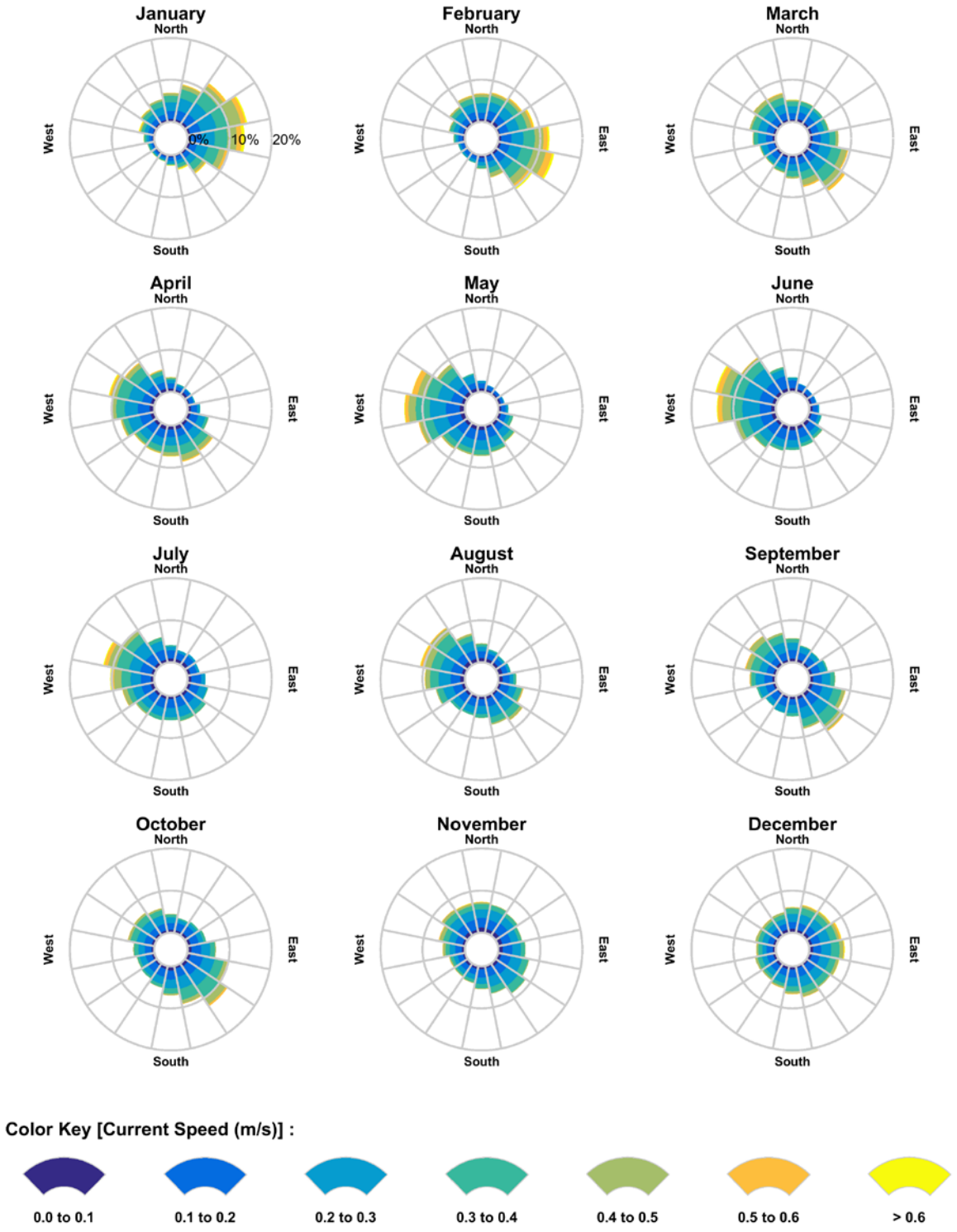


Figure 2.11 Monthly near-surface current distribution (2008-2017, inclusive) derived from the combined HYCOM and HYDROMAP databases near to the Crux Development Well location. The colour key shows the current magnitude, the compass direction provides the direction towards which the current is flowing, and the size of the wedge gives the percentage of the record.

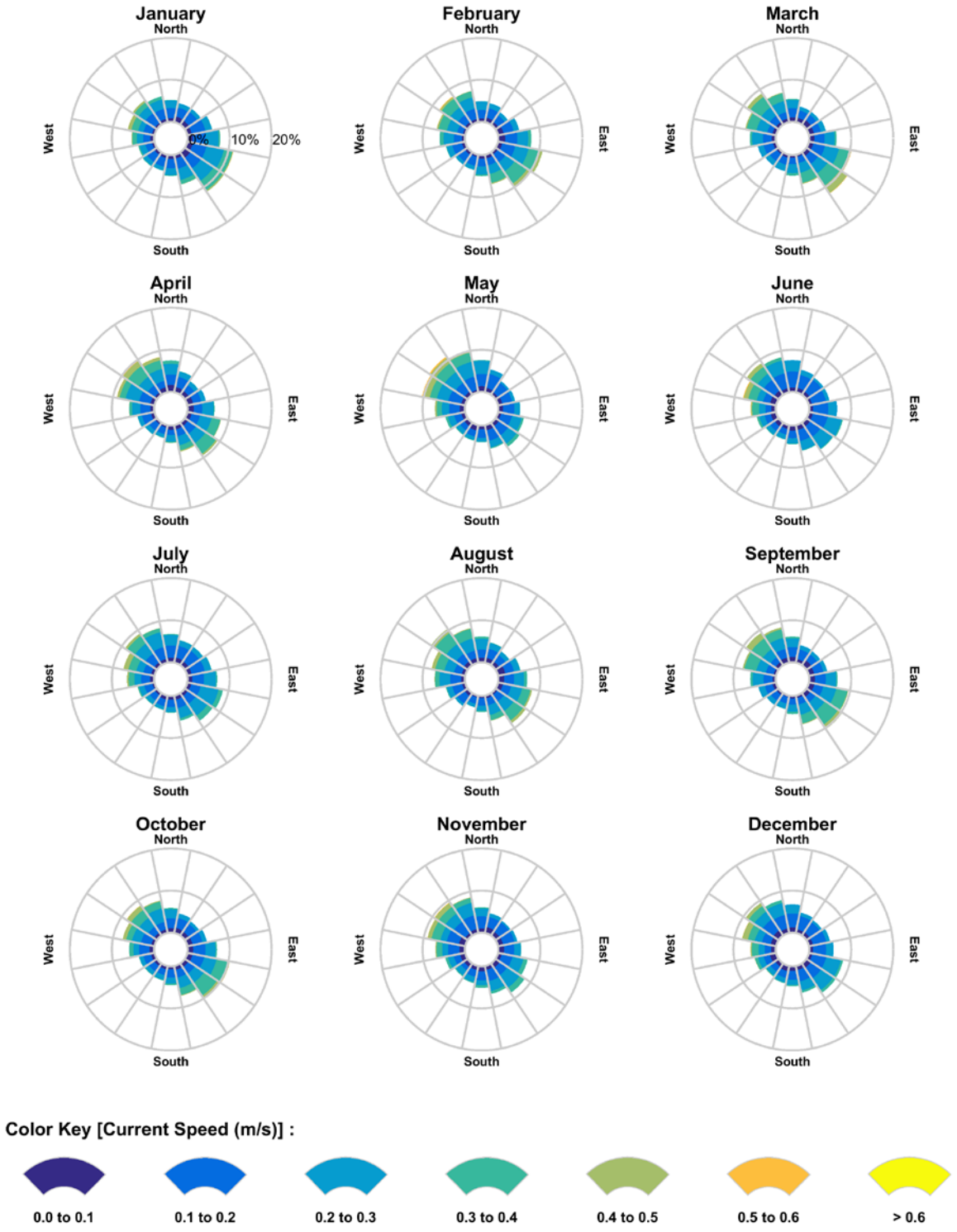


Figure 2.12 Monthly near-seabed current distribution (2008-2017, inclusive) derived from the combined HYCOM and HYDROMAP databases near to the Crux Development Well location. The colour key shows the current magnitude, the compass direction provides the direction towards which the current is flowing, and the size of the wedge gives the percentage of the record.

3 Modelling Methods

3.1 Sediment Dispersion Model: MUDMAP

MUDMAP is a three-dimensional plume model used by industry and regulators to aid in assessing the potential environmental effects from operational discharges such as drill cuttings, drilling fluids and produced formation water. The model has been applied to hundreds of assessments in over 35 countries, including Australia.

The model itself is an enhancement of the Offshore Operators Committee (OOC) model and calculates the fates of discharges through three distinct stages, as defined by laboratory and field studies (Koh & Chang, 1973; Khondaker, 2000):

- Stage 1: **Convective descent stage** – free fall of the combined mass of fluids and cuttings;
- Stage 2: **Dynamic collapse stage** – the collapse of the combined mass as it meets the seabed (or water surface); and
- Stage 3: **Passive dispersion stage** – the transport and dispersion of discharged fluids and particles by local currents. For drill cuttings and mud particles that have higher density than seawater, this phase also calculates sinking and settlement to the seabed.

Each stage plays an integral role on different time and distance scales. The governing equations and solutions of MUDMAP were built on the formulae originally developed by Koh & Chang (1973) and extended by the work of Brandsma & Sauer Jr (1983), known as the OOC model, for Stages 1 and 2 of plume motion.

The far-field calculation (passive dispersion stage) employs a particle-based, random walk procedure. The model predicts the dynamics of the discharge material and resulting seabed concentrations and bottom thicknesses over the near-field (i.e. the immediate area of the discharge) and the far-field (the wider region). Figure 3.1 shows a conceptual diagram of the dispersion and fates of drill cuttings and fluids discharge to the ocean and an idealised representation of the three discharge phases.

Settling under currents is selective for particle size, with the larger particles (rocks, gravel to sand) tending to settle quickly, forming a pile that aligns with the predominant current axis. Smaller particles (especially silts and clays) tend to remain suspended for exponentially longer time periods and will therefore be dispersed more widely by local currents. Dispersion of the finer discharged material will tend to be enhanced with increased current speeds and water depth, and with greater variation in current direction over time and depth.

MUDMAP can simulate up to six classes of material (each with up to 6 sub-categories, for a total of 36 sub-categories). Each material class can be set up with a unique density and particle-size distribution. During the dispersion stage, particles are transported in three dimensions according to the current data and horizontal and vertical dispersion coefficients at each time step, following the governing equations.

MUDMAP has been extensively validated and applied for discharge operations in Australian coastal and ocean waters, and around the world (e.g. Burns *et al.*, 1999; Spaulding, 1994; King & McAllister, 1997, 1998).

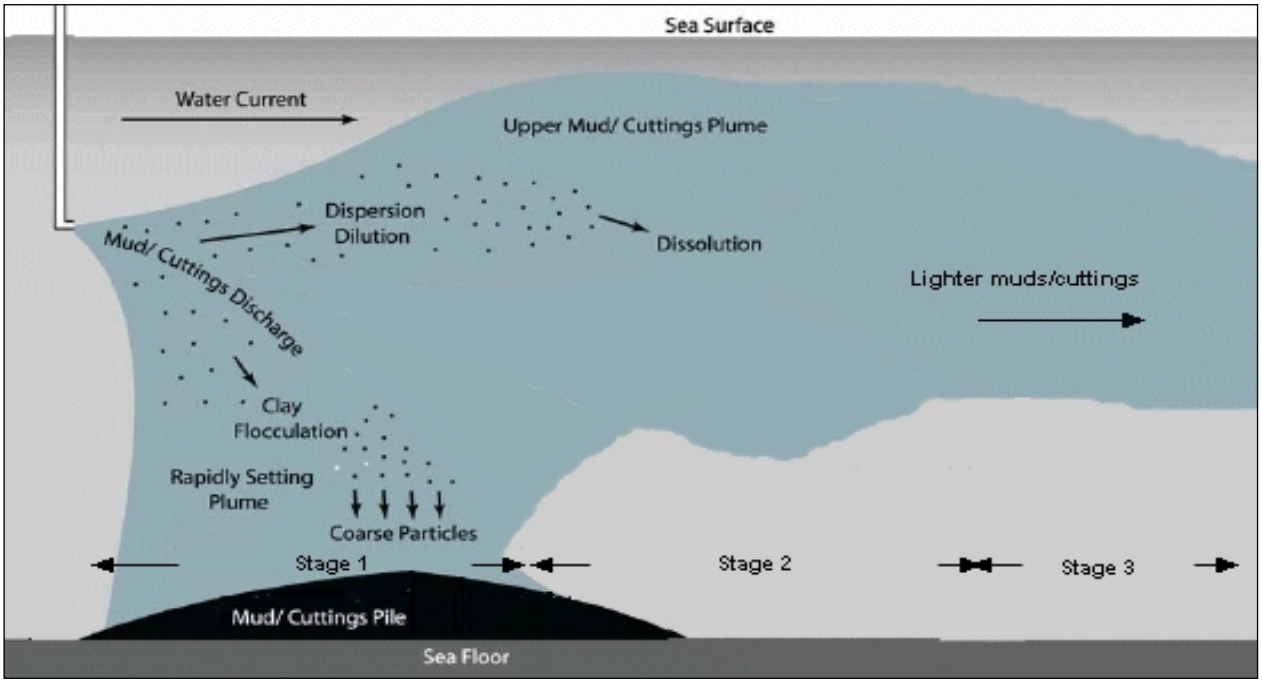


Figure 3.1 Conceptual diagram showing the general behaviour of cuttings and muds discharged to the ocean and the idealised representation of the three discharge phases (Neff, 2005).

3.2 Discharge Program

Based on the current well design and consistent with other similar industry standard drilling programs, the Crux wells are expected to comprise five drilling intervals (Table 3.1). A total of five wells of identical profile will be drilled from one drill centre (one location).

The Conductor and Surface intervals (42" and 32" bore diameters, respectively) will be drilled using seawater with bentonite sweeps. The extracted drill cuttings and drilling muds will be discharged directly to the seafloor. A riser will then be installed for the remainder of the drilling to circulate the cuttings and muds to the drilling rig where cuttings will be separated then discharged to the sea surface. With the riser in place, water based mud (WBM) will be used in the drilling of the Intermediate 1 (17 ½" bore diameter) interval, then synthetic based mud (SBM) will be used in the drilling of the Intermediate 2 (12 ¼" bore diameter) and Production (8 ½" bore diameter) intervals.

Estimates for the volumes of mud discharged during each interval are based on assumed rates of loss from the separation/dryer system, where fluids can adhere to cuttings. It is expected that the percentage volume of solids within the drilling mud is 3% when drilling with seawater/gel sweeps, 6% when drilling with WBM, and 10% when drilling with SBM. The drill cuttings and WBM/SBM will be discharged overboard from the rig above the sea surface from a vertically downward orientated discharge pipe. The drilling plan for the Crux foundation wells involves 33.5 days of drilling per well, comprising 2 days for the near seabed discharges and 31.5 days for the surface discharges. In total, 167.5 days of actual drilling will be required to complete all 5 proposed wells.

Table 3.1 Summary of the estimated volumes of discharged drill cuttings and unrecoverable mud solids for each well interval.

Well Interval	Hole Diameter (inches)	Discharge Method	Cuttings Volume Discharged (m^3)	Muds (Solids Only)		Discharge Duration (days)
				Type	Volume Discharged (m^3)	
Conductor	36	Returned directly to the seafloor	72	Seawater/Gel	12	1
Surface	32	Returned directly to the seafloor	119	Seawater/Gel	18	1
Intermediate 1	17½	Cuttings and WBM brought to drilling rig, then discharged to surface	477	WBM	208	11.5
Intermediate 2	12¼	Cuttings and SBM brought to drilling rig, separated/dried, then discharged to surface	191	SBM	4	9
Production	8½	Cuttings and SBM brought to drilling rig, separated/dried, then discharged to surface	32	SBM	5	11
Totals			**891**	**-**	**247**	**33.5**

Note: Only discharged solids used as model input.
WBM – Water Based Mud.
SBM – Synthetic Based Mud.

3.3 Discharge Input Data

The input data used to set up the MUDMAP dispersion model included, for each well interval:

- Volume and discharge duration of the cuttings and unrecovered muds;
- Particle size distribution and settling velocities of discharged cuttings and unrecoverable muds;
- Bulk density of the discharged cuttings and unrecoverable muds;
- Temperature and salinity profiles of the receiving waters;
- Diameter and orientation of the discharge pipe;
- Height/depth of the discharge point relative to mean sea level; and
- Depth-varying current data to represent local physical forcing.

Table 3.2 provides a summary of the discharge configuration and the estimated volumes of cuttings and muds used as input into the discharge model. The modelling inputs for the Crux drilling programme are based on the current well design and information from previous drilling campaigns undertaken by Shell for the Prelude FLNG project, and the Auriga-1 exploration well which was targeting the Crux field. Considering this, the estimated volumes of drill cuttings and mud are considered representative of that expected to be discharged from drilling

of the Crux development wells. The discharges for all five wells incorporated totals of 4,455 m^3 of drill cuttings and 1,235 m^3 of drilling muds over a period of 167.5 days.

Each model simulation represented the sequential completion of all well intervals, with rates and depth of discharge varying to represent the drilling program. Discharge was represented in the model to occur over the defined discharge duration; however, the simulations were run for an additional "run-on" period of 6.5 days to allow for assessment of dispersion of the finer sediment fractions.

In configuring the model, bulk densities of 2,601 kg/m^3 and 4,200 kg/m^3 were assumed for the cuttings and muds, respectively, following Nedwed (2004).

It is proposed that conventional drilling methods will be used, so the particle size distributions for cuttings and drilling muds were represented by literature data for conventional drilling which suggest particle sizes would be expected to vary between 0.016 mm and 6 mm in diameter. The model was set up with four main particle classes to represent large, medium and light cuttings, and drilling fluid solids (i.e. mud particles). The proportion of each size class was adjusted for each well interval according to the proposed proportion of muds and cuttings, as shown in Table 3.3.

It is worth noting that particle size has a greater influence on the rate of settling than density (Neff, 2005). Therefore, when setting up the material for discharge in the model, each particle size class was distributed across up to six sub-categories with specific settling velocities. The settling velocities for the various size sub-categories were derived from empirical data provided by Dyer (1986), as summarised in Table 3.4.

Table 3.2 Key inputs to the drill cuttings and unrecoverable mud solids dispersion modelling.

Parameter	Crux Development Well
Volume of cuttings discharged (m^3)	891 (single 1-well discharge)
Volume of muds discharged (m^3)	247 (single 1-well discharge)
Total volume of cuttings discharged (m^3)	4,455 (multiple 5-well discharge)
Total volume of muds discharged (m^3)	1,235 (multiple 5-well discharge)
Density of drill cuttings (kg/m^3)	2,601
Density of drilling synthetic base mud (kg/m^3)	4,200
Near seabed discharge duration	10 days (multiple 5-well discharge)
Sea surface discharge duration	167.5 days (multiple 5-well discharge)
Depth of near seabed discharges	2 m above seabed
Depth of sea surface discharges	Above mean sea level (168.5 m water depth)
Sea surface discharge pipe orientation	Vertically downwards
Sea surface discharge pipe diameter (inches)	8

Table 3.3 Proportional contribution of the particle size classes for each well interval.

Material Class	Conductor Interval (%)	Surface Interval (%)	Intermediate 1 Interval (%)	Intermediate 2 Interval (%)	Production Interval (%)
Large Cuttings (0.45 mm – 6 mm)	48	40	39	55	49
Medium Cuttings (0.15 mm – 0.40 mm)	21	21	17	20	21
Light Cuttings (0.02 mm – 0.10 mm)	17	17	14	19	17
Drilling Fluid Solids (0.016 mm – 0.063 mm)	14	13	30	2	12

Table 3.4 Discharge particle characteristics and size distribution of cuttings, water based mud (WBM) and synthetic based mud (SBM) assumed for modelling of the well intervals.

Sediment Characteristic			Particle Size Distribution (%)				
Class	Grain Size (mm)	Settling velocity (cm/s)	Conductor Interval	Surface Interval	Intermediate 1 Interval	Intermediate 2 Interval	Production Interval
Large Cuttings	6	54	10	10	8	12	11
	5	50	10	10	8	12	11
	2	29	10	10	8	12	11
	1	13	7	7	6	8	7
	0.5	8	7	7	6	8	7
	0.45	7	3	4	3	4	4
Medium Cuttings	0.4	6	3	4	3	4	4
	0.35	5	3	4	3	4	4
	0.3	4	3	4	3	4	4
	0.25	3	3	4	3	4	4
	0.2	2	3	4	3	4	4
	0.15	2	3	4	3	4	4
Light Cuttings	0.1	0.80	3	4	3	4	4
	0.05	0.22	3	4	3	4	4
	0.04	0.15	3	4	3	4	4
	0.03	0.08	3	4	3	8	6
	0.02	0.04	3	4	3	0	0
Drilling Fluid Solids	0.063	0.34	0.20	0.19	0.43	0	0
	0.05	0.22	0.81	0.75	2	0.11	1
	0.035	0.11	2	2	4	0.27	2
	0.026	0.06	3	3	6	2	10
	0.02	0.04	4	4	8	0	0
	0.016	0.03	5	4	10	0	0

3.4 Grid Configuration

A uniformly sized rectangular grid covering a 20 km (longitude, x-direction) by 20 km (latitude, y-direction) region around the well location was employed to calculate the concentration of drill cuttings and muds in the water column and on the seafloor. The resolution of each grid cell was approximately 20 m (x) x 20 m (y) x 10 m (z).

3.5 Mixing Parameters

The horizontal and vertical dispersion coefficients are used in dispersion modelling to represent the mixing and diffusion processes caused by turbulence, which are sub-grid processes at the scale of the hydrodynamic model drivers. The dispersion coefficients are expressed in units of rate of area change (m^2/s). Increasing the horizontal dispersion coefficient will increase the horizontal spread of the discharge plume and decrease the centreline concentrations. Increasing the vertical dispersion coefficient spreads the discharge further across the vertical layers.

The horizontal turbulent diffusion of the plume is dependent on the hydrodynamic conditions (i.e. wind, wave and current) and the physical scale of the plume compared to the scales of the oceanic processes that disperse the plume. For a plume of approximately 10-100 m width, dispersion occurs primarily through small-scale horizontal swirling motions and vertical mixing, with a horizontal dispersion rate of the order of 0.1 m^2/s. As the plume grows to a scale of 1-10 km, it begins to be subject to mesoscale eddies and horizontal dispersion rate becomes of the order of a few to tens of m^2/s. At even larger scales, the plume would be larger than the mesoscale eddies and eddy mixing becomes the dominant mechanism, with a rate of horizontal dispersion of 100-1,000 m^2/s.

For this project, with an open ocean environment and length scales of 10 m to 1 km, a horizontal diffusion rate of 0.25 m^2/s was applied. A value of 0.10 cm^2/s was set for the vertical dispersion coefficient to account for the influence of turbulence within the water column, as well as wave-induced turbulence. The values are based on previous experience and informed by studies by Copeland (1996).

3.6 Stochastic Outcomes

A stochastic modelling approach was followed for the assessment of drill cuttings and fluids discharge in this study, with 120 replicate simulations carried out over the ten-year hindcast period (one per calendar month). The results of all replicate simulations for each calendar month were combined and statistically analysed to develop the distribution of outcomes based on time and event. These statistics were then presented as contours of maximum occurrence.

Note: considering the stochastic modelling methodology applied, the contour figures of water column concentration do not represent the location of the plume at any point in time but are a statistical summary of the range of outcomes across all replicate simulations and time steps. Similarly, sedimentation results are presented as a statistical summary of the range of final outcomes of maximum bottom thickness and bottom concentration levels across all replicate simulations for each month assessed.

3.7 Reporting Thresholds

The MUDMAP model can track and predict sediment concentrations and thickness to very low levels that may not be of practical and ecological significance; therefore, a series of minimum detectable levels and impact thresholds were defined for reporting of the model-predicted outcomes.

Table 3-5 presents a summary of the natural and impact threshold levels used in this study for assessment of sedimentation.

Table 3-5 Natural and impact threshold levels for bottom thickness.

Parameter	Natural Threshold Level (mm)	Impact Threshold Level (mm)	
		Low Exposure	High Exposure
Bottom Thickness – single (1) well discharge	0.015	1	10
Bottom Thickness – multiple (5) well discharge	0.07		

A study by Glen (1997) found that the maximum natural sedimentation rate for Northwest Australia is 223.21 cm/thousand years (ka). As a conservative measure, a minimum threshold thickness of 0.015 mm was calculated from the maximum natural sedimentation rate of 2.23 mm/year (or 0.0061 mm/day) multiplied by the discharge duration (33.5 days/well).

Impact thresholds of 1 mm (low exposure) and 10 mm (high exposure) have been applied in this study and are based on available literature and are considered industry standard. A study by Trannum et al. (2009) showed a significant decrease of species, abundance of individuals, Shannon-Wiener diversity, and biomass of marine animals with increasing depth of WBM cuttings (3-24 mm) on sediment in the microcosms. Therefore, a conservative 1 mm impact threshold was selected as representative of low exposure. A study by Kjeilen-Eilertsen *et al.* (2004) showed that deposition greater than 9.6 mm is likely to cause smothering impacts on benthic ecosystems, including corals. It is also worth noting that a study by Smit *et al.* (2008) established a thickness threshold of greater than 6.5 mm would be needed before potential harm to benthic macrofauna. This sediment thickness threshold is based on data from shallow-water fauna.

It is important to note that the predicted sedimentation is quoted as the level above any background sedimentation process relevant to the Crux Development Well location. Moderate levels of sediment mobility are expected in this region due to the drift and tidal current magnitudes, and therefore it is expected that these results are conservative (i.e. more sedimentation predicted than would be the case).

4 Modelling Results

4.1 Overview

Discharges of drill cuttings and drilling muds were modelled for the Crux well design, which is expected to comprise five well sections: Conductor, Surface, Intermediate 1, Intermediate 2 and Production. Discharges from the Conductor and Surface sections will occur near the seabed, whereas discharges from the remaining sections will occur at the surface (see Section 3.2). The drilling programme was assumed to have a total duration of 33.5 days per well. Shell intends to drill five wells from one drill centre (one location), requiring approximately 167.5 days in total to drill.

The modelling results for a single well (drill cuttings and drilling muds), single well (drill cuttings only), and five wells (drill cuttings and drilling muds) are presented in Section 4.2, Section 4.3 and Section 4.4, respectively. Each of the results sections presents the monthly model results and the integration (annualised) of all model results to assess the regional coverage of all discharge operations.

If drilling were to occur at alternative locations within the Crux development area, similar sedimentation outcomes may be expected given the likelihood of similar metocean conditions. However, drilling in areas of more complex bathymetry, particularly in close proximity to the shoals within the Crux development area, may result in patterns of sedimentation being more clearly influenced by that bathymetry.

4.2 Drill Cuttings and Drilling Muds (Single Well)

4.2.1 Discussion of Annualised Results

The results for each month were integrated to define the likely coverage area of bottom thickness above the thresholds for ‘any time’ or current conditions modelled.

Figure 4.1 shows the annualised distribution of sediment thickness calculated for deposits of drill cuttings and drilling muds. The results presented in the figure are aggregates of all stochastic simulations commencing throughout the ten-year hindcast period.

The modelling results demonstrated that larger particles (greater than 0.25 mm diameter) were predicted to settle typically within 250 m from the well, while the currents transported the smaller sediments (less than 0.25 mm) further away from the well.

Table 4.1 shows the predicted maximum bottom thickness, area of coverage and the maximum distance well location to the drill cuttings and drilling muds thresholds (0.015 mm, 1 mm and 10 mm).

The maximum thickness (or height of mound) was predicted to be 377.5 mm adjacent to the well location (Table 4.1).

Modelling predicted a zone of potential influence at the natural threshold level, with thicknesses of 0.015 mm or greater expected up to ~2 km from the well location while covering an area ~7.96 km^2 (796 ha). This potential zone of influence was more localised at the low (1 mm) and high (10 mm) exposure thresholds, with drill cuttings and drilling muds not expected beyond 326 m and 68 m, respectively. Total areas of coverage at the low (1 mm) and high (10 mm) exposure threshold were 0.008 km^2 (0.8 ha) and 0.194 km^2 (19.4 ha), respectively.

Modelling indicates that sedimentation resulting from discharges of drill cuttings and drilling fluids is not likely to have any impact above the natural threshold (0.015 mm) at the shoals closest to the well site.

4.2.2 Discussion of Monthly Results

The outcomes of the sediment dispersion modelling assessment are summarised, for each month, in Table 4.2, with maximum values presented for sediment bottom thickness, area of coverage above the 0.015 mm, 1 mm and 10 mm thresholds, and maximum distance from the well to these thresholds.

Figure 5.1 to Figure 5.12 show the distributions of sediment thickness calculated for deposits of drill cuttings and drilling muds on the seafloor for operations commencing on the first day of each calendar month (January to December). The results presented in each monthly figure are aggregates of all stochastic simulations commencing in all corresponding months during the ten-year hindcast period.

Sediments larger than 0.25 mm in diameter are predicted to typically settle out within 250 m of the well, with displacement occurring on either side of the well in response to the prevailing currents. Finer sediments are forecast to disperse more widely, with the finest sediments contributing a lower proportion of sediment to deposits greater than 0.015 mm (natural threshold) thick. Deposits exceeding the 0.015 mm minimum thickness are calculated to extend up to between 1,710 m (July) and 2,002 m (January) from the well site. At the low (1 mm) exposure threshold, drill cuttings and drilling muds are expected to extend up to between 229 m (December) and 326 m (February) for the well site. Drill cuttings and drilling muds were modelled to extend up to between 47 m (February) and 68 m (November) at the high (10 mm) threshold.

Deposits of finer sediments are consistently calculated to build up along the tidal axis on either side of the source rather than displace to a particular side, indicating that tidal currents will have influence over movement of the finer particles and that ocean currents will have a small impact on the net movement direction and distance travelled before settlement occurs. The directions in which sediments are calculated to settle vary only slightly among the monthly simulations, which is indicative of the high influence of tidal currents at the source and the relative lack of variation in ocean current conditions over the ten-year hindcast period.

The maximum thickness (or height of mound) calculated at any location in any simulation is forecast to fall in the range of 276 mm (November) to 378 mm (January), adjacent to the well location, and quickly decrease with distance from the well. The minimum and maximum predicted areas of sediment coverage at thicknesses greater than 0.015 mm are ~4.6 km^2 (May) and ~6.5 km^2 (November), respectively. At the low (1 mm) exposure threshold, the minimum and maximum predicted areas are predicted to be greatly reduced and range between 0.114 km^2 (June) and 0.140 km^2 (February), respectively. At the high (10 mm) exposure threshold, this is reduced further, with minimum and maximum predicted areas ranging from 0.004 km^2 (February) and 0.007 km^2 (November), respectively.

Modelling indicates that sedimentation resulting from discharges of drill cuttings and drilling fluids is not likely to have any impact above the natural threshold (0.015 mm) at the shoals closest to the well site.

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4.2.3 Results Tables and Figures

Table 4.1 Predicted maximum bottom thickness, area of coverage above the 0.015 mm, 1 mm and 10 mm thresholds, and maximum distance to these thresholds resulting from the drill cuttings and drilling muds discharge programme. The results are calculated across all simulations during the period 2008-2017.

Period	Maximum Bottom Thickness (mm)	Total Area of Coverage (km^2) above Threshold			Maximum Distance (m) from Well to Threshold		
		0.015 mm	1 mm	10 mm	0.015 mm	1 mm	10 mm
Annualised	377.5	7.96	0.194	0.008	2,002	326	68

Table 4.2 Predicted maximum bottom thickness, area of coverage above the 0.015 mm, 1 mm and 10 mm thresholds, and maximum distance to these thresholds resulting from the drill cuttings and drilling muds discharge programme. The results are calculated across all simulations commencing on the first day of each calendar month during the period 2008-2017.

Month	Maximum Bottom Thickness (mm)	Total Area of Coverage (km^2) above Threshold			Maximum Distance (m) from Well to Threshold		
		0.015 mm	1 mm	10 mm	0.015 mm	1 mm	10 mm
January	377.5	5.42	0.138	0.005	2,002	298	50
February	281.0	5.16	0.140	0.004	1,884	326	47
March	282.0	5.25	0.133	0.005	1,944	290	45
April	285.6	5.52	0.129	0.004	1,829	257	47
May	279.0	4.60	0.120	0.005	1,786	278	49
June	277.2	4.91	0.114	0.005	1,728	270	47
July	280.8	5.01	0.122	0.006	1,710	259	48
August	277.9	5.52	0.127	0.005	1,865	258	53
September	278.3	5.70	0.130	0.005	1,800	270	48
October	282.8	5.09	0.125	0.005	1,917	271	50
November	276.2	6.45	0.126	0.007	1,919	248	68
December	277.1	5.68	0.124	0.005	1,853	229	49
Minimum	**276.2**	**4.60**	**0.114**	**0.004**	**1,710**	**229**	**47**
Maximum	**377.5**	**6.45**	**0.140**	**0.007**	**2,002**	**326**	**68**

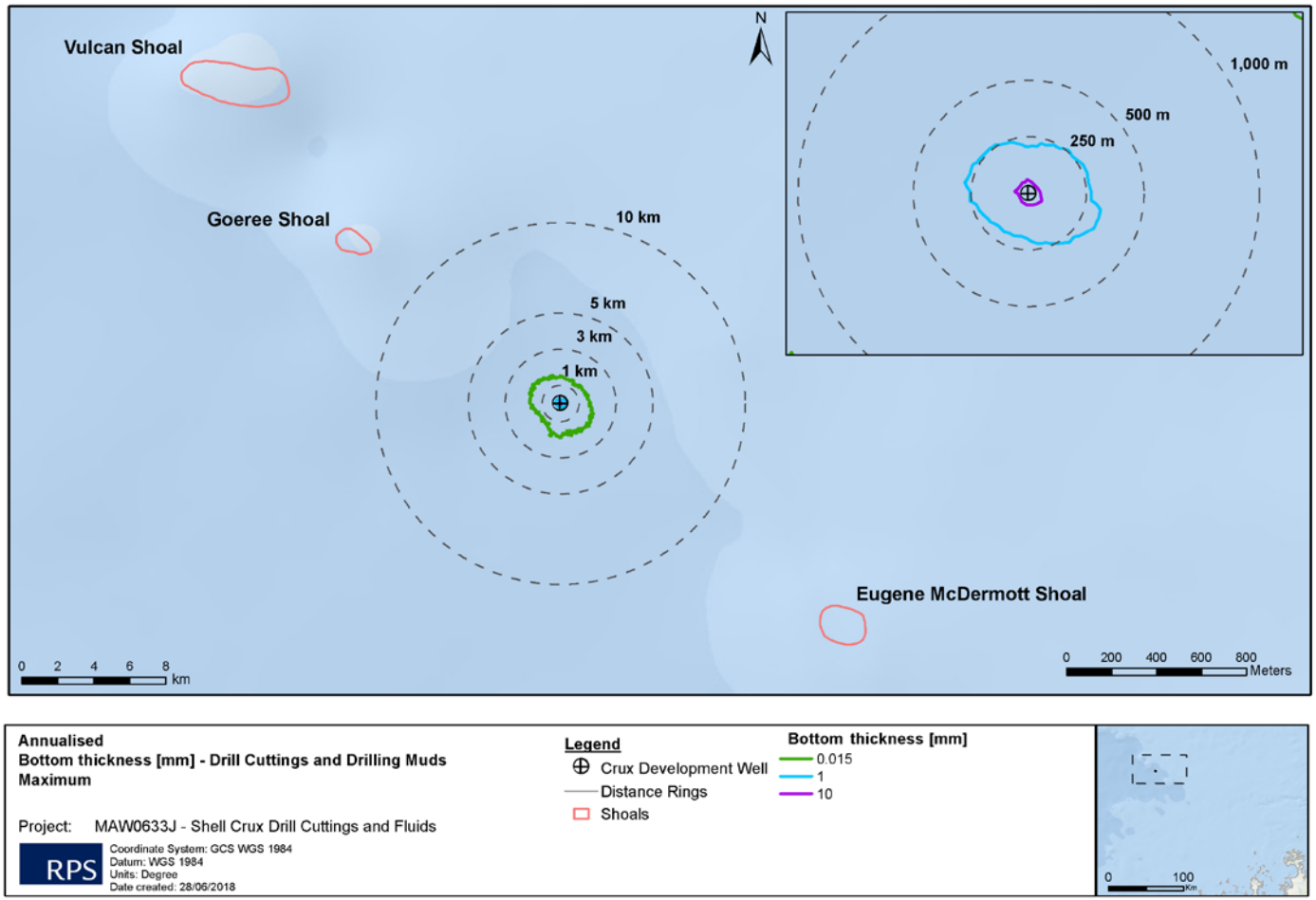


Figure 4.1 **Predicted maximum bottom thickness resulting from the drill cuttings and drilling muds discharge programme. The maximum concentrations are calculated across all simulations during the period 2008-2017.**

4.3 Drill Cuttings Only (Single Well)

4.3.1 Discussion of Annualised Results

The results for each month were integrated to define the likely coverage area of bottom thickness above the thresholds for 'any time' or current conditions modelled.

Figure 4.2 shows the annualised distribution of sediment thickness calculated for deposits of drill cuttings. The results presented in the figure are aggregates of all stochastic simulations commencing throughout the ten-year hindcast period.

The modelling results demonstrated that larger particles (greater than 0.25 mm diameter) were predicted to settle typically within 250 m from the well, while the currents transported the smaller sediments (less than 0.25 mm) further away from the well.

Table 4.3 shows the predicted maximum bottom thickness, area of coverage and the maximum distance well location to the drill cuttings and drilling muds thresholds (0.015 mm, 1 mm and 10 mm).

The maximum thickness (or height of mound) was predicted to be 374.3 mm adjacent to the well location (Table 4.3).

Modelling predicted a zone of potential influence at the natural threshold level, with thicknesses of 0.015 mm or greater expected up to ~1.9 km from the well location while covering an area ~6.77 km^2 (677 ha). This potential zone of influence was more localised at the low (1 mm) and high (10 mm) exposure thresholds, with drill cuttings not expected beyond 326 m and 62 m, respectively. Total areas of coverage at the low (1 mm) and high (10 mm) exposure threshold were 0.007 km^2 (0.7 ha) and 0.188 km^2 (18.8 ha), respectively.

Modelling indicates that sedimentation resulting from discharges of drill cuttings is not likely to have any impact above the natural threshold (0.015 mm) at the shoals closest to the well site.

4.3.2 Discussion of Monthly Results

The outcomes of the sediment dispersion modelling assessment are summarised, for each month, in Table 4.4, with maximum values presented for sediment bottom thickness, area of coverage above the 0.015 mm, 1 mm and 10 mm thresholds, and maximum distance from the well to these thresholds.

Figure 5.13 to Figure 5.24 show the distributions of sediment thickness calculated for deposits of only drill cuttings on the seafloor for operations commencing on the first day of each calendar month (January to December). The results presented in each monthly figure are aggregates of all stochastic simulations commencing in all corresponding months during the ten-year hindcast period.

The outcomes of this analysis, where the finer sediments associated with drilling muds are excluded, indicate that the maximum thicknesses and spatial extents will be slightly reduced, reflecting the reduced proportion of fines within the overall discharge.

Deposits exceeding the 0.015 mm minimum thickness are calculated to extend up to between 1,624 m (December) and 1,928 m (March) from the well site. At the low (1 mm) exposure threshold, drill cuttings are expected to extend up to between 228 m (December) and 326 m (February) for the well site. Drill cuttings were modelled to extend up to between 44 m (March) and 62 m (November) at the high (10 mm) threshold.

The maximum thickness (or height of mound) calculated at any location in any simulation is forecast to fall in the range of ~275 mm (November) to ~374 mm (January), adjacent to the well location and quickly decrease with distance from the well. The minimum and maximum predicted areas of sediment coverage at thicknesses greater than 0.015 mm are ~4.3 km^2 (May) and ~5.3 km^2 (November), respectively. At the low (1 mm) exposure threshold, the minimum and maximum predicted areas are predicted to be greatly reduced and range

between 0.109 km^2 (June) and 0.132 km^2 (February), respectively. At the high (10 mm) exposure threshold, this is reduced further, with minimum and maximum predicted areas ranging from 0.004 km^2 (February) and 0.006 km^2 (November), respectively.

Modelling indicates that sedimentation resulting from discharges of drill cuttings is not likely to have any impact above the natural threshold (0.015 mm) at the shoals closest to the well site.

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4.3.3 Results Tables and Figures

Table 4.3 Predicted maximum bottom thickness, area of coverage above the 0.015, mm 1 mm and 10 mm thresholds, and maximum distance to these thresholds resulting from only the drill cuttings volumes of the discharge programme. The results are calculated across all simulations during the period 2008-2017.

Period	Maximum Bottom Thickness (mm)	Total Area of Coverage (km^2) above Threshold			Maximum Distance (m) from Well to Threshold		
		0.015 mm	1 mm	10 mm	0.015 mm	1 mm	10 mm
Annualised	374.3	6.77	0.188	0.007	1,928	326	62

Table 4.4 Predicted maximum bottom thickness, area of coverage above the 0.015 mm, 1 mm and 10 mm thresholds, and maximum distance to these thresholds resulting from only the drill cuttings volumes of the discharge programme. The results are calculated across all simulations commencing on the first day of each calendar month during the period 2008-2017.

Month	Maximum Bottom Thickness (mm)	Total Area of Coverage (km^2) above Threshold			Maximum Distance (m) from Well to Threshold		
		0.015 mm	1 mm	10 mm	0.015 mm	1 mm	10 mm
January	374.3	4.92	0.129	0.005	1,731	287	45
February	278.4	4.94	0.132	0.004	1,821	318	46
March	279.5	4.94	0.125	0.004	1,928	284	44
April	281.8	4.84	0.119	0.004	1,698	248	45
May	277.0	4.33	0.111	0.004	1,722	277	45
June	275.9	4.44	0.109	0.005	1,694	269	47
July	278.5	4.62	0.117	0.005	1,704	241	46
August	276.3	4.97	0.120	0.005	1,785	252	48
September	276.5	4.81	0.122	0.004	1,764	255	47
October	280.4	4.75	0.119	0.004	1,775	259	45
November	274.8	5.31	0.120	0.006	1,663	241	62
December	275.9	4.87	0.117	0.005	1,624	228	50
Minimum	**274.8**	**4.33**	**0.109**	**0.004**	**1,624**	**228**	**44**
Maximum	**374.3**	**5.31**	**0.132**	**0.006**	**1,928**	**326**	**62**

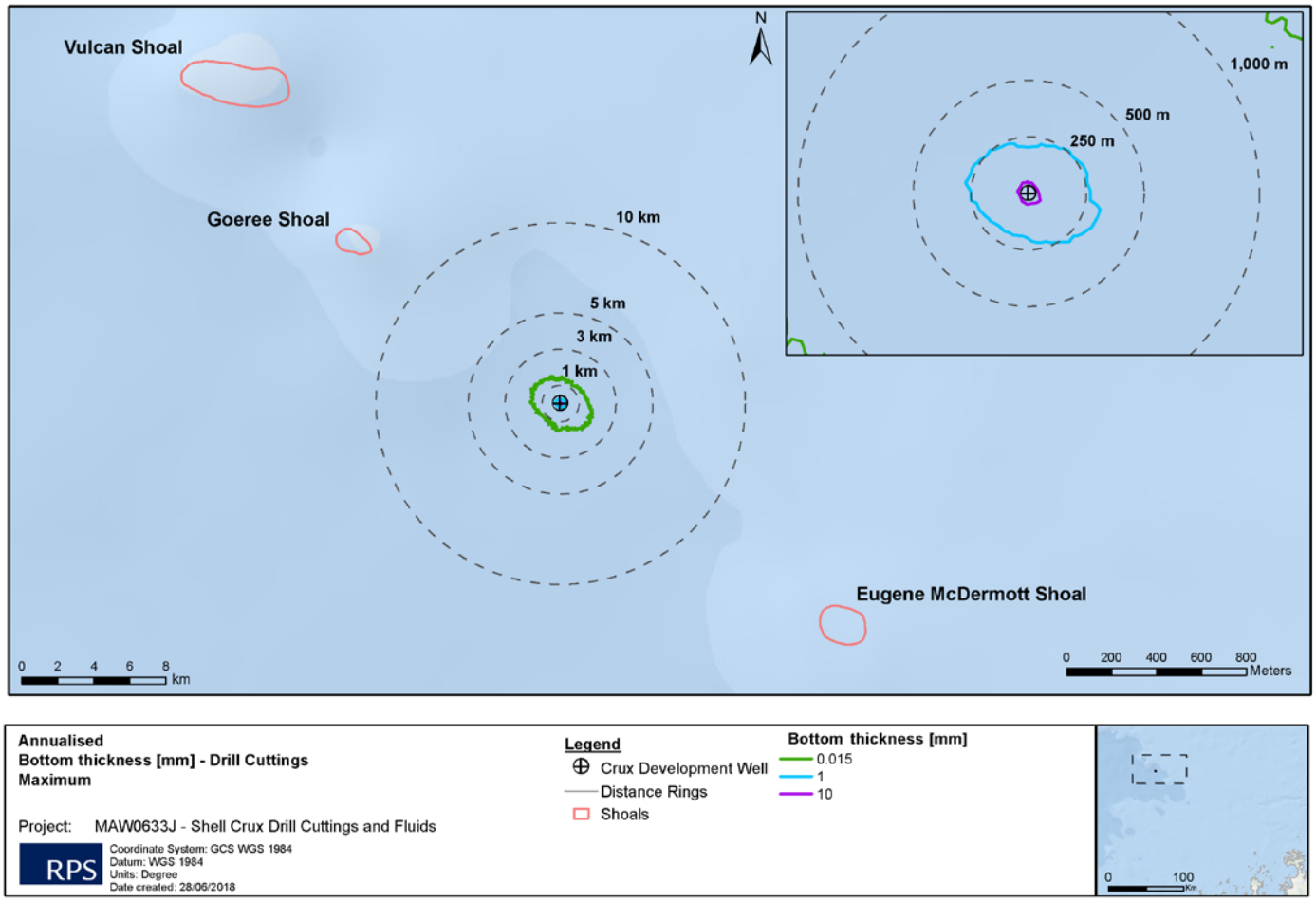


Figure 4.2 **Predicted maximum bottom thickness resulting from the drill cuttings discharge programme. The maximum concentrations are calculated across all simulations during the period 2008-2017.**

4.4 Drill Cuttings and Drilling Muds (Five Wells)

4.4.1 Discussion of Annualised Results

The results for each month were integrated to define the likely coverage area of bottom thickness above the thresholds for 'any time' or current conditions modelled.

Table 4.5 shows the annualised distribution of sediment thickness calculated for deposits of drill cuttings. The results presented in the figure are aggregates of all stochastic simulations commencing throughout the ten-year hindcast period.

The modelling results demonstrated that larger particles (greater than 0.25 mm diameter) were predicted to settle typically within 250 m from the well, while the currents transported the smaller sediments (less than 0.25 mm) further away from the well.

Table 4.5 shows the predicted maximum bottom thickness, area of coverage and the maximum distance well location to the minimum drill cuttings and drilling muds thresholds (0.07 mm, 1 mm and 10 mm).

The maximum thickness (or height of mound) was predicted to be 1,888 mm adjacent to the well location (Table 4.5).

Modelling predicted a relatively wide zone of potential influence at the natural threshold level, with thicknesses of 0.07 mm or greater expected up to ~2 km from the well location while covering an area ~8.61 km^2 (861 ha). This potential zone of influence was more localised at the low (1 mm) and high (10 mm) exposure thresholds, with drill cuttings and drilling muds not expected beyond 658 m and 248 m, respectively. Total areas of coverage at the low (1 mm) and high (10 mm) exposure threshold were 0.115 km^2 (11.5 ha) and 0.875 km^2 (87.5 ha), respectively.

Modelling indicates that sedimentation resulting from discharges of drill cuttings and drilling fluids is not likely to have any impact above the natural threshold (0.015 mm) at the shoals closest to the well site.

4.4.2 Discussion of Monthly Results

The outcomes of the sediment dispersion modelling assessment are summarised, for each month, in Table 4.4, with maximum values presented for sediment bottom thickness, area of coverage above the 0.07 mm, 1 mm and 10 mm thresholds, and maximum distance from the well to these thresholds.

Figure 5.25 to Figure 5.36 show the distributions of sediment thickness calculated for deposits of drill cuttings and drilling muds on the seafloor for operations commencing on the first day of each calendar month (January to December). The results presented in each monthly figure are aggregates of all stochastic simulations commencing in all corresponding months during the ten-year hindcast period.

Sediments larger than 0.25 mm in diameter are predicted to typically settle out within 250 m of the well, with displacement occurring on either side of the well in response to the prevailing currents. Finer sediments are forecast to disperse more widely, with the finest sediments contributing a lower proportion of sediment to deposits greater than 0.07 mm (natural threshold) thick. Deposits exceeding the 0.07 mm minimum thickness are calculated to extend up to between 1,832 m (July) and 2,057 m (February) from the well site. At the low (1 mm) exposure threshold, drill cuttings and drilling muds are expected to extend up to between 528 m (August) and 658 m (February) for the well site. Drill cuttings and drilling muds were modelled to extend up to between 188 m (July) and 233 m (February) at the high (10 mm) threshold.

Deposits of finer sediments are consistently calculated to build up along the tidal axis on either side of the source rather than displace to a particular side, indicating that tidal currents will have influence over movement of the finer particles and that ocean currents will have a small impact on the net movement direction and distance travelled before settlement occurs. The directions in which sediments are calculated to settle vary

only slightly among the monthly simulations, which is indicative of the high influence of tidal currents at the source and the relative lack of variation in ocean current conditions over the ten-year hindcast period.

The maximum thickness (or height of mound) calculated at any location in any simulation is forecast to fall in the range of 1,381 mm (November) to 1,888 mm (January), adjacent to the well location and quickly decrease with distance from the well. The minimum and maximum predicted areas of sediment coverage at thicknesses greater than 0.07 mm are ~4.9 km^2 (May) and ~7.1 km^2 (November), respectively. At the low (1 mm) exposure threshold, the minimum and maximum predicted areas are predicted to be greatly reduced and range between 0.482 km^2 (May) and 0.613 km^2 (January), respectively. At the high (10 mm) exposure threshold, this is reduced further, with minimum and maximum predicted areas ranging from 0.068 km^2 (May) and 0.082 km^2 (February), respectively.

Modelling indicates that sedimentation resulting from discharges of drill cuttings and drilling fluids is not likely to have any impact above the natural threshold (0.07 mm) at the shoals closest to the well site.

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4.4.3 Results Tables and Figures

Table 4.5 Predicted maximum bottom thickness, area of coverage above the 0.07 mm, 1 mm and 10 mm thresholds, and maximum distance to these thresholds resulting from the drill cuttings and drilling muds discharge programme. The results are calculated across all simulations during the period 2008-2017.

Period	Maximum Bottom Thickness (mm)	Total Area of Coverage (km^2) above Threshold			Maximum Distance (m) from Well to Threshold		
		0.07 mm	1 mm	10 mm	0.07 mm	1 mm	10 mm
Annualised	1,888	8.61	0.875	0.115	2,057	658	248

Table 4.6 Predicted maximum bottom thickness, area of coverage above the 0.07 mm, 1 mm and 10 mm thresholds, and maximum distance to these thresholds resulting from the drill cuttings and drilling muds discharge programme. The results are calculated across all simulations commencing on the first day of each calendar month during the period 2008-2017.

Month	Maximum Bottom Thickness (mm)	Total Area of Coverage (km^2) above Threshold			Maximum Distance (m) from Well to Threshold		
		0.07 mm	1 mm	10 mm	0.07 mm	1 mm	10 mm
January	1,888	5.77	0.613	0.080	2,035	647	208
February	1,405	5.44	0.562	0.082	2,057	658	233
March	1,410	5.57	0.505	0.074	1,925	597	227
April	1,428	5.90	0.512	0.072	1,901	548	191
May	1,395	4.89	0.482	0.068	1,849	571	212
June	1,386	5.25	0.503	0.068	1,900	595	207
July	1,404	5.30	0.511	0.072	1,832	541	188
August	1,390	5.88	0.507	0.077	1,950	528	207
September	1,392	6.13	0.525	0.076	1,830	533	213
October	1,414	5.39	0.522	0.077	1,882	594	216
November	1,381	7.10	0.570	0.071	2,047	528	197
December	1,386	6.13	0.559	0.069	1,911	537	179
Minimum	**1,381**	**4.89**	**0.482**	**0.069**	**1,832**	**528**	**188**
Maximum	**1,888**	**7.10**	**0.613**	**0.082**	**2,057**	**658**	**233**

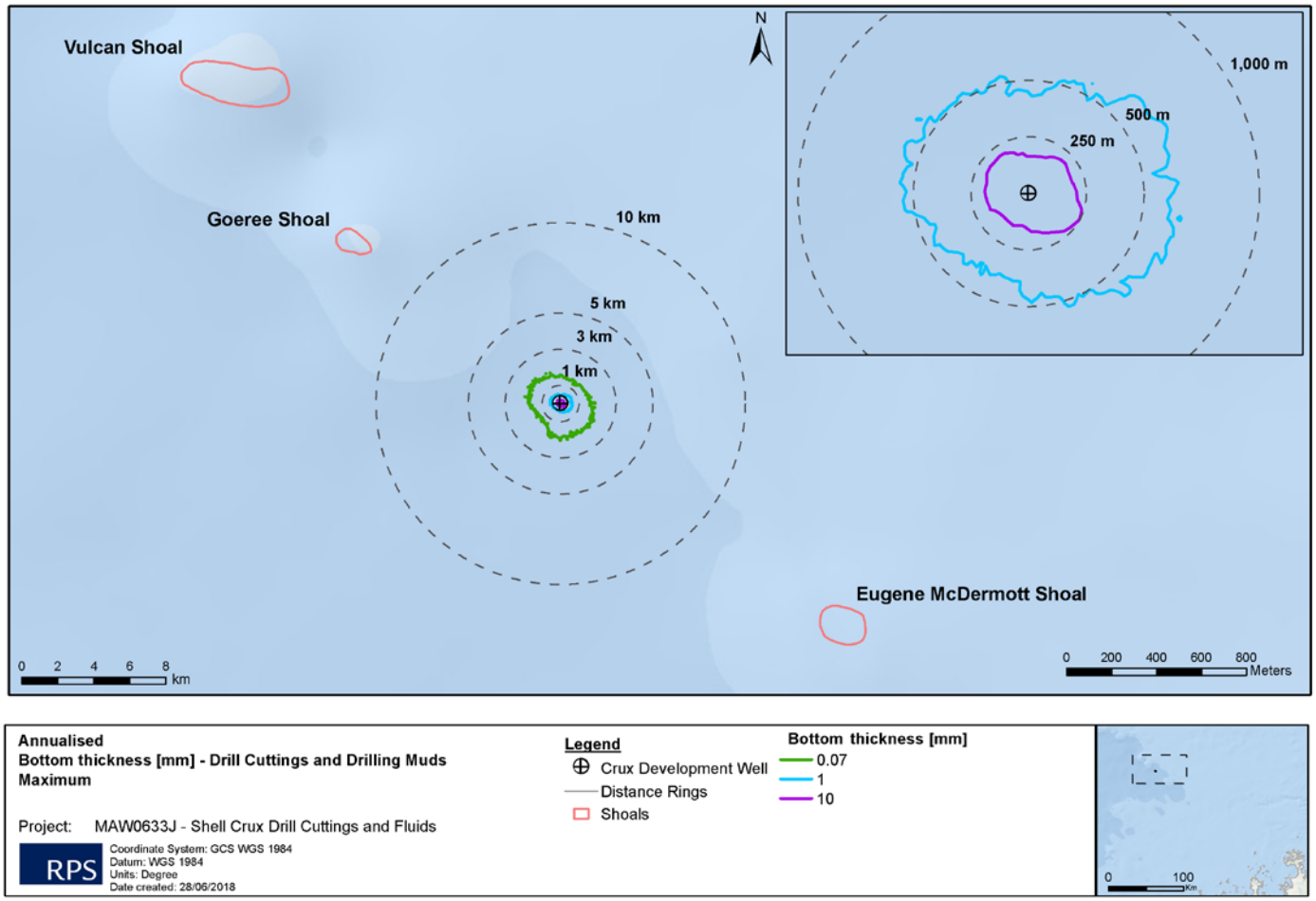


Figure 4.3 **Predicted maximum bottom thickness resulting from the drill cuttings and drilling muds discharge programme. The maximum concentrations are calculated across all simulations during the period 2008-2017.**

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Appendix A
Monthly Figures

Drill Cuttings & Drilling Muds (Single Well)

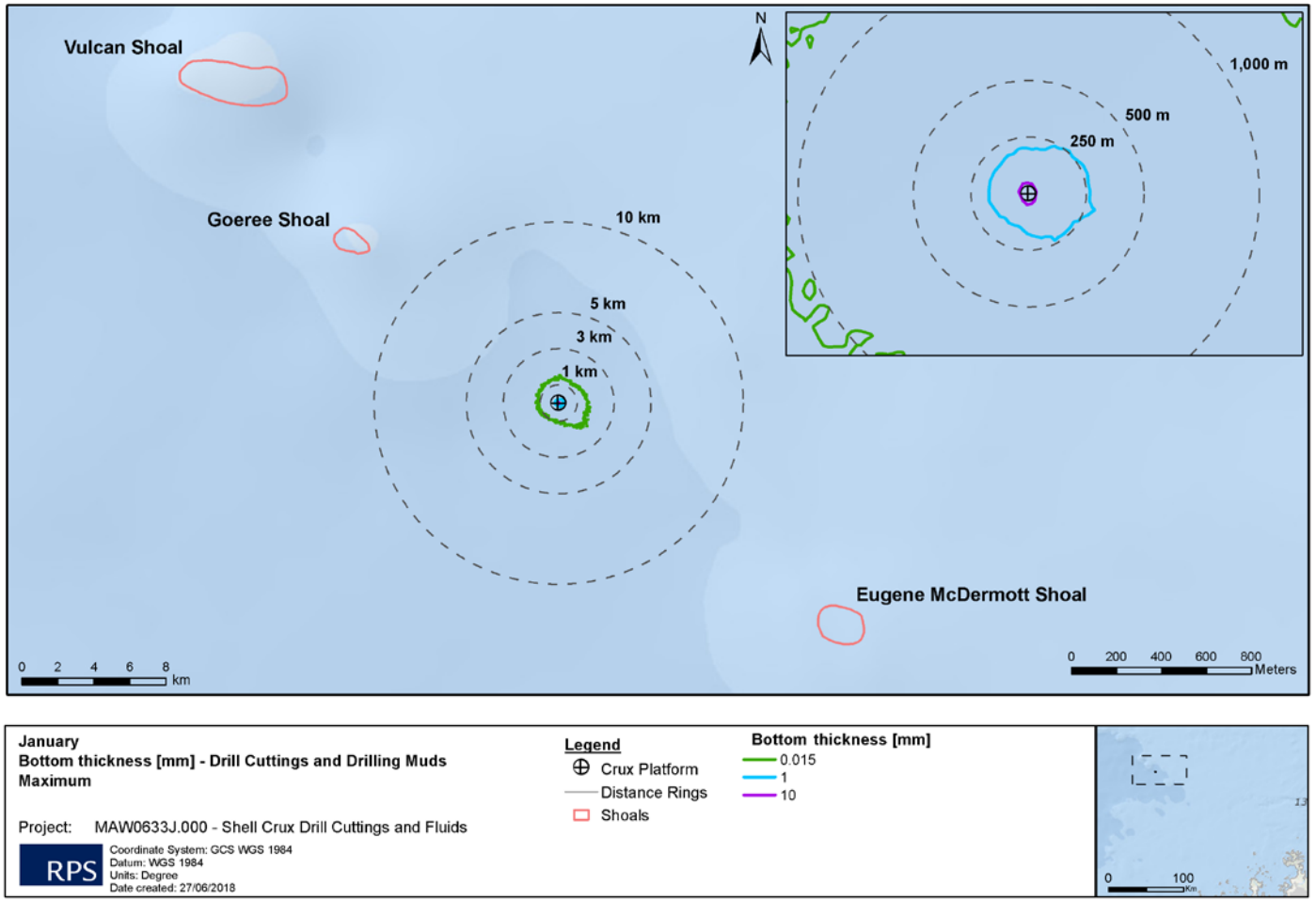


Figure 5.1 **Predicted maximum bottom thickness resulting from the drill cuttings and drilling muds discharge programme. The maximum concentrations are calculated across all simulations commencing on 1st January during the period 2008-2017.**

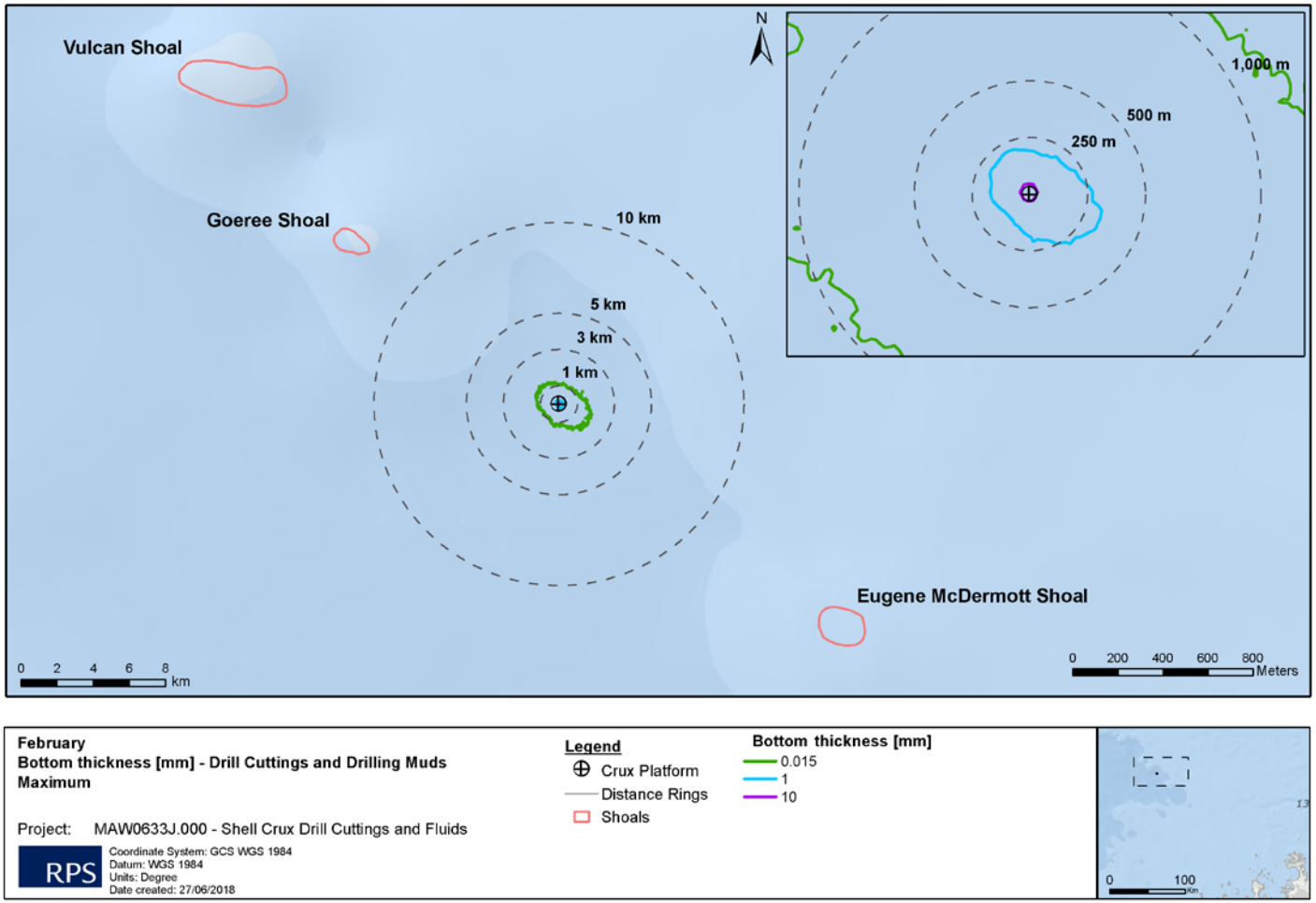


Figure 5.2 **Predicted maximum bottom thickness resulting from the drill cuttings and drilling muds discharge programme. The maximum concentrations are calculated across all simulations commencing on 1st February during the period 2008-2017.**

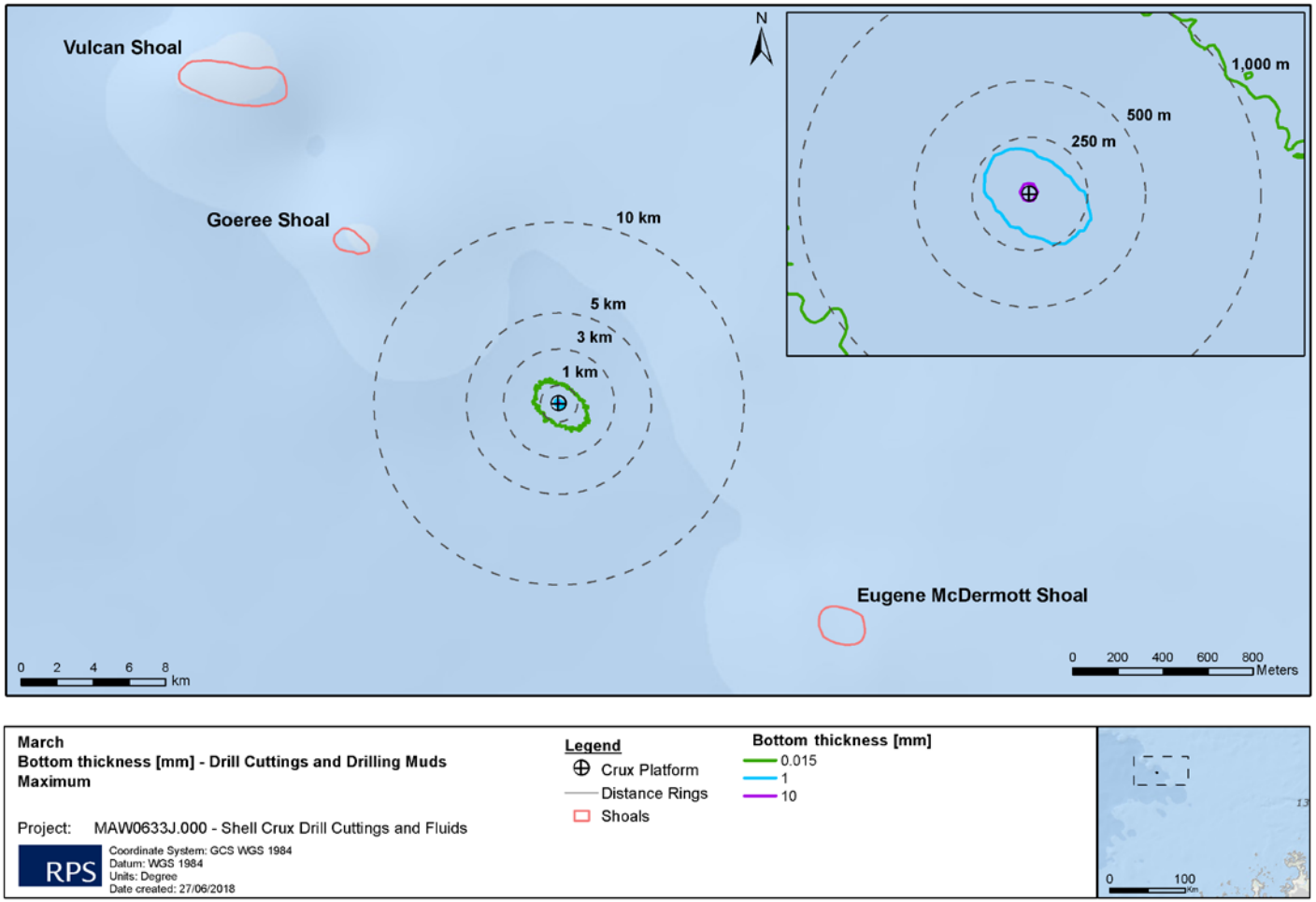


Figure 5.3 **Predicted maximum bottom thickness resulting from the drill cuttings and drilling muds discharge programme. The maximum concentrations are calculated across all simulations commencing on 1st March during the period 2008-2017.**

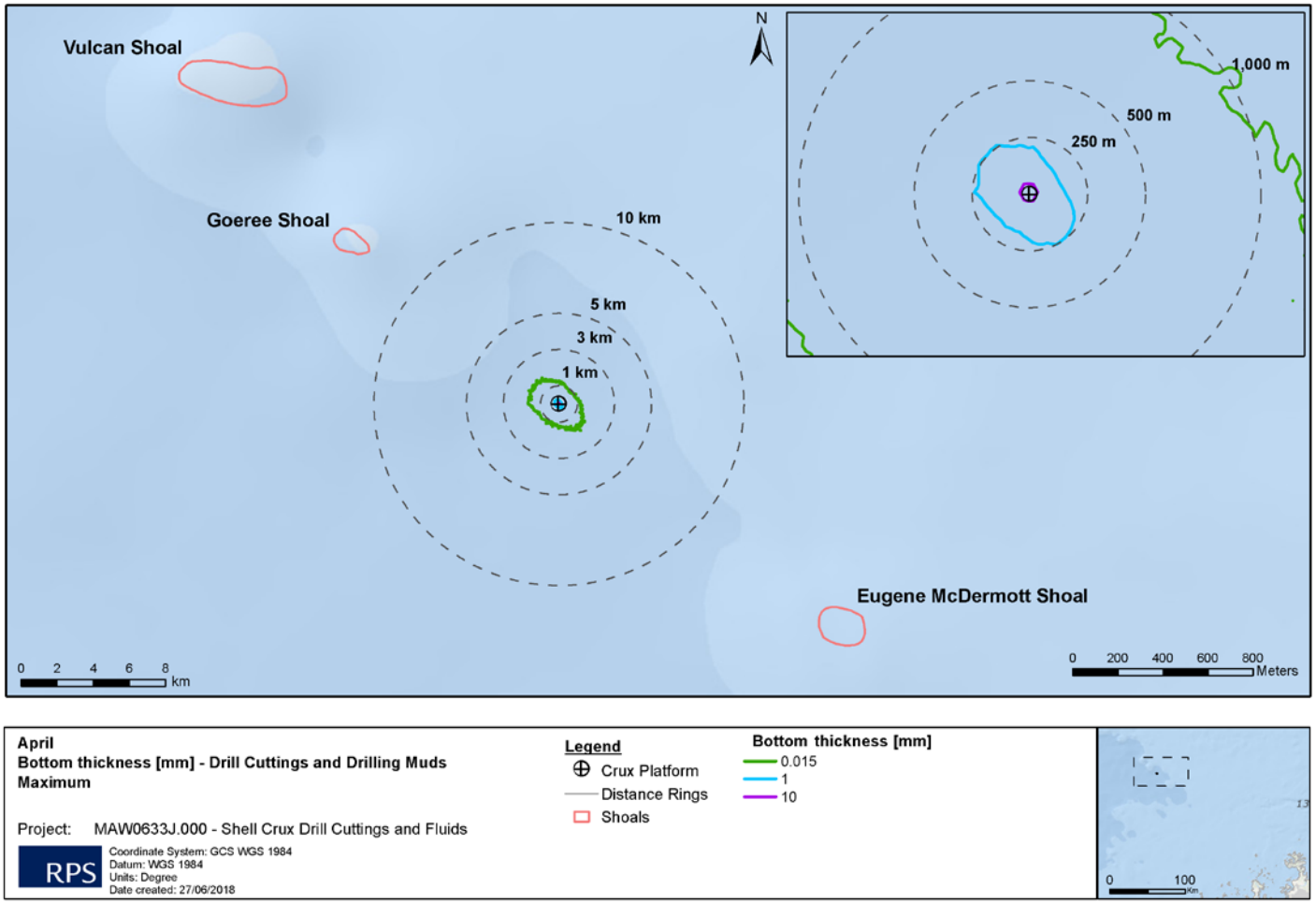


Figure 5.4 **Predicted maximum bottom thickness resulting from the drill cuttings and drilling muds discharge programme. The maximum concentrations are calculated across all simulations commencing on 1st April during the period 2008-2017.**

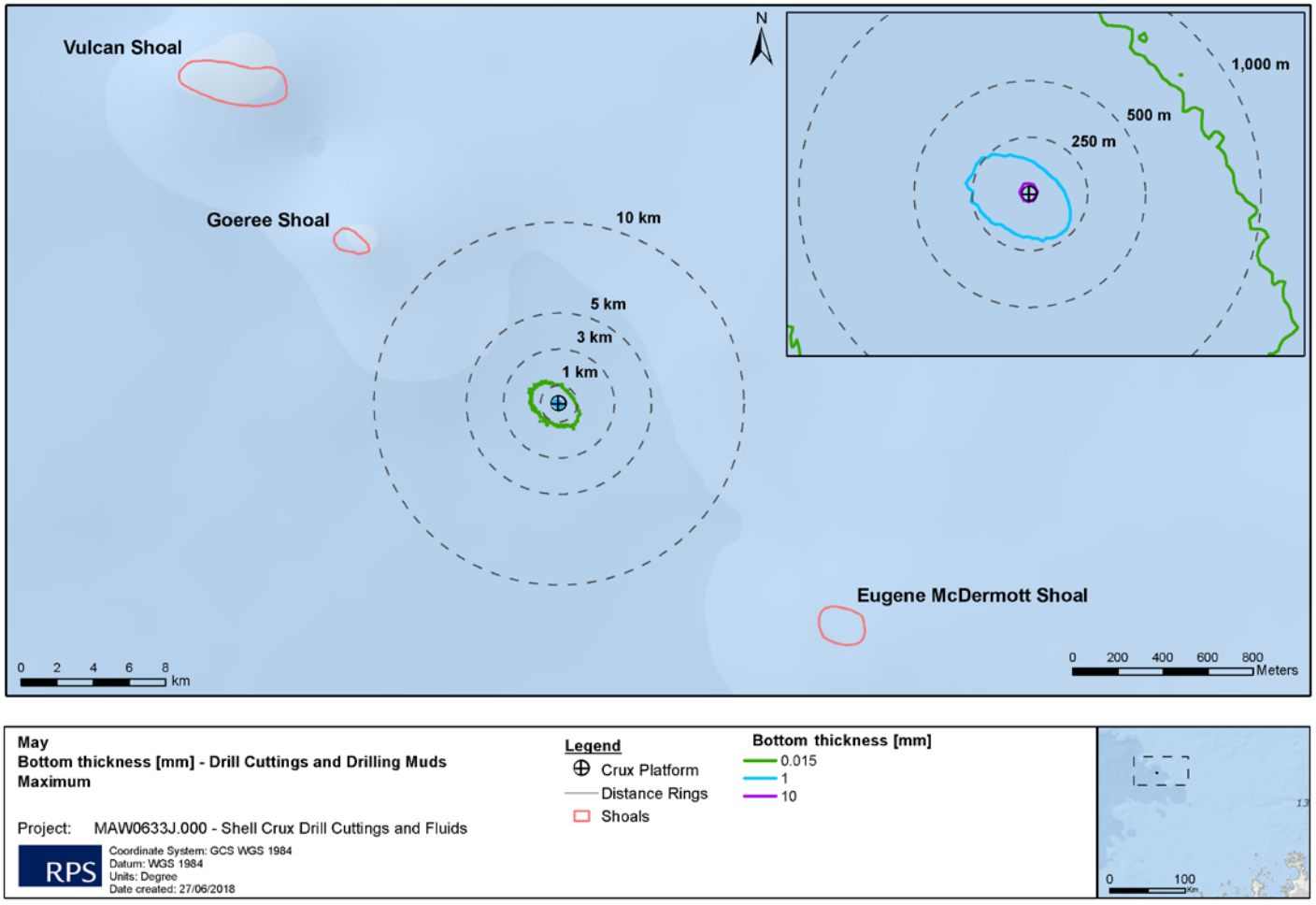


Figure 5.5 **Predicted maximum bottom thickness resulting from the drill cuttings and drilling muds discharge programme. The maximum concentrations are calculated across all simulations commencing on 1st May during the period 2008-2017.**

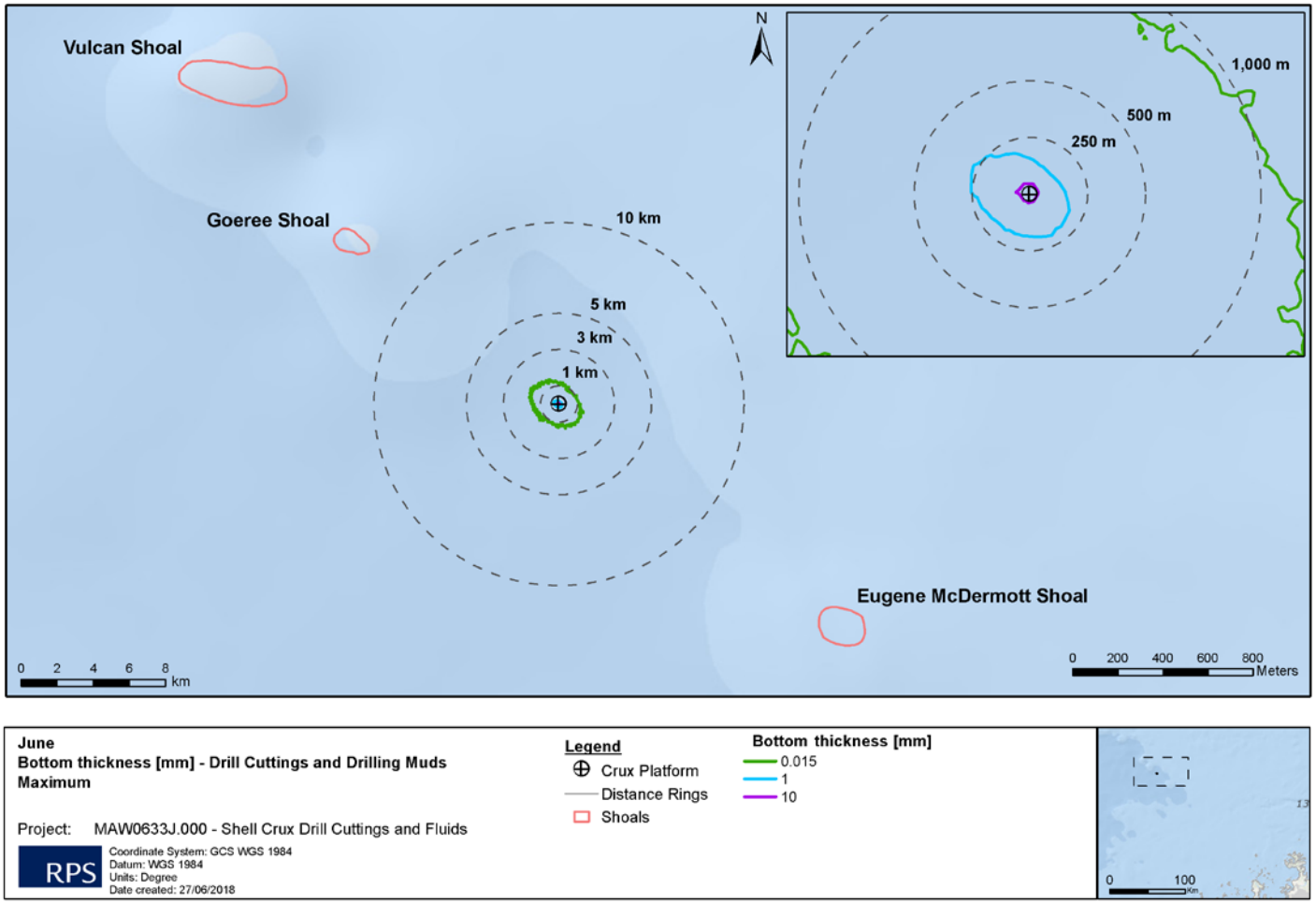


Figure 5.6 **Predicted maximum bottom thickness resulting from the drill cuttings and drilling muds discharge programme. The maximum concentrations are calculated across all simulations commencing on 1st June during the period 2008-2017.**

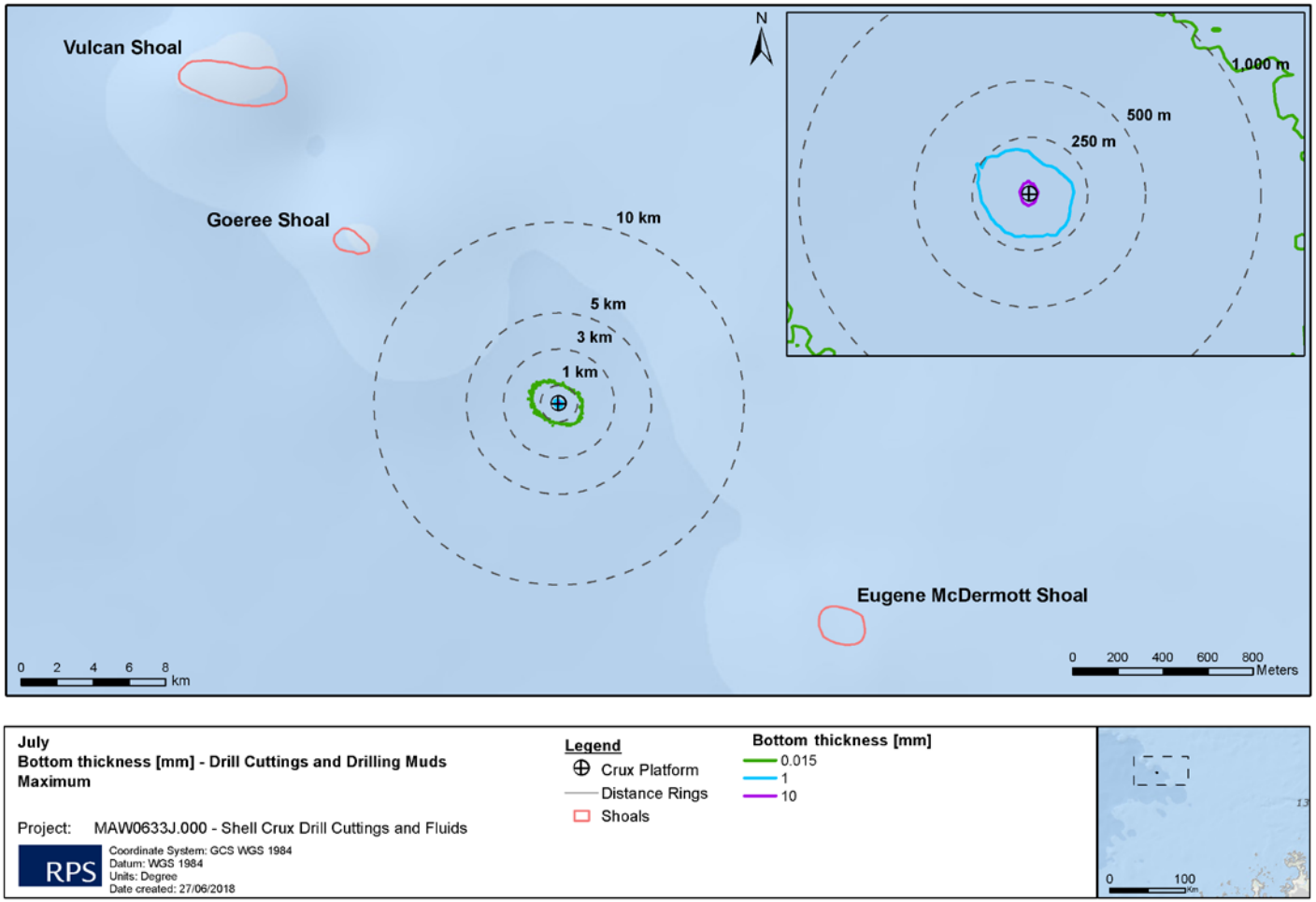


Figure 5.7 **Predicted maximum bottom thickness resulting from the drill cuttings and drilling muds discharge programme. The maximum concentrations are calculated across all simulations commencing on 1st July during the period 2008-2017.**

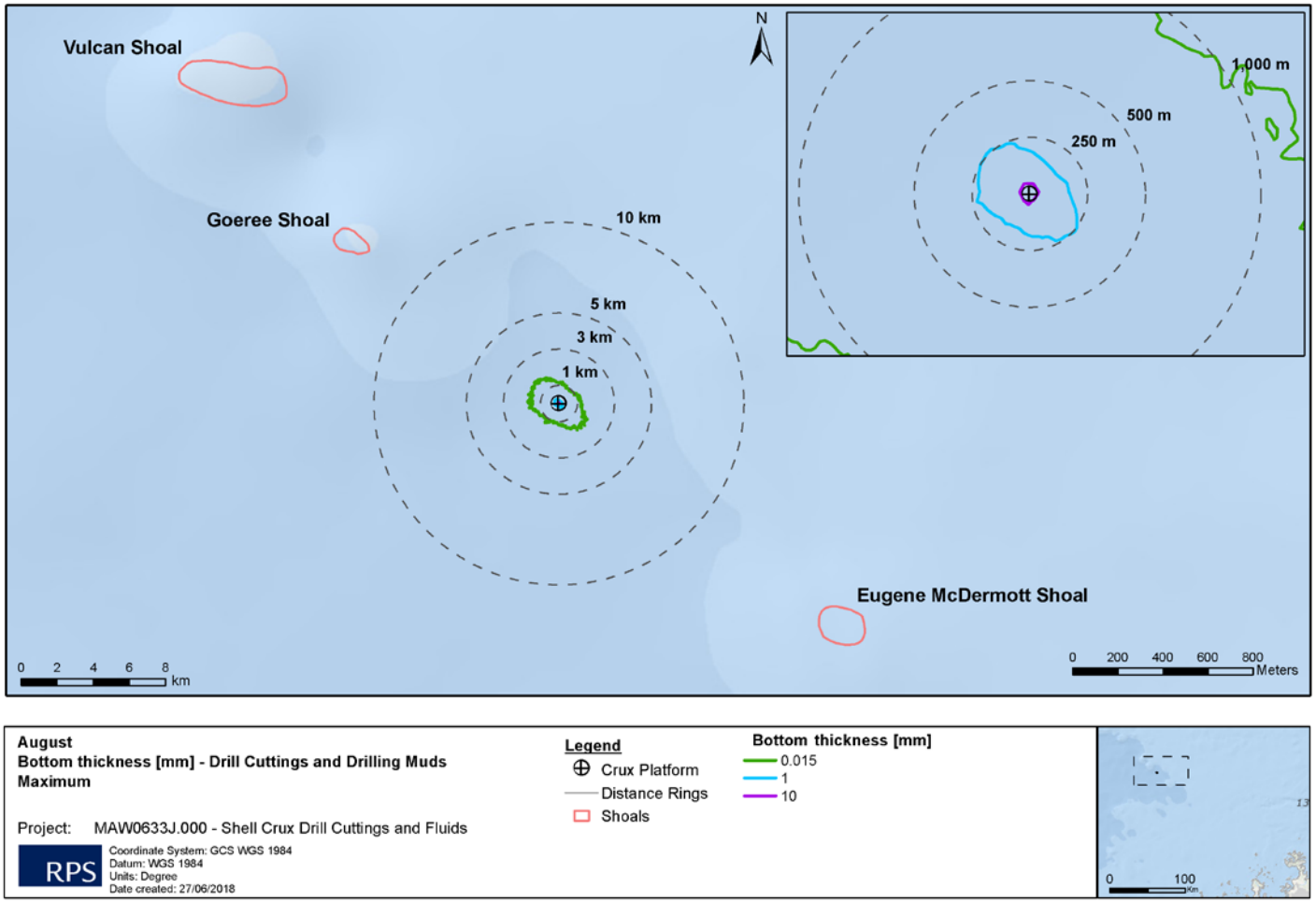


Figure 5.8 **Predicted maximum bottom thickness resulting from the drill cuttings and drilling muds discharge programme. The maximum concentrations are calculated across all simulations commencing on 1st August during the period 2008-2017.**

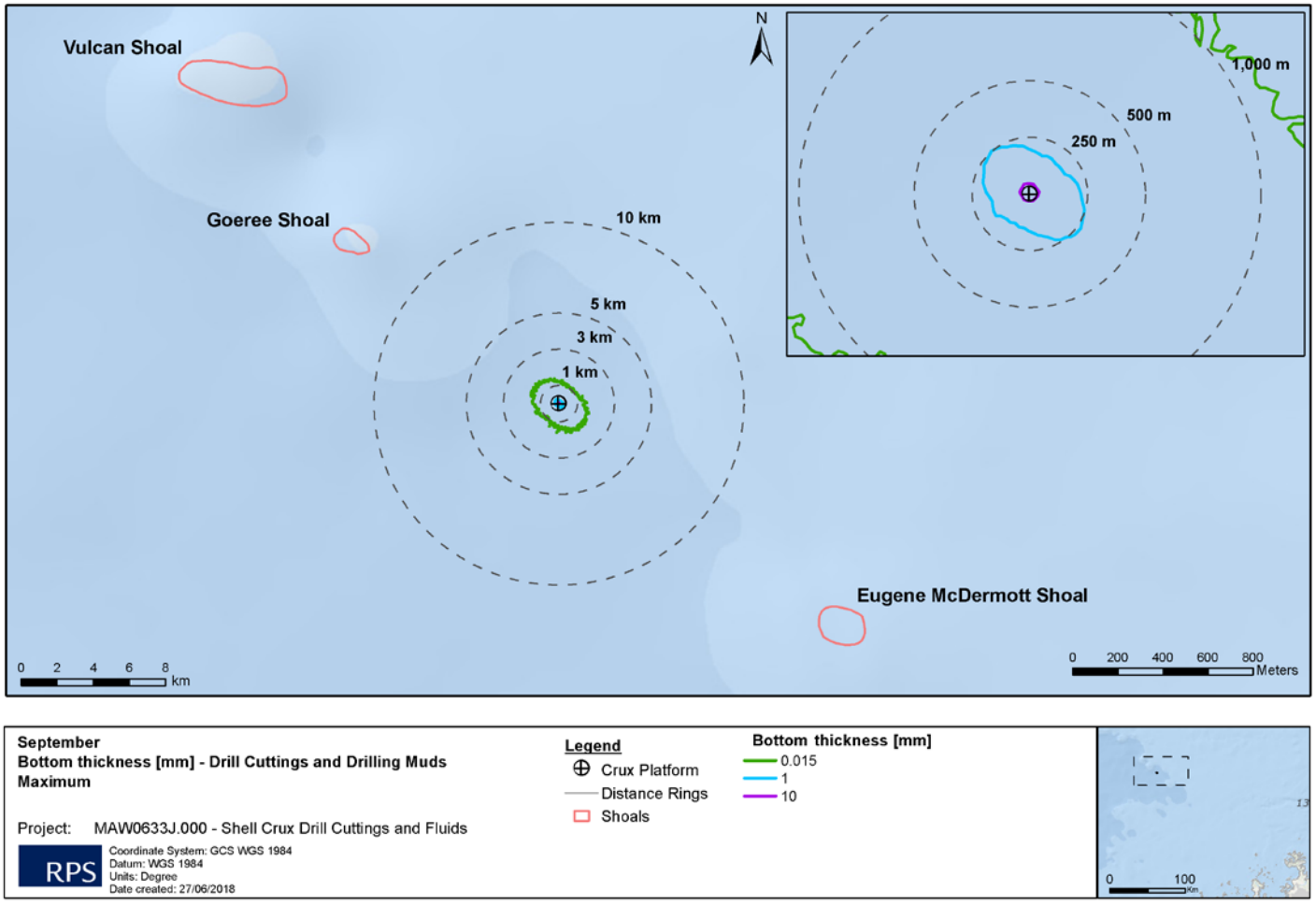


Figure 5.9 **Predicted maximum bottom thickness resulting from the drill cuttings and drilling muds discharge programme. The maximum concentrations are calculated across all simulations commencing on 1st September during the period 2008-2017.**

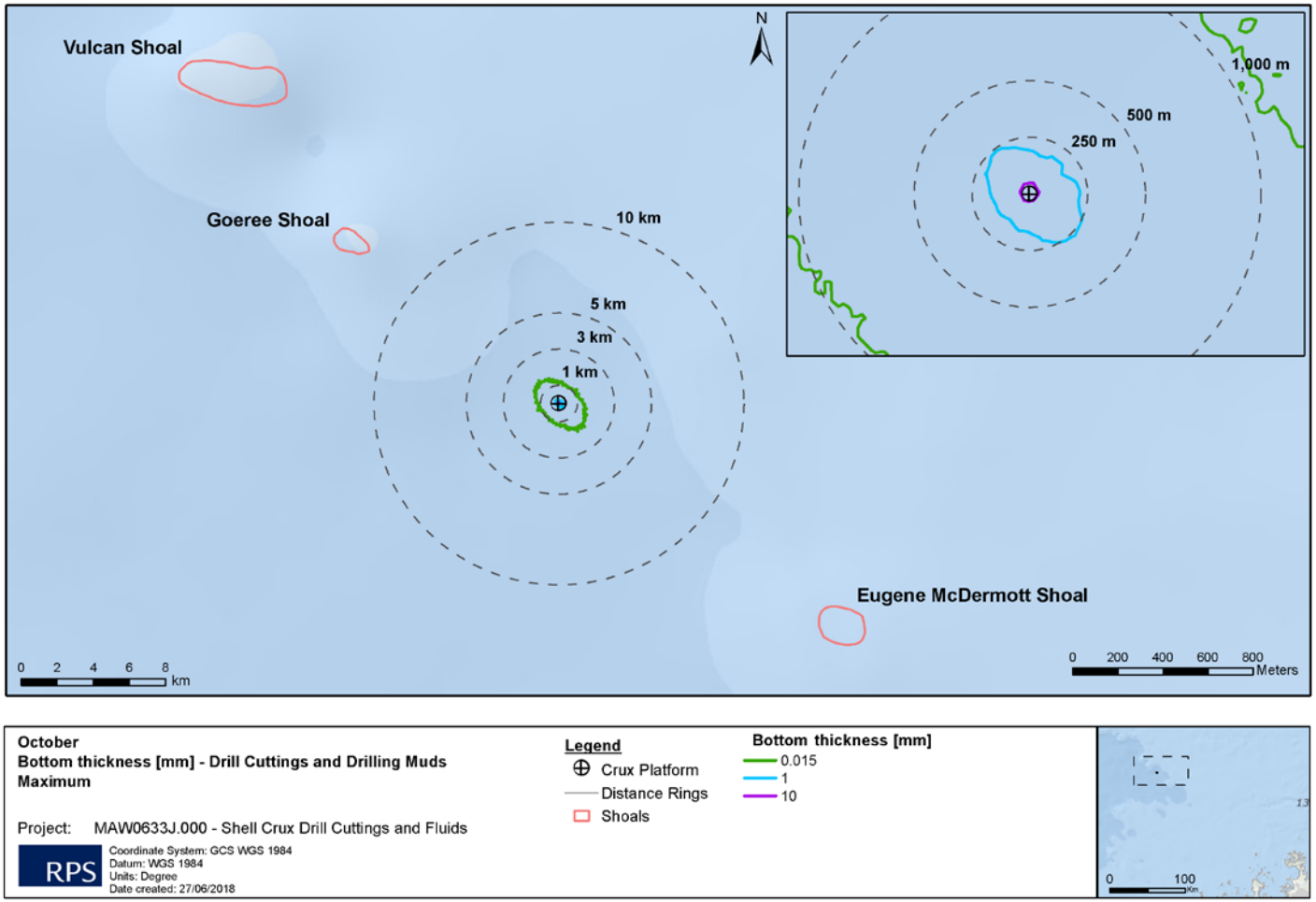


Figure 5.10 **Predicted maximum bottom thickness resulting from the drill cuttings and drilling muds discharge programme. The maximum concentrations are calculated across all simulations commencing on 1st October during the period 2008-2017.**

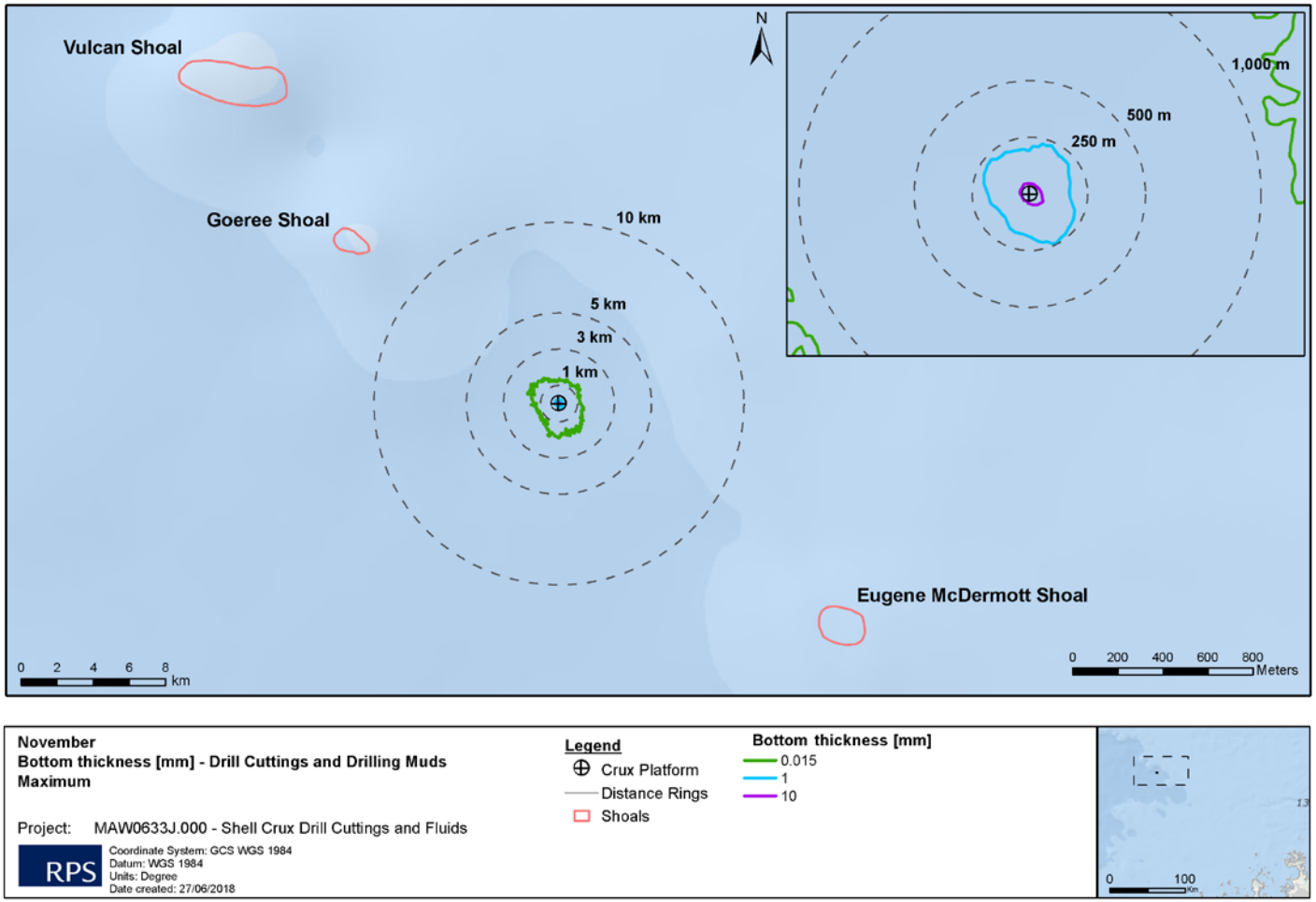


Figure 5.11 **Predicted maximum bottom thickness resulting from the drill cuttings and drilling muds discharge programme. The maximum concentrations are calculated across all simulations commencing on 1st November during the period 2008-2017.**

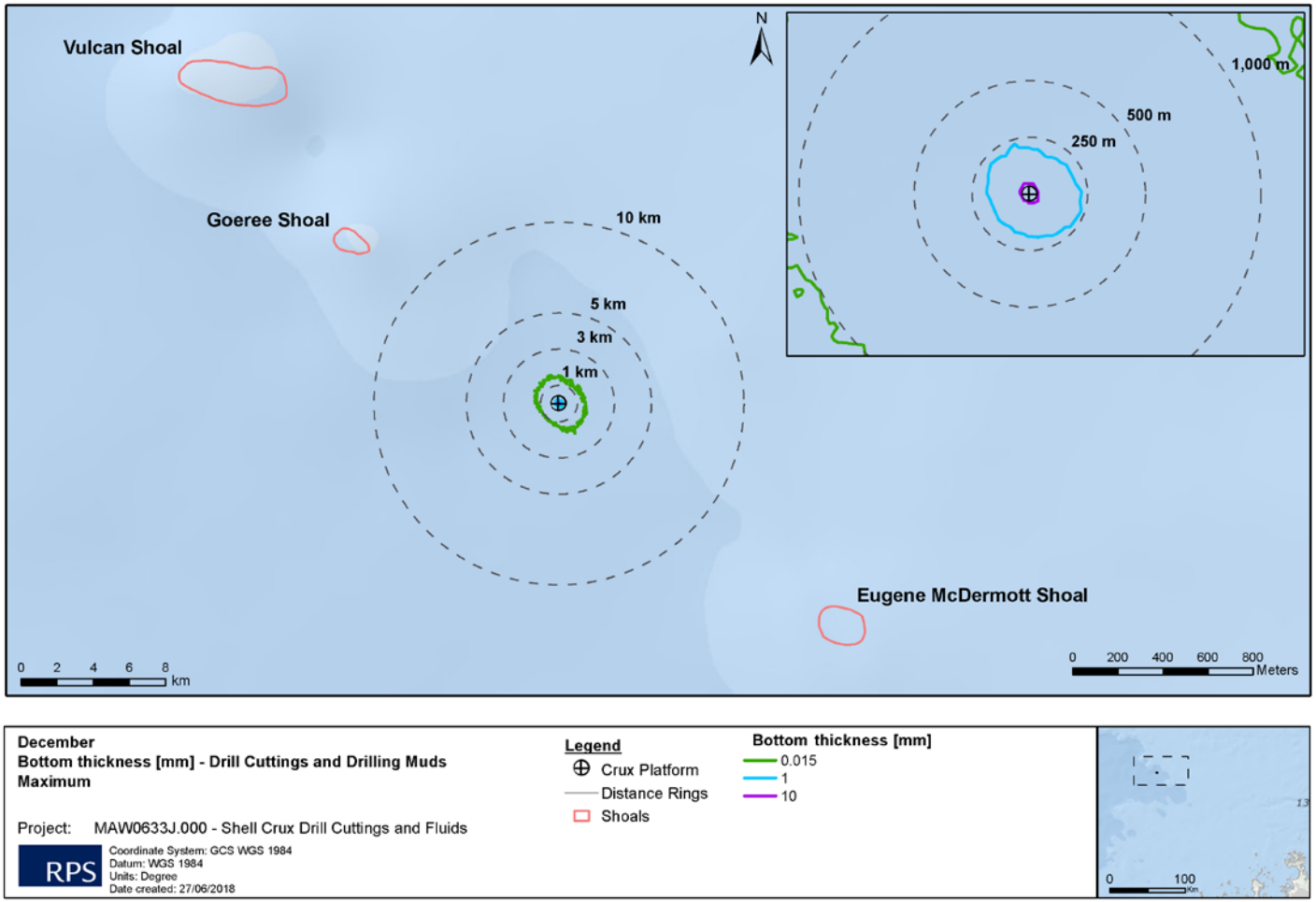


Figure 5.12 **Predicted maximum bottom thickness resulting from the drill cuttings and drilling muds discharge programme. The maximum concentrations are calculated across all simulations commencing on 1st December during the period 2008-2017.**

Drill Cuttings Only (Single Well)

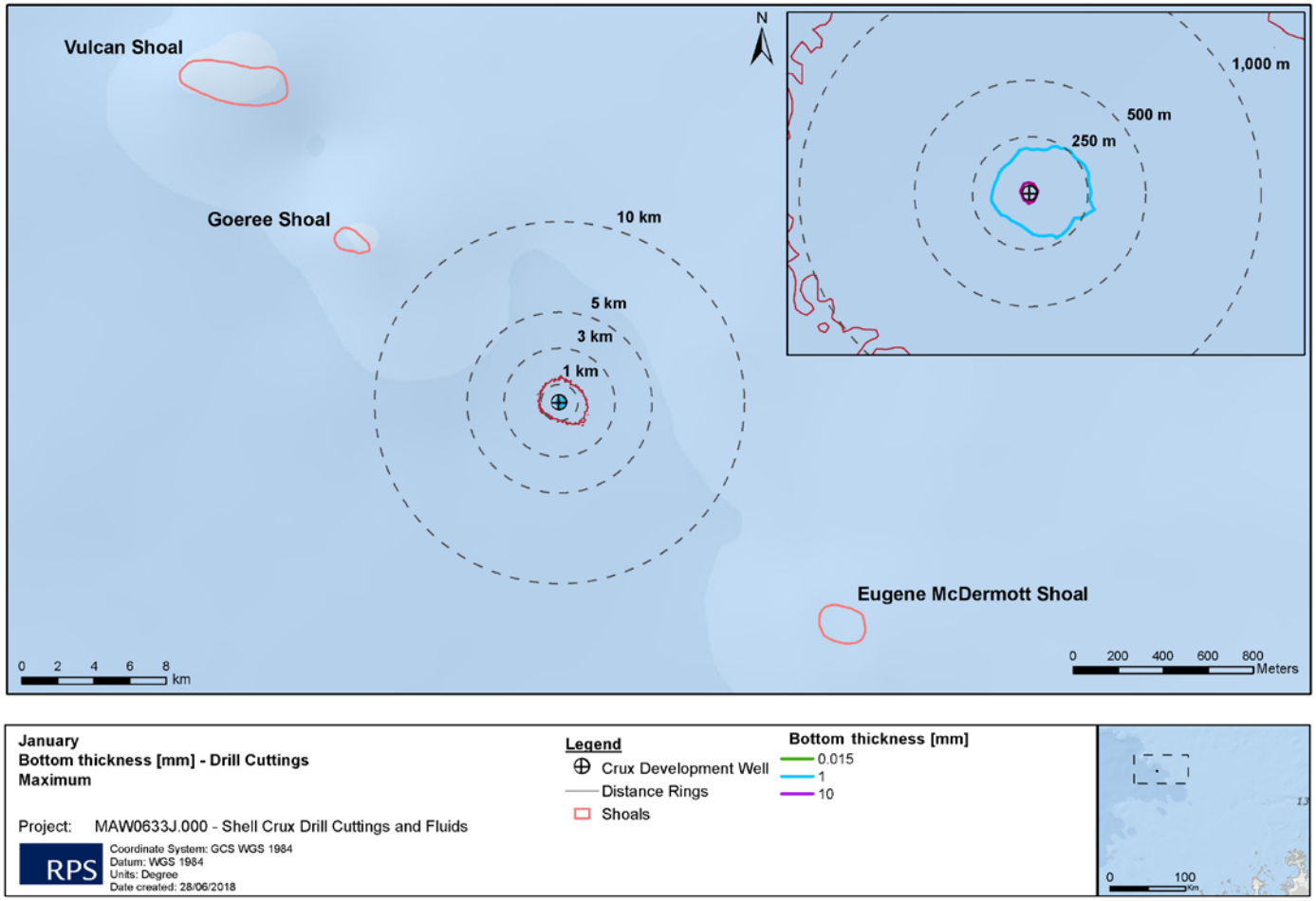


Figure 5.13 **Predicted maximum bottom thickness resulting from only the drill cuttings volumes of the discharge programme. The maximum concentrations are calculated across all simulations commencing on 1st January during the period 2008-2017.**

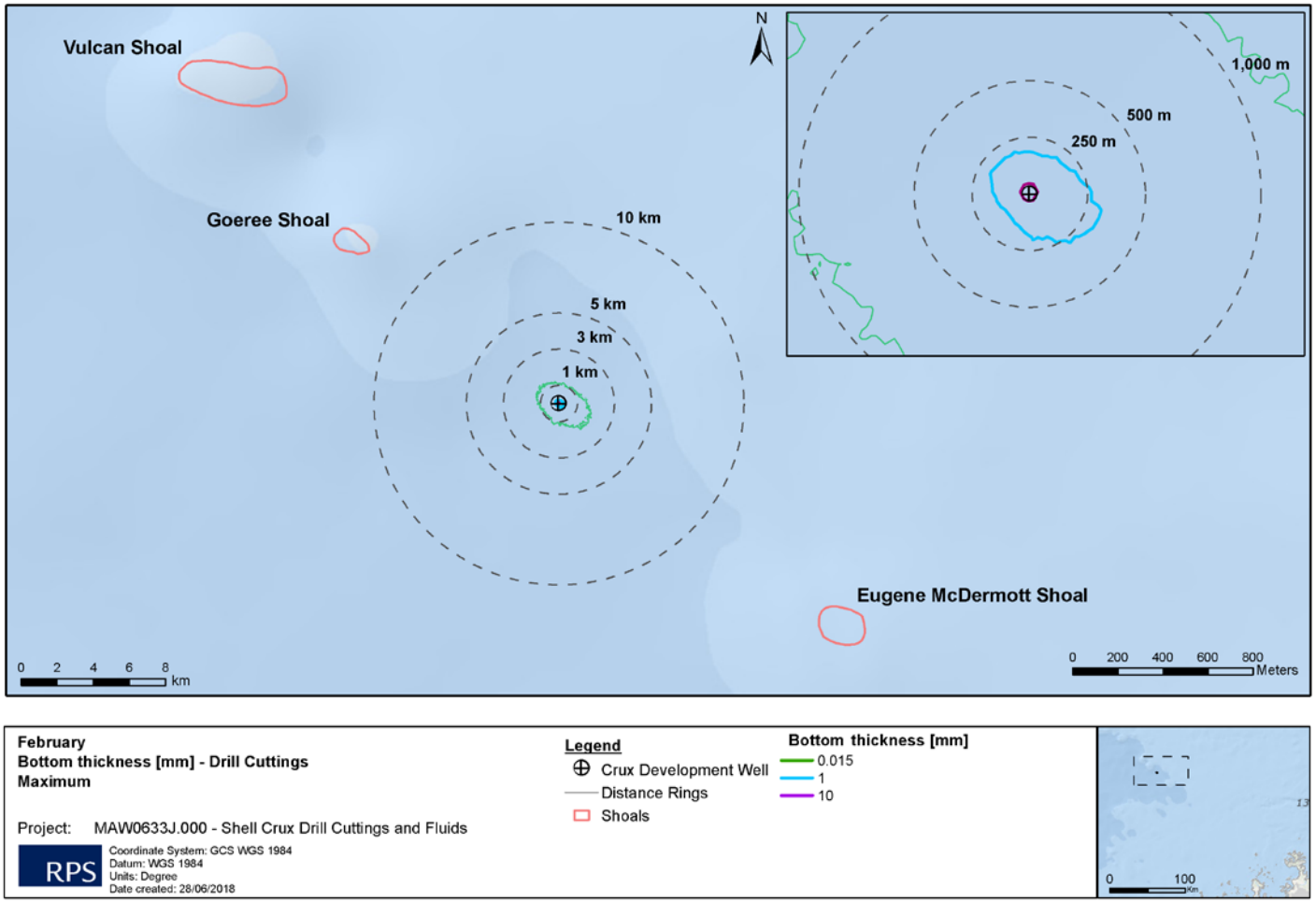


Figure 5.14 **Predicted maximum bottom thickness resulting from only the drill cuttings volumes of the discharge programme. The maximum concentrations are calculated across all simulations commencing on 1st February during the period 2008-2017.**

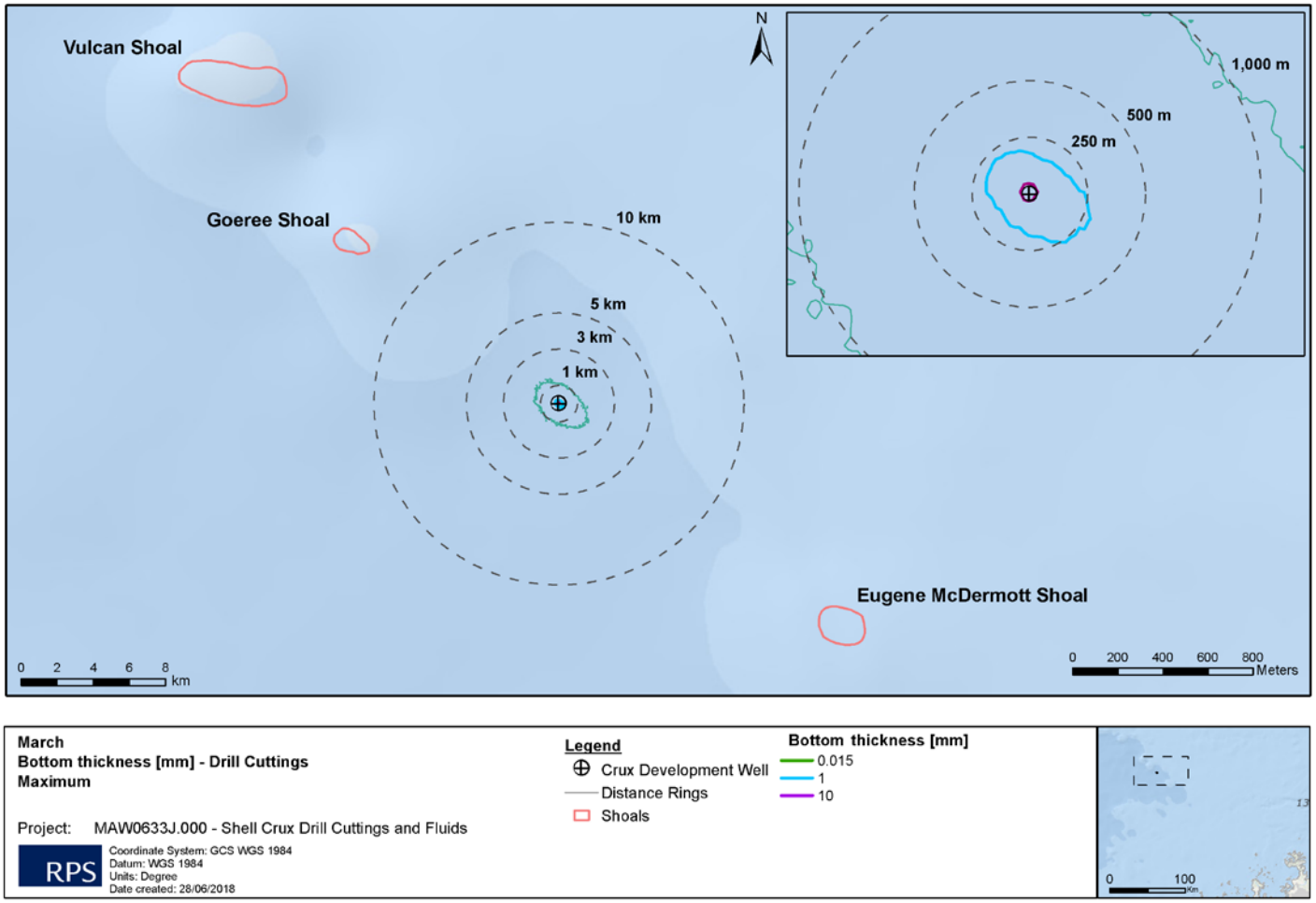


Figure 5.15 **Predicted maximum bottom thickness resulting from only the drill cuttings volumes of the discharge programme. The maximum concentrations are calculated across all simulations commencing on 1st March during the period 2008-2017.**

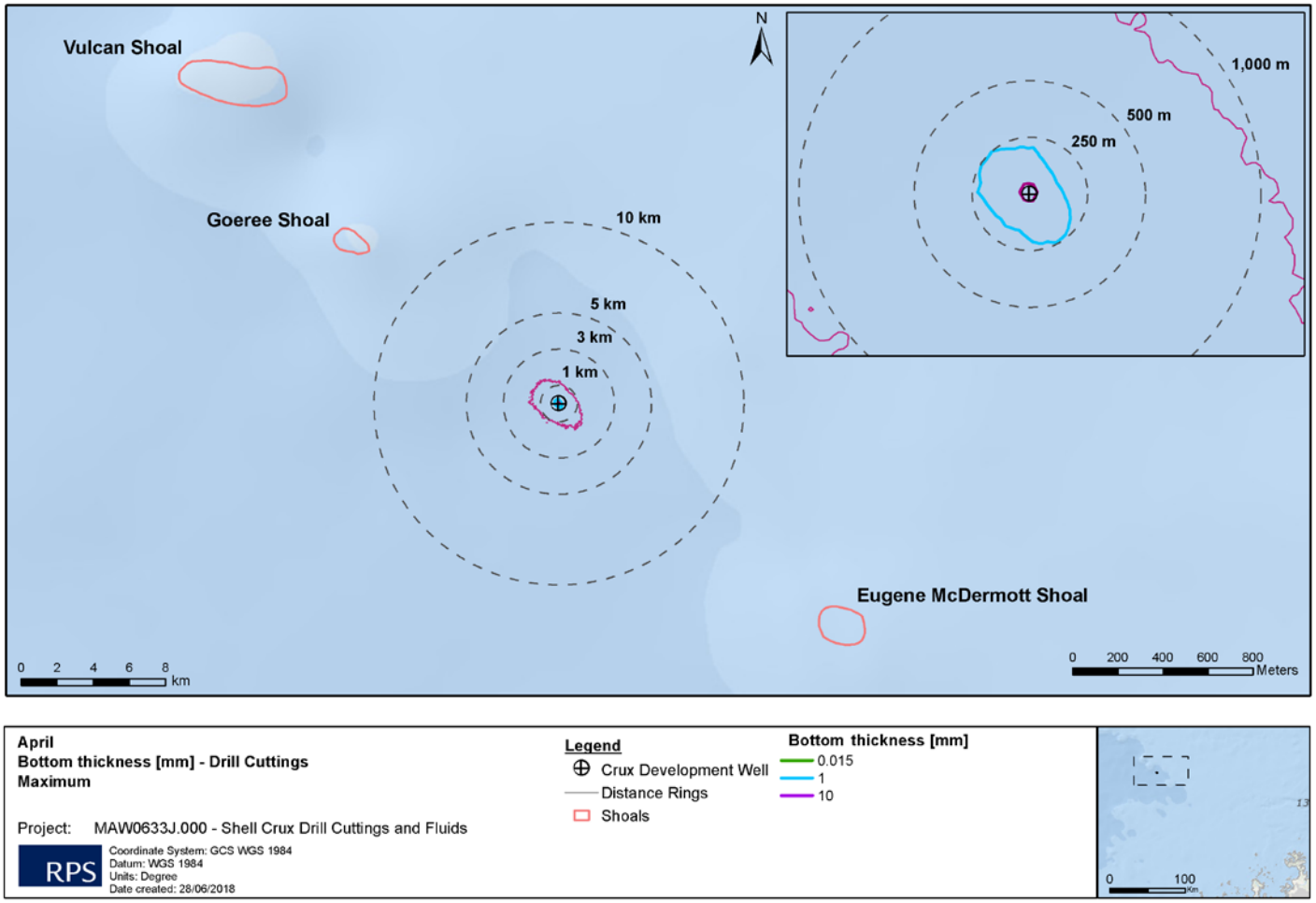


Figure 5.16 **Predicted maximum bottom thickness resulting from only the drill cuttings volumes of the discharge programme. The maximum concentrations are calculated across all simulations commencing on 1st April during the period 2008-2017.**

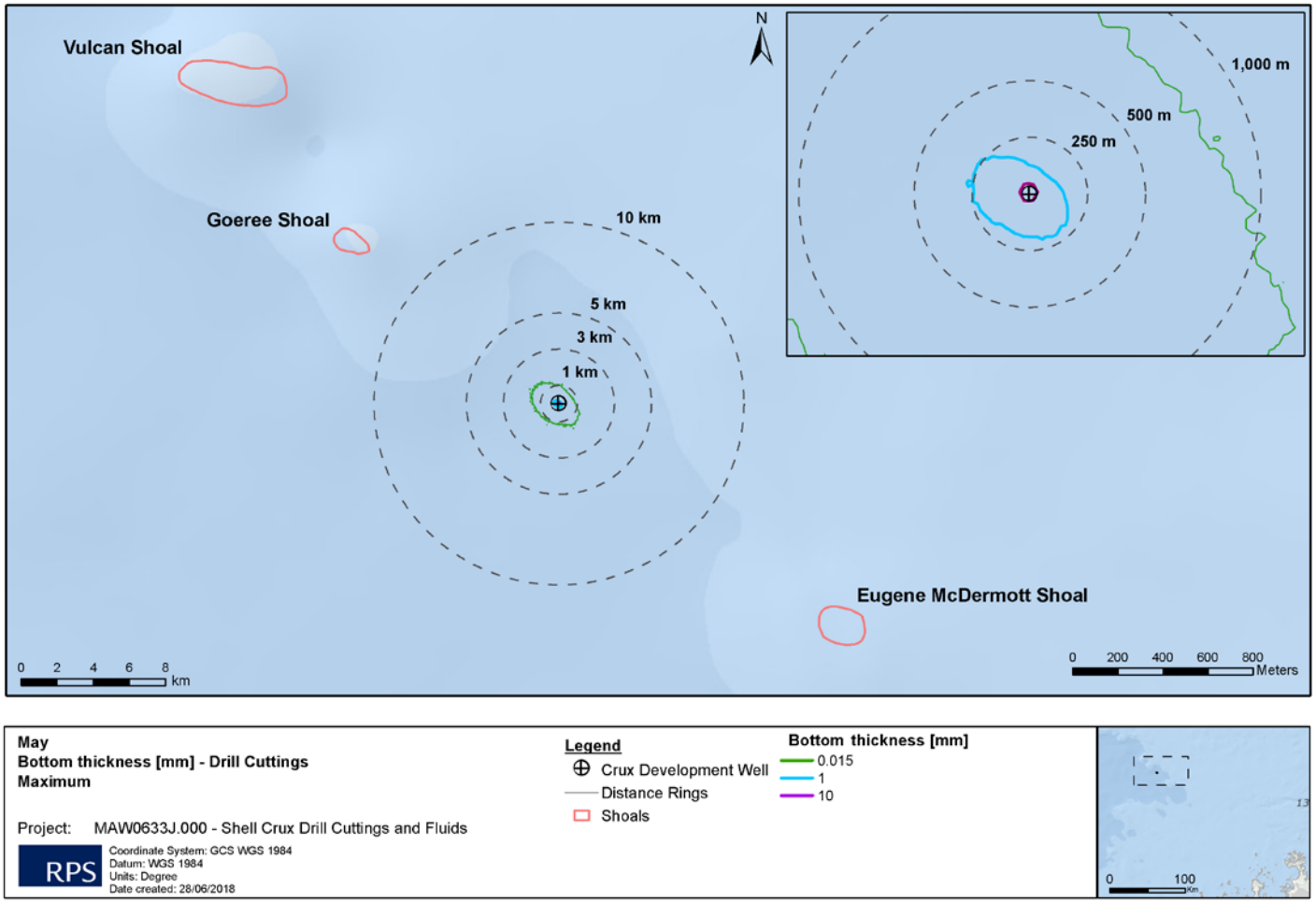


Figure 5.17 **Predicted maximum bottom thickness resulting from only the drill cuttings volumes of the discharge programme. The maximum concentrations are calculated across all simulations commencing on 1st May during the period 2008-2017.**

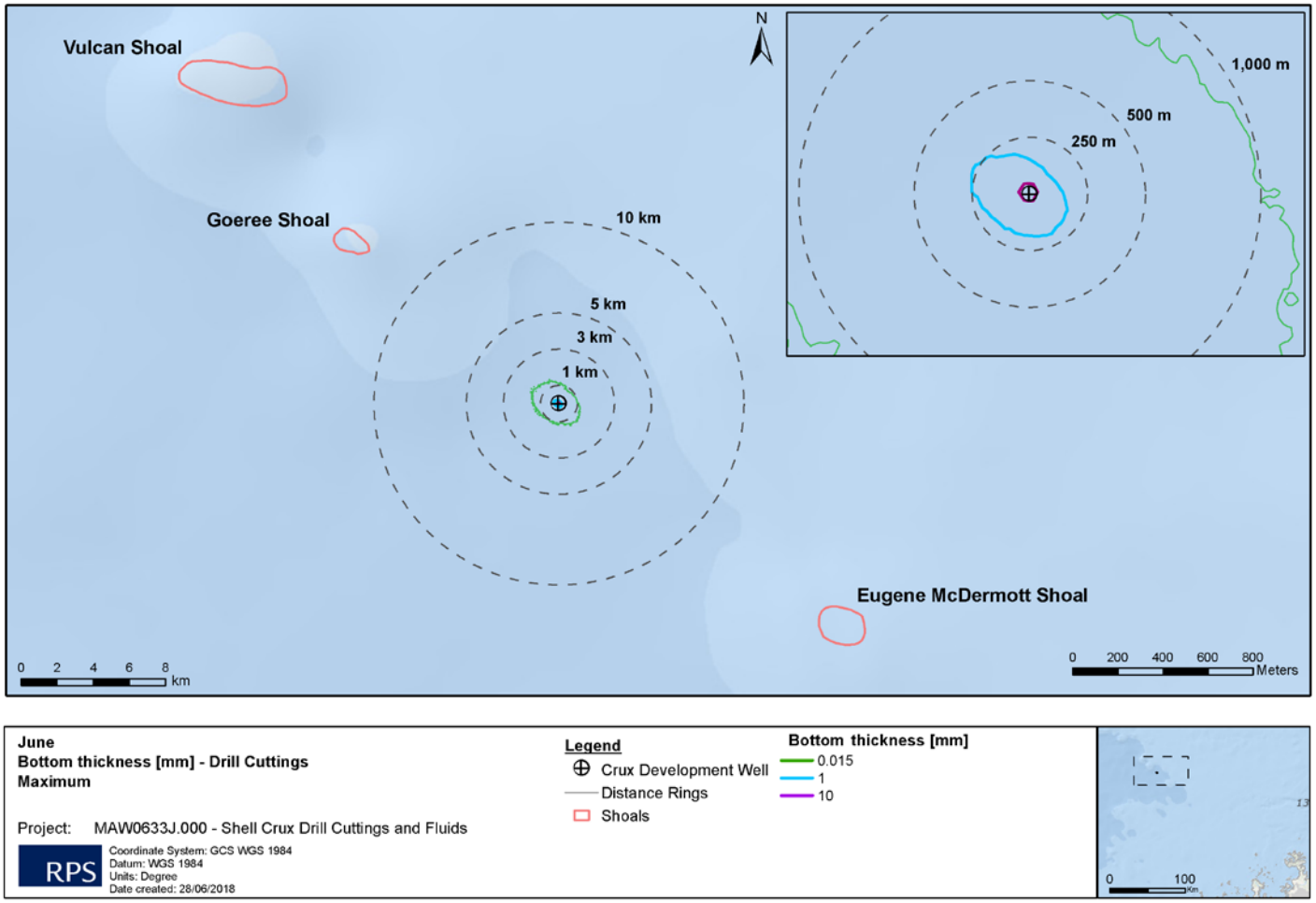


Figure 5.18 **Predicted maximum bottom thickness resulting from only the drill cuttings volumes of the discharge programme. The maximum concentrations are calculated across all simulations commencing on 1st June during the period 2008-2017.**

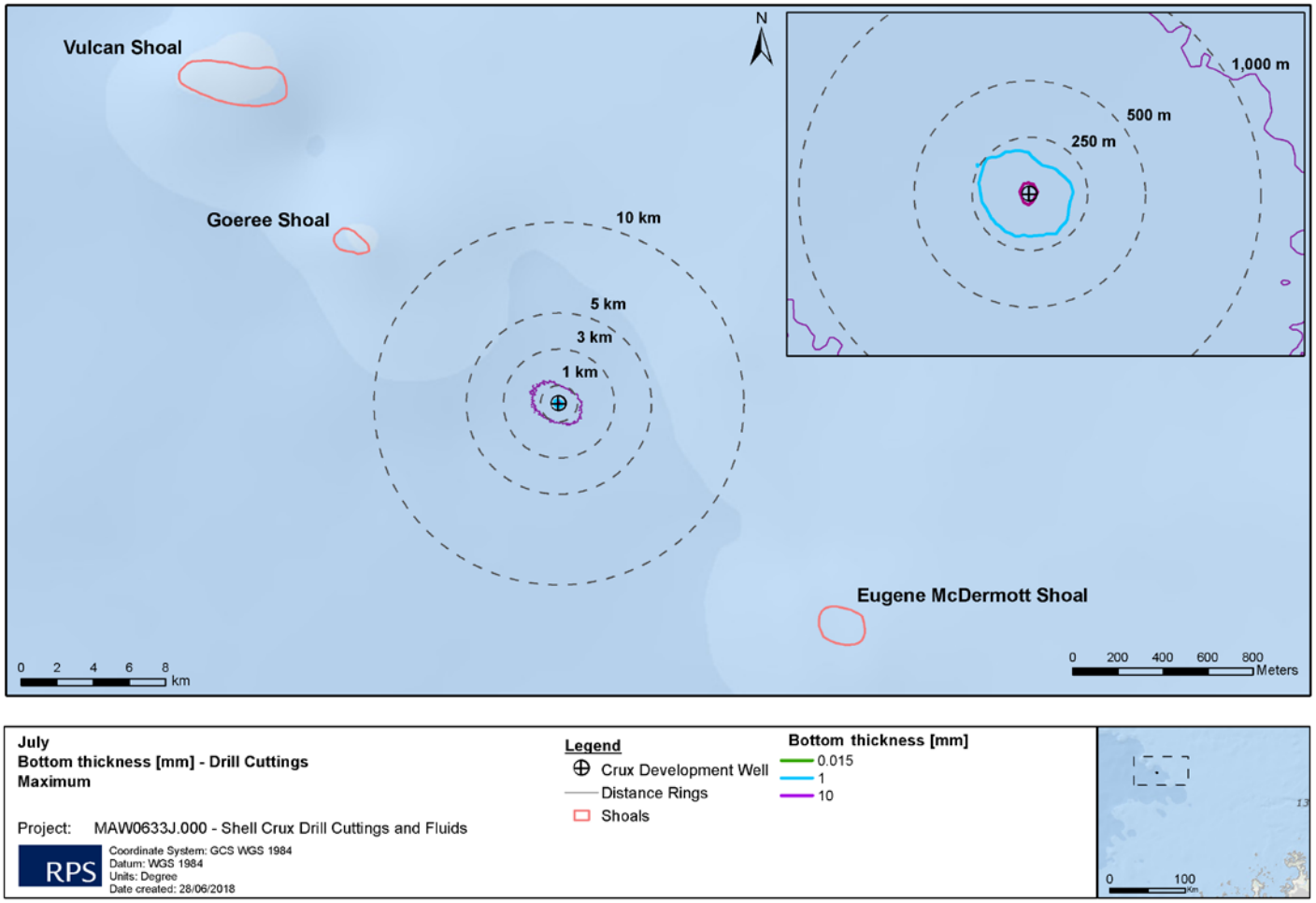


Figure 5.19 **Predicted maximum bottom thickness resulting from only the drill cuttings volumes of the discharge programme. The maximum concentrations are calculated across all simulations commencing on 1st July during the period 2008-2017.**

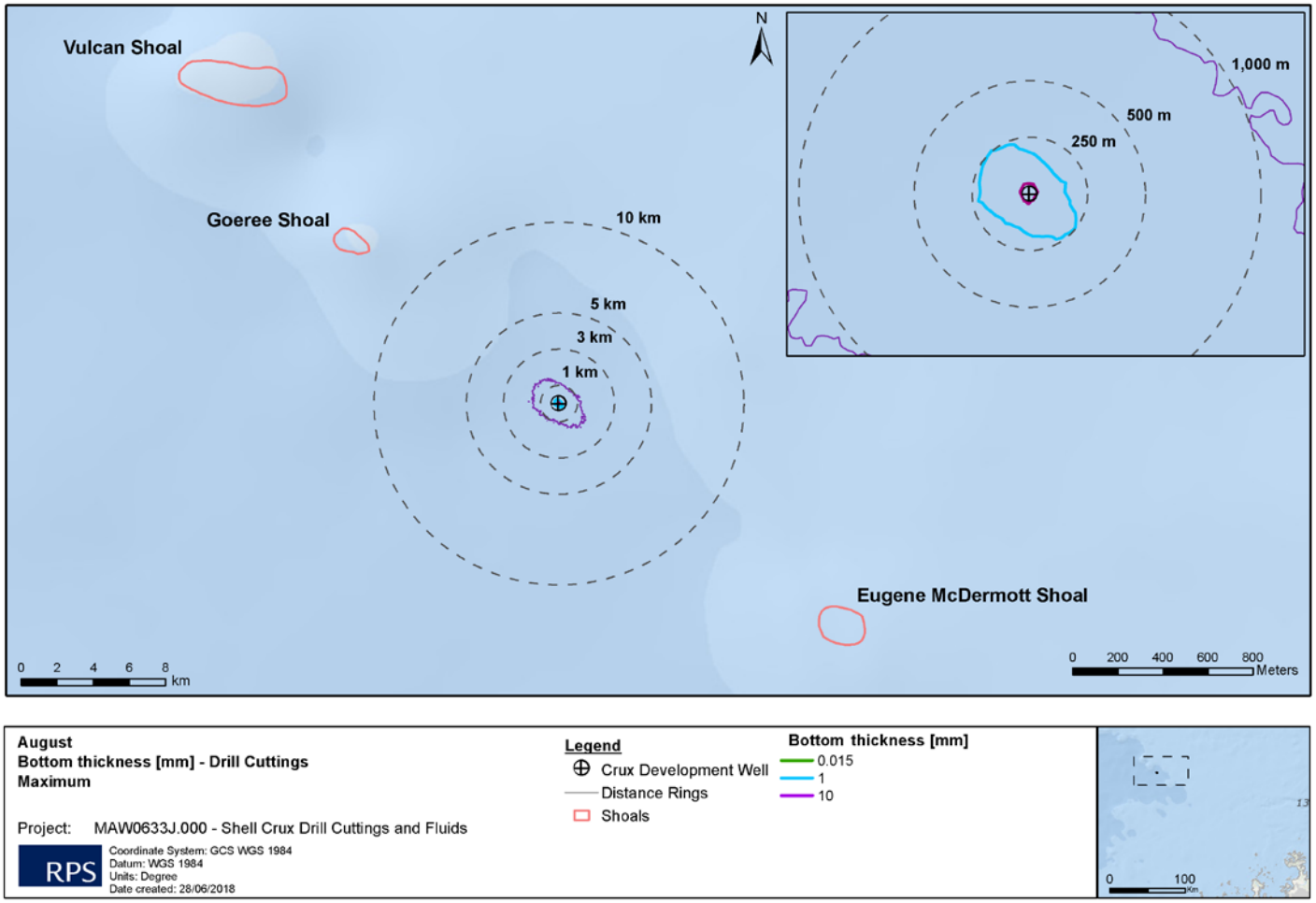


Figure 5.20 **Predicted maximum bottom thickness resulting from only the drill cuttings volumes of the discharge programme. The maximum concentrations are calculated across all simulations commencing on 1st August during the period 2008-2017.**

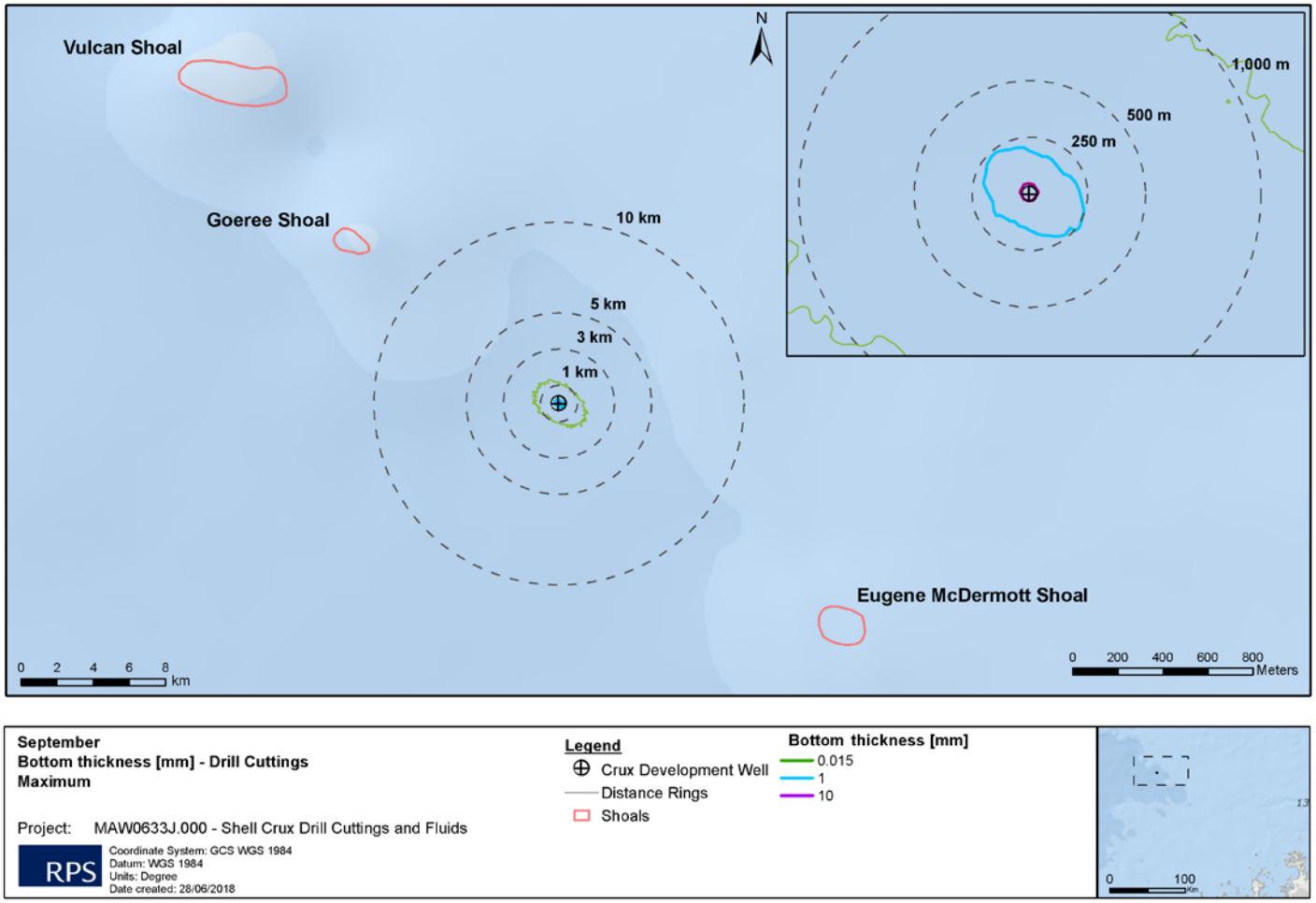


Figure 5.21 **Predicted maximum bottom thickness resulting from only the drill cuttings volumes of the discharge programme. The maximum concentrations are calculated across all simulations commencing on 1st September during the period 2008-2017.**

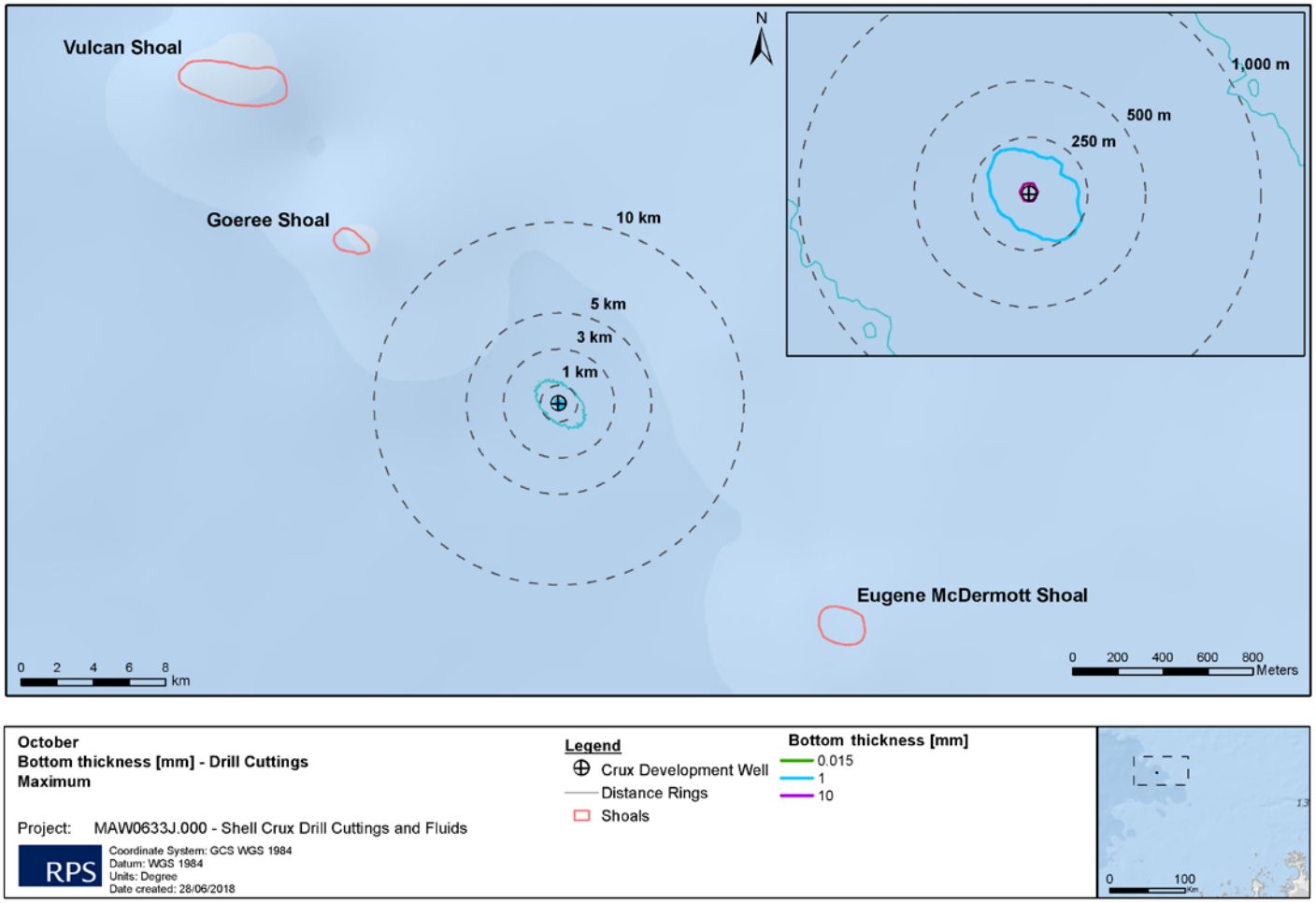


Figure 5.22 **Predicted maximum bottom thickness resulting from only the drill cuttings volumes of the discharge programme. The maximum concentrations are calculated across all simulations commencing on 1st October during the period 2008-2017.**

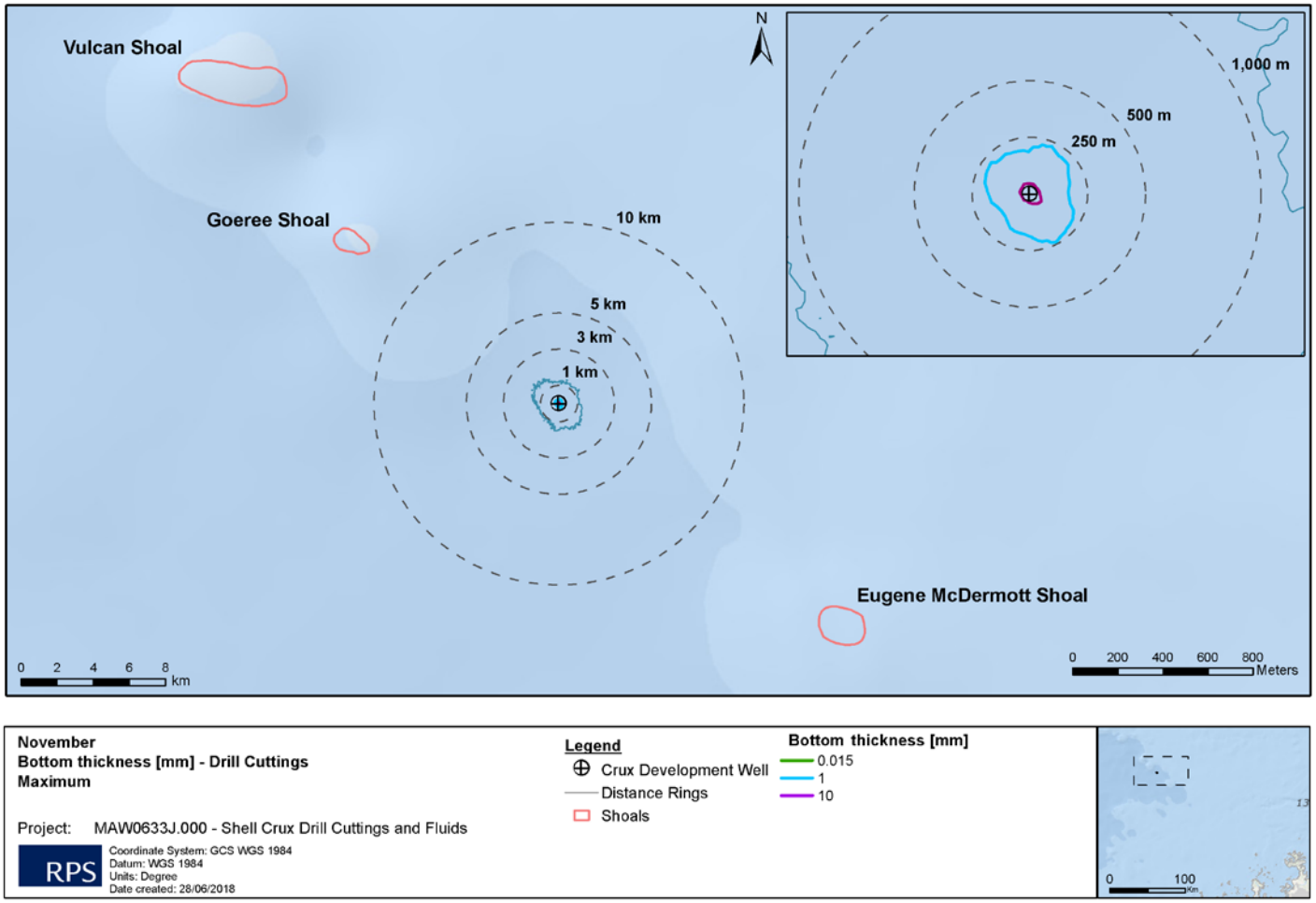


Figure 5.23 **Predicted maximum bottom thickness resulting from only the drill cuttings volumes of the discharge programme. The maximum concentrations are calculated across all simulations commencing on 1st November during the period 2008-2017.**

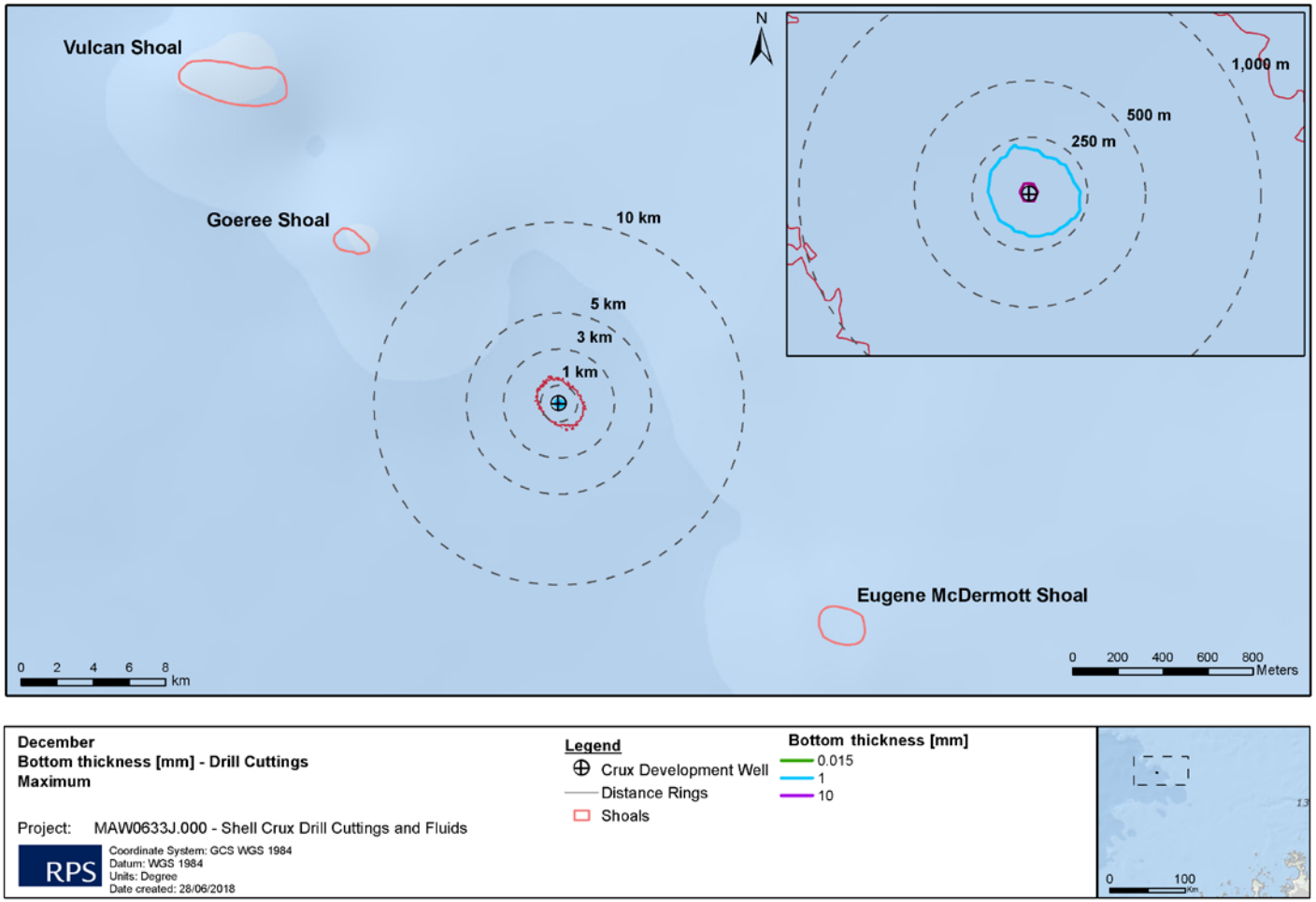


Figure 5.24 **Predicted maximum bottom thickness resulting from only the drill cuttings volumes of the discharge programme. The maximum concentrations are calculated across all simulations commencing on 1st December during the period 2008-2017.**

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Drill Cuttings & Drilling Muds (Five Wells)

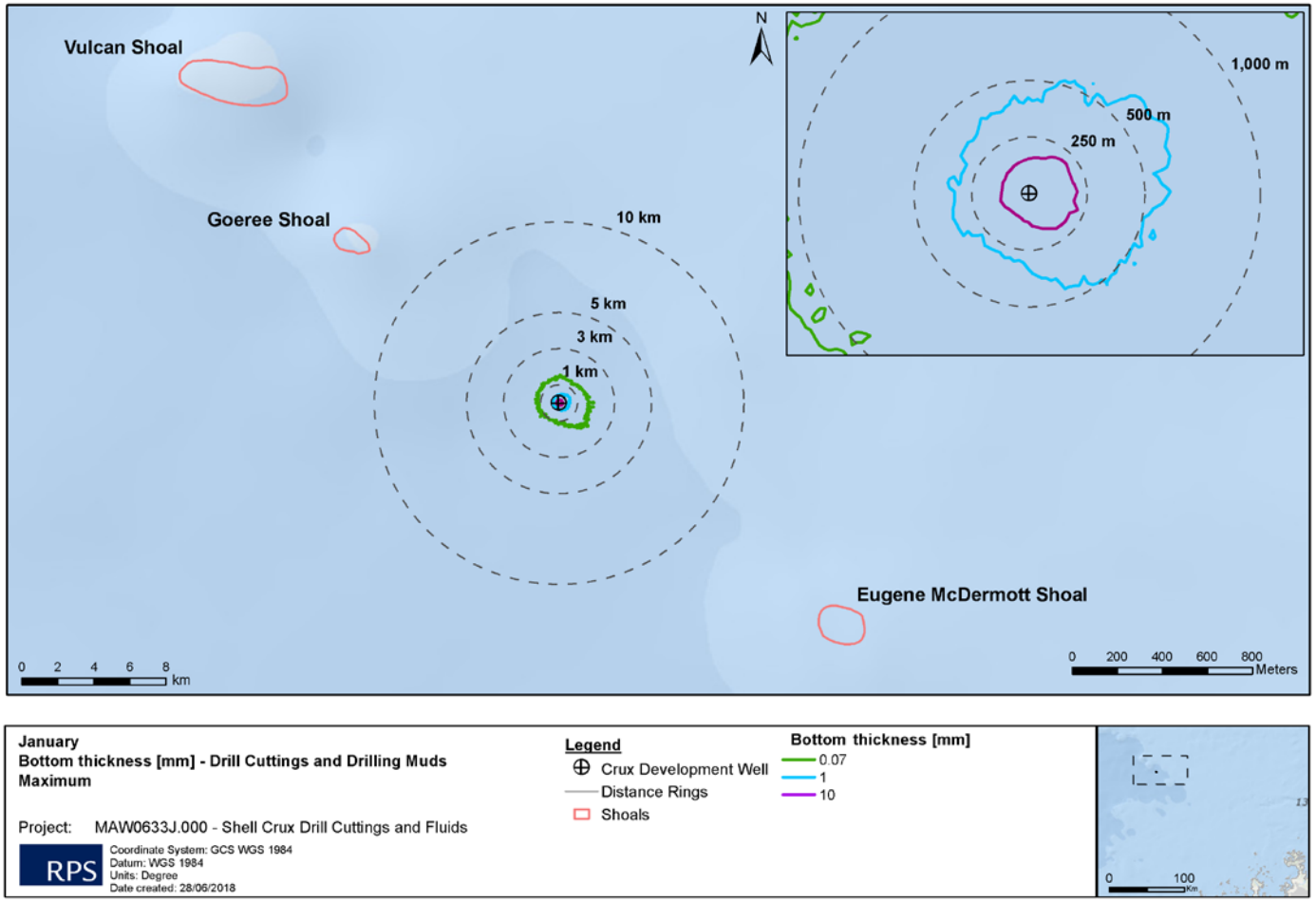


Figure 5.25 **Predicted maximum bottom thickness resulting from the drill cuttings and drilling muds discharge programme. The maximum concentrations are calculated across all simulations commencing on 1st January during the period 2008-2017.**

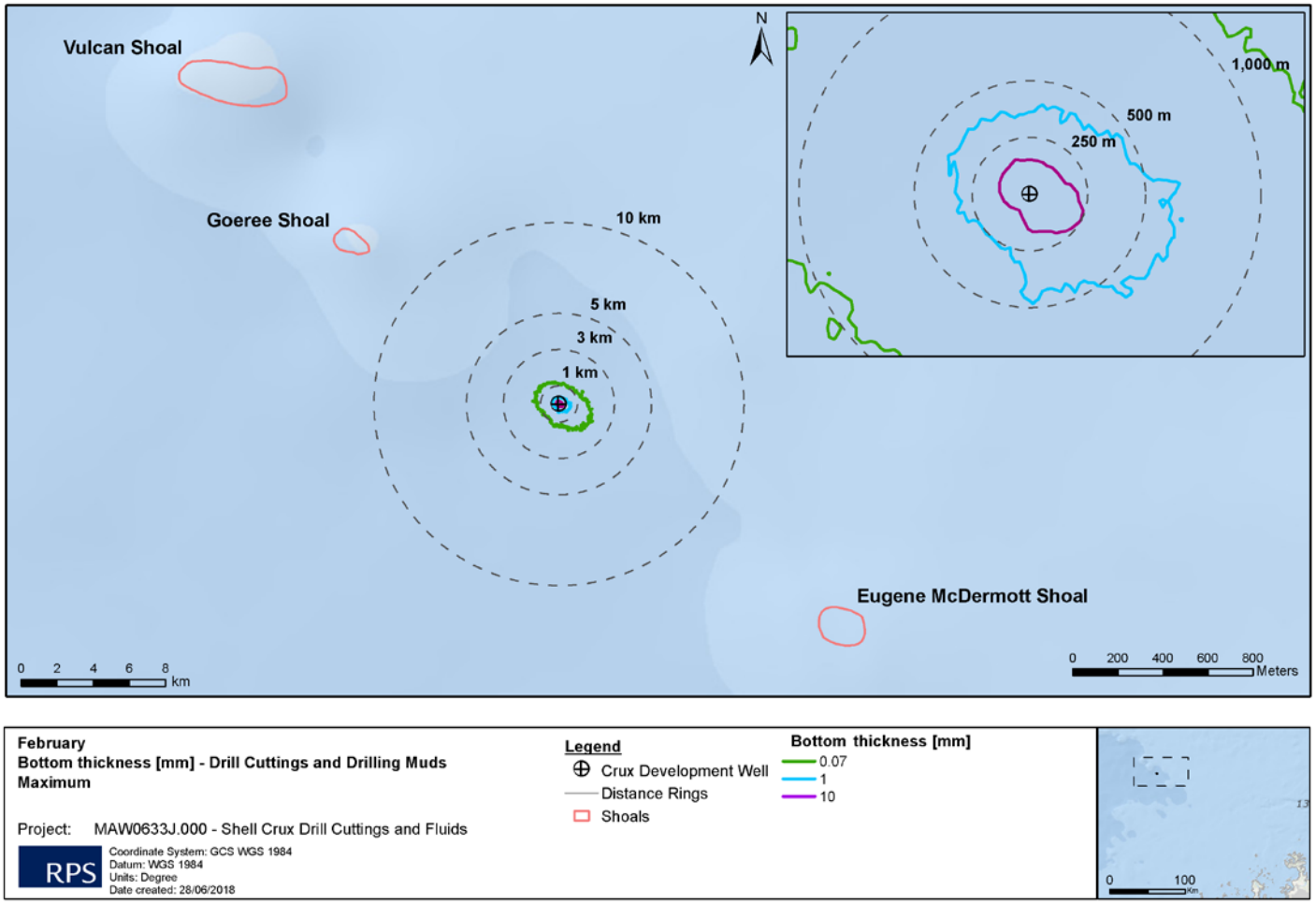


Figure 5.26 **Predicted maximum bottom thickness resulting from the drill cuttings and drilling muds discharge programme. The maximum concentrations are calculated across all simulations commencing on 1st February during the period 2008-2017.**

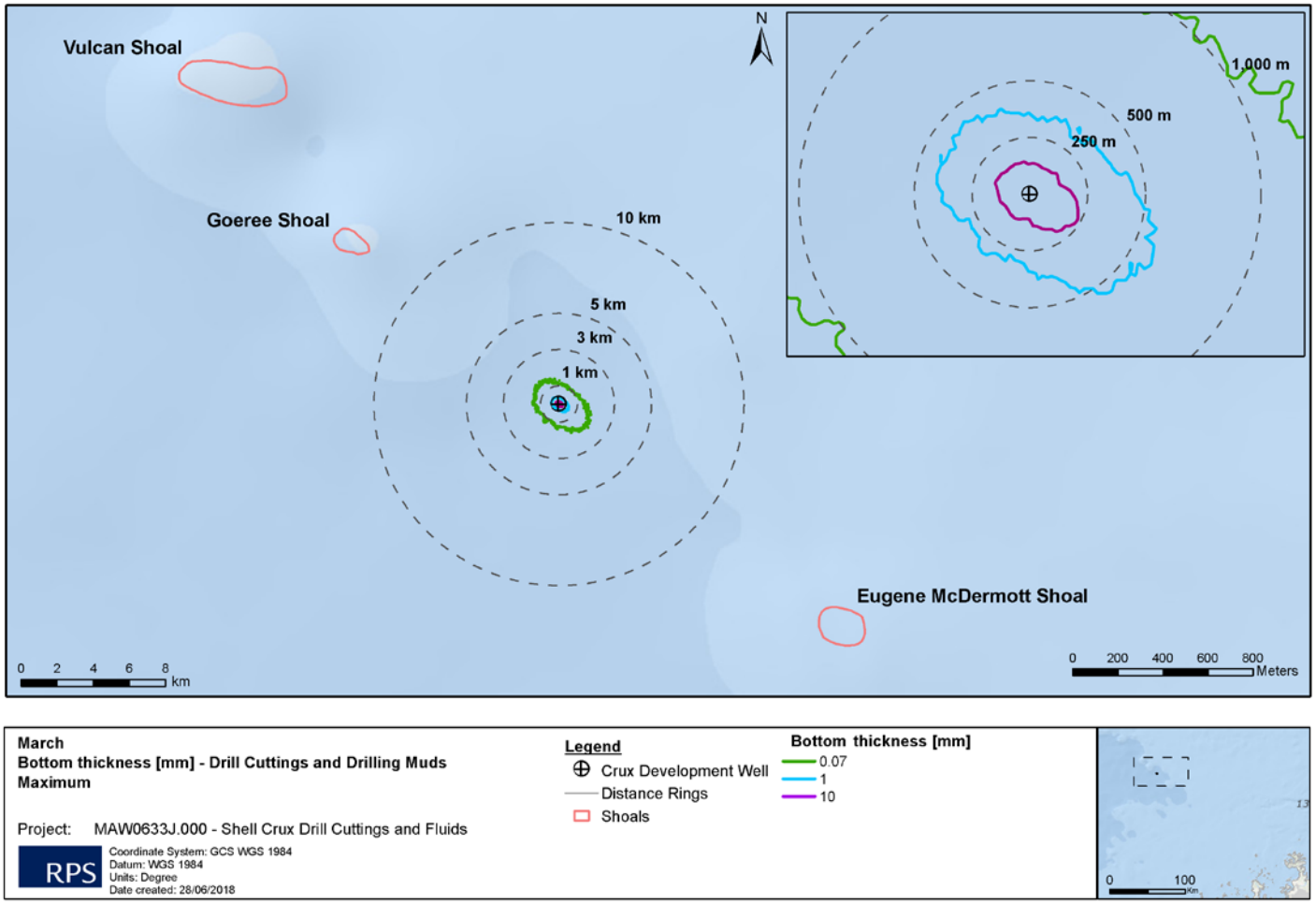


Figure 5.27 **Predicted maximum bottom thickness resulting from the drill cuttings and drilling muds discharge programme. The maximum concentrations are calculated across all simulations commencing on 1st March during the period 2008-2017.**

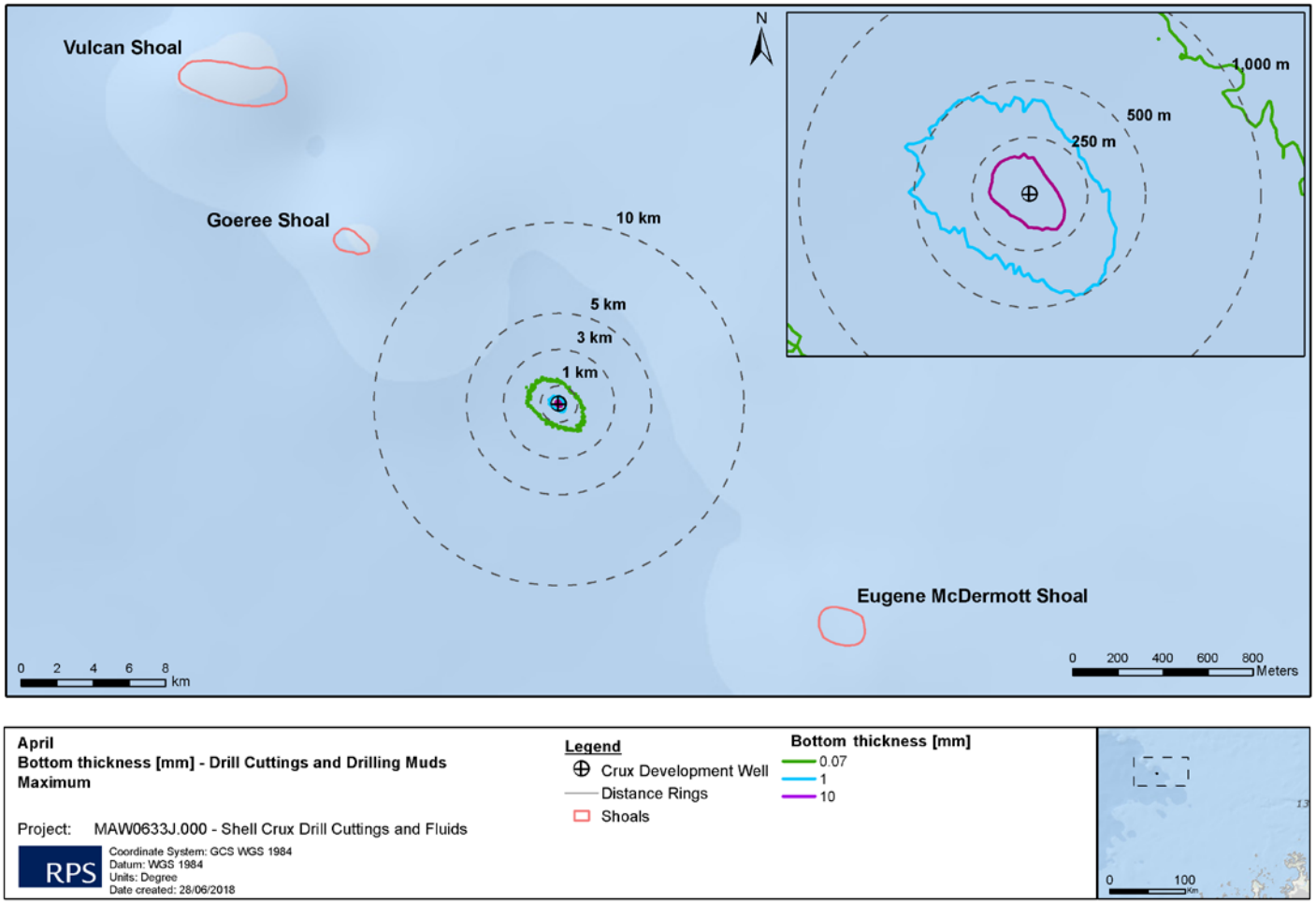


Figure 5.28 **Predicted maximum bottom thickness resulting from the drill cuttings and drilling muds discharge programme. The maximum concentrations are calculated across all simulations commencing on 1st April during the period 2008-2017.**

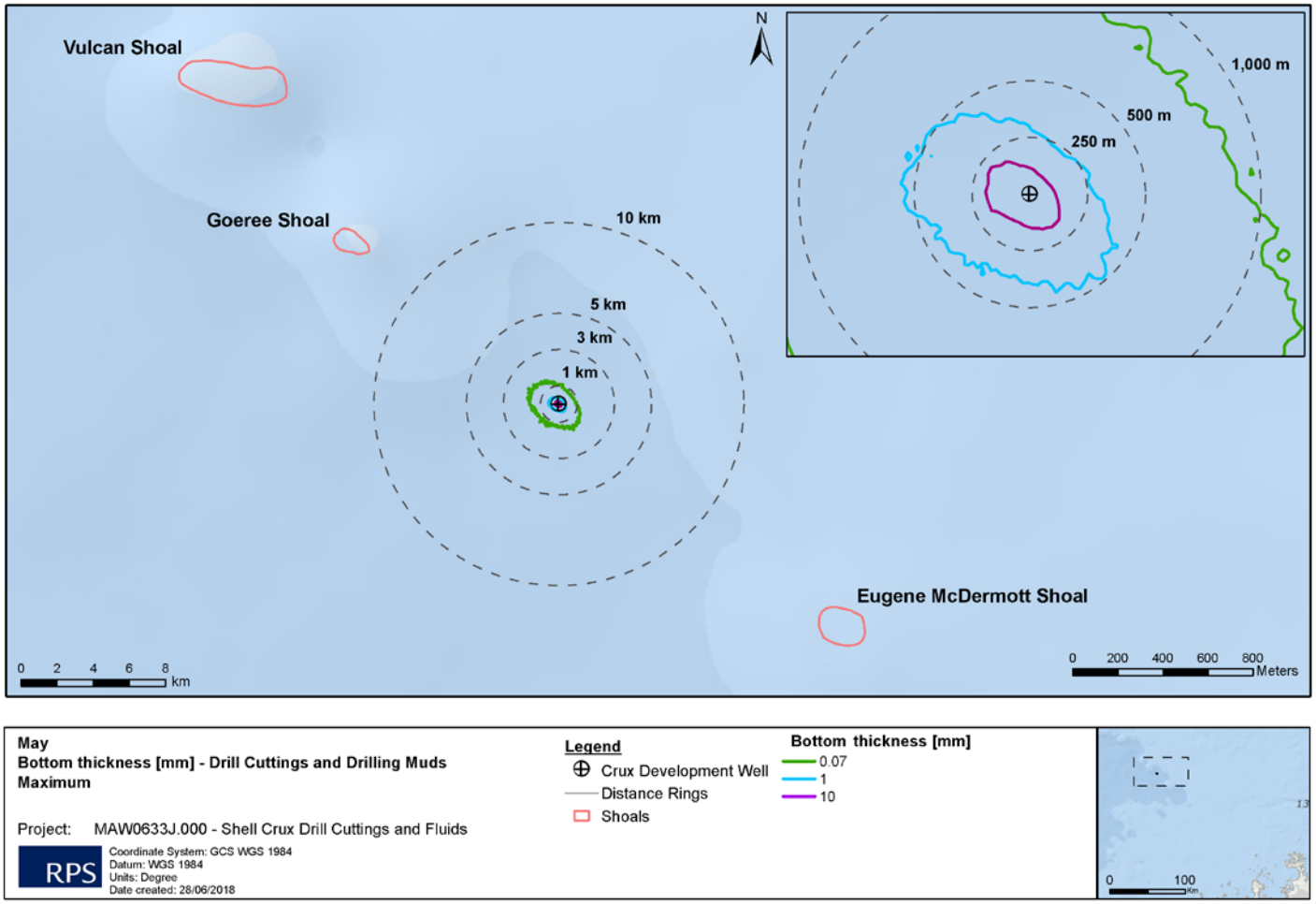


Figure 5.29 **Predicted maximum bottom thickness resulting from the drill cuttings and drilling muds discharge programme. The maximum concentrations are calculated across all simulations commencing on 1st May during the period 2008-2017.**

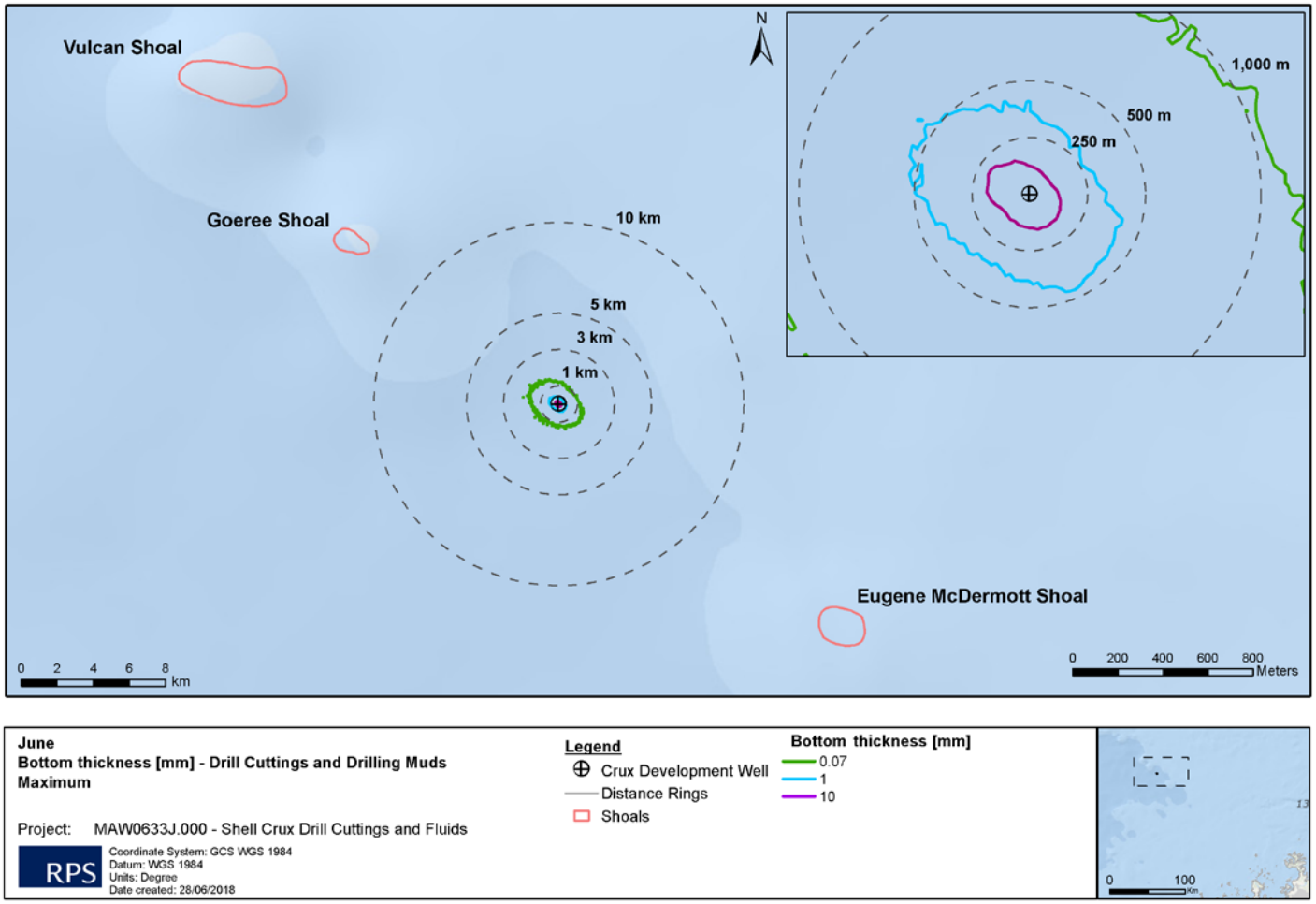


Figure 5.30 **Predicted maximum bottom thickness resulting from the drill cuttings and drilling muds discharge programme. The maximum concentrations are calculated across all simulations commencing on 1st June during the period 2008-2017.**

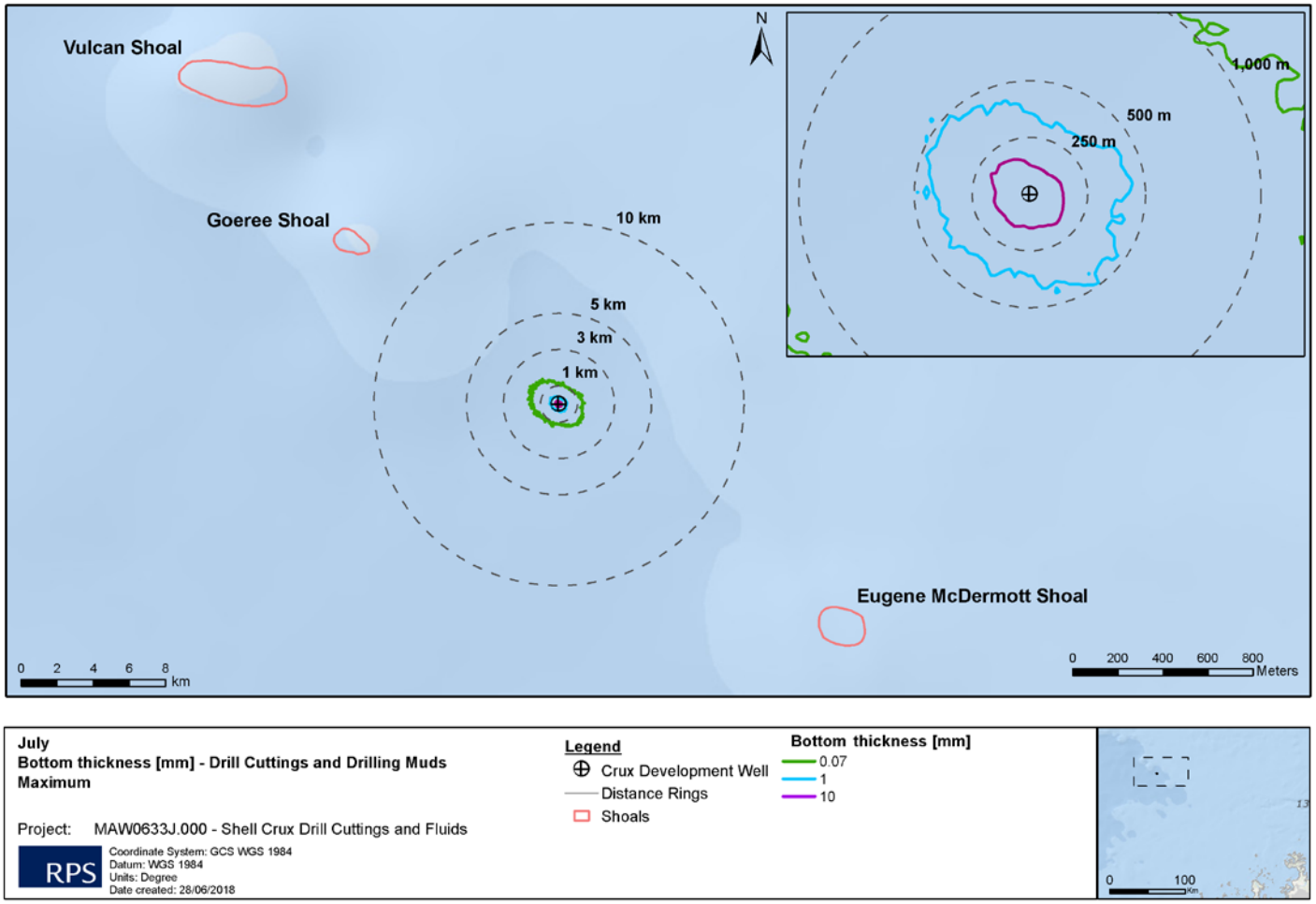


Figure 5.31 **Predicted maximum bottom thickness resulting from the drill cuttings and drilling muds discharge programme. The maximum concentrations are calculated across all simulations commencing on 1st July during the period 2008-2017.**

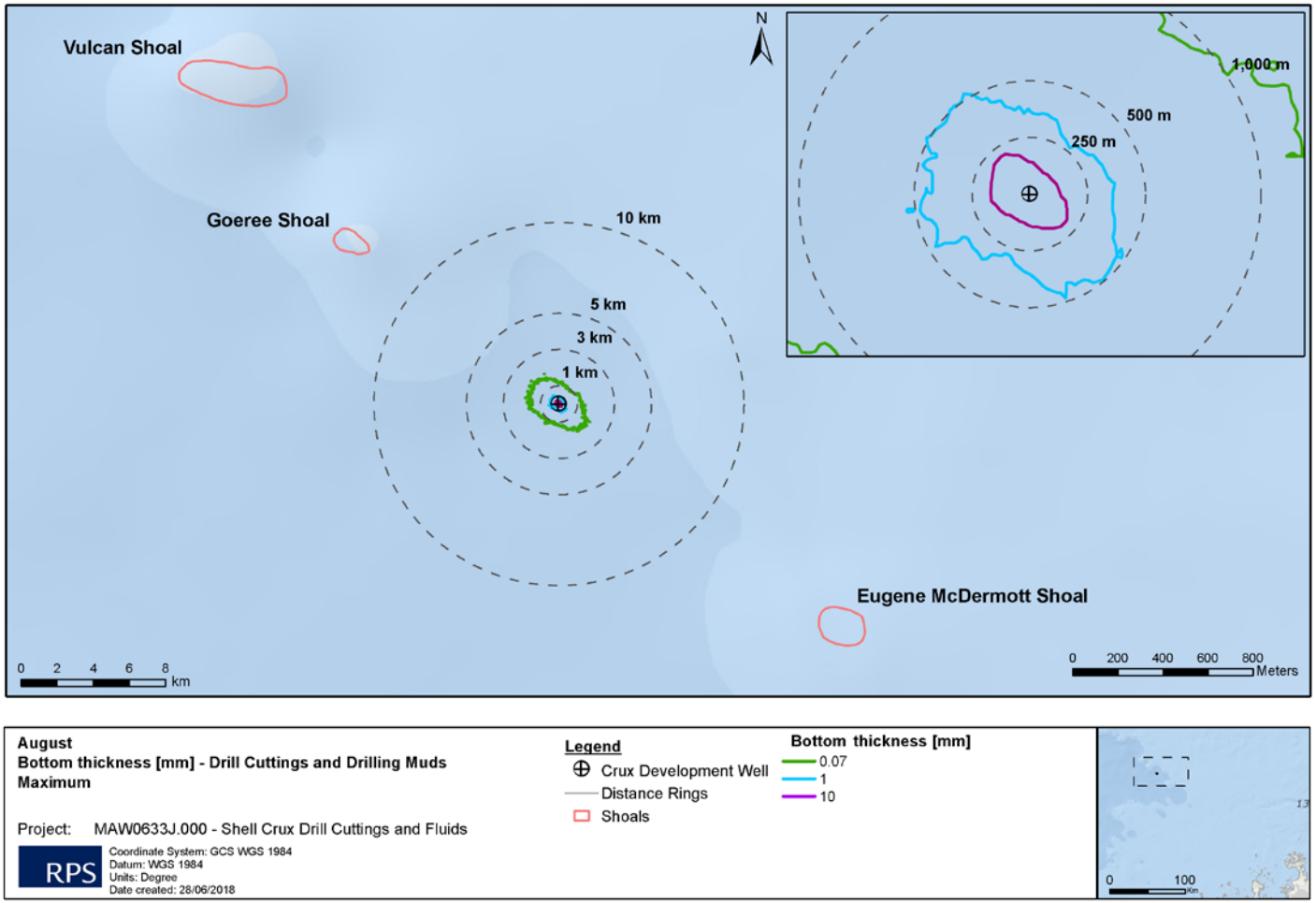


Figure 5.32 **Predicted maximum bottom thickness resulting from the drill cuttings and drilling muds discharge programme. The maximum concentrations are calculated across all simulations commencing on 1st August during the period 2008-2017.**

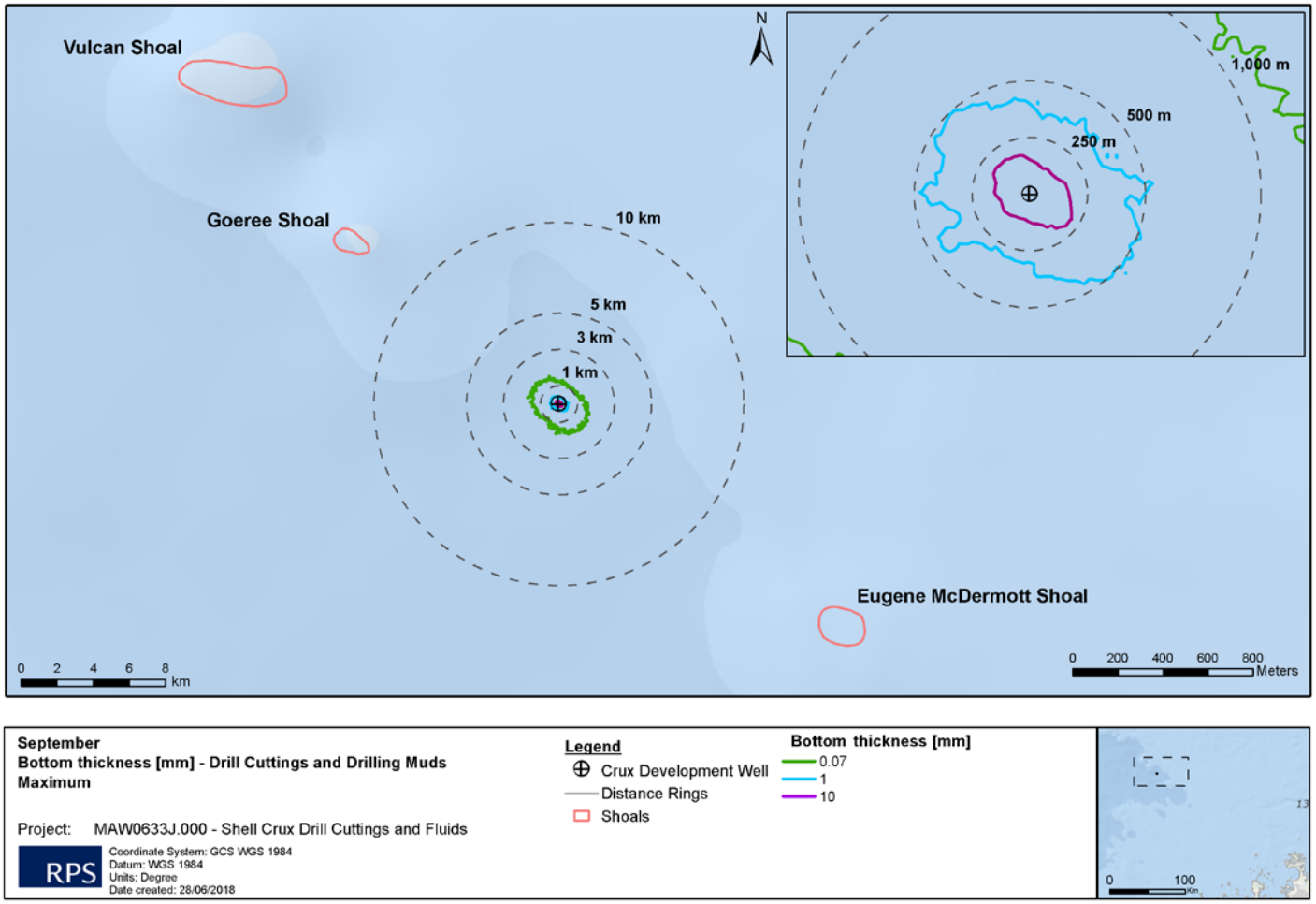


Figure 5.33 Predicted maximum bottom thickness resulting from the drill cuttings and drilling muds discharge programme. The maximum concentrations are calculated across all simulations commencing on 1st September during the period 2008-2017.

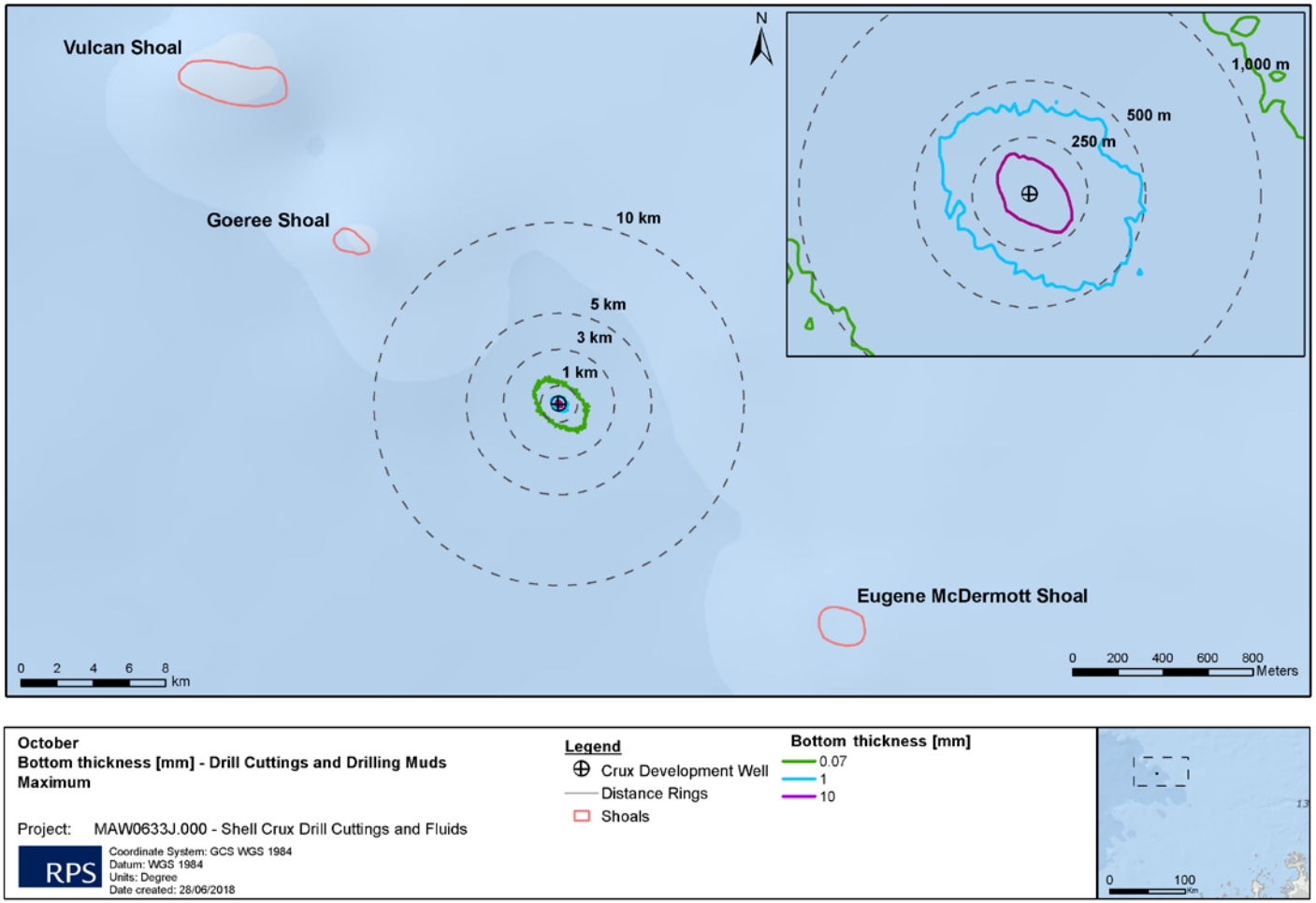


Figure 5.34 **Predicted maximum bottom thickness resulting from the drill cuttings and drilling muds discharge programme. The maximum concentrations are calculated across all simulations commencing on 1st October during the period 2008-2017.**

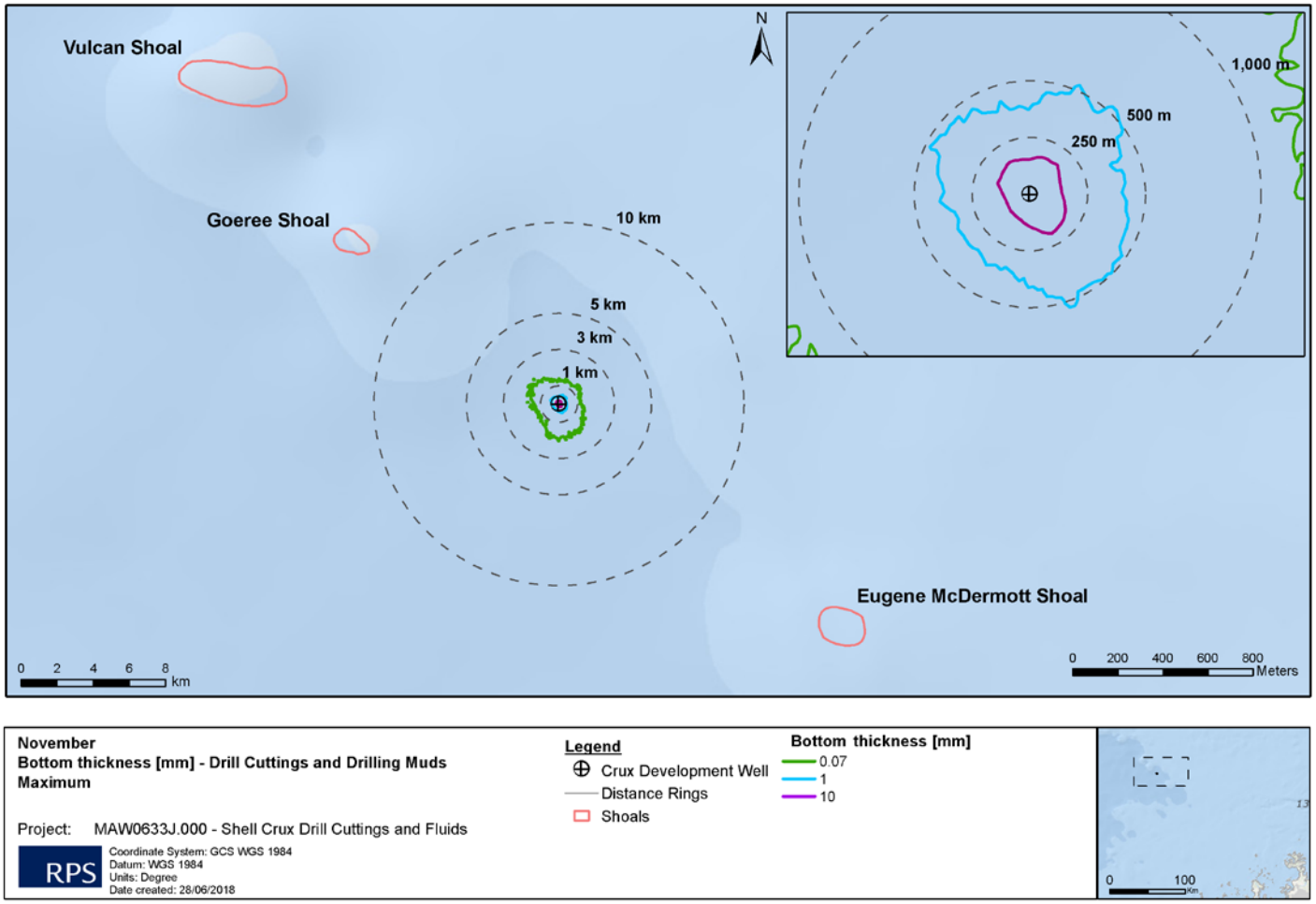


Figure 5.35 Predicted maximum bottom thickness resulting from the drill cuttings and drilling muds discharge programme. The maximum concentrations are calculated across all simulations commencing on 1st November during the period 2008-2017.

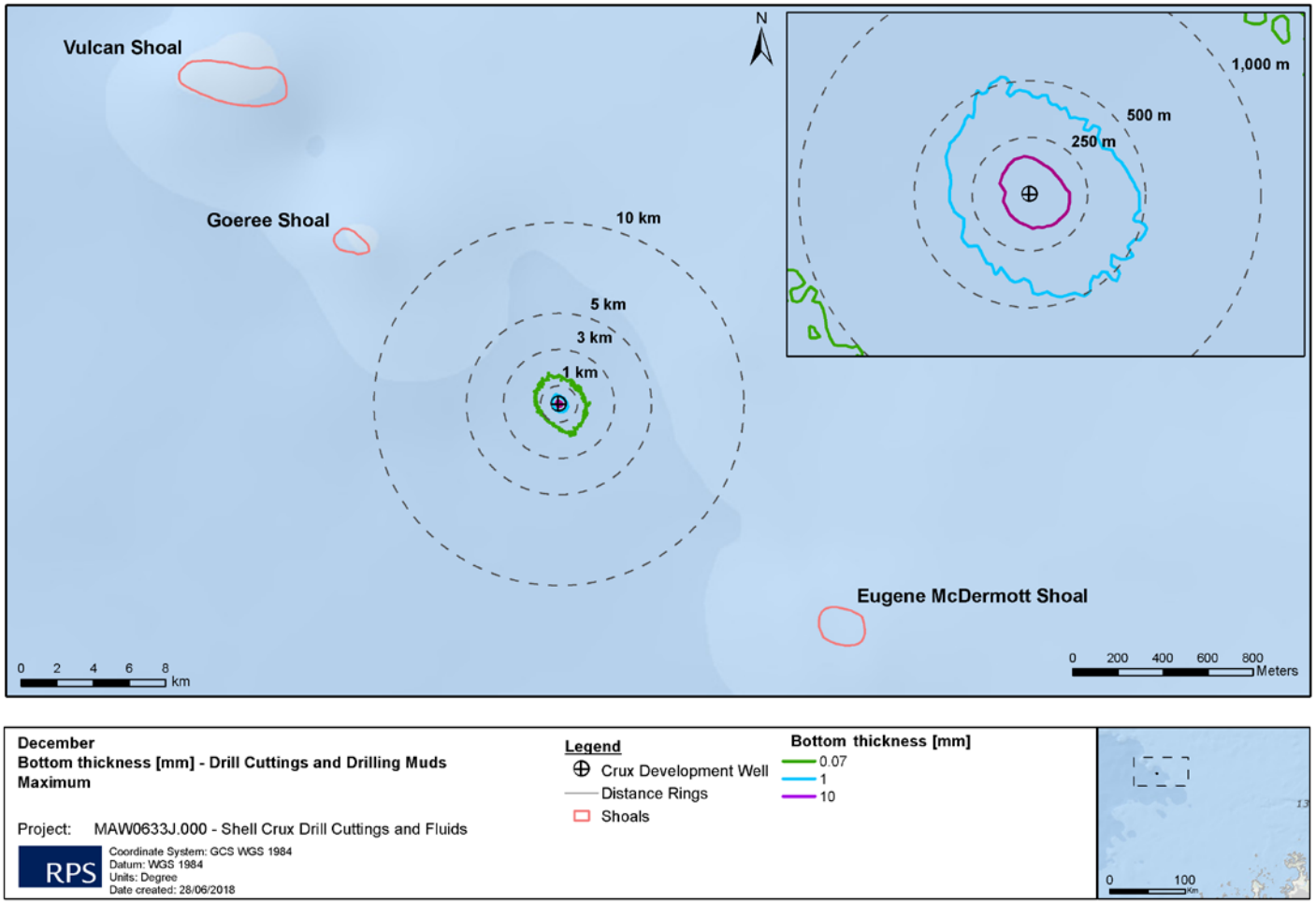


Figure 5.36 **Predicted maximum bottom thickness resulting from the drill cuttings and drilling muds discharge programme. The maximum concentrations are calculated across all simulations commencing on 1st December during the period 2008-2017.**

Appendix E: PFW Modelling Study (RPS 2018b)

REPORT

Shell Crux Project

Marine Dispersion Modelling of PFW Discharges

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Sasha Zigic		19/09/2018

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Appendices

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RPS

1 Introduction

1.1 Background

RPS has been commissioned by CDM Smith Australia Pty Ltd (CDM Smith), on behalf of Shell Australia Pty Ltd (Shell), to undertake a marine dispersion modelling study of proposed water discharges from the Crux platform (Table 1.1). The Crux platform is located in the northern Browse Basin in offshore Commonwealth marine waters, approximately 190 km offshore north-west Australia and 620 km north-north-east of Broome.

Produced formation water (PFW) occurs naturally within the same rock strata as the hydrocarbons and comprises condensed water and saline formation water.

Operation of the fixed-jacket Crux platform will include discharges of PFW separated from the hydrocarbon production stream. The characteristics of the PFW discharge will transition during the operational life of the Crux platform. Discharges are expected to comprise mostly condensed water with minimal formation water produced during the early operations phase (approximately 8-9 years) (i.e. pre-formation water breakthrough). At around 9 years of operation the water produced will transition to a mixture of condensed water and formation water (i.e. post-formation water breakthrough). The amount of formation water is expected to comprise a greater proportion of the discharge as the field nears end of life, as is typically the case of maturing hydrocarbon fields.

Operational design for the facility has identified that the PFW discharges will vary from ambient seawater in terms of temperature, salinity, and the presence of trace amounts of process chemicals.

The principal aim of the study was to quantify the likely extents of the near-field and far-field mixing zones based on the required dilution levels for each of the identified constituents in the PFW discharge. This will indicate whether concentrations of any constituents are likely to be above stated threshold concentrations at the limits of the mixing zones (i.e. are not predicted to be diluted below the relevant threshold).

To accurately determine the dilution of the PFW discharge and the total potential area of influence, the effect of near-field mixing needs to be considered first, followed by an investigation of the far-field mixing. Different modelling approaches are required for calculating near-field and far-field dilutions due to the differing hydrodynamic scales.

To assess the rate of mixing of the process chemicals in the PFW stream from the Crux platform, dispersion modelling was carried out for two flow rates: 287 m^3/d (maximum flow rate during the early operations phase, i.e. first 8-9 years of operation) and 3,179.8 m^3/d (maximum flow rate during the later operations phase, i.e. after year 9 of operations).

The potential area that may be influenced by the PFW discharge stream was assessed for three distinct seasons: (i) summer (December to February); (ii) the transitional periods (March and September to November); and (iii) winter (April to August). This approach assists with understanding the seasonal variability of the PFW discharge stream in the context of nearest environmental values and sensitivities that would be at risk of exposure.

The closest non-transient environmental values and sensitivities to the proposed Crux platform are the submerged shoals of Goeree Shoal (13 km to the north-west), Eugene McDermott Shoal (18 km to the south-east) and Vulcan Shoal (22 km to the north-west) (Figure 1.1).

Table 1.1 Location of the proposed Crux platform used as the release site for the PFW dispersion modelling assessment.

Release Site	Latitude (°S)	Longitude (°E)	Water Depth (m)
Crux Platform	12° 57’ 52.46”	124° 26’ 33.21”	170

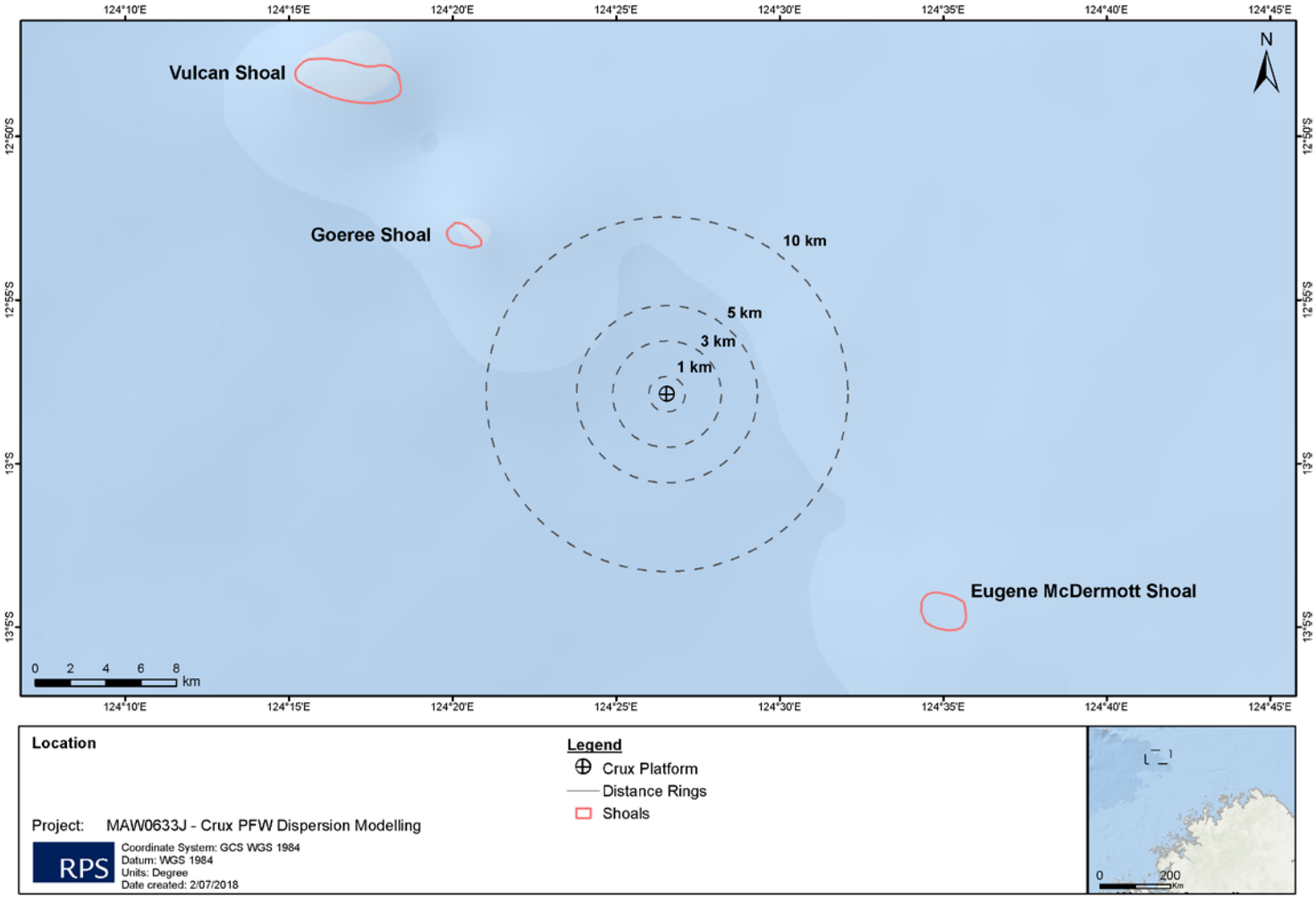


Figure 1.1 Location of the proposed Crux platform relative to the nearest submerged shoals.

1.2 Modelling Scope

The physical mixing of the PFW plume was first investigated for the near-field mixing zone. The limits of the near-field mixing zone are defined by the area where the levels of mixing and dilution are controlled by the plume's initial jet momentum and the buoyancy flux, resulting from density differences between the plume and the receiving water. When the plume encounters a boundary such as the water surface, near-field mixing is complete. At this point, the plume is considered to enter the far-field mixing zone.

The scope of the modelling included the following components:

1. Collation of a suitable three-dimensional, spatially-varying current data set surrounding the proposed Crux platform location for a ten-year (2008-2017) hindcast period. The current data set included the combined influence of drift and tidal currents and was suitably long as to be indicative of interannual variability in ocean currents. The current data set was validated against the metocean data collected in the Crux development area.
2. Derivation of statistical distributions for the current speed and directions for use in the near-field modelling. Analyses included percentile distributions and development of current roses. This analysis was important to ensure that current data samples applied in the dispersion model were statistically representative.
3. Collation of seasonally-varying vertical water density profiles at the Crux development area for use as input to the dispersion models.
4. Near-field modelling conducted for each unique discharge to assess the initial mixing of the discharge due to turbulence and subsequent entrainment of ambient water. This modelling was conducted at high spatial and temporal resolution (scales of metres and seconds, respectively).
5. Outcomes from the near-field modelling included estimates of the width, shape and orientation of the plumes, and resulting contaminant concentrations and dilutions, for each discharge at a range of incident current speeds.
6. Establishment of a far-field dispersion model to repeatedly assess discharge scenarios under different sample conditions, with each sample represented by a unique time-sequence of current flow, chosen at random from the time series of current data.
7. Analysis of the results of all simulations to quantify, by return frequency, the potential extent and shape of the mixing zone.

2 Modelling Methods

2.1 Near-Field Modelling

2.1.1 Overview

Numerical modelling was applied to quantify the area of influence of PFW water discharges, in terms of the distribution of the maximum contaminant concentrations that might occur with distance from the source given defined discharge configurations, source concentrations, and the distribution of the metocean conditions affecting the discharge location.

The dispersion of the PFW discharge will depend, initially, on the geometry and hydrodynamics of the discharges themselves, where the induced momentum and buoyancy effects dominate over background processes. This region is generally referred to as the near-field zone and is characterised by variations over short time and space scales. As the discharges mix with the ambient waters, the momentum and buoyancy signatures are eroded, and the background – or ambient – processes become dominant.

The shape and orientation of the discharged water plumes, and hence the distribution and dilution rate of the plume, will vary significantly with natural variation in prevailing water currents. Therefore, to best calculate the likely outcomes of the discharges, it is necessary to simulate discharge under a statistically representative range of current speeds representative of the Crux development area.

2.1.2 Description of Near-Field Model: Updated Merge

The near-field mixing and dispersion of the water discharge was simulated using the Updated Merge (UM3) flow model. The UM3 model is a three-dimensional Lagrangian steady-state plume trajectory model designed for simulating single and multiple-port submerged discharges in a range of configurations, available within the Visual Plumes modelling package provided by the United States Environmental Protection Agency (Frick *et al.*, 2003). The UM3 model was selected because it has been extensively tested for various discharges and found to predict observed dilutions more accurately (Roberts & Tian, 2004) than other near-field models (i.e. RSB and CORMIX).

In the UM3 model, the equations for conservation of mass, momentum, and energy are solved at each time step, giving the dilution along the plume trajectory. To determine the change of each term, UM3 follows the shear (or Taylor) entrainment hypothesis and the projected-area-entrainment (PAE) hypothesis, which quantifies forced entrainment in the presence of a background ocean current. The flows begin as round buoyant jets and can merge to a plane buoyant jet (Carvalho *et al.*, 2002). Model output consists of plume characteristics including centreline dilution, rise-rate, width, centreline height and plume diameter. Dilution is reported as the “effective dilution”, the ratio of the initial concentration to the concentration of the plume at a given point, following Baumgartner *et al.* (1994).

The near-field zone ends where the discharged plume reaches a physical boundary or assumes the same density as the ambient water.

Figure 2.1 shows a conceptual diagram of the dispersion and fates of a negatively buoyant discharge and the idealised representation of the discharge phases.

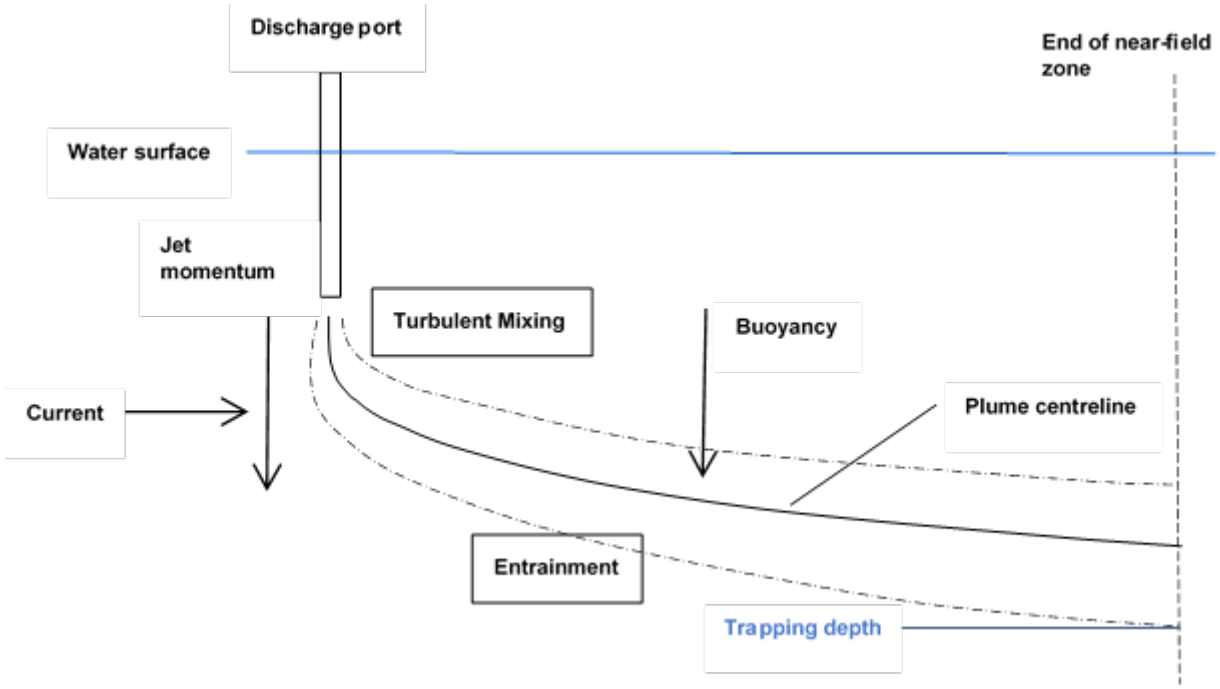


Figure 2.1 Conceptual diagram showing the general behaviour of a negatively buoyant discharge.

2.1.3 Setup of Near-Field Model

2.1.3.1 Discharge Characteristics

The PFW discharge characteristics are summarised in Table 2.1. The discharge was assumed to occur 10 m below the water surface through a single outlet, and was anticipated to have a salinity and temperature of 92.2 parts per thousand (ppt) and 44 °C, respectively.

During the modelling, it was identified that the PFW discharge location would likely be above the sea surface from the Crux platform. To account for this, an additional modelling exercise was undertaken to assess the potential changes in mixing and dilution that may occur if the PFW stream is discharged from the Crux platform above the sea surface rather than below the water surface. This supplemental report is provided in Appendix A and compares the near-field (and far-field) outcomes of one below-surface discharge scenario and one above-surface discharge scenario.

The volumes of PFW generated from the platform will vary over the life of the field. In general, PFW volumes are lowest at the start of production and peak towards the end of each field's lifecycle. Based on the engineering definitions available at the time of undertaking the dispersion modelling study, the maximum flow rates during early operations (i.e. first 8-9 years) and later in the field life (i.e. after year 9) are estimated as 287 m^3/d and 3,179.8 m^3/d, respectively.

Concentrations of constituents within the discharges are described in Table 2.2. These concentrations are conservative estimates for the pre-formation water breakthrough discharge which occurs earlier in the life of the operation. The required dilution factor relates to the number of dilutions required to achieve the 99% Species Protection Level threshold concentration, as defined in the Australian and New Zealand Environment and Conservation Council and Agricultural and Resource Management Council of Australia and New Zealand

(ANZECC & ARMCANZ) (2000) guidelines. This is the highest level of protection provided in the ANZECC & ARMCANZ (2000) guidelines for toxicants in marine water.

Table 2.1 Summary of PFW discharge characteristics.

Parameter	Value/Design
Flow rate (m^3/d)	287 (maximum flow rate during early operations) 3,179.8 (maximum flow rate during later operations)
Outlet pipe internal diameter (m) [in]	0.152 [6]
Outlet pipe orientation	Horizontal
Depth of pipe below sea surface (m)	10
Discharge salinity (ppt)	92.2
Discharge temperature (^oC)	44

Table 2.2 Constituents contained within the PFW discharges.

Constituent	Source Concentration (mg/L)	99% Species Protection Level Threshold Concentration (as defined by the ANZECC & ARMCANZ (2000) Guidelines) (mg/L)	Required Dilution Factor to Reach 99% Species Protection Level
Benzene	240	0.5	480
Naphthalene, phenanthrene, dibenzothiophene (NPD)	10.7	$5.0*10^{-2}$	214
Phenol	0.757	0.27	2.8
Cadmium (Cd)	$4.6*10^{-3}$	$7.0*10^{-4}$	6.6
Chromium (III/VI) (Cr)	$2.48*10^{-2}$	$1.4*10^{-4}$	177.1
Copper (Cu)	$9.2*10^{-3}$	$3.0*10^{-4}$	30.7
Lead (Pb)	$4.6*10^{-3}$	$2.2*10^{-3}$	2.1
Nickel (Ni)	$1.91*10^{-2}$	$7.0*10^{-3}$	2.7
Zinc (Zn)	$2.94*10^{-2}$	$7.0*10^{-3}$	4.2

2.1.3.2 Ambient Environmental Conditions

Inputs of ambient environmental conditions to the UM3 model included a vertical profile of temperature and salinity, along with constant current speeds and general direction. The temperature and salinity profiles are required to accurately account for the buoyancy of the diluting plume, while the current speeds control the intensity of initial mixing and the deflection of the PFW plume. These inputs are described in the following sections.

2.1.3.2.1 Ambient Temperature and Salinity

Temperature and salinity data based on one year of measurements carried out at the Crux development area by RPS between April 2016 and May 2017 (2017) was supplied for the study.

Temperature and salinity data applied to the near-field modelling was sourced from the World Ocean Atlas 2013 (WOA13) database produced by the National Oceanographic Data Centre (National Oceanic and Atmospheric Administration) and its co-located World Data Center for Oceanography (Levitus *et al.*, 2013).

For both data sets, annualised mean temperature profiles were calculated. Figure 2.2 presents a comparison of the WOA13 and RPS-measured annualised temperature profiles. From the profiles, it is evident that the WOA13 temperature structure offer a good match with the measured data and can be considered representative of the conditions in the Crux development area.

Table 2.3 shows the average seasonal water temperature and salinity levels at varying depths from 0 to 170 m. This data can be considered representative of seasonal conditions in the Crux development area.

The seasonal temperature profiles exhibit a reasonably consistent reduction in temperature with increasing depth. Salinity levels are generally more consistent and exhibit a vertically well-mixed water body (34.19 – 34.59 practical salinity unit, PSU), irrespective of season or depth.

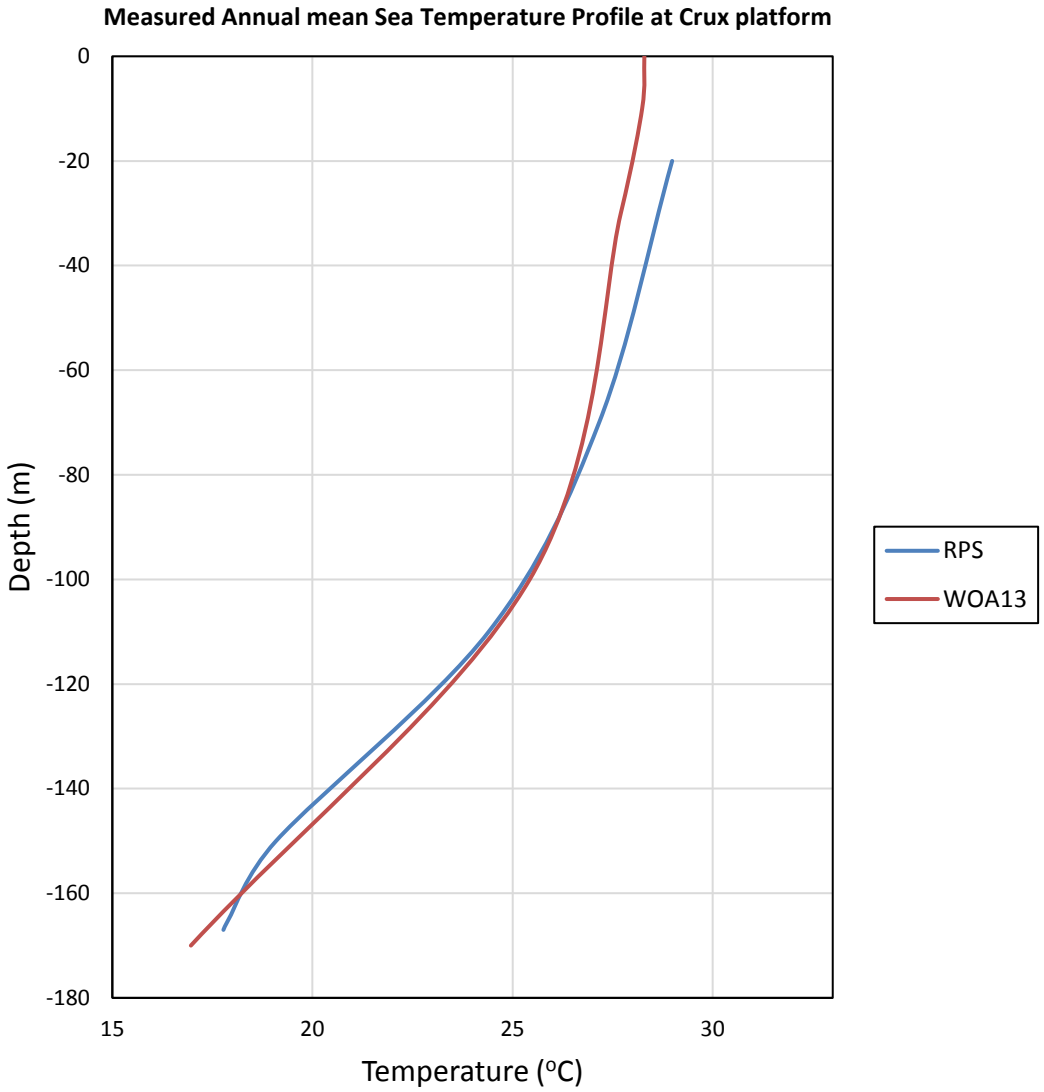


Figure 2.2 **Comparison of World Ocean Atlas 2013 and RPS measured annual temperature profiles at Crux platform location.**

Table 2.3 Average temperature and salinity levels adjacent to the proposed Crux platform.

Season	Depth (m)	Temperature (°C)	Salinity (PSU)
Summer	0	29.62	34.58
	10	29.54	34.57
	30	28.89	34.55
	100	25.35	34.54
	170	17.86	34.63
Transitional	0	27.34	34.19
	10	27.33	34.21
	30	27.18	34.23
	100	24.43	34.33
	170	16.25	34.59
Winter	0	28.49	34.34
	10	28.39	34.35
	30	27.48	34.39
	100	24.82	34.39
	170	16.98	34.59

2.1.3.2.2 Ambient Current

Ocean current data was sourced from a 10-year hindcast data set of combined large-scale ocean (HYCOM) and tidal currents. The data was statistically analysed to determine the 5th, 50th and 95th percentile current speeds. These statistical current speeds can be considered representative of seasonal conditions in the Crux development area.

Table 2.4 presents the steady-state, unidirectional current speeds at varying depths used as input to the near-field model as forcing for each discharge case:

- 5th percentile current speed: weak currents, low dilution and slow advection.
- 50th percentile (median) current speed: average currents, moderate dilution and advection.
- 95th percentile current speed: strong currents, high dilution and rapid advection to nearby areas.

The 5th, 50th and 95th percentile values are referenced as weak, medium and strong current speeds, respectively.

RPS

Table 2.4 Adopted ambient current conditions adjacent to the proposed Crux platform.

Season	Depth (m)	5th Percentile (Weak) Current Speed (m/s)	50th Percentile (Medium) Current Speed (m/s)	95th Percentile (Strong) Current Speed (m/s)
Summer	0	0.068	0.248	0.495
	10	0.060	0.218	0.415
	30	0.059	0.207	0.392
	100	0.055	0.193	0.378
	170	0.051	0.187	0.355
Transitional	0	0.063	0.223	0.434
	10	0.060	0.212	0.411
	30	0.057	0.206	0.400
	100	0.054	0.200	0.378
	170	0.050	0.191	0.357
Winter	0	0.058	0.216	0.455
	10	0.055	0.197	0.399
	30	0.054	0.194	0.386
	100	0.054	0.192	0.387
	170	0.051	0.187	0.347

2.2 Far-Field Modelling

2.2.1 Overview

The far-field modelling expands on the near-field work by allowing the time-varying nature of currents to be included, and the potential for recirculation of the plume back to the discharge location to be assessed. In this case, concentrations near the discharge point can be increased due to the discharge plume mixing with the remnant plume from an earlier time. This may be a potential source of episodic increases in pollutant concentrations in the receiving waters.

2.2.2 Description of Far-Field Model: MUDMAP

The mixing and dispersion of the discharges was predicted using the three-dimensional discharge and plume behaviour model, MUDMAP (Koh & Chang, 1973; Khondaker, 2000).

The far-field calculation (passive dispersion stage) employs a particle-based, random walk procedure. Any chemicals/constituents within the discharge stream are represented by a sample of Lagrangian particles. These particles are moved in three dimensions over each subsequent time step according to the prevailing local current data as well as horizontal and vertical mixing coefficients.

MUDMAP treats the Lagrangian particles as conservative tracers (i.e. they are not removed over time to account for chemical interactions, decay or precipitation). Predicted concentrations will therefore be

conservative overestimates where these processes actually do occur. Each particle represents a proportion of the discharge, by mass, and particles are released at a given rate to represent the rate of the discharge (mass per unit time). Concentrations of constituents are predicted over time by counting the number of particles that occur within a given depth level and grid square and converting this value to mass per unit volume.

The system has been extensively validated and applied for discharge operations in Australian waters (e.g. Burns *et al.*, 1999; King & McAllister, 1997, 1998).

2.2.3 Stochastic Modelling

A stochastic modelling procedure was applied in the far-field modelling to sample a representative set of conditions that could affect the distribution of constituents. This approach involves multiple (100) simulations of a given discharge scenario and season, with each simulation being carried out under a randomly-selected period of currents. This methodology ensures that the calculated movement and fate of each discharge is representative of the range of prevailing currents at the discharge location. Once the stochastic modelling is complete, all simulations are statistically analysed to develop the distribution of outcomes based on time and event.

2.2.4 Setup of Far-Field Model

2.2.4.1 Discharge Characteristics

The MUDMAP model simulated the discharge into a time-varying current field with the initial dilution set by the near-field results described in Section 2.1.

Both PFW discharge flow rates were modelled as a continuous discharge using 100 simulations for each season. Once the simulations were complete, they were reported on a seasonal basis: (i) summer (December to February); (ii) transitional (March and September to November) and (iii) winter (April to August).

Table 2.5 Summary of far-field PFW discharge modelling assumptions.

Parameter	Value/Design
Hindcast modelling period	2008 to 2017
Seasons	Summer (December to February) Transitional (March and September to November) Winter (April to August)
Flow rate (m^3/d)	287 (maximum flow rate during early operations phase) 3,179.8 (maximum flow rate during later operations phase)
Discharge salinity (ppt)	92.2
Discharge temperature (^oC)	44
Number of simulations	300 (100 per season)
Simulated discharge type	Continuous
Simulated discharge period (days)	5

2.2.4.2 Mixing Parameters

The horizontal and vertical dispersion coefficients represent the mixing and diffusion caused by turbulence, both of which are sub-grid-scale processes. Both coefficients are expressed in units of rate of area change per second (m^2/s). Increasing the horizontal dispersion coefficient will increase the horizontal spread of the discharge plume and decrease the centreline concentrations faster. Increasing the vertical dispersion coefficient spreads the discharge across the vertical layers (or depths) faster.

Spatially constant, conservative dispersion coefficients of 0.15 m^2/s and 0.00005 m^2/s were used to control the spreading of the PFW plume in the horizontal and vertical directions, respectively. Each of the mixing parameters was selected following extensive sensitivity testing to recreate the plume characteristics predicted by the near-field modelling. It would be expected that the in-situ mixing dynamics would be greater under average and high energy conditions by a factor of 10 (King & McAllister, 1997, 1998) and thus the far-field model results are designed to produce a worst-case result for concentration extents.

2.2.4.3 Grid Configuration

MUDMAP uses a three-dimensional grid to represent the geographic region under study (water depth and bathymetric profiles). Due to the rapid mixing and small-scale effect of the effluent discharge, it was necessary to use a fine grid with a resolution of 20 m x 20 m to track the movement and fate of the discharge plume. The extent of the grid region measured approximately 20 km (longitude or x-axis) by 20 km (latitude or y-axis), which was subdivided horizontally into 1,000 x 1,000 cells. The vertical resolution was set to 1 m.

2.2.5 Regional Ocean Currents

2.2.5.1 Overview

The area of interest for this study is typified by strong tidal flows over the shallower regions, particularly along the inshore region of the Kimberley Coast. However, the offshore regions with water depths exceeding 100-200 m experience significant large-scale drift currents. These drift currents can be relatively strong (1-2 knots) and complex, manifesting as a series of eddies, meandering currents and connecting flows. These offshore drift currents also tend to persist longer (days to weeks) than tidal current flows (hours between reversals) and thus will have greater influence upon the net trajectory of contaminant plumes over time scales exceeding a few hours.

Wind shear on the water surface also generates local-scale currents that can persist for extended periods (hours to days) and result in long trajectories. Hence, the current-induced transport of plumes can be variably affected by combinations of tidal, wind-induced and density-induced drift currents. Depending on their local influence, it is important to consider all these potential advective mechanisms to rigorously understand patterns of potential transport from a given discharge location.

To appropriately allow for temporal and spatial variation in the current field, dispersion modelling requires the current speed and direction over a spatial grid covering the potential migration zone of plumes. Estimates of the net currents were derived by combining predictions of the drift currents, available from a mesoscale ocean model, with estimates of the tidal currents generated by an RPS model set up for the study area. These estimates are considered representative of the oceanographic currents that influence the Crux development area. Shell has also collected 12 months of metocean data in the Crux development area, with this data being used to validate the hydrodynamic model used in this modelling study. Refer to Section 2.2.5.4 for further discussion of the tidal and current model validation.

A composite modelled ocean current data product was derived by combining predictions of mesoscale circulation currents, available at daily resolution from global ocean models, with predictions of the hourly tidal

currents generated by the RPS HYDROMAP model. By combining a drift current model with a tidal model, the influences of inter-annual and seasonal drift patterns, and the more regular variations in tide, were included.

2.2.5.2 Mesoscale Circulation

Large-scale and mesoscale ocean circulation (also referred to as drift currents) will be the dominant driver of long-term (> several days) transport of effluent plumes. Mesoscale ocean processes are generally defined as having horizontal spatial scales of 10-500 km, and periods of 10-200 days, and processes with scales greater than this are referred to as large-scale. The major persistent large-scale and mesoscale surface currents off Western Australia are presented in Figure 2.3. They are characterised as follows:

- **Buoyancy driven circulation**. The main buoyancy-driven feature in the region is the Indonesian Throughflow (ITF) which conducts warm water from the equator into the Indian Ocean. Buoyancy gradients across the continental shelf due to differential heating and cooling and/or surface runoff may also drive three-dimensional circulation patterns.
- **Wind (Ekman) driven circulation**. The Australian North West Shelf has an annual wind cycle (easterly winds during winter, south-westerly winds during summer) which drives seasonal variability in surface circulation patterns.
- **Eddies and jets**. These non-linear features evolve from the large-scale and mesoscale flow field interacting with the bathymetry. These are random features and it is generally hard to predict their exact timing and location.

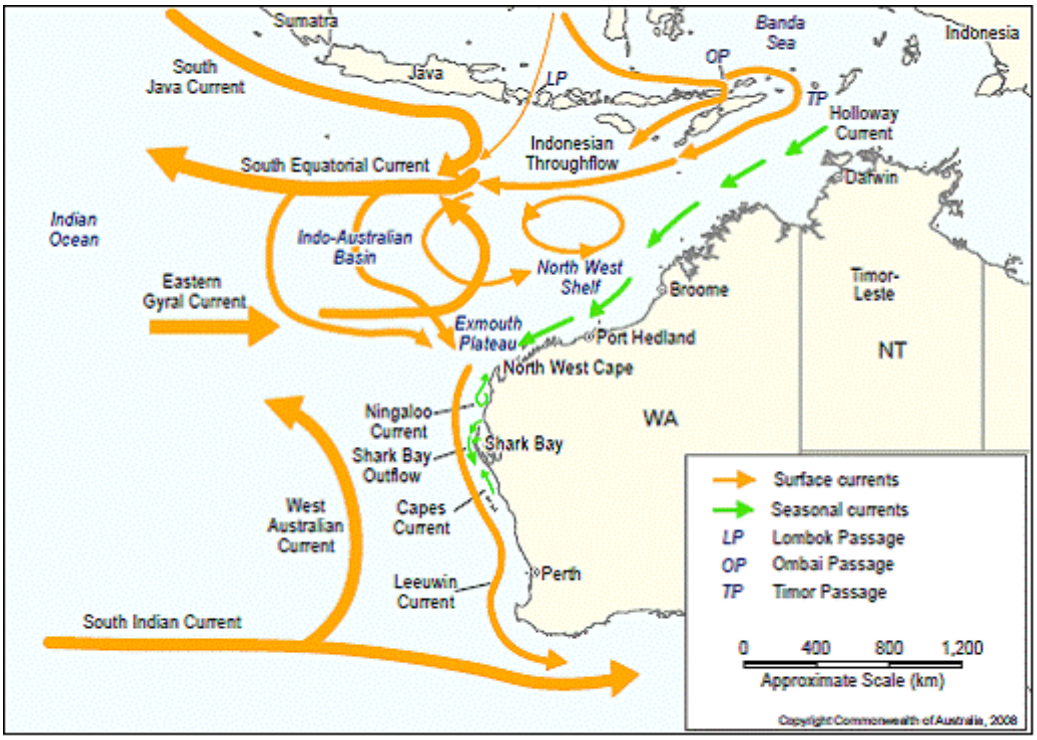


Figure 2.3 A map of the major currents off the West Australian coast (DEWHA, 2008).

2.2.5.2.1 Description of Mesoscale Model: HYCOM

Representation of the drift currents was available from the output of the global circulation model the Hybrid Coordinate Ocean Model (HYCOM; Bleck, 2002; Chassignet *et al.*, 2007, 2009), created by the National Ocean Partnership Program (NOPP), as part of the US Global Ocean Data Assimilation Experiment (GODAE). The HYCOM model is a three-dimensional model that assimilates ocean observations of sea surface temperature, sea surface salinity and surface height, obtained by satellite observations, along with atmospheric forcing conditions from atmospheric models to predict drift currents generated by such forces as wind shear, density and sea height variations and the rotation of the earth.

The HYCOM model is configured to combine the three vertical coordinate types currently in use in ocean models: depth (*z*-levels), density (isopycnal layers), and terrain-following (σ-levels). HYCOM uses isopycnal layers in the open, stratified ocean, but uses the layered continuity equation to make a dynamically smooth transition to a terrain-following coordinate in shallow coastal regions, and to *z*-level coordinates in the mixed layer and/or unstratified seas. Thus, this hybrid coordinate system allows for the extension of the geographic range of applicability to shallow coastal seas and unstratified parts of the world ocean. It maintains the significant advantages of an isopycnal model in stratified regions while allowing more vertical resolution near the surface and in shallow coastal areas, hence providing a better representation of the upper ocean physics. The model has global coverage with a horizontal resolution of 1/12th of a degree (approximately 7 km at mid-latitudes) and a temporal resolution of one day.

A hindcast data set of HYCOM currents was obtained for a ten-year period spanning 2008 to 2017 (inclusive).

Figure 2.4 shows the seasonal surface current roses near the proposed Crux platform. The data shows that the surface current speeds and directions vary between seasons. In general, during summer (December to February) currents have the strongest average speed (0.25 m/s with a maximum of 0.65 m/s) and tend to flow west-southwest. During winter (April to August), current flow conditions are more variable and flow mostly toward the west-southwest and east-northeast. During transitional conditions (March and September to November), the current flow is less variable and predominantly toward the west.

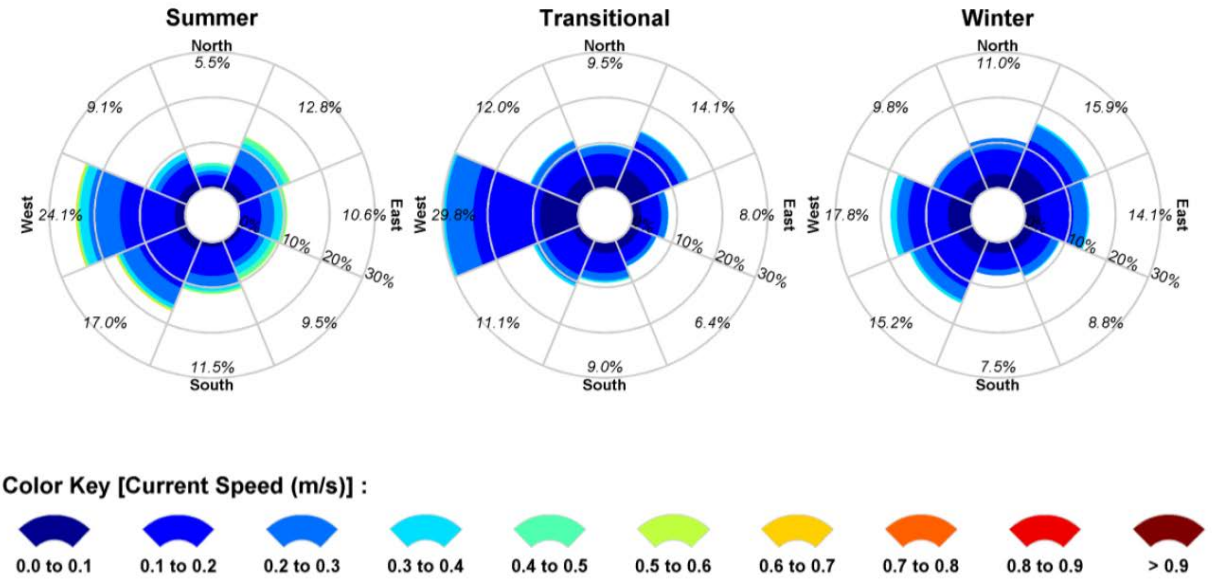


Figure 2.4 Seasonal current distribution (2008-2017, inclusive) derived from the HYCOM database near to the proposed Crux platform. The colour key shows the current magnitude, the compass direction provides the direction towards which the current is flowing, and the size of the wedge gives the percentage of the record.

2.2.5.3 Tidal Currents

2.2.5.3.1 Description of Tidal Model: HYDROMAP

As the HYCOM model does not include tidal forcing, and because the data is only available at a daily frequency, a tidal model was developed for the study region using RPS' three-dimensional hydrodynamic model, HYDROMAP.

The model formulations and output (current speed, direction and sea level) of this model have been validated through field measurements around the world for more than 25 years (Isaji & Spaulding, 1984, 1986; Isaji *et al.*, 2001; Zigic *et al.*, 2003). HYDROMAP current data has also been widely used as input to forecasts and hindcasts of oil spill migrations in Australian waters. This modelling system forms part of the National Marine Oil Spill Contingency Plan for the Australian Maritime Safety Authority (AMSA) (AMSA, 2002).

HYDROMAP simulates the flow of ocean currents within a model region due to forcing by astronomical tides, wind stress and bottom friction. The model employs a sophisticated dynamically nested-gridding strategy, supporting up to six levels of spatial resolution within a single domain. This allows for higher resolution of currents within areas of greater bathymetric and coastline complexity, or of particular interest to a study.

The numerical solution methodology of HYDROMAP follows that of Davies (1977a, 1977b) with further developments for model efficiency by Owen (1980) and Gordon (1982). A more detailed presentation of the model can be found in Isaji & Spaulding (1984).

2.2.5.3.2 Tidal Grid Setup

A HYDROMAP model was established over a domain that extended approximately 3,300 km east-west by 3,100 km north-south over the eastern Indian Ocean. The grid extends beyond Eucla in the south and beyond Bathurst Island in the north (Figure 2.5).

Four layers of sub-gridding were applied to provide variable resolution throughout the domain. The resolution at the primary level was 15 km. The finer levels were defined by subdividing these cells into 4, 16 and 64 cells, resulting in resolutions of 7.5 km, 3.75 km and 1.88 km. The finer grids were allocated in a step-wise fashion to areas where higher resolution of circulation patterns was required to resolve flows through channels, around shorelines or over more complex bathymetry. Approximately 98,600 cells were used to define the region.

Bathymetric data used to define the three-dimensional shape of the study domain was extracted from the CMAP electronic chart database and supplemented where necessary with manual digitisation of chart data supplied by the Australian Hydrographic Office. Depths in the domain ranged from shallow intertidal areas through to approximately 7,200 m.

2.2.5.3.3 Tidal Boundary Conditions

Ocean boundary data for the HYDROMAP model was obtained from the TOPEX/Poseidon global tidal database (TPXO7.2) of satellite-measured altimetry data, which provided estimates of tidal amplitudes and phases for the eight dominant tidal constituents (designated as K_2, S_2, M_2, N_2, K_1, P_1, O_1 and Q_1) at a horizontal scale of approximately 0.25°. Using the tidal data, sea surface heights are firstly calculated along the open boundaries at each time step in the model.

The TOPEX/Poseidon satellite data is produced, and quality controlled by the US National Atmospheric and Space Agency (NASA). The satellites, equipped with two highly accurate altimeters capable of taking sea level measurements accurate to less than ±5 cm, measured oceanic surface elevations (and the resultant tides) for over 13 years (1992–2005). In total, these satellites carried out more than 62,000 orbits of the planet. The TOPEX/Poseidon tidal data has been widely used amongst the oceanographic community, being the subject of more than 2,100 research publications (e.g. Andersen, 1995; Ludicone *et al.*, 1998; Matsumoto *et al.*, 2000;

Kostianoy *et al.*, 2003; Yaremchuk & Tangdong, 2004; Qiu & Chen, 2010). As such, the TOPEX/Poseidon tidal data is considered suitably accurate for this study.

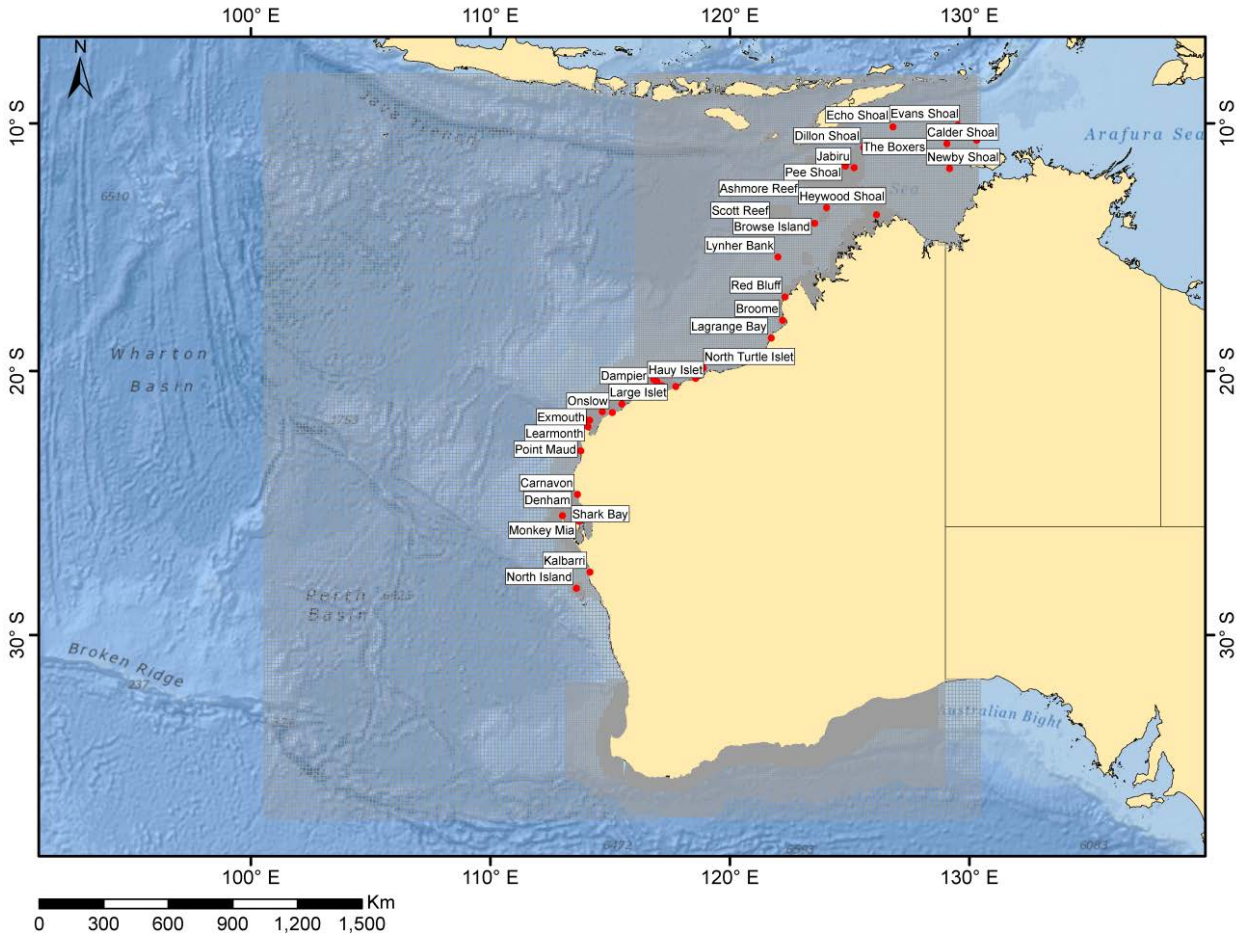


Figure 2.5 Hydrodynamic model grid (grey wire mesh) used to generate the tidal currents, showing the full domain in context with the continental land mass and the locations available for tidal comparisons (red labelled dots). Higher-resolution areas are indicated by the denser mesh zones.

2.2.5.4 Tidal and Current Model Validation

The suitability of the modelled tidal and drift current data products was evaluated by comparing the predicted currents to those measured at the Crux development area. The following sections describe the sources of both the modelled and measured data, the comparison methodology, and the outcomes of the comparisons for both the tidal and drift current components.

2.2.5.4.1 Data Sources

A tidal model was developed for the study region using RPS' three-dimensional hydrodynamic model, HYDROMAP. HYDROMAP simulates the flow of ocean currents within a model region due to forcing by astronomical tides, wind stress and bottom friction. This model is described in Section 2.2.5.3.

A mesoscale ocean current data sets was selected for the study: HYCOM (Hybrid Coordinate Ocean Model) Consortium's global ocean model, HYCOM. This model is described in Section 2.2.5.2.

A data set of measured currents was collected by RPS at the Crux development area between April 2016 and May 2017 (RPS, 2017). This data set includes a series of point current measurements made at six depths through the water column using CM04 current meters mounted on a floating mooring. The measurement depths are approximately 20 m, 70 m, 110 m, 150 m, 165 m and 167 m below the water surface. The temporal resolution of the data is 1 minute. The raw data was quality-controlled by RPS and only data identified as high-quality was used for comparison to model data. For the measurements at a 20 m water depth, there is approximately a 7-week gap in the data between early September and late October 2016.

2.2.5.4.2 Model Validation Skills

Overview

The mesoscale and tidal current models were validated through quantitative and visual comparisons of measured and modelled data.

Statistics

A quantitative analysis of a model's skill at replicating the environmental conditions was conducted using the Index of Agreement (IOA), presented in Willmott (1981), and the Mean Absolute Error (MAE), discussed in Willmott (1982) and Willmott & Matsuura (2005). Other traditional error estimates, such as the correlation coefficient and the root mean square error (RMSE) are problematic and prone to ambiguities and bias (Willmott & Matsuura, 2005; Willmott, 1982). Consequently, they are not reported in isolation here.

The MAE is simply the average of the absolute values of the differences between the observed and modelled values. MAE is a more natural measure of average error (Willmott & Matsuura, 2005) and more readily understood. The IOA is determined using the following formula:

$$\mathrm{IOA} = 1 - \frac{\sum |X_{\mathrm{model}} - X_{\mathrm{obs}}|^2}{\sum \left(|X_{\mathrm{model}} - \overline{X_{\mathrm{obs}}}| + |X_{\mathrm{obs}} - \overline{X_{\mathrm{obs}}}| \right)^2}$$

In this equation, X represents the variable being compared and $\bar{X}$ represents the mean of that variable over time.

A perfect agreement can be said to exist between the model and field observations if the IOA gives a measure of one, and complete disagreement will produce an IOA measure of zero (Wilmott, 1981). Although it is difficult to find guidelines for what values of the IOA might represent a good agreement, Willmott *et al.* (1985) suggests that values meaningfully larger than 0.5 represent good model performance. Clearly, the higher the IOA and the lower the MAE, the better the model performance.

An important point to note regarding both, and in fact most, measures of model performance, is that slight phase differences in the series can result in a seemingly poor statistical comparison, particularly in rapidly changing series such as tidal direction or water elevation where the tidal range is large. It is therefore always important to consider both the statistics and the visual representation of the comparison (Willmott *et al.*, 1985). Statistical comparison of current direction can be misleading; skill measures of direction can become biased where the directional fluctuations are near 0-360°. Therefore, we have based the quantitative assessment on the U and V current components and not magnitude and direction.

Time Series

In addition to bulk statistical measures, model performance for the measurement period was assessed visually with the aid of scatterplots and rose plots. The scatterplots show the correlation between the x- and y-components of the measured and modelled data. The rose plots show the frequency of current direction by sector, and magnitude by colour, to allow comparison of current direction between modelled and measured data.

The model performance was also evaluated against time series plots of water level, U (east-west) velocity component, V (north/south) velocity component, current speed and current direction data. This approach is valuable because statistical measures of model skill can heavily penalise errors in phase (i.e. time lags) even when the dynamics of flow are broadly reproduced.

2.2.5.4.3 Tidal Elevation Validation

For verification of the tidal elevation predictions, the model output was compared against independent predictions of tides using the XTide database (Flater, 1998). The XTide database contains harmonic tidal constituents derived from measured water level data at locations around the world. Of more than 80 tidal stations within the HYDROMAP model domain, 18 sites near the Crux development area were used for comparison.

Time series comparisons were completed for a six-month period from January to June 2010. The statistics are summarised in Table 2.6, and indicate excellent model performance in this region. Water level time series for these locations are shown in Figure 2.6, Figure 2.7 and Figure 2.8 for a one-month period (March 2010). All comparisons show that the model produces a very good match to the known tidal behaviour for a wide range of tidal amplitudes and clearly represents the varying diurnal and semi-diurnal nature of the tidal signal.

For the purposes of understanding the limitations in accuracy of the tidal predictions, the RMSE and MAE in Table 2.6 should be noted. On average, the model predictions are within 0.1-0.3 m of XTide predictions based on known constituent data at any point in time. Often the error is mostly attributable to errors of phase in the tidal signal, with the magnitude of the tidal rise and fall over each tide well represented. However, in the application of the data predictions to operational circumstances, the potential errors should be considered.

The model skill was further evaluated through a comparison of the predicted and observed tidal constituents, derived from an analysis of model-predicted time-series at each location. A scatter plot of the observed and modelled amplitude (top) and phase (bottom) of the five dominant tidal constituents (S_2, M_2, N_2, K_1 and O_1) is presented in Figure 2.9. The red line on each plot shows the 1:1 line, which would indicate a perfect match between the modelled and observed data. Note that the data is generally closely aligned to the 1:1 line demonstrating the high quality of the model performance.

Table 2.6 Statistical comparison of predicted surface elevation data from HYDROMAP and XTide at 18 locations in the tidal model domain (January to July 2010).

Tide Station	Longitude (°E)	Latitude (°S)	IOA	CC	MAE (m)	RMSE (m)
Ashmore Reef	123.02	12.22	0.99	0.99	0.14	0.18
Browse Island	123.55	14.10	0.97	0.97	0.36	0.45
Calder Shoal	129.07	10.85	0.97	0.97	0.17	0.21
Cape Legendre	116.83	20.35	0.99	0.99	0.12	0.14
Dillon Shoal	125.60	11.00	0.97	0.95	0.18	0.22
Echo Shoal	126.82	10.15	0.97	0.94	0.17	0.21
Evans Shoal	129.53	10.08	0.98	0.98	0.11	0.14
Goodrich Bank	130.32	10.70	0.99	0.97	0.13	0.16
Heywood Shoal	124.05	13.47	0.98	0.96	0.27	0.33
Jabiru	125.20	11.83	097	0.95	0.22	0.27
Loxton Shoal	128.72	09.60	0.99	0.98	0.10	0.13
Lynedoch Bank	130.82	10.03	0.98	0.98	0.12	0.15
Lynher Bank	122.02	15.47	0.98	0.97	0.26	0.31
Newby Shoal	129.18	11.87	0.98	0.96	0.23	0.27
Pee Shoal	124.83	11.77	0.97	0.94	0.23	0.27
Scott Reef	121.80	14.05	0.99	0.98	0.16	0.19
The Boxers	128.35	11.45	0.97	0.96	0.16	0.20
Troughton Island	126.13	13.75	0.97	0.95	0.27	0.33

Notes: *IOA Index of Agreement – values close to 1 represent a high level of agreement.*
CC Correlation Coefficient – values close to 1 represent very good correlation.
MAE Mean Absolute Error – the lower the value, the smaller the error.
RMSE Root Mean Square Error – the lower the value, the smaller the error.

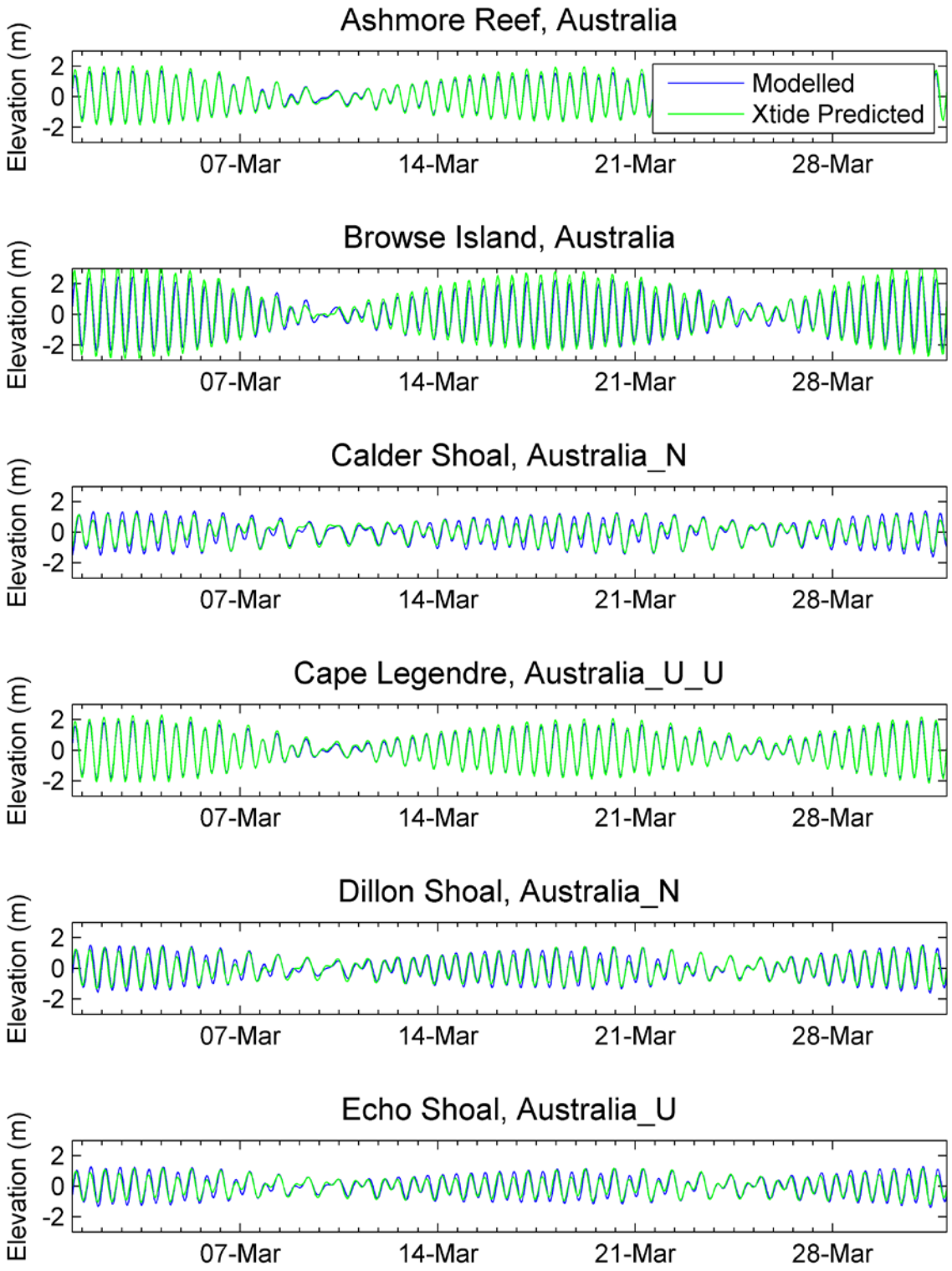


Figure 2.6 Time series comparisons between predicted surface elevation data from HYDROMAP (blue line) and XTide (green line) at six locations in the tidal model domain (March 2010).

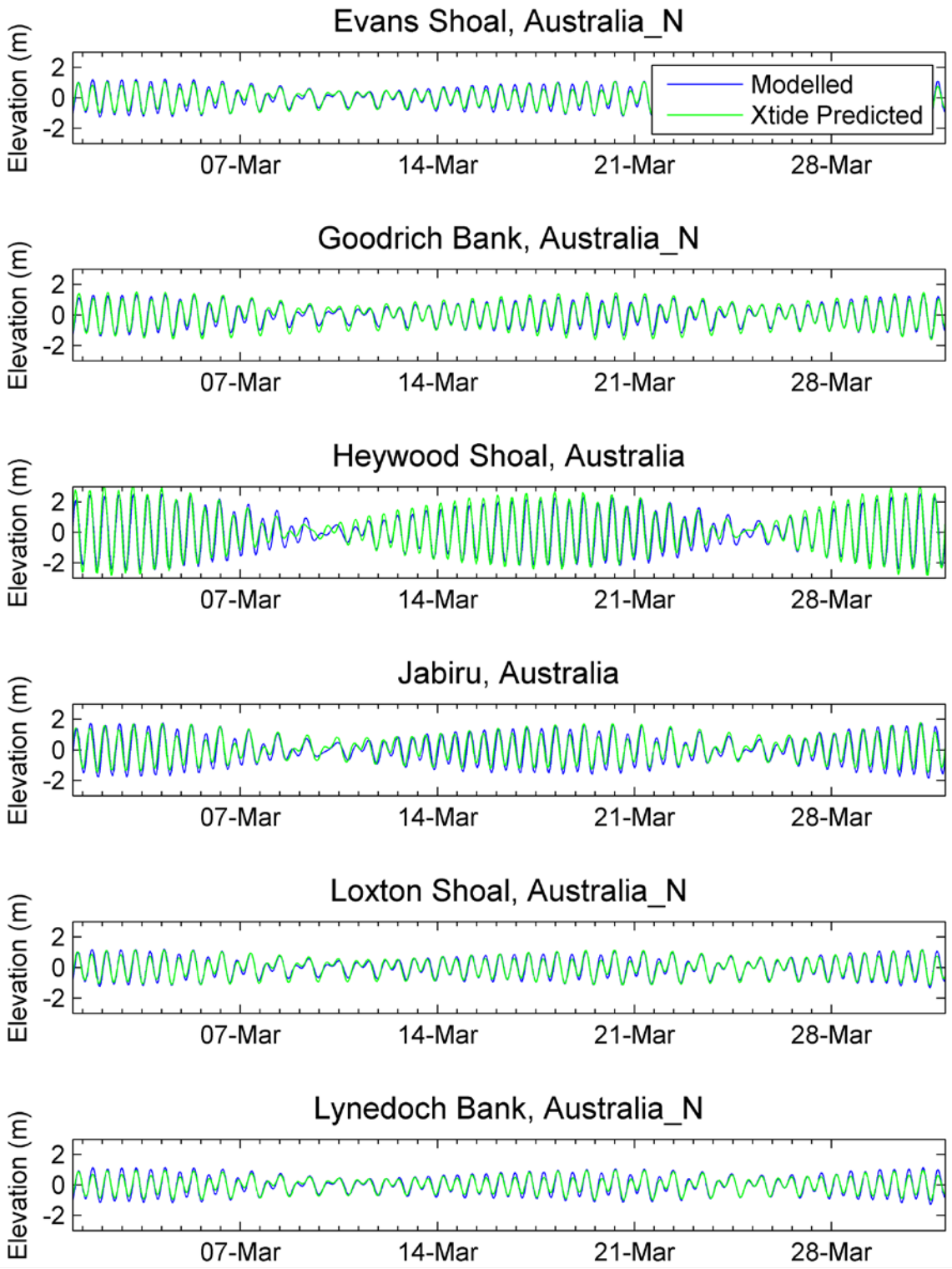


Figure 2.7 Time series comparisons between predicted surface elevation data from HYDROMAP (blue line) and XTide (green line) at six locations in the tidal model domain (March 2010).

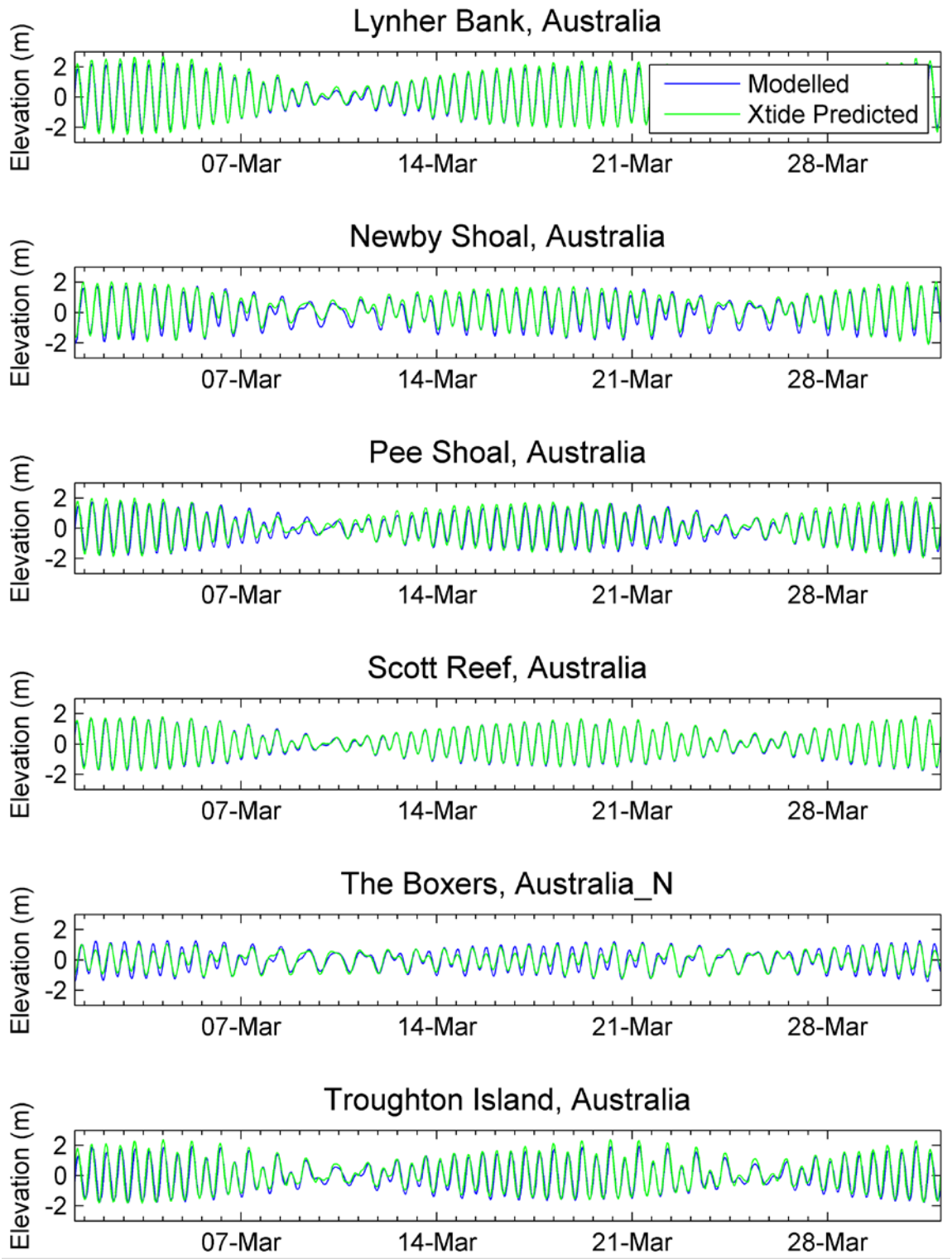


Figure 2.8 Time series comparisons between predicted surface elevation data from HYDROMAP (blue line) and XTide (green line) at six locations in the tidal model domain (March 2010).

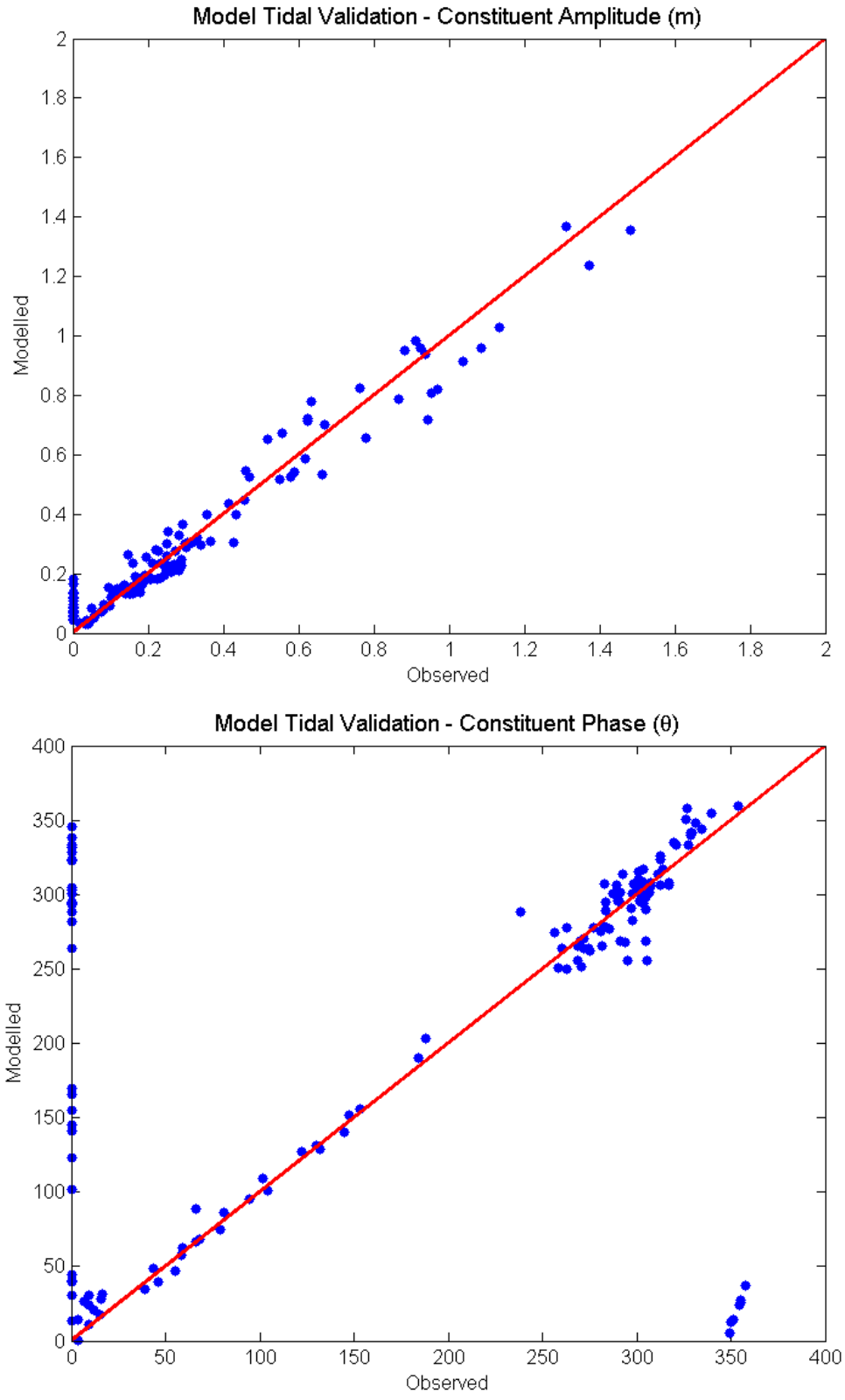


Figure 2.9 Comparisons between predicted tidal constituent amplitudes (top) and phases (bottom) from HYDROMAP and XTide at all stations in the tidal model domain. The red line indicates a 1:1 correlation between the respective data sets.

2.2.5.4.4 Composite Current Data Set Validation: HYDROMAP + HYCOM

A composite modelled ocean current data product was derived by combining predictions of mesoscale circulation currents, available at daily resolution from the HYCOM ocean model, with predictions of the hourly tidal currents generated by the RPS HYDROMAP model.

To verify the modelled current predictions, the composite model outputs at the Crux development area were compared against the unfiltered site-specific current measurements. The model results were validated through both quantitative and visual comparisons between measured and modelled data at each depth where both data sets were available.

Time series comparison of composite model outputs and measured current magnitude, direction, and U/V velocity components at water depths of 20 m, 70 m and 110 m are presented in Figure 2.10, Figure 2.11 and Figure 2.12, respectively, for one month during winter (June 2016) and summer (December 2016). The time series comparisons reveal that the composite model offers a good match with the measured U/V velocity components at all water depths in both winter and summer, with the magnitudes and timings of the peaks and troughs matching well.

The IOA and MAE values derived from comparisons of the U/V velocity components at water depths of 20 m, 70 m and 110 m over the full measurement period are presented in Table 2.7. The IOA for each velocity component is high at all water depths, reflecting the good match in the magnitudes and timings of the peaks and troughs in the composite model data and measured data. The MAE for the U/V velocity components is relatively low at approximately 0.1 m/s for all water depths, indicating that the magnitude and range of the velocity components match well; however, a slight overprediction of the current magnitude is evident at times.

To compare directionality, roses for the composite model outputs and measured currents at 20 m, 70 m and 110 m water depths over the full measurement period are shown in Figure 2.12. The roses show that the composite model current direction is a good match with the measured direction. A shift in the dominant current direction from a north/south alignment in the measured data set to a northwest/southeast alignment in the composite model data set is evident at the 20 m water depth, and to a lesser extent also at the 70 m water depth. However, the range and variability in the measured current direction is captured by the composite model data, which matches best with the measured data at the water depth of 110 m.

Based on the validation performance, the composite model data set is a good model of standard conditions at the Crux development area and will adequately resolve local and regional circulation patterns. As such, the model is considered suitable for use in the numerical modelling studies conducted as part of the Crux project.

Table 2.7 Statistical comparison of predicted (HYDROMAP+HYCOM) and observed current speeds along orthogonal component axes at the Crux development area (2016-2017).

Skill Measure	Index of Agreement (IOA)			Mean Absolute Error (MAE) (m/s)		
Depth (m)	20	70	110	20	70	110
U Component	0.72	0.75	0.76	0.11	0.11	0.11
V Component	0.82	0.80	0.78	0.11	0.10	0.10

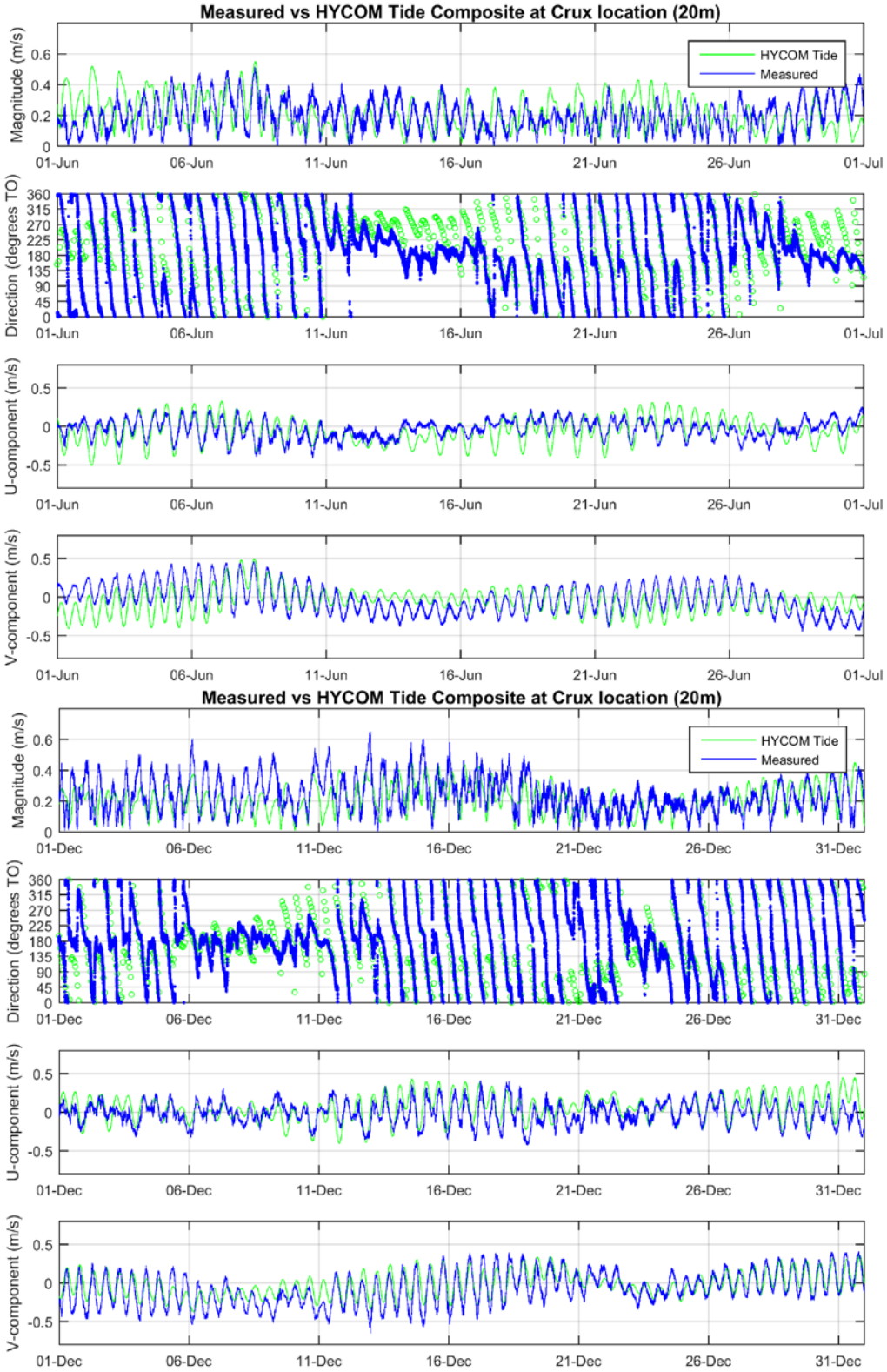


Figure 2.10 Time series comparisons between predicted (HYDROMAP+HYCOM, green line) and measured (blue line) current data at the Crux development area at a depth of approximately 20 m for June 2016 (top panel) and December 2016 (bottom panel).

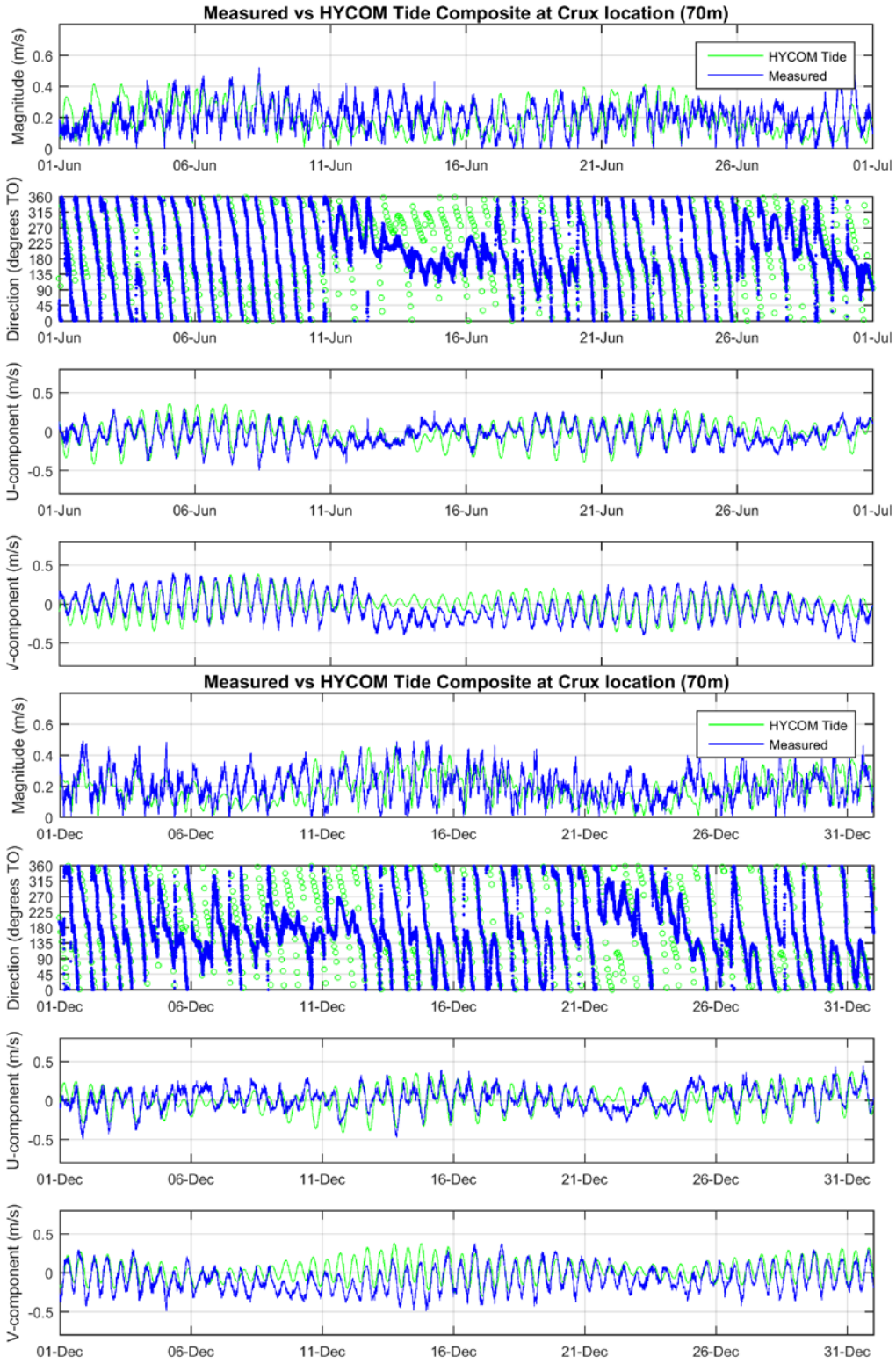


Figure 2.11 Time series comparisons between predicted (HYDROMAP+HYCOM, green line) and measured (blue line) current data at the Crux development area at a depth of approximately 70 m for June 2016 (top panel) and December 2016 (bottom panel).

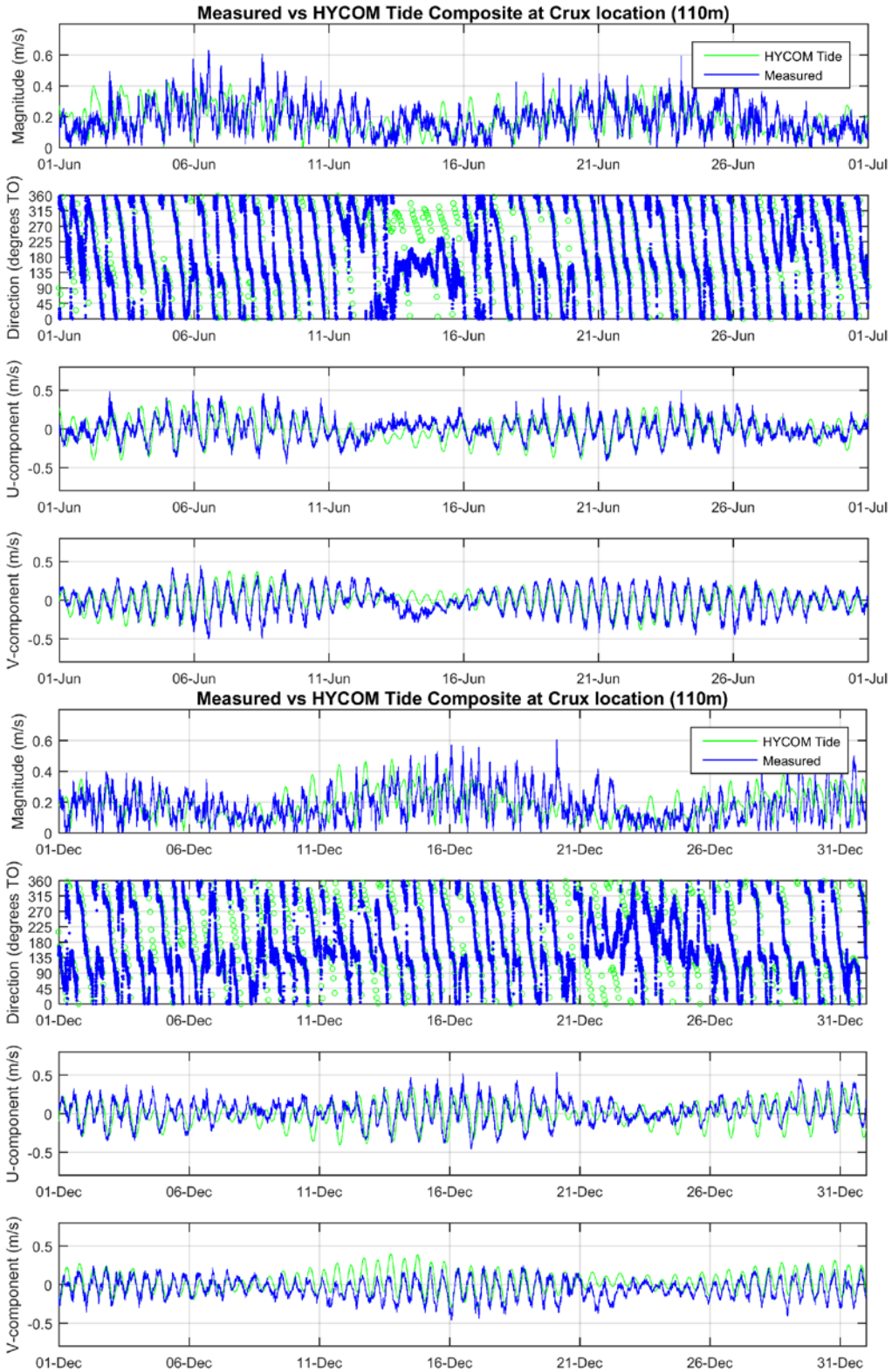


Figure 2.12 Time series comparisons between predicted (HYDROMAP+HYCOM, green line) and measured (blue line) current data at the Crux development area at a depth of approximately 110 m for June 2016 (top panel) and December 2016 (bottom panel).

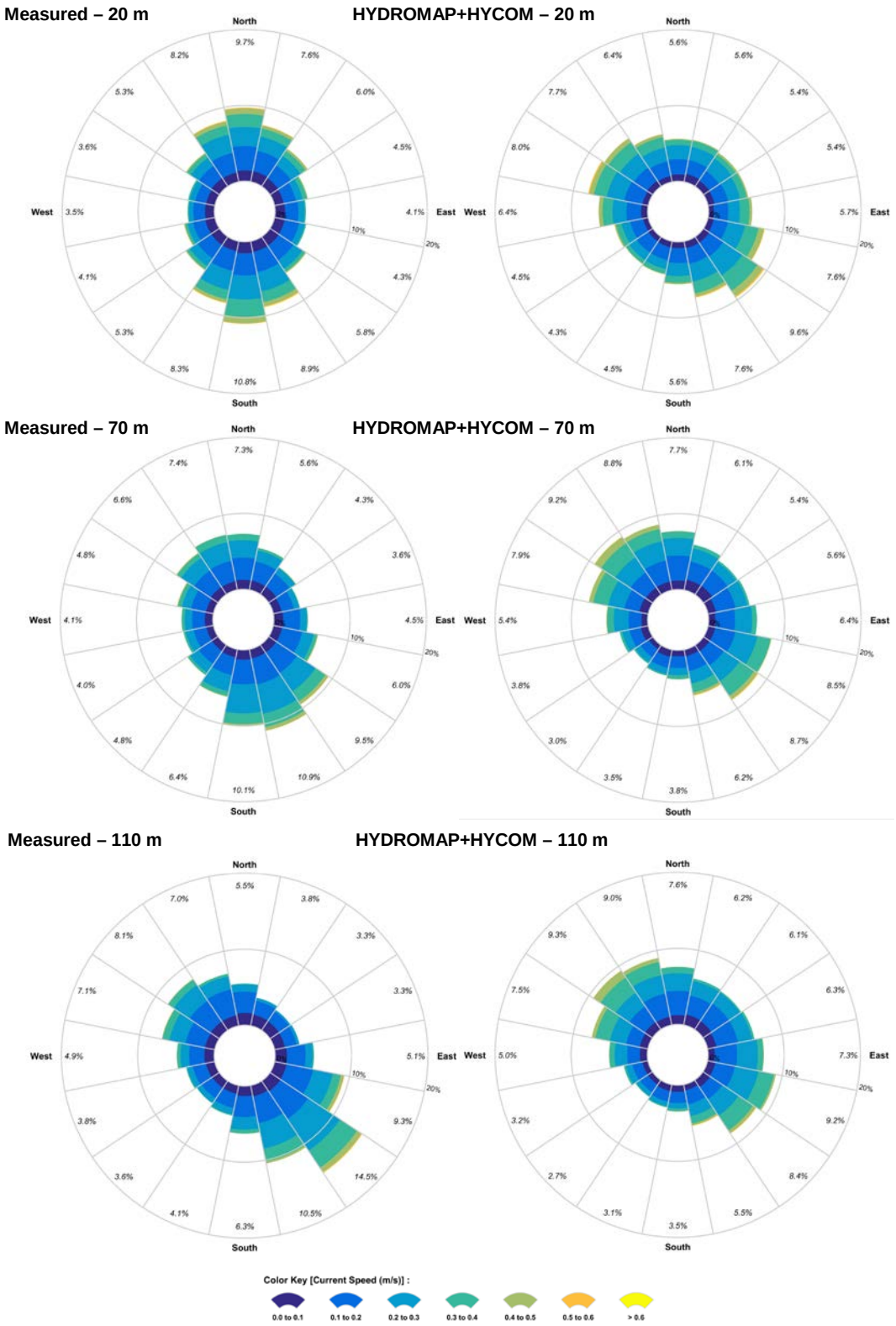


Figure 2.13 Comparative distributions for measured (left column) and predicted (HYDROMAP+HYCOM, right column) current data at the Crux development area (2016-2017) at depths of approximately 20 m (top row), 70 m (middle row) and 110 m (bottom row). The colour key shows the current magnitude, the compass direction provides the direction towards which the current is flowing, and the size of the wedge gives the percentage of the record.

RPS

3 Modelling Results

3.1 Near-Field Modelling

3.1.1 Overview

In the following sections, two tables are presented for each of the modelled flow rates. The first table summarises the predicted plume characteristics in the near-field mixing zone under varying current speeds. The second table summarises the concentrations of all constituents at the end of the near-field mixing zone, the concentration threshold, and the amount of dilution. Any dilution rates indicated in red show that suitable dilution is not achieved during the near-field stage for at least one current-speed case.

Figure 3.1 to Figure 3.6 (note the differing x-axis and y-axis aspect ratios) show the change in average temperature and dilution of the plume under varying flow rates (287 m^3/d and 3,179.8 m^3/d), seasonal conditions (summer, transitional and winter) and current speeds (weak, medium and strong). The figures show the predicted horizontal distances travelled by the plume before the trapping depth is reached (i.e. before the plume becomes neutrally buoyant).

The results show that due to the momentum of the discharge a turbulent mixing zone is created in the immediate vicinity of the discharge point, which is 10 m below the water surface. An increased flow rate is shown to increase the extent of the turbulent mixing zone. Following this initial mixing, the negatively buoyant plumes are predicted to plunge in the water column. The plume is predicted to plunge between 14 m and 55 m below the sea surface depending on flow rate and season. Increased ambient current strengths are shown to reduce the plunge depth and increase the horizontal distance travelled by the plume from the discharge point.

Table 3.1 and Table 3.5 show the predicted plume characteristics for the varying flow rates, seasonal conditions and current speeds. The high currents in the winter season pushed the plume to maximum horizontal distances of 252.3 m and 235.7 m for the 287 m^3/d and 3.179.8 m^3/d flow rate discharges, respectively. The diameter of the plume at the end of the near-field zone ranged from 6 m to 19.5 m for a flow rate of 287 m^3/d, and 13.4 m to 30.2 m for a flow rate of 3.179.8 m^3/d. Increases in current speed serve to restrict the diameter of the plume.

For all seasons and flow rates, the primary factor influencing dilution of the plume is the strength of the ambient current. Weak currents allow the plume to plunge further and reach the trapping depth closer to the discharge point, which slows the rate of dilution (Table 3.1 and Table 3.5). The average dilution levels of the plume upon reaching the trapping depth under medium and strong currents are predicted to be 1:2,760 and 1:3,471 for the 287 m^3/d flow rate, and 1:1,219 and 1:1,568 for the 3.179.8 m^3/d flow rate, respectively. Additionally, the minimum dilution levels of the plume (i.e. dilution of the plume centreline) upon encountering the trapping depth under medium and strong currents are predicted to be 1:792 and 1:894 for the 287 m^3/d flow rate, and 1:318 and 1:406 for the 3.179.8 m^3/d flow rate, respectively. Note that these predictions rely on the persistence of current speed and direction over time and do not account for any build-up of plume concentrations due to slack currents or current reversals.

The results for the 287 m^3/d flow rate (Section 3.1.2; Table 3.2 to Table 3.4) and 3.179.8 m^3/d flow rate (Section 3.1.3; Table 3.6 to Table 3.8) indicate that all constituents of the PFW discharge are expected to reach the required levels of dilution in the near field mixing zone.

RPS

3.1.2 Early Operations Phase: Flow Rate of 287 m^3/d

Table 3.1 Predicted plume characteristics at the end of the near-field mixing zone for the early operations phase flow rate (287 m^3/d) for each season and current speed.

Season	Surface Current Speed (m/s)	Plume Diameter (m) at Depth Below Sea Level (BSL) [m]	Plume Temperature (°C)	Plume-Ambient Temperature Difference (°C)	Plume Dilution (1:x)		Maximum Horizontal Distance (m)
					Minimum	Average	
Summer	Weak (0.06)	12.8 [23.8]	29.21	0.12	592	2,293	19.5
	Medium (0.22)	8.7 [16.5]	29.40	0.07	999	3,864	72.1
	Strong (0.42)	7.0 [15.1]	29.44	0.06	1,238	4,789	133.0
Transitional	Weak (0.06)	10.8 [30.8]	27.99	0.15	423	1,631	15.1
	Medium (0.21)	7.4 [20.1]	28.22	0.09	712	2,760	54.1
	Strong (0.41)	6.0 [17.7]	28.26	0.05	894	3,471	108.5
Winter	Weak (0.05)	19.5 [22.0]	27.21	0.04	1,265	4,895	31.1
	Medium (0.20)	13.4 [15.6]	27.28	0.03	2,129	8,259	118.4
	Strong (0.40)	10.7 [14.4]	27.29	0.02	2,746	10,635	252.3

Table 3.2 Concentrations of all constituents at the end of the near-field stage, and the threshold concentrations and number of dilutions for the summer season. Note from Table 3.1 that dilutions at the 5th, 50th and 95th percentile current speeds were 2,293, 3,864 and 4,789, respectively.

Constituent	Source Concentration (mg/L)	End of Near-Field Concentration (mg/L)			ANZECC & ARMCANZ Threshold Concentration (mg/L)	Required Dilution Factor to Reach 99% Species Protection Level (1:x)
		5th %ile (weak currents)	50th %ile (medium currents)	95th %ile (strong currents)		
		2,293x dilution	3,864x dilution	4,789x dilution		
Benzene	240	$1.0*10^{-2}$	$6.2*10^{-3}$	$5.0*10^{-3}$	0.5	480.0
NPD	10.7	$4.7*10^{-3}$	$2.8*10^{-3}$	$2.2*10^{-3}$	$5.0*10^{-2}$	214.0
Phenol	0.757	$3.3*10^{-4}$	$2.0*10^{-4}$	$1.6*10^{-4}$	0.27	2.8
Cadmium (Cd)	$1.0*10^{-4}$	$4.4*10^{-8}$	$2.6*10^{-8}$	$2.1*10^{-8}$	$7.0*10^{-4}$	6.6
Chromium (III/VI) (Cr)	$7.0*10^{-4}$	$3.1*10^{-7}$	$1.8*10^{-7}$	$1.5*10^{-7}$	$1.4*10^{-4}$	177.1
Copper (Cu)	$3.0*10^{-4}$	$1.3*10^{-7}$	$7.8*10^{-8}$	$6.3*10^{-8}$	$3.0*10^{-4}$	30.7
Lead (Pb)	$1.0*10^{-4}$	$4.4*10^{-8}$	$2.6*10^{-8}$	$2.1*10^{-8}$	$2.2*10^{-3}$	2.1
Nickel (Ni)	$3.0*10^{-4}$	$1.3*10^{-7}$	$7.8*10^{-8}$	$6.3*10^{-8}$	$7.0*10^{-3}$	2.7
Zinc (Zn)	$8.0*10^{-4}$	$3.5*10^{-7}$	$2.1*10^{-7}$	$1.7*10^{-7}$	$7.0*10^{-3}$	4.2

Table 3.3 Concentrations of all constituents at the end of the near-field stage, and the threshold concentrations and number of dilutions for the transitional season. Note from Table 3.1 that dilutions at the 5th, 50th and 95th percentile current speeds were 1,631, 2,760 and 3,471, respectively.

Constituent	Source Concentration (mg/L)	End of Near-Field Concentration (mg/L)			ANZECC & ARMCANZ Threshold Concentration (mg/L)	Required Dilution Factor to Reach 99% Species Protection Level (1:x)
		5th %ile (weak currents)	50th %ile (medium currents)	95th %ile (strong currents)		
		1,631x dilution	2,760x dilution	3,471x dilution		
Benzene	240	$1.5*10^{-2}$	$8.7*10^{-3}$	$6.9*10^{-3}$	0.5	480.0
NPD	10.7	$6.6*10^{-3}$	$3.9*10^{-3}$	$3.1*10^{-3}$	$5.0*10^{-2}$	214.0
Phenol	0.757	$4.6*10^{-4}$	$2.7*10^{-4}$	$2.2*10^{-4}$	0.27	2.8
Cadmium (Cd)	$1.0*10^{-4}$	$6.1*10^{-8}$	$3.6*10^{-8}$	$2.9*10^{-8}$	$7.0*10^{-4}$	6.6
Chromium (III/VI) (Cr)	$7.0*10^{-4}$	$4.3*10^{-7}$	$2.5*10^{-7}$	$2.0*10^{-7}$	$1.4*10^{-4}$	177.1
Copper (Cu)	$3.0*10^{-4}$	$1.8*10^{-7}$	$1.1*10^{-7}$	$8.6*10^{-8}$	$3.0*10^{-4}$	30.7
Lead (Pb)	$1.0*10^{-4}$	$6.1*10^{-8}$	$3.6*10^{-8}$	$2.9*10^{-8}$	$2.2*10^{-3}$	2.1
Nickel (Ni)	$3.0*10^{-4}$	$1.8*10^{-7}$	$1.1*10^{-7}$	$8.6*10^{-8}$	$7.0*10^{-3}$	2.7
Zinc (Zn)	$8.0*10^{-4}$	$4.9*10^{-7}$	$2.9*10^{-7}$	$2.3*10^{-7}$	$7.0*10^{-3}$	4.2

Table 3.4 Concentrations of all constituents at the end of the near-field stage, and the threshold concentrations and number of dilutions for the winter season. Note from Table 3.1 that dilutions at the 5th, 50th and 95th percentile current speeds were 4,895, 8,259 and 10,635, respectively.

Constituent	Source Concentration (mg/L)	End of Near-Field Concentration (mg/L)			ANZECC & ARMCANZ Threshold Concentration (mg/L)	Required Dilution Factor to Reach 99% Species Protection Level (1:x)
		5th %ile (weak currents)	50th %ile (medium currents)	95th %ile (strong currents)		
		4,895x dilution	8,259x dilution	10,635x dilution		
Benzene	240	$4.9*10^{-3}$	$2.9*10^{-3}$	$2.3*10^{-3}$	0.5	480.0
NPD	10.7	$2.2*10^{-3}$	$1.3*10^{-3}$	$1.0*10^{-3}$	$5.0*10^{-2}$	214.0
Phenol	0.757	$1.5*10^{-4}$	$9.2*10^{-5}$	$7.1*10^{-5}$	0.27	2.8
Cadmium (Cd)	$1.0*10^{-4}$	$2.0*10^{-8}$	$1.2*10^{-8}$	$9.4*10^{-9}$	$7.0*10^{-4}$	6.6
Chromium (III/VI) (Cr)	$7.0*10^{-4}$	$1.4*10^{-7}$	$8.5*10^{-8}$	$6.6*10^{-8}$	$1.4*10^{-4}$	177.1
Copper (Cu)	$3.0*10^{-4}$	$6.1*10^{-8}$	$3.6*10^{-8}$	$2.8*10^{-8}$	$3.0*10^{-4}$	30.7
Lead (Pb)	$1.0*10^{-4}$	$2.0*10^{-8}$	$1.2*10^{-8}$	$9.4*10^{-9}$	$2.2*10^{-3}$	2.1
Nickel (Ni)	$3.0*10^{-4}$	$6.1*10^{-8}$	$3.6*10^{-8}$	$2.8*10^{-8}$	$7.0*10^{-3}$	2.7
Zinc (Zn)	$8.0*10^{-4}$	$1.6*10^{-7}$	$9.7*10^{-8}$	$7.5*10^{-8}$	$7.0*10^{-3}$	4.2

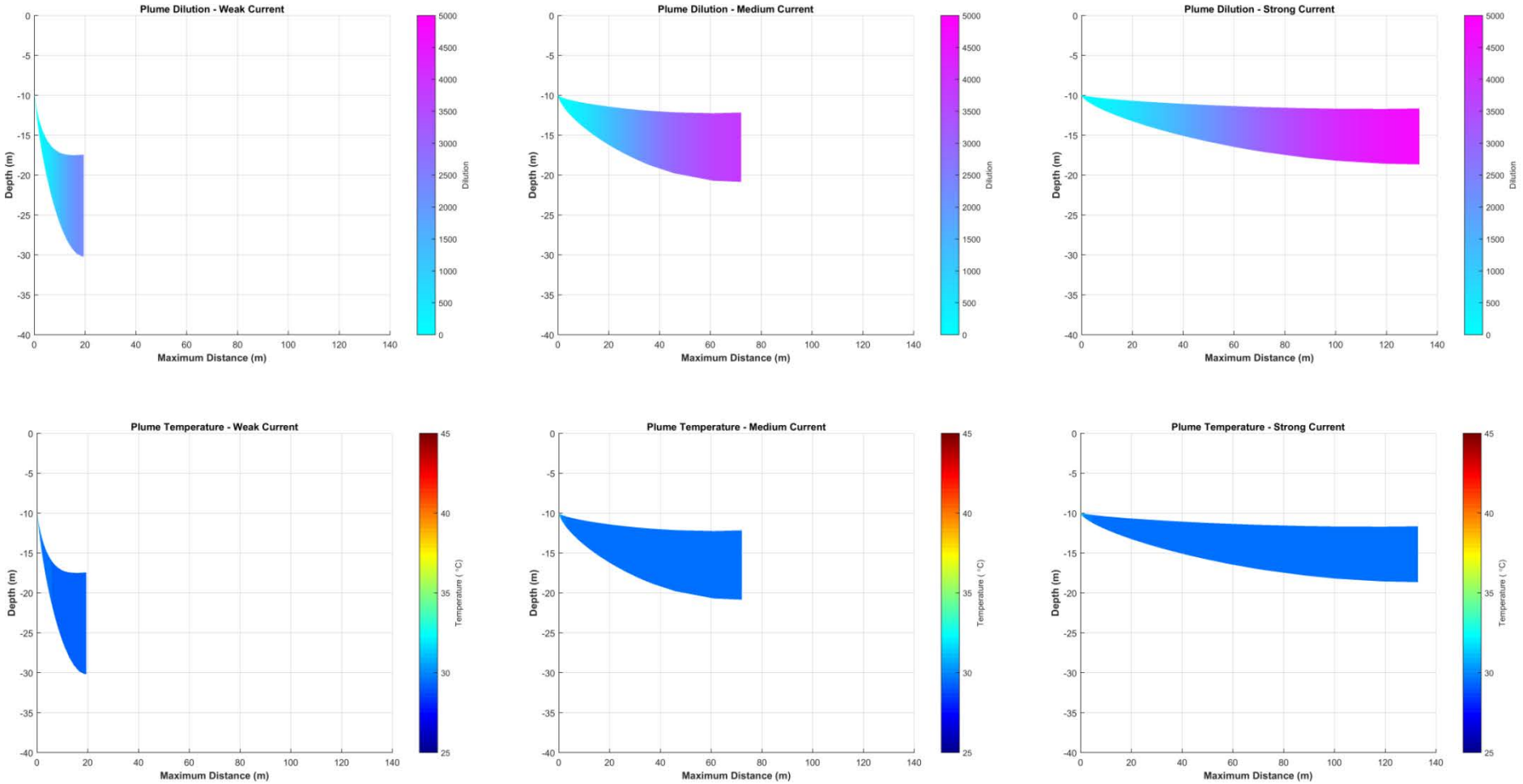


Figure 3.1 Near-field average temperature and dilution results for weak, medium and strong summer currents (287 m^3/d flow rate).

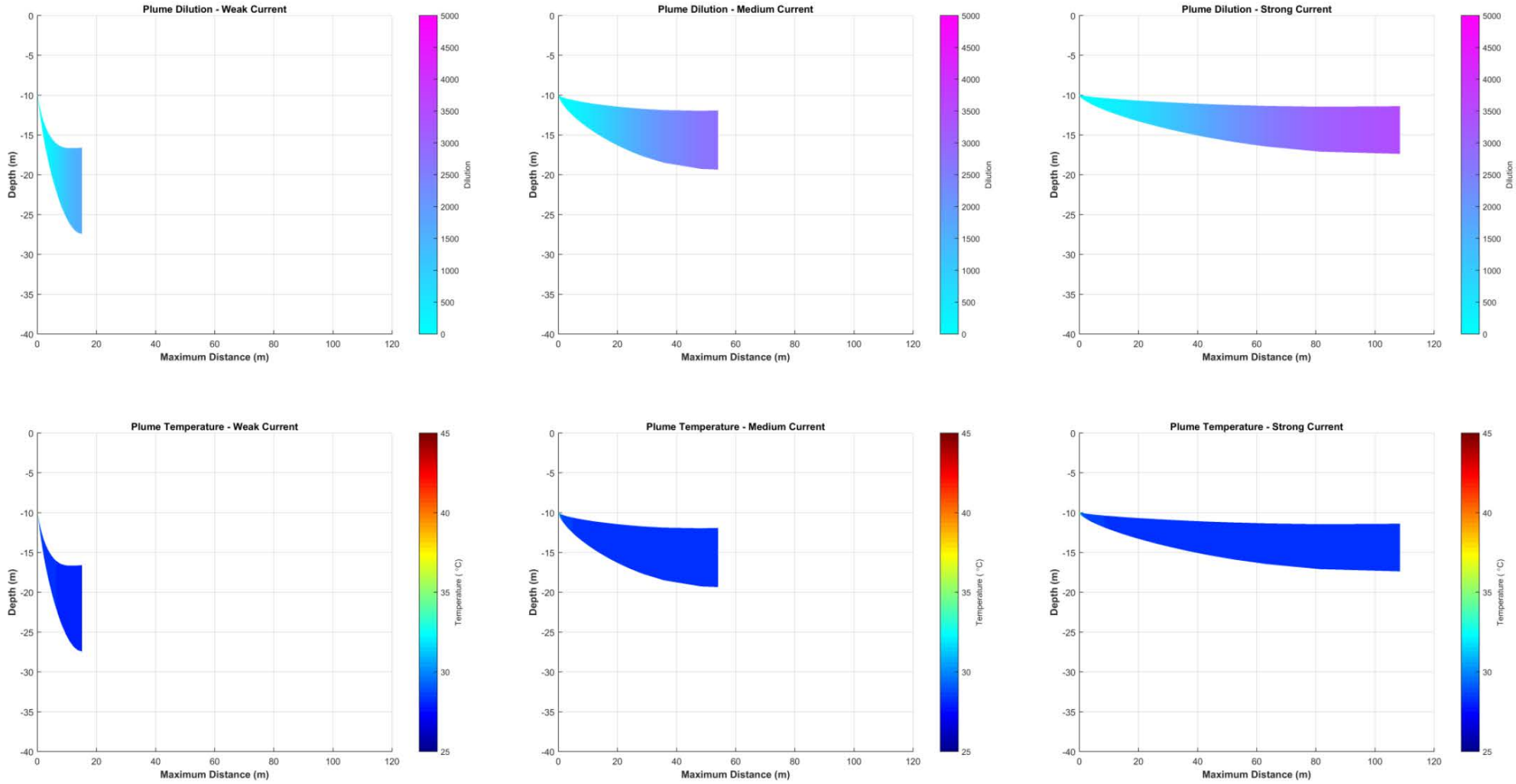


Figure 3.2 Near-field average temperature and dilution results for weak, medium and strong transitional currents (287 m^3/d flow rate).

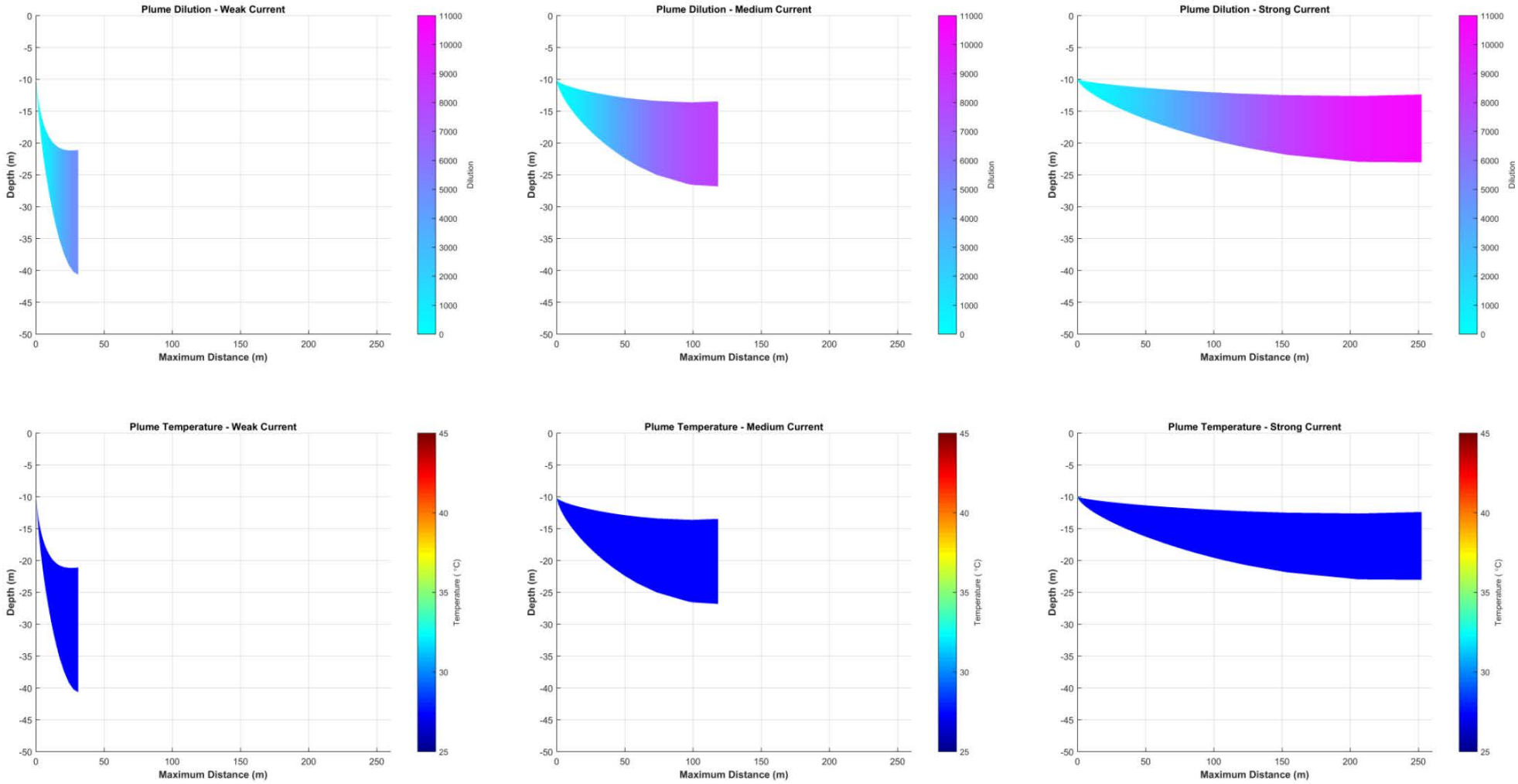


Figure 3.3 Near-field average temperature and dilution results for weak, medium and strong winter currents (287 m^3/d flow rate).

3.1.3 Later Operations Phase: Flow Rate of 3,179.8 m^3/d

Table 3.5 Predicted plume characteristics at the end of the near-field mixing zone for the later operations phase flow rate (3,179.8 m^3/d) for each season and current speed.

Season	Surface Current Speed (m/s)	Plume Diameter (m) at Depth Below Sea Level (BSL) [m]	Plume Temperature (°C)	Plume-Ambient Temperature Difference (°C)	Plume Dilution (1:x)		Maximum Horizontal Distance (m)
					Minimum	Average	
Summer	Weak (0.06)	20.9 [40.5]	28.86	0.50	198	581	22.2
	Medium (0.22)	19.3 [24.9]	29.22	0.16	445	1,699	73.4
	Strong (0.42)	15.8 [21.2]	29.31	0.13	565	2,169	139.6
Transitional	Weak (0.06)	20.3 [54.5]	27.57	0.48	177	537	22.3
	Medium (0.21)	16.5 [32.7]	28.01	0.20	318	1,219	57.4
	Strong (0.41)	13.4 [27.2]	28.11	0.15	406	1,568	112.8
Winter	Weak (0.05)	30.2 [38.9]	27.06	0.20	356	1,091	30.6
	Medium (0.20)	28.7 [22.8]	27.21	0.07	891	3,442	108.0
	Strong (0.40)	23.7 [20.5]	27.25	0.03	1,220	4,696	235.7

Table 3.6 Concentrations of all constituents at the end of the near-field stage, and the threshold concentrations and number of dilutions for the summer season. Note from Table 3.1 that dilutions at the 5th, 50th and 95th percentile current speeds were 581, 1,699 and 2,169, respectively.

Constituent	Source Concentration (mg/L)	End of Near-Field Concentration (mg/L)			ANZECC & ARMCANZ Threshold Concentration (mg/L)	Required Dilution Factor to Reach 99% Species Protection Level (1:x)
		5th %ile (weak currents)	50th %ile (medium currents)	95th %ile (strong currents)		
		581x dilution	1,699x dilution	2,169x dilution		
Benzene	240	$4.1*10^{-2}$	$1.4*10^{-2}$	$1.1*10^{-2}$	0.5	480.0
NPD	10.7	$1.8*10^{-2}$	$6.3*10^{-3}$	$4.9*10^{-3}$	$5.0*10^{-2}$	214.0
Phenol	0.757	$1.3*10^{-3}$	$4.5*10^{-4}$	$3.5*10^{-4}$	0.27	2.8
Cadmium (Cd)	$1.0*10^{-4}$	$1.7*10^{-7}$	$5.9*10^{-8}$	$4.6*10^{-8}$	$7.0*10^{-4}$	6.6
Chromium (III/VI) (Cr)	$7.0*10^{-4}$	$1.2*10^{-6}$	$4.1*10^{-7}$	$3.2*10^{-7}$	$1.4*10^{-4}$	177.1
Copper (Cu)	$3.0*10^{-4}$	$5.2*10^{-7}$	$1.8*10^{-7}$	$1.4*10^{-7}$	$3.0*10^{-4}$	30.7
Lead (Pb)	$1.0*10^{-4}$	$1.7*10^{-7}$	$5.9*10^{-8}$	$4.6*10^{-8}$	$2.2*10^{-3}$	2.1
Nickel (Ni)	$3.0*10^{-4}$	$5.2*10^{-7}$	$1.8*10^{-7}$	$1.4*10^{-7}$	$7.0*10^{-3}$	2.7
Zinc (Zn)	$8.0*10^{-4}$	$1.4*10^{-6}$	$4.7*10^{-7}$	$3.7*10^{-7}$	$7.0*10^{-3}$	4.2

Table 3.7 Concentrations of all constituents at the end of the near-field stage, and the threshold concentrations and number of dilutions for the transitional season. Note from Table 3.1 that dilutions at the 5th, 50th and 95th percentile current speeds were 537, 1,219 and 1,568, respectively.

Constituent	Source Concentration (mg/L)	End of Near-Field Concentration (mg/L)			ANZECC & ARMCANZ Threshold Concentration (mg/L)	Required Dilution Factor to Reach 99% Species Protection Level (1:x)
		5th %ile (weak currents)	50th %ile (medium currents)	95th %ile (strong currents)		
		537x dilution	1,219x dilution	1,568x dilution		
Benzene	240	$4.5*10^{-2}$	$2.0*10^{-2}$	$1.5*10^{-2}$	0.5	480.0
NPD	10.7	$2.0*10^{-2}$	$8.8*10^{-3}$	$6.8*10^{-3}$	$5.0*10^{-2}$	214.0
Phenol	0.757	$1.4*10^{-3}$	$6.2*10^{-4}$	$4.8*10^{-4}$	0.27	2.8
Cadmium (Cd)	$1.0*10^{-4}$	$1.9*10^{-7}$	$8.2*10^{-8}$	$6.4*10^{-8}$	$7.0*10^{-4}$	6.6
Chromium (III/VI) (Cr)	$7.0*10^{-4}$	$1.3*10^{-6}$	$5.7*10^{-7}$	$4.5*10^{-7}$	$1.4*10^{-4}$	177.1
Copper (Cu)	$3.0*10^{-4}$	$5.6*10^{-7}$	$2.5*10^{-7}$	$1.9*10^{-7}$	$3.0*10^{-4}$	30.7
Lead (Pb)	$1.0*10^{-4}$	$1.9*10^{-7}$	$8.2*10^{-8}$	$6.4*10^{-8}$	$2.2*10^{-3}$	2.1
Nickel (Ni)	$3.0*10^{-4}$	$5.6*10^{-7}$	$2.5*10^{-7}$	$1.9*10^{-7}$	$7.0*10^{-3}$	2.7
Zinc (Zn)	$8.0*10^{-4}$	$1.5*10^{-6}$	$6.6*10^{-7}$	$5.1*10^{-7}$	$7.0*10^{-3}$	4.2

Table 3.8 Concentrations of all constituents at the end of the near-field stage, and the threshold concentrations and number of dilutions for the winter season. Note from Table 3.1 that dilutions at the 5th, 50th and 95th percentile current speeds were 1,091, 3,442 and 4,696, respectively.

Constituent	Source Concentration (mg/L)	End of Near-Field Concentration (mg/L)			ANZECC & ARMCANZ Threshold Concentration (mg/L)	Required Dilution Factor to Reach 99% Species Protection Level (1:x)
		5th %ile (weak currents)	50th %ile (medium currents)	95th %ile (strong currents)		
		1,091x dilution	3,442x dilution	4,696x dilution		
Benzene	240	$2.2*10^{-2}$	$7.0*10^{-3}$	$5.1*10^{-3}$	0.5	480.0
NPD	10.7	$9.8*10^{-3}$	$3.1*10^{-3}$	$2.3*10^{-3}$	$5.0*10^{-2}$	214.0
Phenol	0.757	$6.9*10^{-4}$	$2.2*10^{-4}$	$1.6*10^{-4}$	0.27	2.8
Cadmium (Cd)	$1.0*10^{-4}$	$9.2*10^{-8}$	$2.9*10^{-8}$	$2.1*10^{-8}$	$7.0*10^{-4}$	6.6
Chromium (III/VI) (Cr)	$7.0*10^{-4}$	$6.4*10^{-7}$	$2.0*10^{-7}$	$1.5*10^{-7}$	$1.4*10^{-4}$	177.1
Copper (Cu)	$3.0*10^{-4}$	$2.7*10^{-7}$	$8.7*10^{-8}$	$6.4*10^{-8}$	$3.0*10^{-4}$	30.7
Lead (Pb)	$1.0*10^{-4}$	$9.2*10^{-8}$	$2.9*10^{-8}$	$2.1*10^{-8}$	$2.2*10^{-3}$	2.1
Nickel (Ni)	$3.0*10^{-4}$	$2.7*10^{-7}$	$8.7*10^{-8}$	$6.4*10^{-8}$	$7.0*10^{-3}$	2.7
Zinc (Zn)	$8.0*10^{-4}$	$7.3*10^{-7}$	$2.3*10^{-7}$	$1.7*10^{-7}$	$7.0*10^{-3}$	4.2

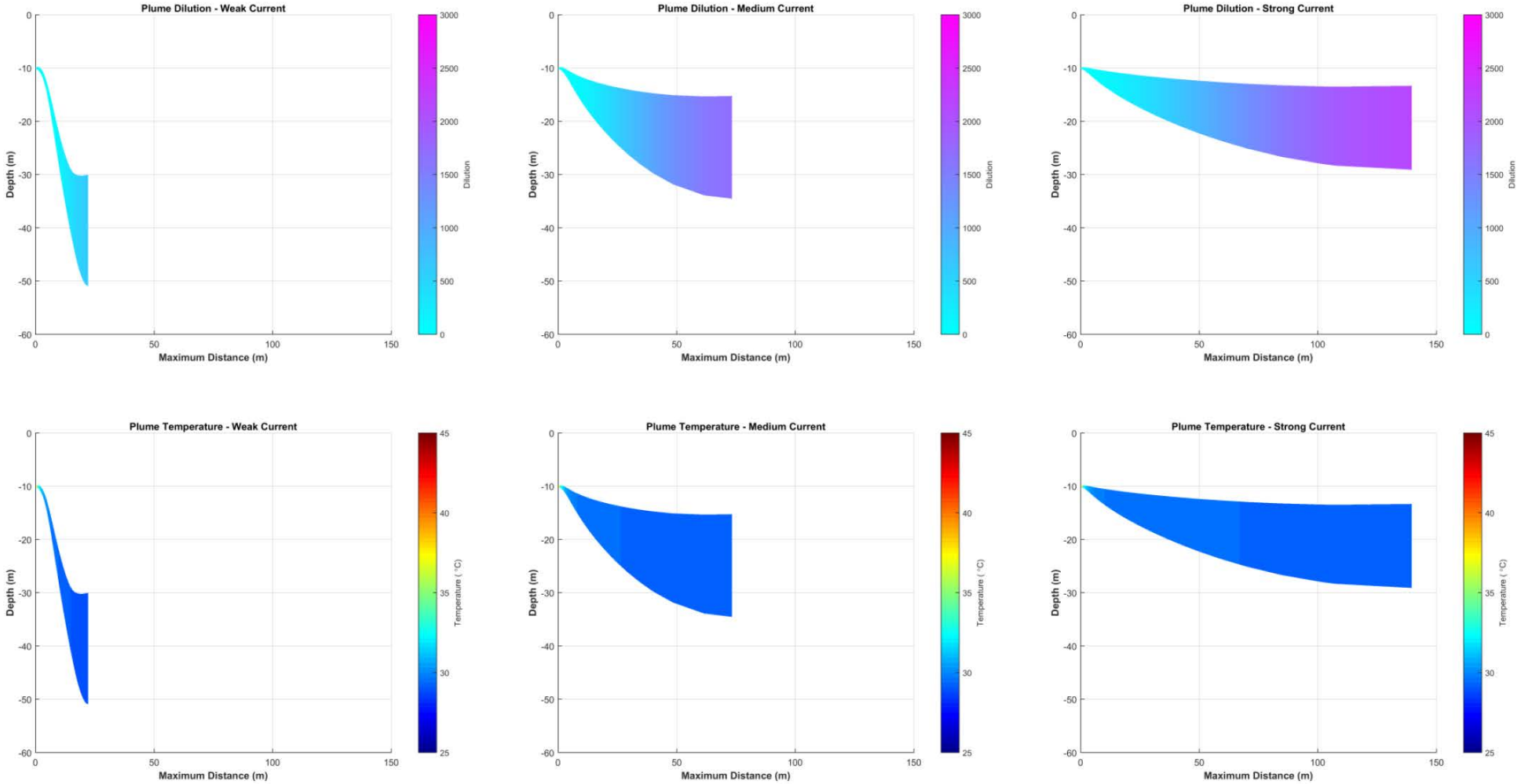


Figure 3.4 Near-field average temperature and dilution results for weak, medium and strong summer currents (3,179.8 m^3/d flow rate).

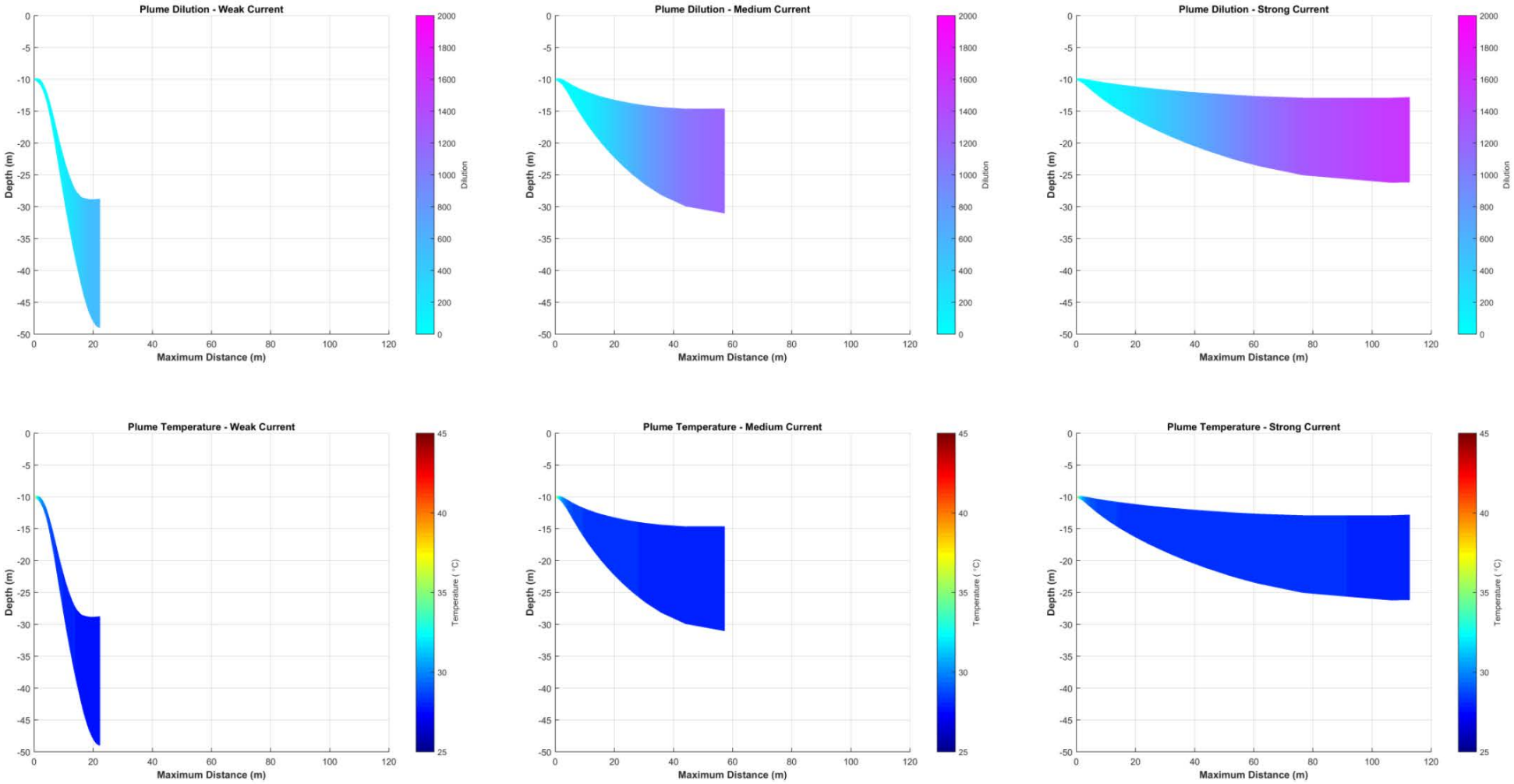


Figure 3.5 Near-field average temperature and dilution results for weak, medium and strong transitional currents (3,179.8 m^3/d flow rate).

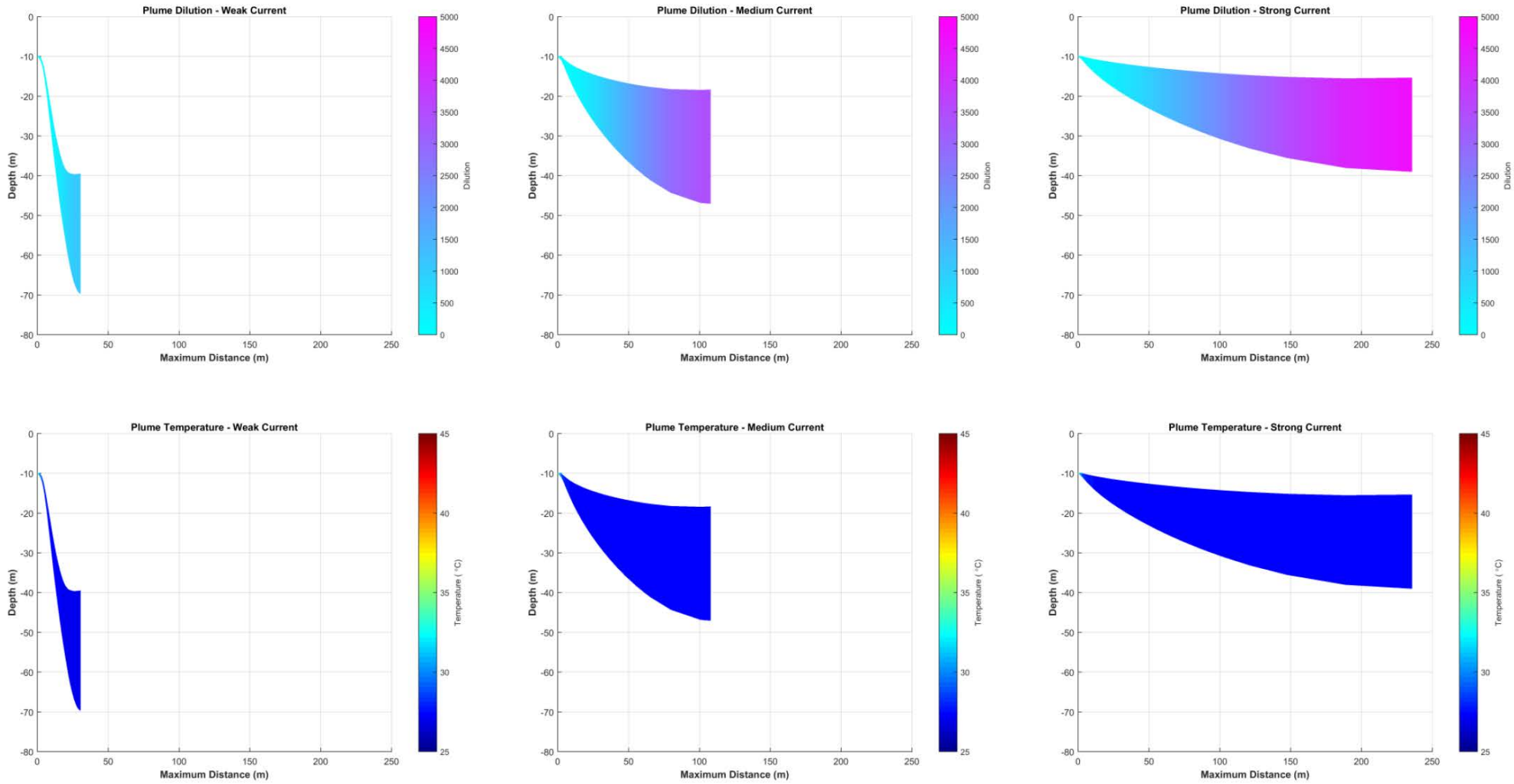


Figure 3.6 **Near-field average temperature and dilution results for weak, medium and strong winter currents (3,179.8 m^3/d flow rate).**

3.2 Far-Field Modelling

3.2.1 Overview

It is important to note that near-field and far-field modelling are used to describe different processes and scales of effect, and therefore the far-field modelling results will not necessarily correspond to the outcomes at the end of the near-field mixing zone for any given discharge scenario. The far-field results included episodes of pooling of the discharge plume under weak currents, which caused lower dilutions (higher concentrations) further from the discharge location when the pooled plume was advected away. Episodes of recirculation – where the plume moved back under the discharge at some later time due to the oscillatory nature of the tide – were also observed, compounding the pooling effect and further lowering the dilution values.

3.2.2 General Observations

Figure 3.7 shows example time series snapshots of predicted dilutions during a single simulation at 3-hour intervals from 00:00 to 15:00 on 2nd December 2016. This simulation – selected merely to be representative of typical conditions – considers the later operations flow rate of 3,179.8 m^3/d. The spatially-varying orientation of the plume with the currents and the rapidly-varying nature of the concentrations around the source can be observed. The snapshots also show the combined effect of the tide and the drift currents, with a clear tidal oscillation.

These snapshots illustrate that the dilutions (and in turn concentrations) become more variable over time because of changes in current speed and direction. Higher dilutions (lower concentrations) are predicted during periods of increased current speed, whereas patches of lower dilutions (higher concentrations) tend to accumulate during the turning of the tide or during periods of weak drift currents. During prolonged periods of lowered current speed, the plume has a more continuous appearance, with higher-concentration patches moving as a unified group. These findings agree with the research of King & McAllister (1997, 1998) who noted that concentrations within effluent plumes generated by an offshore platform were patchy and likely to peak around the reversal of the tides.

Maximum concentrations (lowest dilution) are predicted to occur near where the plume reaches the trapping depth, which ranges from 14-55 m. Concentrations are then expected to reduce as the plume mixes vertically as it moves away from the source.

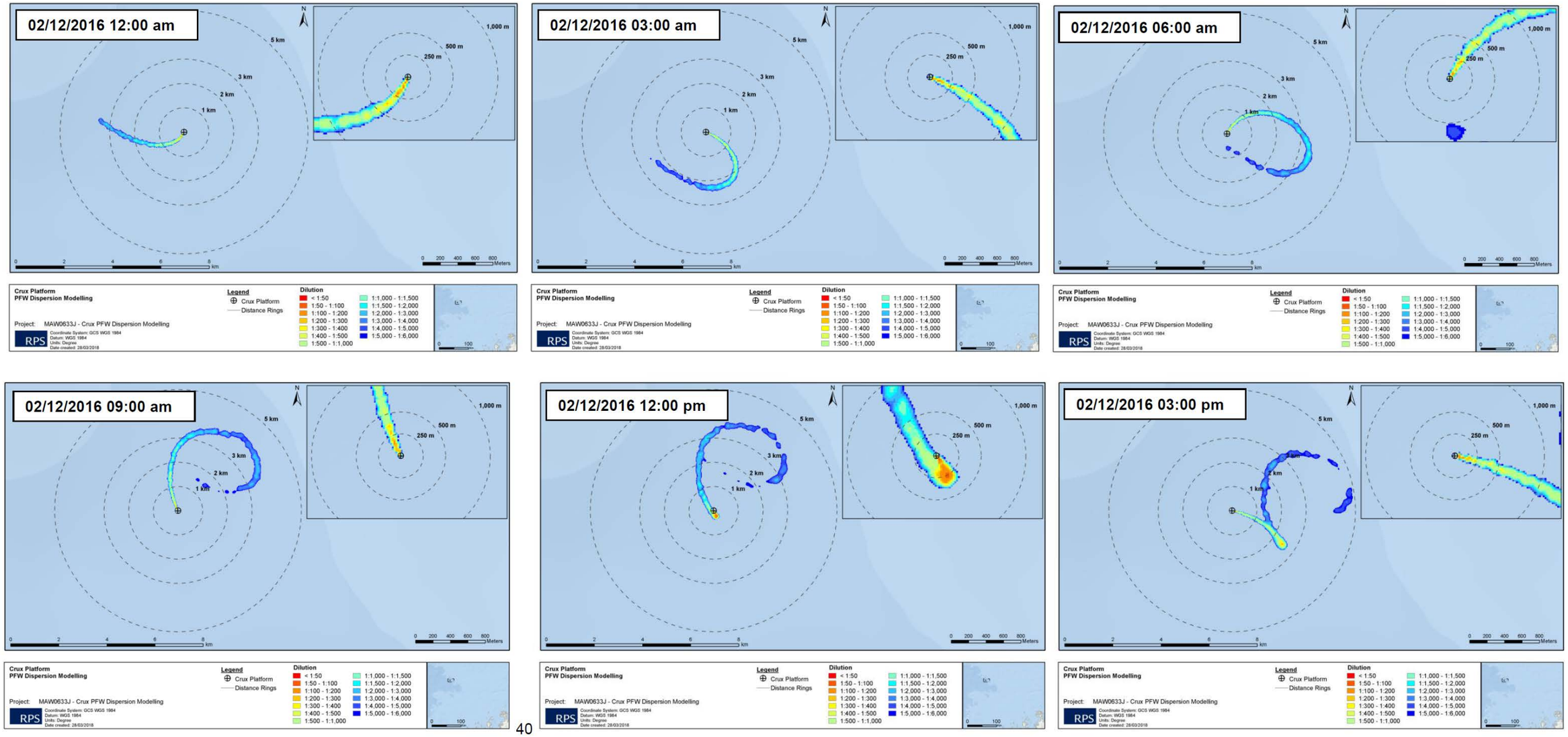


Figure 3.7 Snapshots of predicted dilution levels, at 3-hour intervals from 00:00 to 15:00 on 2nd December 2016, for the later operations phase flow rate (3,179.8 m^3/d).

3.2.3 Seasonal Analysis

The model outputs over the ten-year hindcast period (2008-2017) were combined and analysed on a seasonal basis (summer, transitional and winter). This approach assists with identifying the potential exposure to the shoals nearest to the proposed Crux platform (Goeree Shoal, Eugene McDermott Shoal and Vulcan Shoal) on a seasonal basis whilst considering inter-annual variability in ocean current conditions.

Table 3.9 summarises the minimum dilution achieved at specific radial distances from the discharge location for each flow rate and season.

Table 3.10 provides a summary of the maximum distances from the discharge location to achieve a given dilution for each flow rate and season. The results indicate that the release of effluent under all seasonal conditions results in rapid dispersion of analytes within the ambient environment. Dilution to reach 99% Species Protection Level concentrations is achieved for all analytes within an area of influence ranging from 982 m to 999 m from the Crux platform location, this being the maximum spatial extents of the 1:500 dilution contour in summer and winter, respectively.

Table 3.11 provides a summary of the total area of coverage for a given dilution for each flow rate and season. For all analytes, the area of exposure defined by the 1:500 dilution contour is predicted to reach a maximum of between 1.7 km^2 and 1.8 km^2, the coverage areas predicted in the summer/transitional and winter seasons, respectively.

Figure 3.8 to Figure 3.13 show the aggregated spatial extents of the minimum dilutions for each flow rate and season. Note that the contours represent the lowest predicted dilution (highest concentration) at any given time-step through the water column and do not consider frequency or duration.

The results presented assume that no processes other than dilution would reduce the source concentrations over time.

Table 3.9 Minimum dilution achieved at specific radial distances from the PFW discharge location for each flow rate and season.

Flow rate (m^3/d)	Season	Minimum dilution (1:x) achieved at specific radial distances from discharge location						
		0.1 km	0.5 km	1 km	2 km	3 km	5 km	>5 km
287	Summer	1:639	1:2,686	1:4,881	>1:6,000	>1:6,000	>1:6,000	>1:6,000
	Transitional	1:671	1:2,599	1:4,656	>1:6,000	>1:6,000	>1:6,000	>1:6,000
	Winter	1:628	1:2,551	1:4,517	>1:6,000	>1:6,000	>1:6,000	>1:6,000
3,179.8	Summer	1:73	1:298	1:508	1:971	1:1,302	1:2,503	1:2,503
	Transitional	1:79	1:297	1:501	1:898	1:1,321	1:2,521	1:2,521
	Winter	1:73	1:266	1:497	1:849	1:1,151	1:2,137	1:2,137

Table 3.10 Maximum distance from the PFW discharge location to achieve a given dilution for each flow rate and season.

Flow rate (m^3/d)	Season	Maximum distance (m) from discharge location to achieve given dilution											
		1:50 dilution	1:100 dilution	1:200 dilution	1:300 dilution	1:400 dilution	1:500 dilution	1:1,000 dilution	1:2,000 dilution	1:3,000 dilution	1:4,000 dilution	1:5,000 dilution	1:>6,000 dilution
287	Summer	N/A	N/A	N/A	37	55	63	135	337	595	873	1,004	1,200
	Transitional	N/A	N/A	N/A	37	51	67	125	356	576	823	1,115	1,359
	Winter	N/A	N/A	N/A	37	51	67	146	355	606	846	1,111	1,473
3,179.8	Summer	62	128	314	515	737	982	2,174	4,283	5,637	6,689	7,600	9,172
	Transitional	54	128	303	499	759	995	2,221	4,696	5,642	6,389	7,014	8,668
	Winter	71	135	332	601	807	999	2,263	4,625	6,495	7,814	8,906	9,519

Table 3.11 Total area of coverage for a given dilution for each flow rate and season.

Flow rate (m^3/d)	Season	Total area (km^2) of coverage for given dilution											
		1:50 dilution	1:100 dilution	1:200 dilution	1:300 dilution	1:400 dilution	1:500 dilution	1:1,000 dilution	1:2,000 dilution	1:3,000 dilution	1:4,000 dilution	1:5,000 dilution	1:>6,000 dilution
287	Summer	N/A	N/A	N/A	<0.001	0.003	0.004	0.035	0.23	0.58	1.1	1.8	2.6
	Transitional	N/A	N/A	N/A	<0.001	0.002	0.004	0.036	0.25	0.62	1.2	1.9	2.8
	Winter	N/A	N/A	N/A	<0.001	0.002	0.004	0.039	0.25	0.64	1.2	2.0	2.8
3,179.8	Summer	0.004	0.027	0.18	0.52	1.0	1.7	7.0	25.6	48.1	72.8	94.5	113.5
	Transitional	0.003	0.026	0.18	0.51	1.0	1.7	7.4	25.7	51.3	72.4	90.1	106.6
	Winter	0.004	0.030	0.20	0.56	1.1	1.8	7.8	27.3	50.0	77.2	98.8	117.2

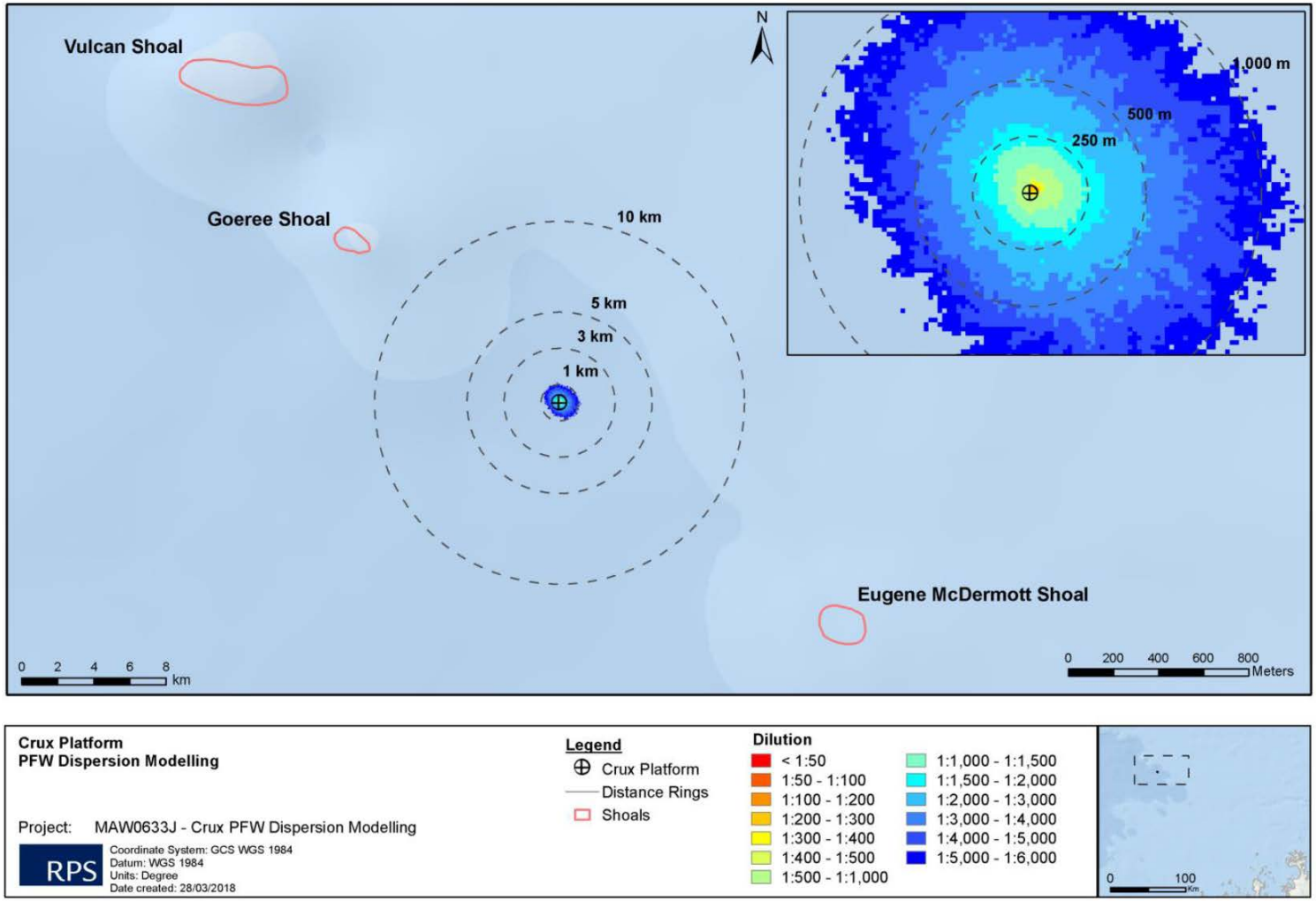


Figure 3.8 Predicted minimum dilutions under summer conditions for the early operations phase flow rate (287 m^3/d).

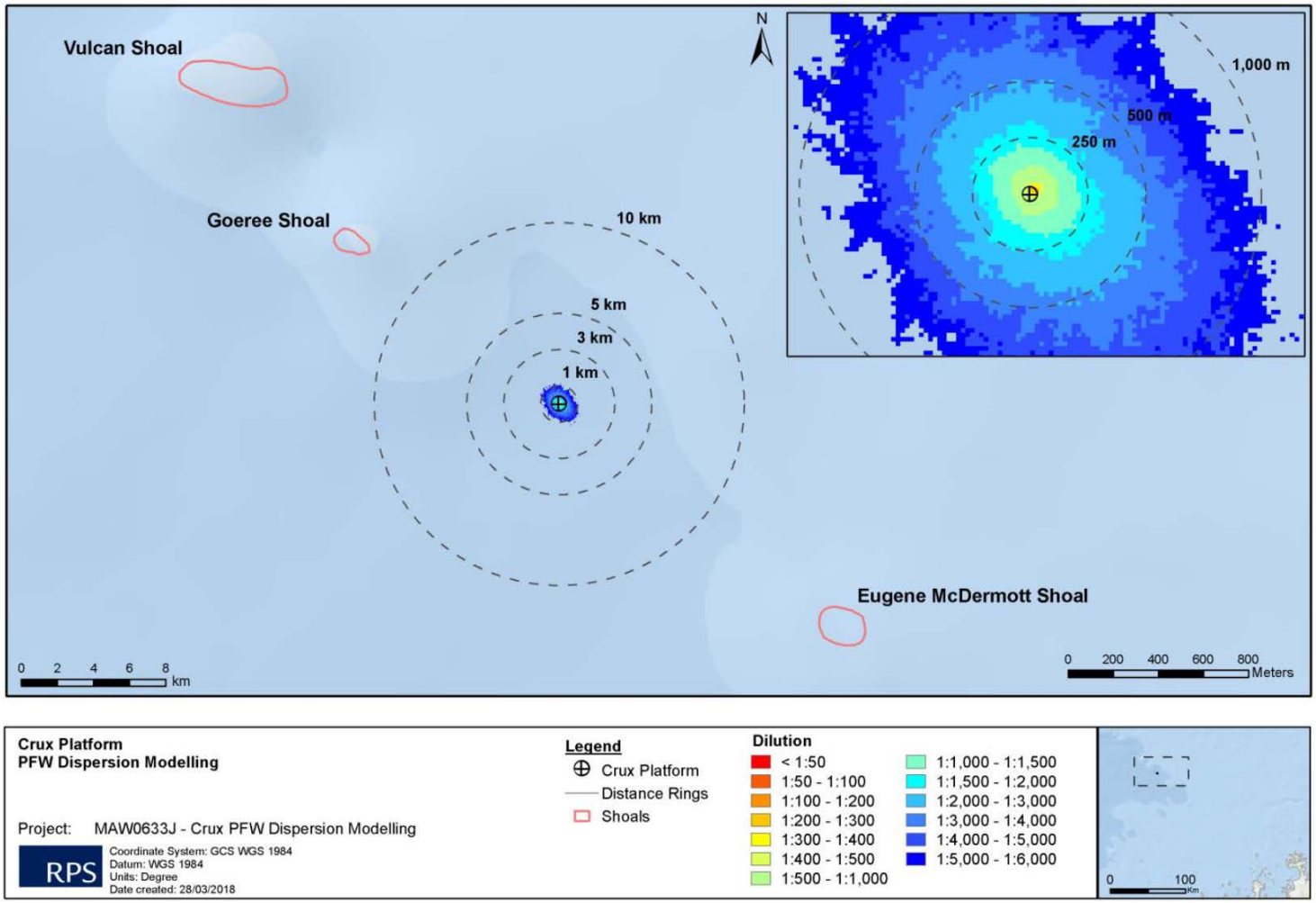


Figure 3.9 Predicted minimum dilutions under transitional conditions for the early operations phase flow rate (287 m^3/d).

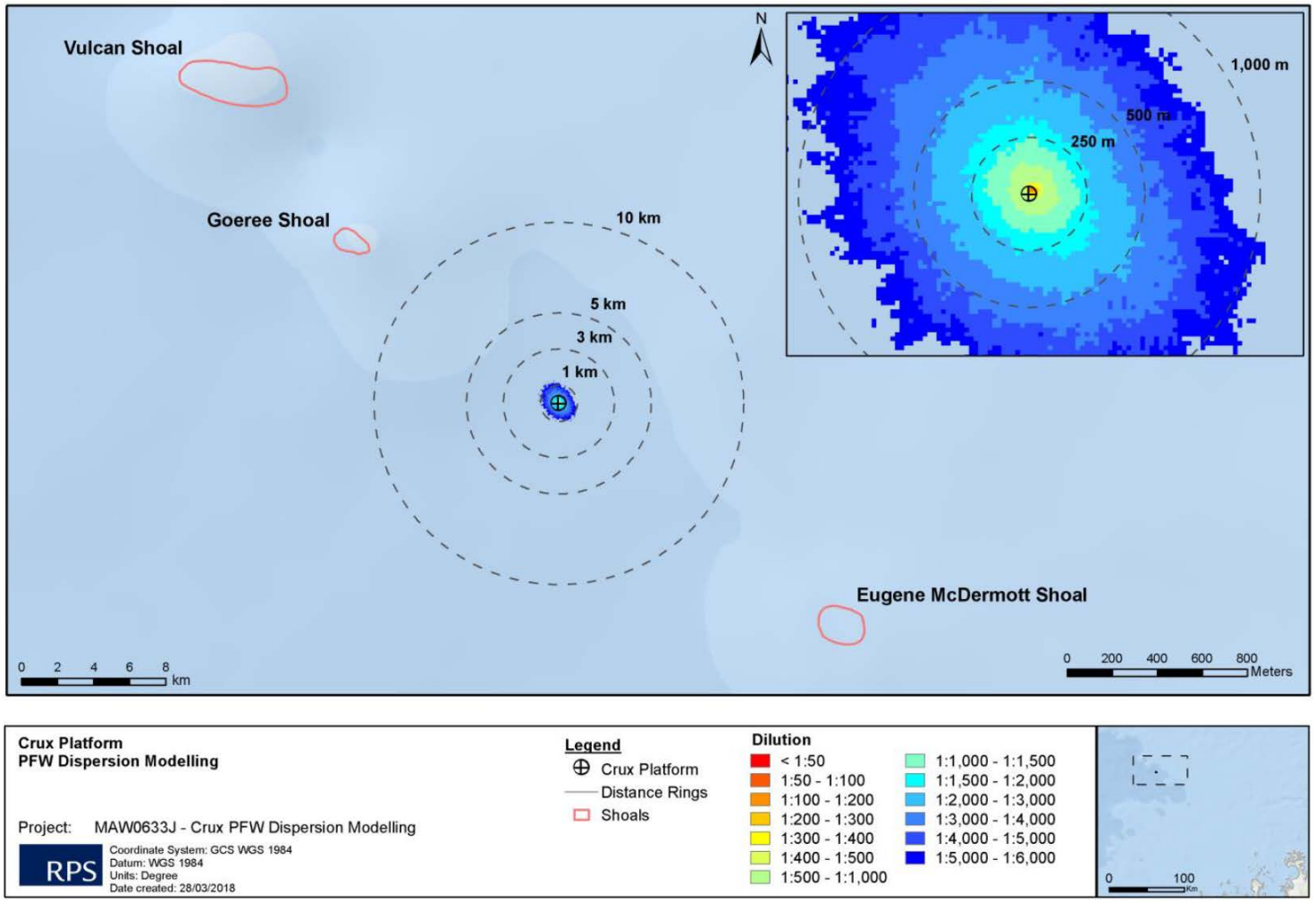


Figure 3.10 Predicted minimum dilutions under winter conditions for the early operations phase flow rate (287 m^3/d).

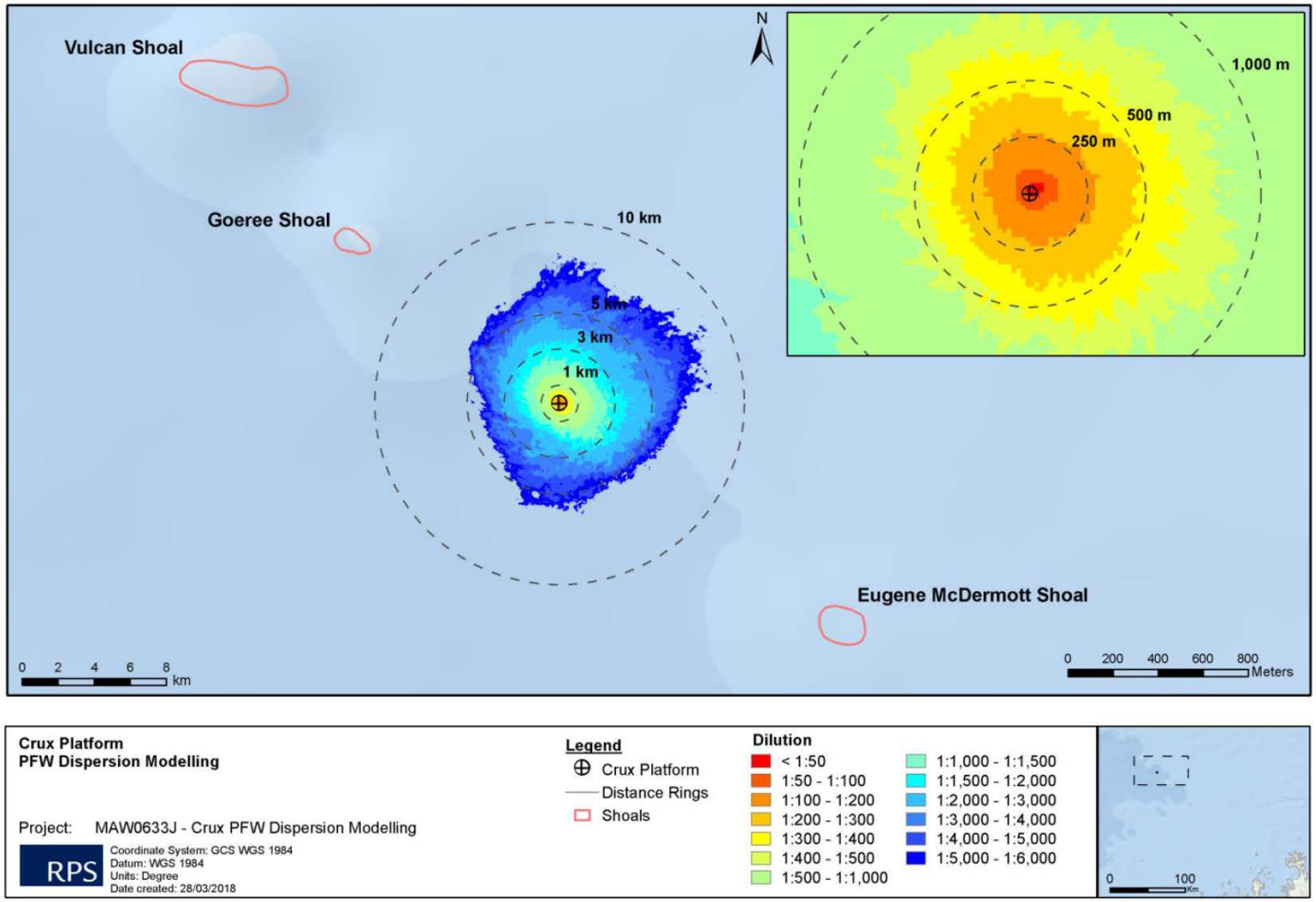


Figure 3.11 Predicted minimum dilutions under summer conditions for the later operations phase flow rate (3,179.8 m^3/d).

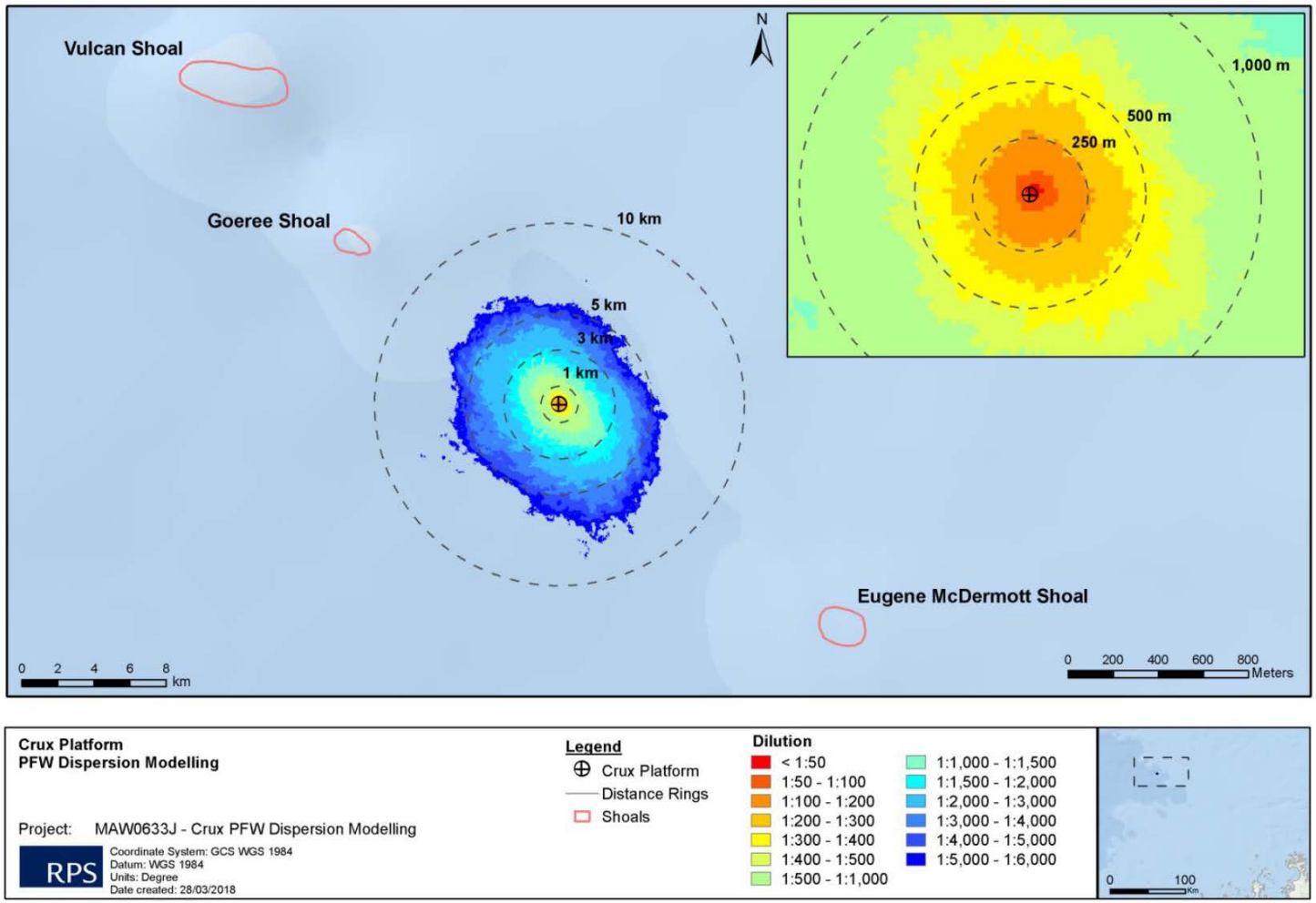


Figure 3.12 Predicted minimum dilutions under transitional conditions for the later operations phase flow rate (3,179.8 m^3/d).

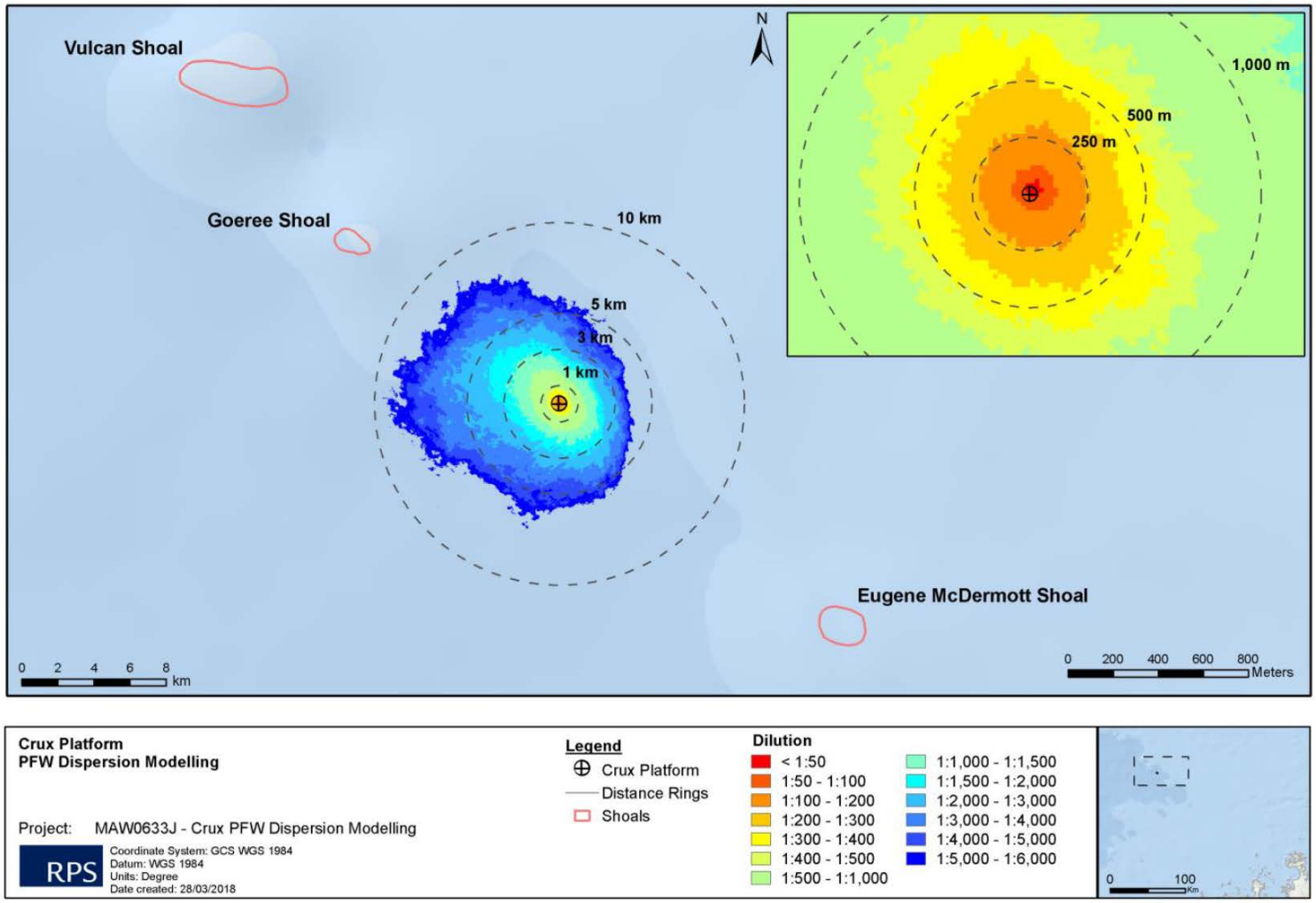


Figure 3.13 Predicted minimum dilutions under winter conditions for the later operations phase flow rate (3,179.8 m^3/d).

3.2.4 Annualised Analysis

The model outputs for each season (summer, transitional and winter) over the ten-year hindcast period (2008-2017) were combined and analysed on an annualised basis.

Table 3.12 shows the maximum distances from the discharge location to achieve a given dilution for each flow rate. The results indicate that the release of effluent under all seasonal conditions results in rapid dispersion of analytes within the ambient environment. Dilution to reach 99% Species Protection Level concentrations is achieved for all analytes within a maximum area of influence of 67 m (at the early operations flow rate of 287 m^3/d) and 999 m (at the later operations flow rate of 3,179.8 m^3/d) from the Crux platform location, this being the maximum spatial extent of the 1:500 dilution contour in any season. At the conservative outer extents of the plume defined by the 1:500 dilution contour, the plume will remain around 11 km from the nearest shoal (Goeree Shoal), and no exposure to harmful contaminant levels is expected for non-transient species.

Table 3.13 shows the total area of coverage for a given dilution for each flow rate. For all analytes, the area of exposure defined by the 1:500 dilution contour is predicted to reach a maximum of 2 km^2 in any season at the maximum later operations flow rate.

Figure 3.14 and Figure 3.15 show the aggregated spatial extents of the minimum dilutions for each flow rate. Note that the contours represent the lowest predicted dilution (highest concentration) at any given time-step through the water column and do not take into account frequency or duration.

The results presented assume that no processes other than dilution would reduce the source concentrations over time.

Table 3.12 Maximum distance from the PFW discharge location to achieve a given dilution for each flow rate.

Flow rate (m^3/d)	Season	Maximum distance (m) from discharge location to achieve given dilution											
		1:50 dilution	1:100 dilution	1:200 dilution	1:300 dilution	1:400 dilution	1:500 dilution	1:1,000 dilution	1:2,000 dilution	1:3,000 dilution	1:4,000 dilution	1:5,000 dilution	1:>6,000 dilution
287	Annualised	N/A	N/A	N/A	37	55	67	146	356	606	873	1,115	1,473
3,179.8	Annualised	71	135	332	601	807	999	2,263	4,696	6,495	7,814	8,906	9,519

Table 3.13 Total area of coverage for a given dilution for each flow rate.

Flow rate (m^3/d)	Season	Total area (km^2) of coverage for given dilution											
		1:50 dilution	1:100 dilution	1:200 dilution	1:300 dilution	1:400 dilution	1:500 dilution	1:1,000 dilution	1:2,000 dilution	1:3,000 dilution	1:4,000 dilution	1:5,000 dilution	1:>6,000 dilution
287	Annualised	N/A	N/A	N/A	<0.001	0.003	0.005	0.042	0.28	0.71	1.4	2.2	3.3
3,179.8	Annualised	0.004	0.032	0.21	0.61	1.2	2.0	9.1	35.5	67.9	104.6	131.9	156.5

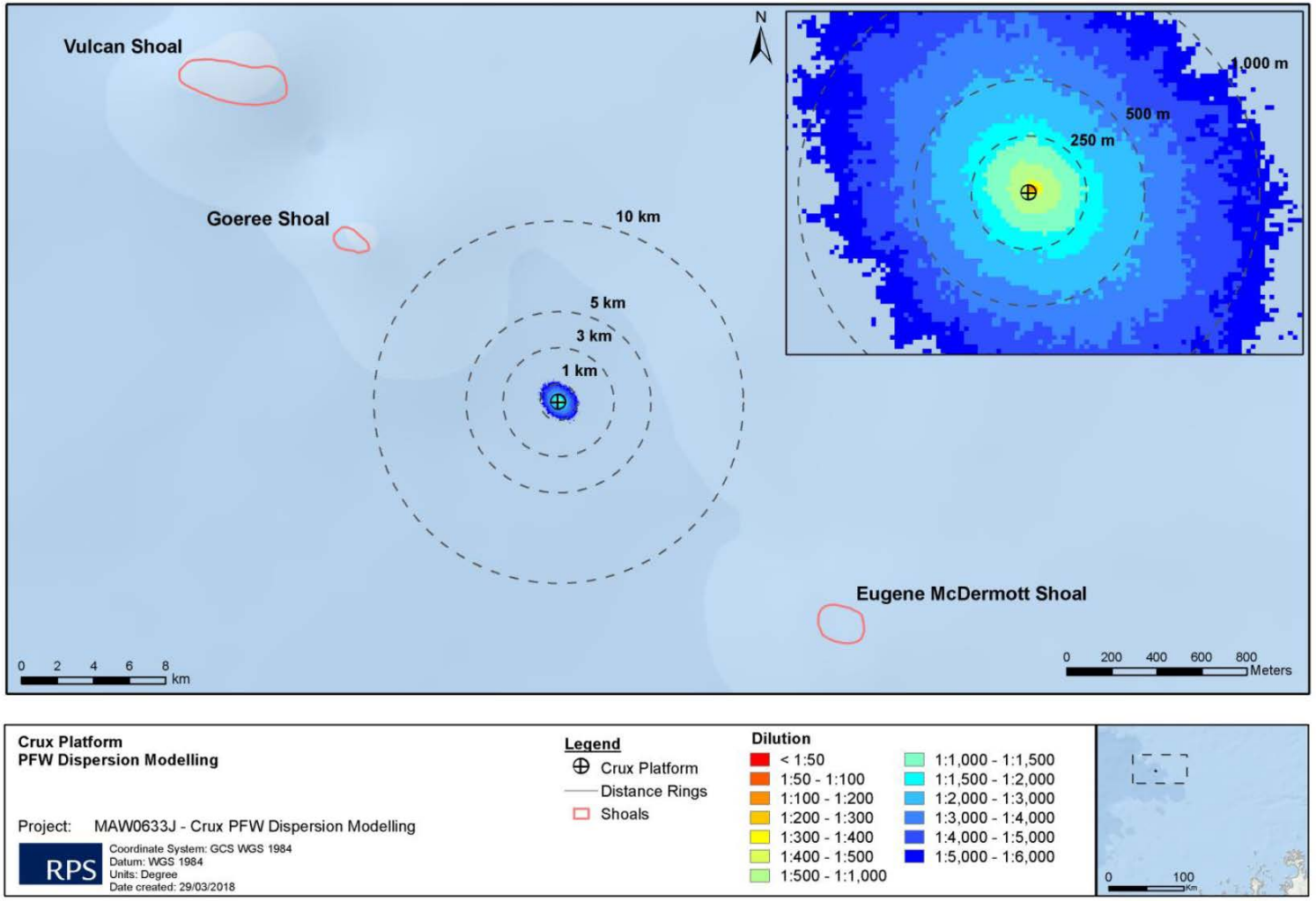


Figure 3.14 Predicted annualised minimum dilutions for the early operations phase flow rate (287 m^3/d).

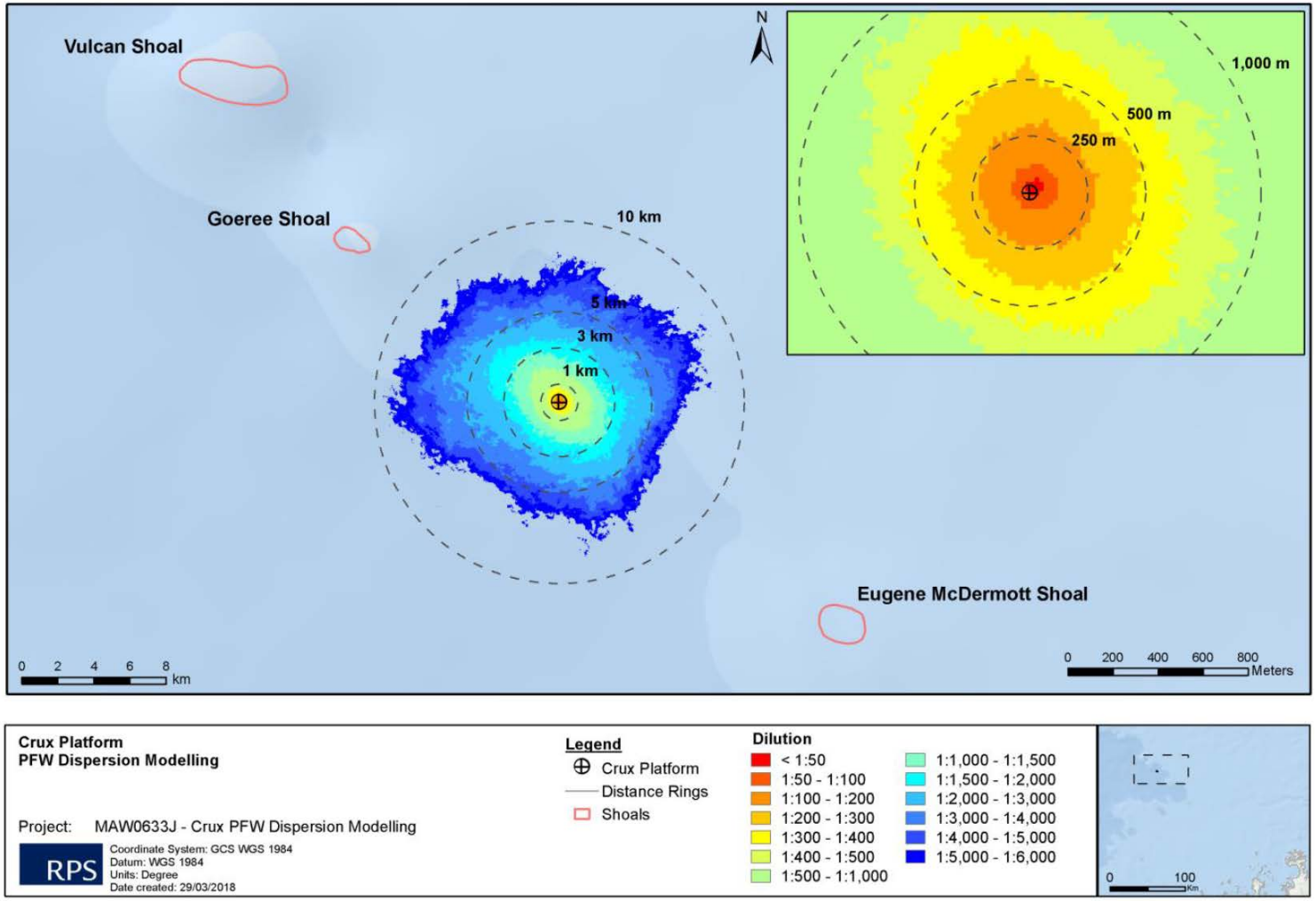


Figure 3.15 Predicted annualised minimum dilutions for the later operations phase flow rate (3,179.8 m^3/d).

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Appendix A

Marine Dispersion Modelling of PFW Discharges – Above Surface Discharge

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A1 Introduction

A1.1 Background

RPS has been commissioned by CDM Smith Australia Pty Ltd (CDM Smith), on behalf of Shell Australia Pty Ltd (Shell), to undertake a marine dispersion modelling study of proposed water discharges from the Crux platform (Table A 1). The Crux platform is located in the northern Browse Basin in offshore Commonwealth marine waters, approximately 190 km offshore north-west Australia and 620 km north-north-east of Broome.

Produced formation water (PFW) occurs naturally within the same rock strata as the hydrocarbons and comprises condensed water and saline formation water.

Operation of the fixed-jacket Crux platform will include discharges of PFW separated from the hydrocarbon production stream. The characteristics of the PFW discharge will transition during the operational life of the Crux platform. Discharges are expected to comprise mostly condensed water with minimal formation water produced during the early operations phase (approximately 8-9 years) (i.e. pre-formation water breakthrough). At around 9 years of operation the water produced will transition to a mixture of condensed water and formation water (i.e. post-formation water breakthrough). The amount of formation water is expected to comprise a greater proportion of the discharge as the field nears end of life, as is typically the case of maturing hydrocarbon fields.

Operational design for the facility has identified that the PFW discharges will vary from ambient seawater in terms of temperature, salinity, and the presence of trace amounts of process chemicals.

The principal aim of the study was to quantify the likely extents of the near-field and far-field mixing zones based on the required dilution levels for each of the identified constituents in the PFW discharge. This will indicate whether concentrations of any constituents are likely to be above stated threshold concentrations at the limits of the mixing zones (i.e. are not predicted to be diluted below the relevant threshold). The outcomes of this study have been provided in Section 3 of the main report.

An additional modelling exercise was undertaken to assess the potential changes in mixing and dilution that may occur if the PFW stream is discharged from the Crux platform above the sea surface rather than below it. This supplemental report compares the near-field and far-field outcomes of one below-surface discharge scenario and one above-surface discharge scenario:

- Case 1: A discharge at a flow rate of 3,179.8 m^3/day occurring 10 m below the water surface through a single horizontal outlet 6 inches in diameter with an anticipated salinity and temperature of 92.2 ppt and 44 °C, respectively.
- Case 2: A discharge at a flow rate of 3,179.8 m^3/day occurring 10 m above the water surface through a single vertical outlet 8 inches in diameter with an anticipated salinity and temperature of 92.2 ppt and 44 °C, respectively.

The potential area that may be influenced by these PFW discharge streams was assessed only for the summer season (December to February).

Table A 1 Location of the proposed Crux platform used as the release site for the PFW dispersion modelling assessment.

Release Site	Latitude (°S)	Longitude (°E)	Water Depth (m)
Crux Platform	12° 57’ 52.46”	124° 26’ 33.21”	170

A2 Discharge Characteristics

A2.1 Overview

The PFW discharge characteristics are summarised in Table A 2.

Table A 2 Summary of PFW discharge characteristics.

Parameter	Value/Design (Case 1)	Value/Design (Case 2)
Flow rate (m^3/d)	3,179.8 (maximum flow rate during later operations)	
Outlet pipe internal diameter (m) [in]	0.152 [6]	0.203 [8]
Outlet pipe orientation	Horizontal	Vertical
Depth of pipe below/above sea surface (m)	10 (below sea surface)	10 (above sea surface)
Discharge salinity (ppt)	92.2	
Discharge temperature (^oC)	44	

A2.2 Case 1: Discharge 10 m Below Sea Surface

The PFW plume will be warmer and considerably more saline than the receiving waters, resulting in negative buoyancy relative to the surrounding water. Following initial turbulent mixing in the immediate vicinity of the discharge, the plume will plunge downwards. The path of the plume during this sinking phase will be deflected by the local current, depending upon the prevailing current speed and the rate of plume sinking. Ambient water will be entrained and mixed as the plume sinks, increasing the buoyancy and slowing the rate of fall, while lowering the concentration of chemical constituents.

Figure A 1 shows a conceptual diagram of the dispersion and fates of a negatively buoyant discharge and the idealised representation of the discharge phases.

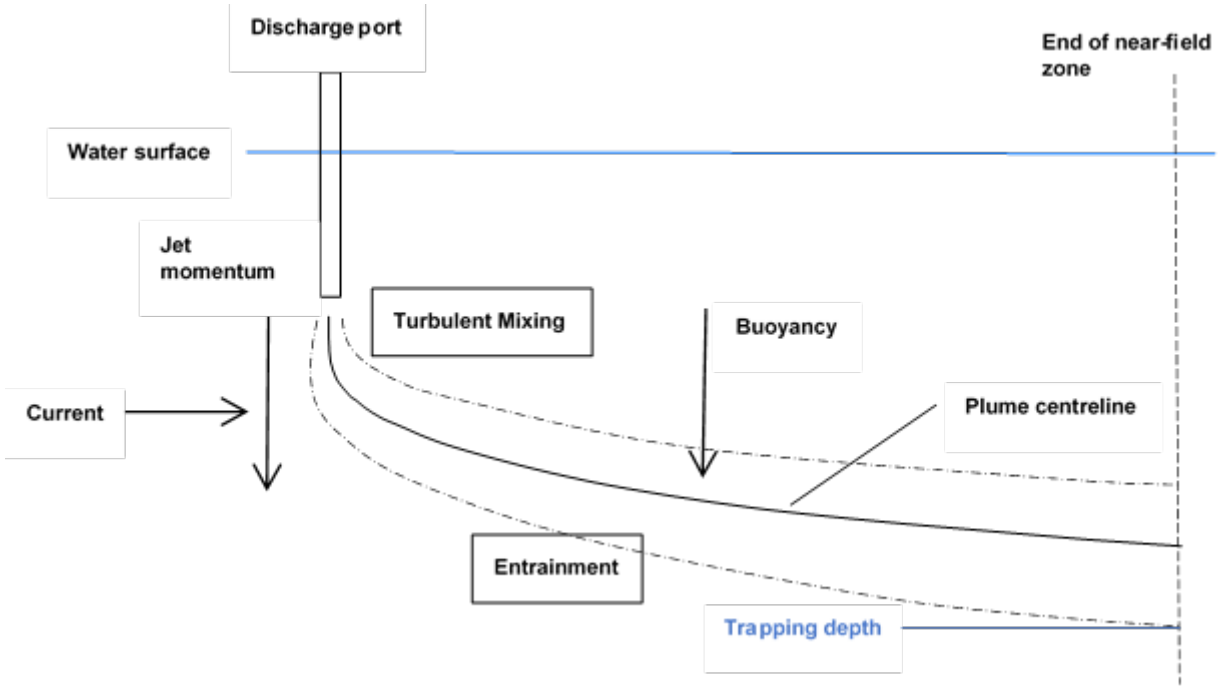


Figure A 1 Conceptual diagram showing the general behaviour of a negatively buoyant discharge.

A2.3 Case 2: Discharge 10 m Above Sea Surface

Large-scale plunging jets impacting a free surface of water, such as the discharge of a PFW stream at a height above the sea surface through a downward-pointing pipe, is a complex problem. The physical phenomena concerning the behaviour of large-scale plunging jets are still not well understood. For jet diameters of more than around 10 cm, studies include those of Guyot *et al.* (2016).

Jet dynamics probes a wide range of physical properties, such as liquid surface tension, viscosity, air entrainment caused by transition between confined and unconfined flows, and density contrast with its environment (Eggers & Villermaux, 2008). On very large scales, gravitational interactions are important. The basic flow state can be both laminar or turbulent. Flow in a pipe is laminar if the Reynolds number (based on the diameter of the pipe) is less than 2,100 and is turbulent if it is greater than 4,000. Between these limits, transitional flow conditions occur. The Reynolds number is calculated as follows:

$$Re = \frac{\rho_l V_0 D_0}{\mu}$$

Where: R_e is the Reynolds number, ρ_l is the volumetric mass density of the liquid, V_0 is the average velocity at the outlet, D_0 is the outlet diameter and μ is the dynamic viscosity of the liquid.

For the purposes of modelling, the above-surface PFW discharge is considered uniform (homogeneous) with no breaking of the jet before it reaches the water surface. For the proposed discharge, a relatively high Reynolds number of ~400,000 indicates that the flow is fully turbulent at the outlet.

Figure A 2 shows a conceptual diagram of the continuous turbulent and laminar flow cases of a large-scale plunging jet, and a resulting negatively buoyant plume.

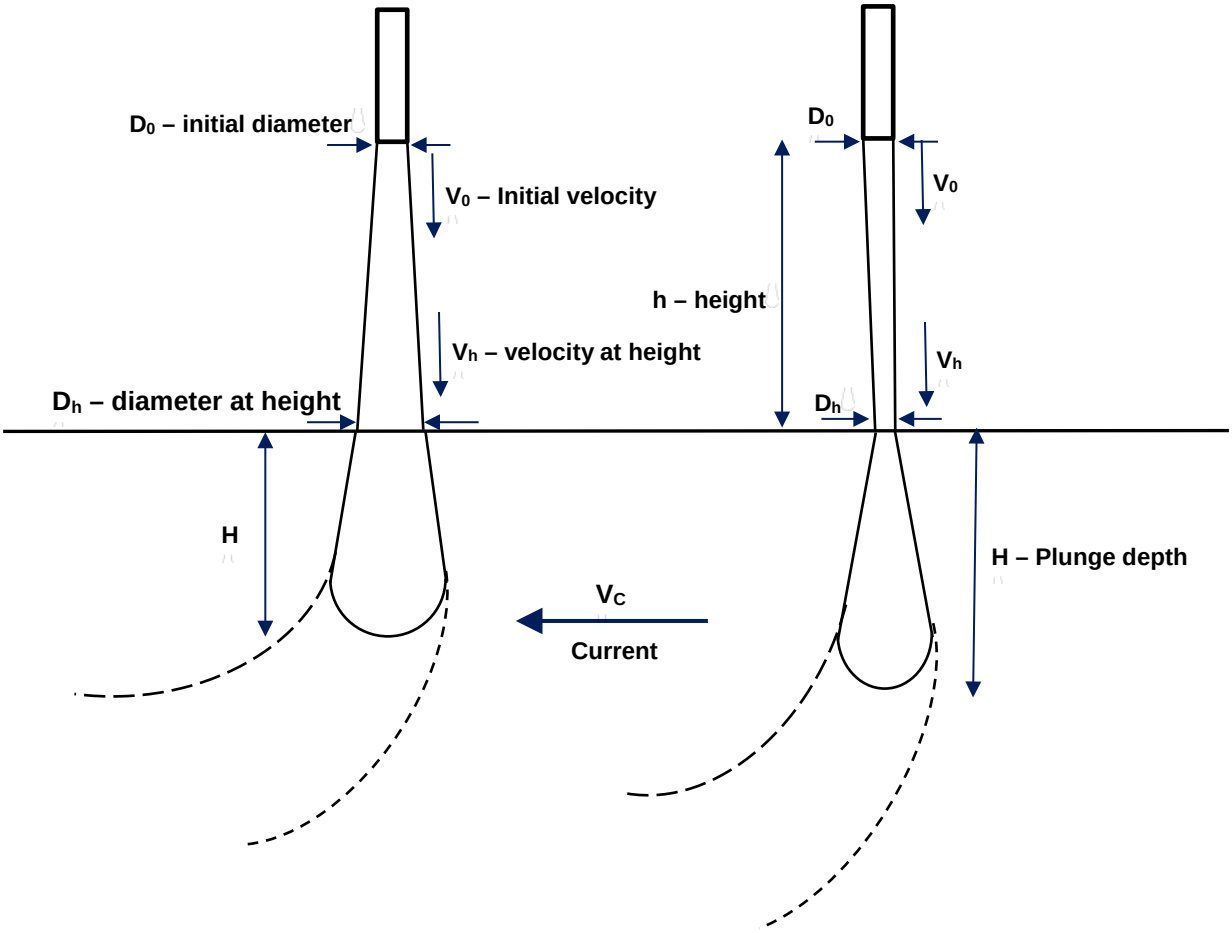


Figure A 2 Conceptual diagram of the continuous turbulent (left) and laminar (right) flow cases of a large-scale plunging jet.

Air entrainment of a plunging jet often occurs when the confined flow of a jet breaks the free-surface of the water causing air-disturbed flows (Guyot *et al.*, 2016). This produces air bubbles under the free surface with an ascent velocity which can impact on the penetration depth of the plume. The following empirical formula proposed by Nakasone (1987), found to be in good agreement with the experimental results detailed in Guyot *et al.* (2016), was used to calculate the penetration depth in this study:

$$H = \frac{2}{3} * H_C$$

Where: H is the penetration depth and H_c is the height of the discharge. The penetration depth was calculated to be 6.7 m below the sea surface.

A3 Modelling Methods

A3.1 Near-Field Modelling

A3.1.1 Overview

An overview of near-field modelling processes is provided in Section 2.1.1 of the main report.

A3.1.2 Description of Near-Field Model: Updated Merge

A description of the UM3 near-field model is provided in Section 2.1.2 of the main report.

A3.1.3 Setup of Near-Field Model

The setup of the near-field model is as described in Section 2.1.3 of the main report, with only summer season conditions being considered.

A3.2 Far-Field Modelling

A3.2.1 Overview

An overview of far-field modelling processes is provided in Section 2.2.1 of the main report.

A3.2.2 Description of Far-Field Model: MUDMAP

A description of the MUDMAP far-field model is provided in Section 2.2.2 of the main report.

A3.2.3 Setup of Far-Field Model

The setup of the far-field model is as described in Sections 2.2.4 and 2.2.5 of the main report, with only summer season conditions being considered and only one simulation run for this period (rather than a stochastic approach).

A4 Modelling Results

A4.1 Near-Field Modelling

A4.1.1 Overview

Forecast plume dimensions and dilutions at the end of the near-field mixing zone for Case 1 (horizontal discharge 10 m below sea level) and Case 2 (vertical discharge 10 m above sea level) under varying current speeds in summer are summarised in Table A 3.

Figure A 3 and Figure A 4 (note the differing x-axis and y-axis aspect ratios) show the change in average temperature and dilution of the plume under varying current speeds (weak, medium and strong) in summer for Case 1 and Case 2, respectively. The figures show the predicted horizontal distances travelled by the plume before the trapping depth is reached (i.e. before the plume becomes neutrally buoyant).

The initial behaviour of the discharge plume is dependent on the discharge conditions (below/above sea surface) and the orientation of the discharge port. For Case 1, the plume moves straight out from the port horizontally and there is no downward momentum. After a period of turbulent mixing due to the momentum of the discharge, the negative buoyancy of the plume causes it to plunge in the water column before it reaches the trapping depth (i.e. the plume becomes neutrally buoyant). For Case 2, the plume plunges downwards after breaking the sea surface, initially due to momentum and then due to its negative buoyancy, before reaching the trapping depth. In both cases, increased ambient current strengths are shown to reduce the plunge depth and increase the horizontal distance travelled by the plume from the discharge point. After the initial behavior of the jet phase of the discharges, the plumes are expected to behave in a similar manner.

The Case 1 plume is forecast to reach neutral density at centreline depths of 21-41 m below the sea surface. This range is forecast to reduce to 14-34 m below the sea surface for the Case 2 plume. In contrast, the minimum and average dilution ranges for Case 2 were predicted to increase in comparison to Case 1, with average dilution ranging between 1:581 and 1:2,169 for Case 1 and between 1:714 and 1:3,290 for Case 2. This is perhaps due to the increased momentum during the initial jet phase of the vertical discharge as it enters the water.

It should be noted that the effects of plunging jet breakup, air entrainment and other non-linear effects were not considered in the modelling process.

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A4.1.2 Results Tables and Figures

Table A 3 Predicted plume characteristics at the end of the near-field mixing zone for the later operations phase flow rate (3,179.8 m^3/d) for each discharge case and current speed.

Discharge Case	Surface Current Speed (m/s)	Plume Diameter (m) at Depth Below Sea Level (BSL) [m]	Plume Temperature (°C)	Plume-Ambient Temperature Difference (°C)	Plume Dilution (1:x)		Maximum Horizontal Distance (m)
					Minimum	Average	
Case 1	Weak (0.06)	20.9 [40.5]	28.86	0.50	198	581	22.2
	Medium (0.22)	19.3 [24.9]	29.22	0.16	445	1,699	73.4
	Strong (0.42)	15.8 [21.2]	29.31	0.13	565	2,169	139.6
Case 2	Weak (0.06)	23.7 [33.9]	29.15	0.46	244	714	16.0
	Medium (0.22)	20.8 [17.9]	29.45	0.16	531	2,020	66.5
	Strong (0.42)	19.0 [14.3]	29.52	0.12	875	3,290	149.2

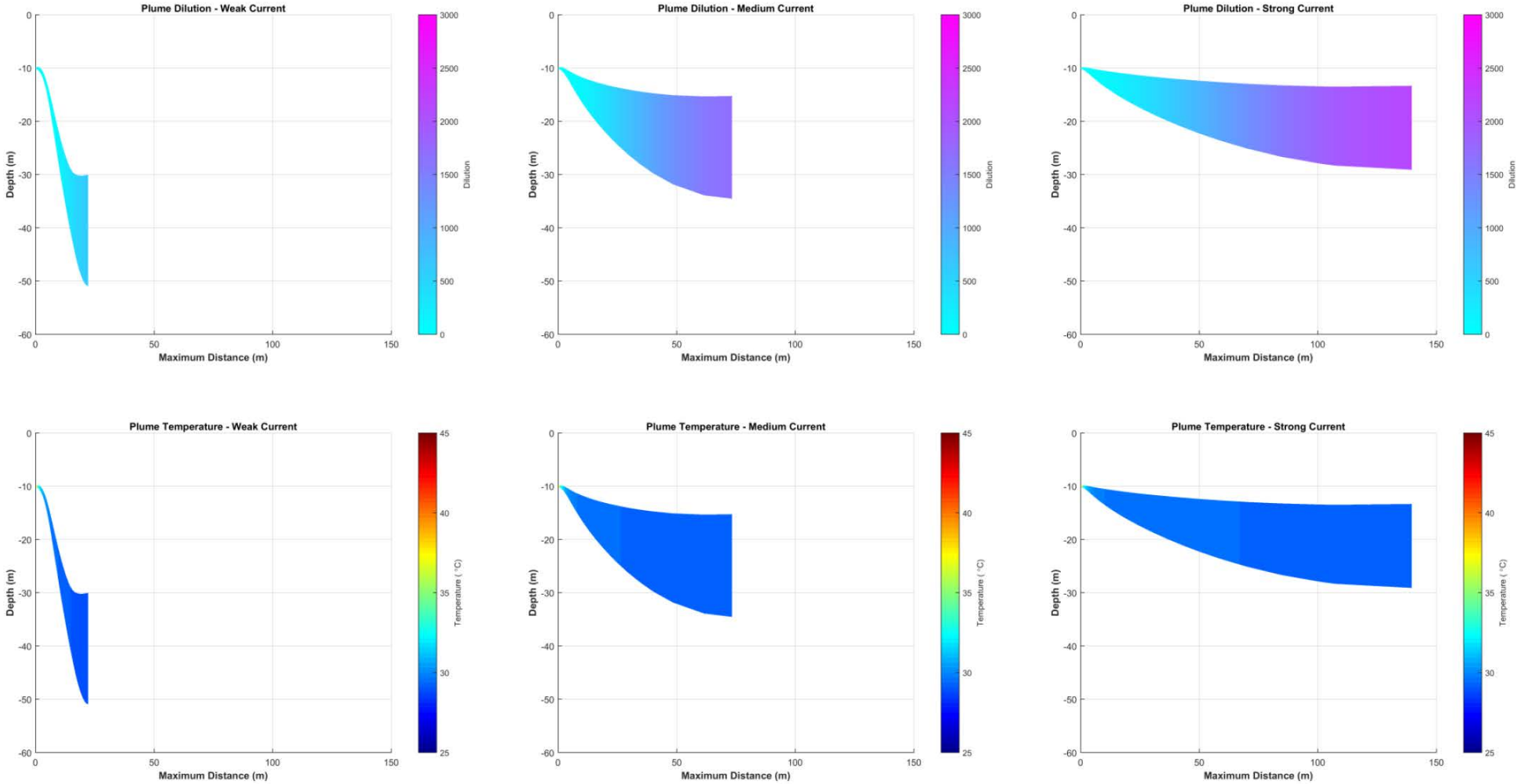


Figure A 3 Near-field Case 1 average temperature and dilution results for weak, medium and strong summer currents (3,179.8 m^3/d flow rate).

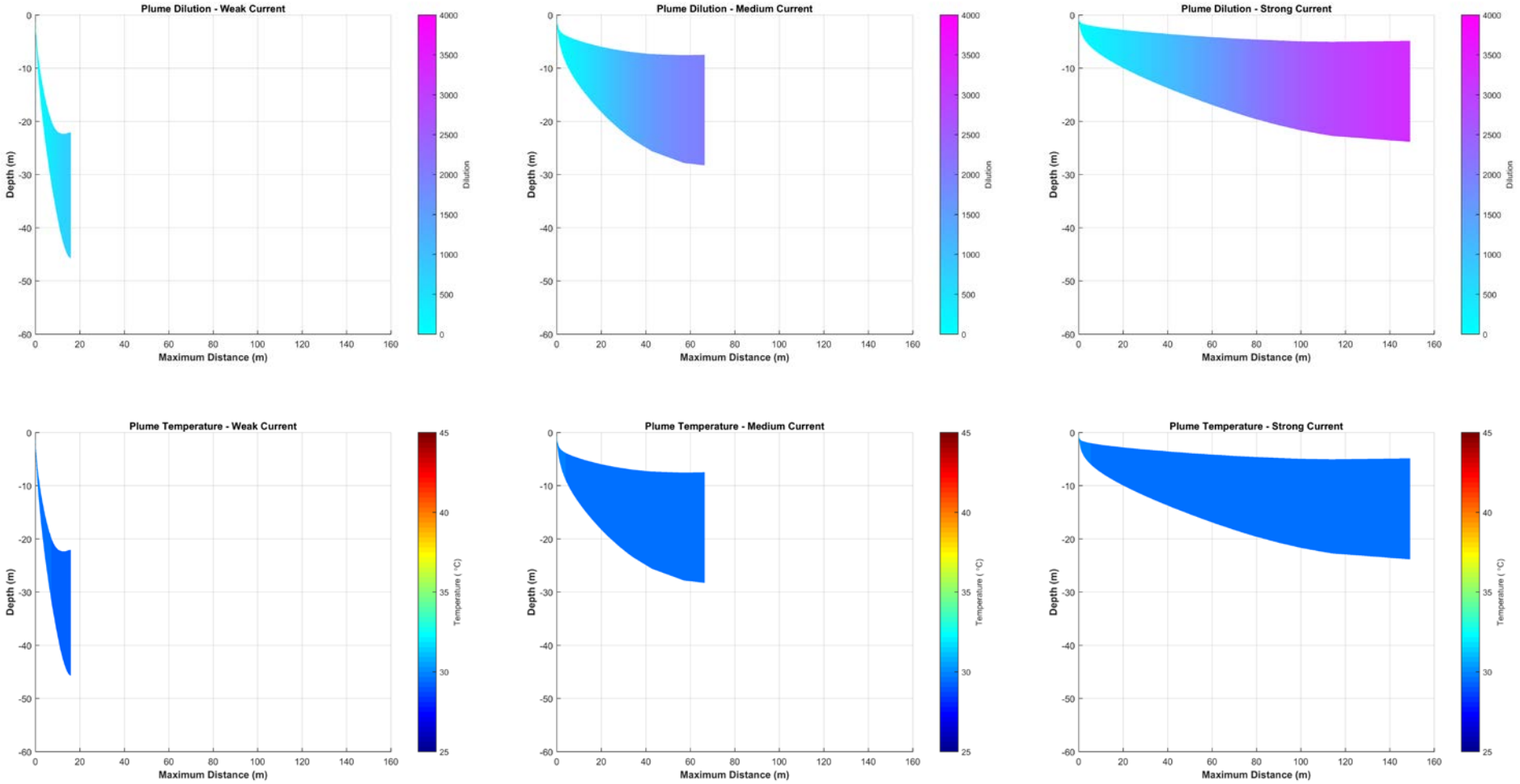


Figure A 4 Near-field Case 2 average temperature and dilution results for weak, medium and strong summer currents (3,179.8 m^3/d flow rate).

A4.2 Far-Field Modelling

A4.2.1 Overview

It is important to note that near-field and far-field modelling are used to describe different processes and scales of effect, and therefore the far-field modelling results will not necessarily correspond to the outcomes at the end of the near-field mixing zone for any given discharge scenario. The far-field results included episodes of pooling of the discharge plume under weak currents, which caused lower dilutions (higher concentrations) further from the discharge location when the pooled plume was advected away. Episodes of recirculation – where the plume moved back under the discharge at some later time due to the oscillatory nature of the tide – were also observed, compounding the pooling effect and further lowering the dilution values.

A single model simulation for Case 1 (horizontal discharge 10 m below sea level) and Case 2 (vertical discharge 10 m above sea level) was run to compare forecast dilutions and plume dimensions in the far-field during summer conditions within the ten-year hindcast period (2008-2017).

Table A 4 summarises the minimum dilution achieved at specific radial distances from the discharge location for each discharge case.

Table A 5 provides a summary of the maximum distances from the discharge location to achieve a given dilution for each discharge case. The results indicate that, for a release of effluent under typical summer conditions, Case 1 exhibited lower dilution (higher concentrations) within 2 km of the discharge location when compared to Case 2. This effect was reversed for distances beyond 2 km, with Case 2 exhibiting lower dilution (higher concentrations).

Figure A 5 and Figure A 6 show the spatial extents of the minimum dilutions for each discharge case during typical summer conditions. Note that the contours represent the lowest predicted dilution (highest concentration) at any given time-step through the water column and do not consider frequency or duration.

From the near-field modelling (Section A4.1), the above-surface discharge plume (Case 2) is predicted to have a reduced plunge depth due to the nature of the discharge, so the plume in the far-field is subjected to a current regime closer to the water surface than the Case 1 plume. This is highlighted when comparing the spatial extent and distribution of the dilution contours for Case 1 (Figure A 5) and Case 2 (Figure A 6). The Case 2 results show a reduced footprint and higher dilution (lower concentrations) near the discharge location, indicating increased mixing due to the influence of a stronger current regime. The influence of stronger currents may also result in plume remnants travelling further from the discharge location in Case 2.

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A4.2.2 Results Tables and Figures

Table A 4 Minimum dilution achieved at specific radial distances from the PFW discharge location for each discharge case.

Discharge Case	Minimum dilution (1:x) achieved at specific radial distances from discharge location						
	0.1 km	0.5 km	1 km	2 km	3 km	5 km	>5 km
Case 1	1:114	1:355	1:596	1:1,015	1:1,647	1:2,834	1:2,834
Case 2	1:133	1:386	1:698	1:1,219	1:1,673	1:2,583	1:2,583

Table A 5 Maximum distance from the PFW discharge location to achieve a given dilution for each discharge case.

Discharge Case	Maximum distance (m) from discharge location to achieve given dilution							
	1:50 dilution	1:100 dilution	1:300 dilution	1:500 dilution	1:1,000 dilution	1:3,000 dilution	1:5,000 dilution	1:>6,000 dilution
Case 1	35	78	392	783	1,909	5,280	7,225	7,750
Case 2	N/A	44	380	660	1,518	5,917	8,698	9,041

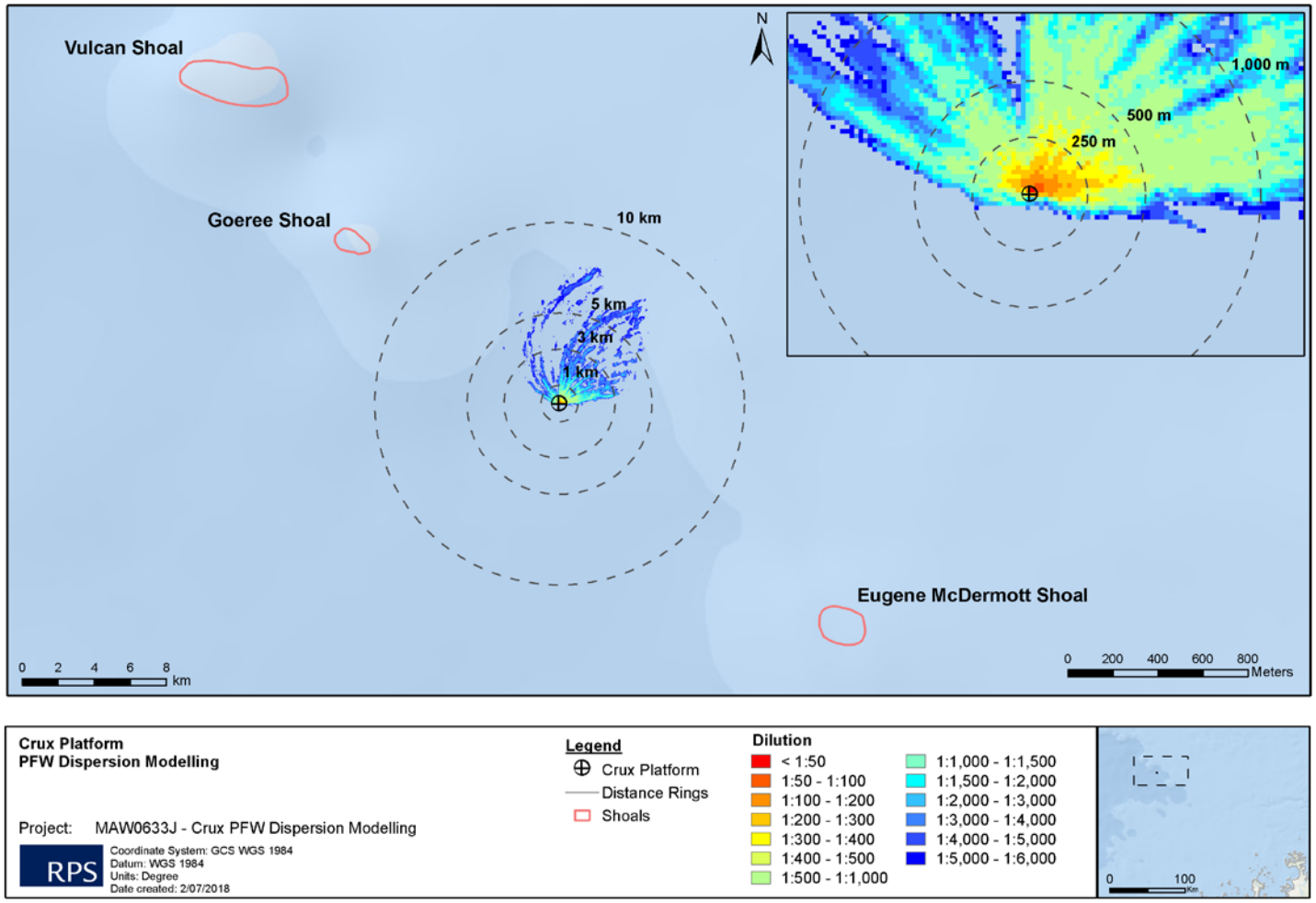


Figure A 5 Predicted Case 1 minimum dilutions under summer conditions for the later operations phase flow rate (3,179.8 m^3/d).

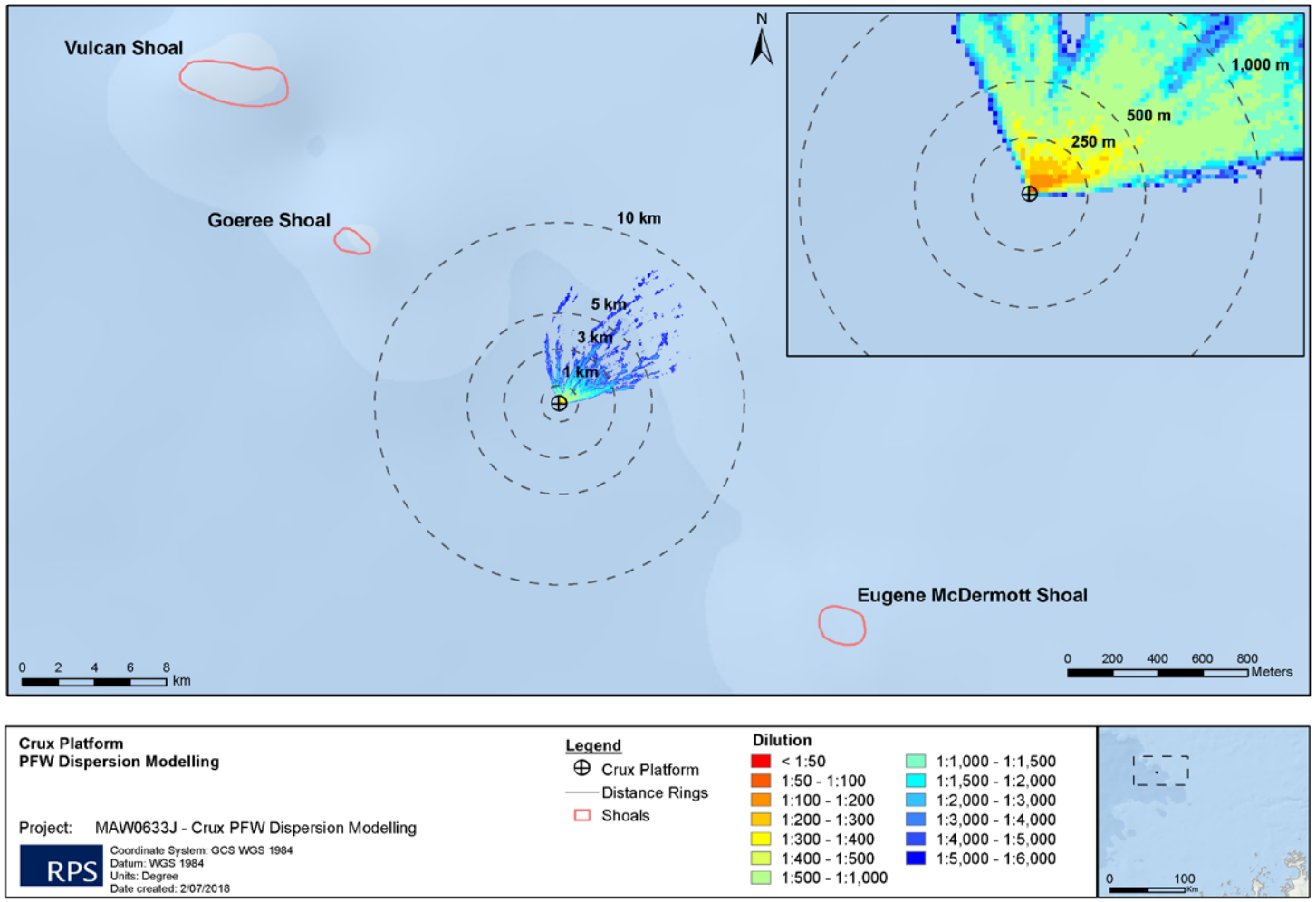


Figure A 6 Predicted Case 2 minimum dilutions under summer conditions for the later operations phase flow rate (3,179.8 m^3/d).

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Appendix F: Pipeline and Hydrotest Discharge Modelling Study (RPS 2018c)

REPORT

Shell Crux Project

Marine Dispersion Modelling of Pipeline Hydrotest Discharges

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1 Introduction

1.1 Background

RPS has been commissioned by CDM Smith Australia Pty Ltd (CDM Smith), on behalf of Shell Australia Pty Ltd (Shell), to undertake a marine dispersion modelling study of proposed water discharges from pipeline hydrotest operations at the Crux end of the export pipeline (i.e. at the proposed Crux Not Normally Manned (NNM) platform location) (Table 1.1). The Crux NNM platform (herein referred to as the 'Crux platform') is located in the northern Browse Basin in offshore Commonwealth marine waters, approximately 190 km offshore north-west Australia and 620 km north-north-east of Broome.

During pre-commissioning activities for the Crux project, Shell will undertake system leak testing, dewatering and preservation of the infield subsea facilities. Chemically-treated seawater will be used for hydrostatic pipeline testing (or hydrotesting) of the infield subsea facilities. The water will be chemically treated with biocide, a hydrate inhibitor and an oxygen scavenger to ensure that corrosion attributable to oxygen, bacterial and microbial action does not occur. While the actual location of hydrotest discharge (potentially at either the Prelude or Crux end of the export pipeline) is unknown at this early stage of engineering definition, this study has conservatively assumed discharge at the Crux end.

The principal aim of the study was to quantify the likely extents of the near-field and far-field mixing zones based on the required dilution levels for each of the identified constituents (i.e. biocide) in the hydrotest discharge from the export pipeline, as this is representative of the largest volume of hydrotest water that will be discharged from Crux project activities. This will indicate whether concentrations of any contaminants are still likely to be above defined threshold levels at the limits of the mixing zones (i.e. are not predicted to be diluted below the relevant threshold).

To accurately determine the dilution of the hydrotest discharge and the total potential area of influence, the effect of near-field mixing needs to be considered first, followed by an investigation of the far-field mixing performance. Different modelling approaches are required for calculating near-field and far-field dilutions due to the differing hydrodynamic scales.

To assess the rate of mixing of the biocide in the hydrotest plume from the Crux export pipeline, dispersion modelling was carried out for a flow rate of 0.3 m^3/s (based on 0.3 m^3 volume per metre of pipe and 1 m/s pig speed) over a discharge duration of 44 hours, yielding a total discharge volume of 47,520 m^3.

The potential area that may be influenced by the hydrotest discharge plume was assessed for three distinct seasons: (i) summer (December to February); (ii) the transitional periods (March and September to November); and (iii) winter (April to August).

Table 1.1 Location of the proposed Crux platform used as the release site for the export pipeline hydrotest dispersion modelling assessment.

Release Site	Latitude (°S)	Longitude (°E)	Water Depth (m)
Crux platform (i.e. Crux end of the export pipeline)	12° 57' 52.46"	124° 26' 33.21"	170

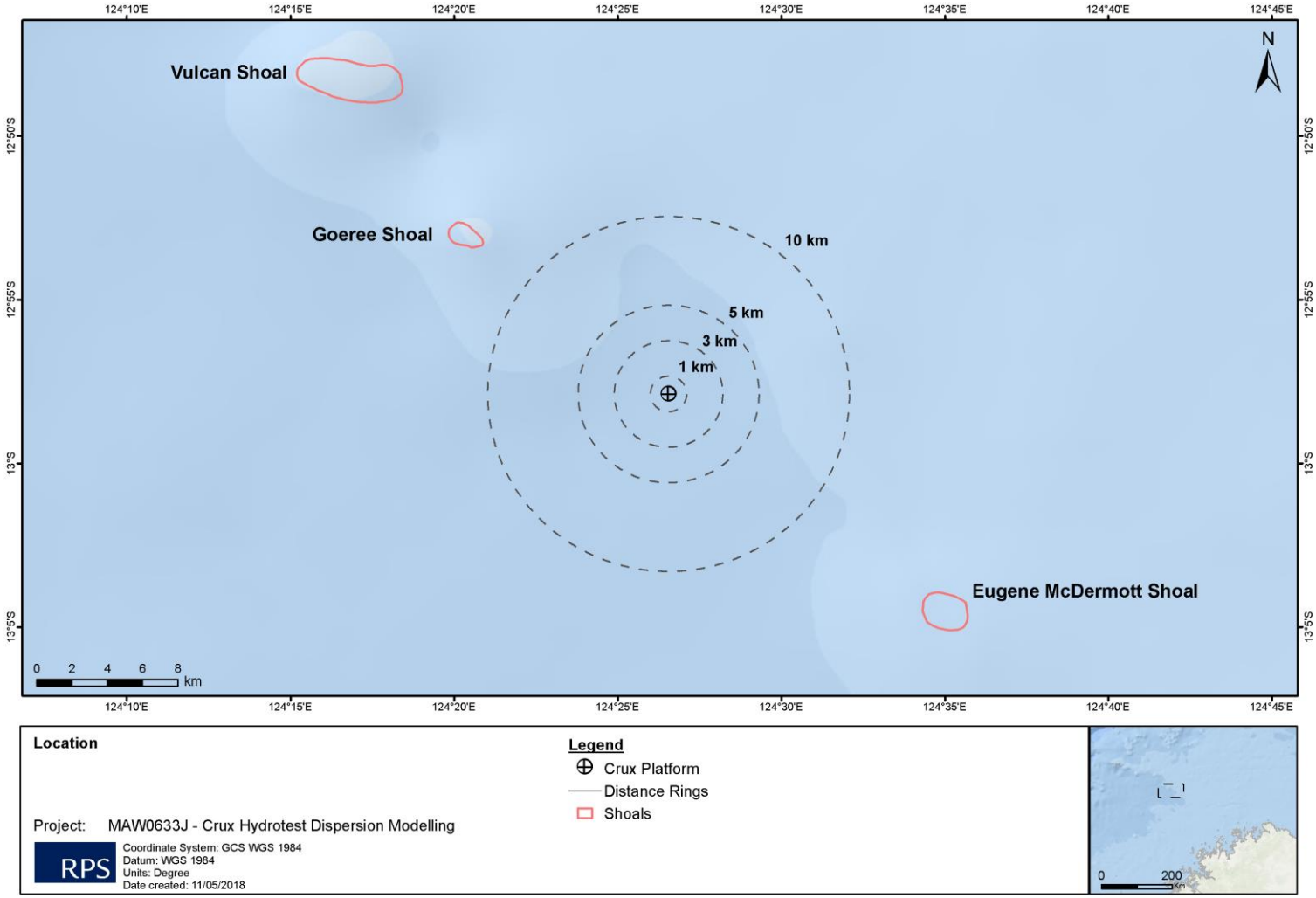


Figure 1.1 Location of the proposed Crux platform relative to the nearest submerged shoals.

1.2 Modelling Scope

The physical mixing of the hydrotest plume was first investigated for the near-field mixing zone. The limits of the near-field mixing zone are defined by the area where the levels of mixing and dilution are controlled by the plume's initial jet momentum and the buoyancy flux, resulting from density differences between the plume and the receiving water. When the plume encounters a boundary such as the seabed, near-field mixing is complete. At this point, the plume is considered to enter the far-field mixing zone.

The scope of the modelling included the following components:

1. Collation of a suitable three-dimensional, spatially-varying current data set surrounding the proposed Crux platform location for a ten-year (2008-2017) hindcast period. The current data set included the combined influence of drift and tidal currents and was suitably long as to be indicative of interannual variability in ocean currents. The current data set was validated against the metocean data collected in the Crux development area.
2. Derivation of statistical distributions for the current speed and directions for use in the near-field modelling. Analyses included percentile distributions and development of current roses. This analysis was important to ensure that current data samples applied in the dispersion model were statistically representative.
3. Collation of seasonally-varying vertical water density profiles at the Crux development area for use as input to the dispersion models.
4. Near-field modelling conducted for each unique discharge to assess the initial mixing of the discharge due to turbulence and subsequent entrainment of ambient water. This modelling was conducted at high spatial and temporal resolution (scales of metres and seconds, respectively).
5. Outcomes from the near-field modelling included estimates of the width, shape and orientation of the plumes, and resulting contaminant concentrations and dilutions, for each discharge at a range of incident current speeds.
6. Establishment of a far-field dispersion model to repeatedly assess discharge scenarios under different sample conditions, with each sample represented by a unique time-sequence of current flow, chosen at random from the time series of current data.
7. Analysis of the results of all simulations to quantify, by return frequency, the potential extent and shape of the mixing zone.

2 Modelling Methods

2.1 Near-Field Modelling

2.1.1 Overview

Numerical modelling was applied to quantify the area of influence of the hydrotest water discharges, in terms of the distribution of the maximum contaminant concentrations that might occur with distance from the source given defined discharge configurations, source concentrations, and the distribution of the metocean conditions affecting the discharge location.

The dispersion of the hydrotest water discharge will depend, initially, on the geometry and hydrodynamics of the discharges themselves, where the induced momentum and buoyancy effects dominate over background processes. This region is generally referred to as the near-field zone and is characterised by variations over short time and space scales. As the discharges mix with the ambient waters, the momentum and buoyancy signatures are eroded, and the background – or ambient – processes become dominant.

The shape and orientation of the discharged water plumes, and hence the distribution and dilution rate of the plume, will vary significantly with natural variation in prevailing water currents. Therefore, to best calculate the likely outcomes of the discharges, it is necessary to simulate discharge under a statistically representative range of current speeds representative of the Crux development area.

2.1.2 Description of Near-Field Model: Updated Merge

The near-field mixing and dispersion of the water discharge was simulated using the Updated Merge (UM3) flow model. The UM3 model is a three-dimensional Lagrangian steady-state plume trajectory model designed for simulating single and multiple-port submerged discharges in a range of configurations, available within the Visual Plumes modelling package provided by the United States Environmental Protection Agency (Frick *et al.*, 2003). The UM3 model was selected because it has been extensively tested for various discharges and found to predict observed dilutions more accurately (Roberts & Tian, 2004) than other near-field models (i.e. RSB and CORMIX).

In the UM3 model, the equations for conservation of mass, momentum, and energy are solved at each time step, giving the dilution along the plume trajectory. To determine the change of each term, UM3 follows the shear (or Taylor) entrainment hypothesis and the projected-area-entrainment (PAE) hypothesis, which quantifies forced entrainment in the presence of a background ocean current. The flows begin as round buoyant jets and can merge to a plane buoyant jet (Carvalho *et al.*, 2002). Model output consists of plume characteristics including centreline dilution, rise-rate, width, centreline height and plume diameter. Dilution is reported as the “effective dilution”, the ratio of the initial concentration to the concentration of the plume at a given point, following Baumgartner *et al.* (1994).

The near-field zone ends where the discharged plume reaches a physical boundary or assumes the same density as the ambient water.

Figure 2.1 shows a conceptual diagram of the dispersion and fates of negatively buoyant discharge and the idealised representation of the discharge phases.

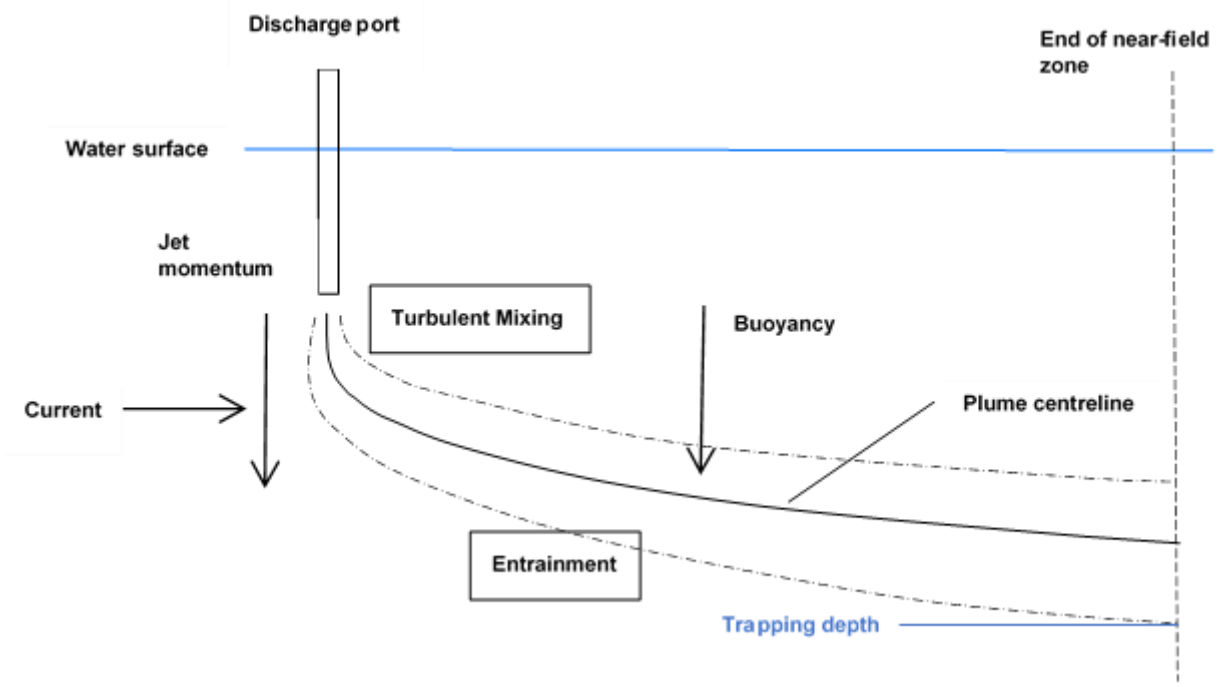


Figure 2.1 Conceptual diagram showing the general behaviour of a negatively buoyant discharge.

2.1.3 Setup of Near-Field Model

2.1.3.1 Discharge Characteristics

The hydrotest discharge characteristics are summarised in Table 2.1. The discharge was assumed to occur 166.5 m below the water surface (2 m above the seabed) through a single outlet and was anticipated to have a salinity and temperature of 34.5 parts per thousand (ppt) and 16.9 °C (average near-seabed water temperature), respectively.

The volume of hydrotest water is 47,520 m^3 and represents the full capacity of the pipeline. Based on the engineering definitions available at the time of undertaking the dispersion modelling study, it is anticipated that the dewatering of the export pipeline will take approximately 44 hours at an average flow rate of 0.3 m^3/s (0.3 m^3 volume per metre of pipe and 1 m/s pig speed).

The concentration of the constituents (biocide) within the discharge is described in Table 2.2. The concentration of biocide was conservatively set at 500 ppm. Although it is anticipated that the residual biocide concentration at the time of discharge will be significantly lower than the initial concentration (i.e. the biocide is expected to be fully used up at the time of commissioning of the export pipeline), the residual discharge concentration was assumed to be the same as the initial dosing concentration.

The biocide threshold concentration/trigger value used as part of this study was 1 ppm (equivalent to 1 mg/L) and is based on the published acute toxicity test data, including that presented in the Wheatstone Project Offshore Facilities and Produced Formation Water Discharge Management Plan: Stage 1 (Chevron, 2015). Note that ecotoxological studies are typically undertaken using constant doses of toxicants for periods of 48 to 96 hours. Results obtained using this approach are difficult to apply directly to the natural environment, where the concentrations and exposure durations for toxicants can vary rapidly. Based on the initial

concentration of biocide in the hydrotest water, a dilution of 1:500 is required to reduce the concentration of biocide to the impact threshold.

Table 2.1 Summary of hydrotest discharge characteristics.

Parameter	Value/Design
Discharge volume (m^3)	47,520
Discharge duration (hours)	44
Flow rate (m^3/s)	0.3
Outlet pipe internal diameter (m)	0.62
Outlet pipe orientation	Horizontal
Depth of pipe below sea surface (m)	166.5
Discharge salinity (ppt)	34.5
Discharge temperature (°C)	16.9

Table 2.2 Constituents contained within the hydrotest discharge.

Contaminant	Source Concentration (ppm)	Threshold Concentration (ppm)	Required Dilution Factor
Biocide	500	1	500

2.1.3.2 Ambient Environmental Conditions

Inputs of ambient environmental conditions to the UM3 model included a vertical profile of temperature and salinity, along with constant current speeds and general direction. The temperature and salinity profile are required to accurately account for the buoyancy of the diluting plume, while the current speeds control the intensity of initial mixing and the deflection of the hydrotest plume. These inputs are described in the following sections.

2.1.3.2.1 Ambient Temperature and Salinity

Temperature and salinity data based on one year of measurements carried out at the Crux development area by RPS between April 2016 and May 2017 (2017) was supplied for the study.

Temperature and salinity data applied to the near-field modelling was sourced from the World Ocean Atlas 2013 (WOA13) database produced by the National Oceanographic Data Centre (National Oceanic and Atmospheric Administration) and its co-located World Data Center for Oceanography (Levitus *et al.*, 2013).

For both data sets, annualised mean temperature profiles were calculated. Figure 2.2 presents a comparison of the WOA13 and RPS-measured annualised temperature profiles. From the profiles, it is evident that the WOA13 temperature structure offer a good match with the measured data and can be considered representative of the conditions in the Crux development area.

Table 2.3 shows the average seasonal water temperature and salinity levels at varying depths from 0 to 170 m. This data can be considered representative of seasonal conditions in the Crux development area.

The seasonal temperature profiles exhibit a reasonably consistent reduction in temperature with increasing depth. Salinity levels are generally more consistent and exhibit a vertically well-mixed water body (34.19 – 34.59 practical salinity unit, PSU), irrespective of season or depth.

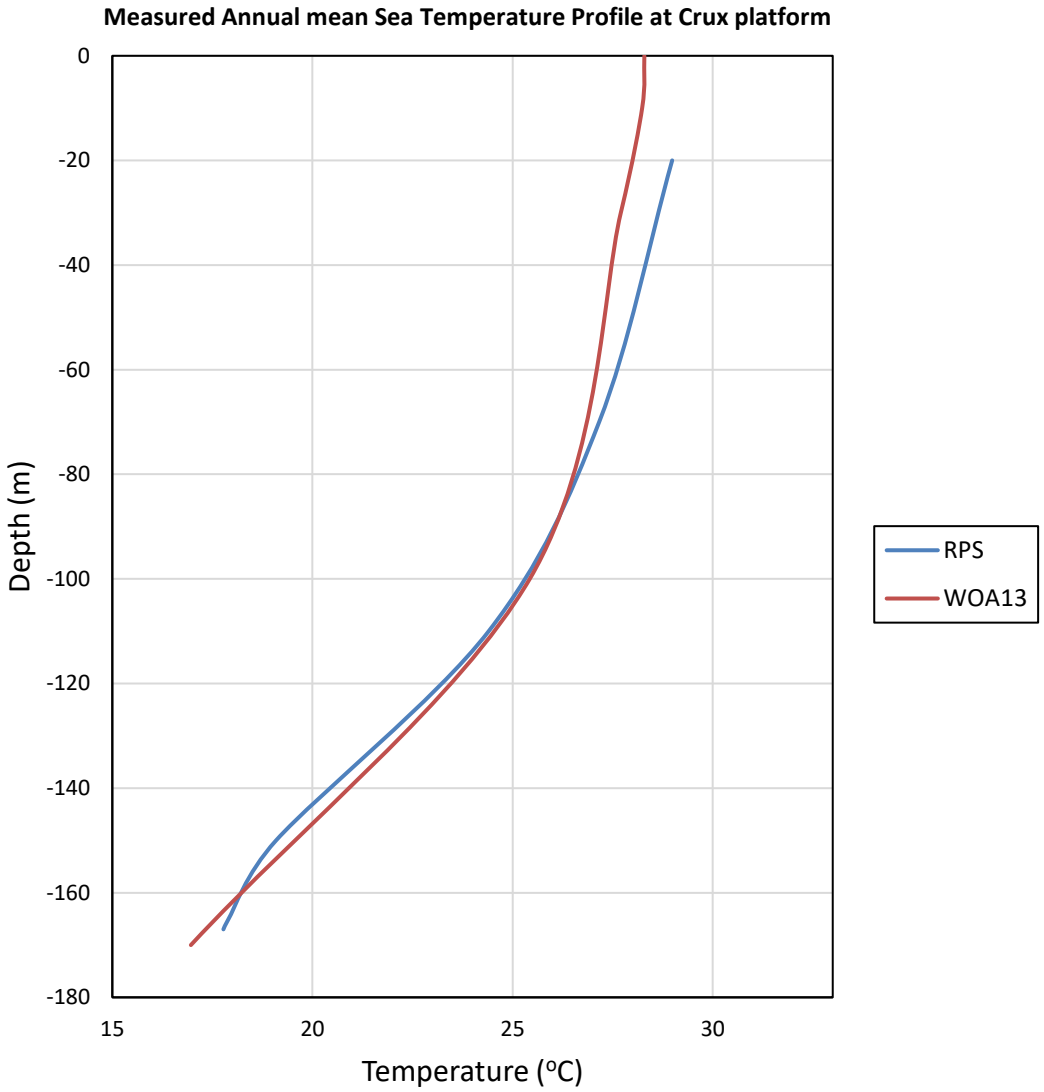


Figure 2.2 Comparison of World Ocean Atlas 2013 and RPS measured annual temperature profiles at Crux platform location.

Table 2.3 Average temperature and salinity levels adjacent to the proposed Crux platform.

Season	Depth (m)	Temperature (°C)	Salinity (PSU)
Summer	0	29.62	34.58
	10	29.54	34.57
	30	28.89	34.55
	100	25.35	34.54
	170	17.86	34.63
Transitional	0	27.34	34.19
	10	27.33	34.21
	30	27.18	34.23
	100	24.43	34.33
	170	16.25	34.59
Winter	0	28.49	34.34
	10	28.39	34.35
	30	27.48	34.39
	100	24.82	34.39
	170	16.98	34.59

2.1.3.2.2 Ambient Current

Ocean current data was sourced from a 10-year hindcast data set of combined large-scale ocean (HYCOM) and tidal currents. The data was statistically analysed to determine the 5th, 50th and 95th percentile current speeds. These statistical current speeds can be considered representative of seasonal conditions in the Crux development area.

Table 2.4 presents the steady-state, unidirectional current speeds at varying depths used as input to the near-field model as forcing for each discharge case:

- 5th percentile current speed: weak currents, low dilution and slow advection.
- 50th percentile (median) current speed: average currents, moderate dilution and advection.
- 95th percentile current speed: strong currents, high dilution and rapid advection to nearby areas.

The 5th, 50th and 95th percentile values are referenced as weak, medium and strong current speeds, respectively.

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Table 2.4 Adopted ambient current conditions adjacent to the proposed Crux platform.

Season	Depth (m)	5th Percentile (Weak) Current Speed (m/s)	50th Percentile (Medium) Current Speed (m/s)	95th Percentile (Strong) Current Speed (m/s)
Summer	0	0.068	0.248	0.495
	10	0.060	0.218	0.415
	30	0.059	0.207	0.392
	100	0.055	0.193	0.378
	170	0.051	0.187	0.355
Transitional	0	0.063	0.223	0.434
	10	0.060	0.212	0.411
	30	0.057	0.206	0.400
	100	0.054	0.200	0.378
	170	0.050	0.191	0.357
Winter	0	0.058	0.216	0.455
	10	0.055	0.197	0.399
	30	0.054	0.194	0.386
	100	0.054	0.192	0.387
	170	0.051	0.187	0.347

2.2 Far-Field Modelling

2.2.1 Overview

The far-field modelling expands on the near-field work by allowing the time-varying nature of currents to be included, and the potential for recirculation of the plume back to the discharge location to be assessed. In this case, concentrations near the discharge point can be increased due to the discharge plume mixing with the remnant plume from an earlier time. This may be a potential source of episodic increases in pollutant concentrations in the receiving waters.

2.2.2 Description of Far-Field Model: MUDMAP

The mixing and dispersion of the discharges was predicted using the three-dimensional discharge and plume behaviour model, MUDMAP (Koh & Chang, 1973; Khondaker, 2000).

The far-field calculation (passive dispersion stage) employs a particle-based, random walk procedure. Any chemicals/constituents within the discharge stream are represented by a sample of Lagrangian particles. These particles are moved in three dimensions over each subsequent time step according to the prevailing local current data as well as horizontal and vertical mixing coefficients.

MUDMAP treats the Lagrangian particles as conservative tracers (i.e. they are not removed over time to account for chemical interactions, decay or precipitation). Predicted concentrations will therefore be

conservative overestimates where these processes actually do occur. Each particle represents a proportion of the discharge, by mass, and particles are released at a given rate to represent the rate of the discharge (mass per unit time). Concentrations of constituents are predicted over time by counting the number of particles that occur within a given depth level and grid square and converting this value to mass per unit volume.

The system has been extensively validated and applied for discharge operations in Australian waters (e.g. Burns *et al.*, 1999; King & McAllister, 1997, 1998).

2.2.3 Stochastic Modelling

A stochastic modelling procedure was applied in the far-field modelling to sample a representative set of conditions that could affect the distribution of constituents. This approach involves multiple (100) simulations of a given discharge scenario and season, with each simulation being carried out under a randomly-selected period of currents. This methodology ensures that the calculated movement and fate of each discharge is representative of the range of prevailing currents at the discharge location. Once the stochastic modelling is complete, all simulations are statistically analysed to develop the distribution of outcomes based on time and event.

2.2.4 Setup of Far-Field Model

2.2.4.1 Discharge Characteristics

The MUDMAP model simulated the discharge into a time-varying current field with the initial dilution set by the near-field results described in Section 2.1.

The hydrotest discharge over 44 hours was modelled using 100 simulations for each season. Once the simulations were complete, they were reported on a seasonal basis: (i) summer (December to February); (ii) transitional (March and September to November) and (iii) winter (April to August).

Table 2.5 Summary of far-field hydrotest discharge modelling assumptions.

Parameter	Value/Design
Hindcast modelling period	2008 to 2017
Seasons	Summer (December to February) Transitional (March and September to November) Winter (April to August)
Discharge volume (m^3)	47,520
Discharge duration (hours)	44
Flow rate (m^3/s)	0.3
Discharge salinity (ppt)	34.5
Discharge temperature (^oC)	16.9
Number of simulations	300 (100 per season)
Discharge duration (hours)	44
Simulated period (days)	5

2.2.4.2 Mixing Parameters

The horizontal and vertical dispersion coefficients represent the mixing and diffusion caused by turbulence, both of which are sub-grid-scale processes. Both coefficients are expressed in units of rate of area change per second (m^2/s). Increasing the horizontal dispersion coefficient will increase the horizontal spread of the discharge plume and decrease the centreline concentrations faster. Increasing the vertical dispersion coefficient spreads the discharge across the vertical layers (or depths) faster.

Spatially constant, conservative dispersion coefficients of 0.15 m^2/s and 0.00005 m^2/s were used to control the spreading of the hydrotest plume in the horizontal and vertical directions, respectively. Each of the mixing parameters was selected following extensive sensitivity testing to recreate the plume characteristics predicted by the near-field modelling. It would be expected that the in-situ mixing dynamics would be greater under average and high energy conditions by a factor of 10 (King & McAllister, 1997, 1998) and thus the far-field model results are designed to produce a worst-case result for concentration extents.

2.2.4.3 Grid Configuration

MUDMAP uses a three-dimensional grid to represent the geographic region under study (water depth and bathymetric profiles). Due to the rapid mixing and small-scale effect of the effluent discharge, it was necessary to use a fine grid with a resolution of 20 m x 20 m to track the movement and fate of the discharge plume. The extent of the grid region measured approximately 20 km (longitude or x-axis) by 20 km (latitude or y-axis), which was subdivided horizontally into 1,000 x 1,000 cells. The vertical resolution was set to 1 m.

2.2.5 Regional Ocean Currents

2.2.5.1 Overview

The area of interest for this study is typified by strong tidal flows over the shallower regions, particularly along the inshore region of the Kimberley Coast. However, the offshore regions with water depths exceeding 100-200 m experience significant large-scale drift currents. These drift currents can be relatively strong (1-2 knots) and complex, manifesting as a series of eddies, meandering currents and connecting flows. These offshore drift currents also tend to persist longer (days to weeks) than tidal current flows (hours between reversals) and thus will have greater influence upon the net trajectory of contaminant plumes over time scales exceeding a few hours.

Wind shear on the water surface also generates local-scale currents that can persist for extended periods (hours to days) and result in long trajectories. Hence, the current-induced transport of plumes can be variably affected by combinations of tidal, wind-induced and density-induced drift currents. Depending on their local influence, it is important to consider all these potential advective mechanisms to rigorously understand patterns of potential transport from a given discharge location.

To appropriately allow for temporal and spatial variation in the current field, dispersion modelling requires the current speed and direction over a spatial grid covering the potential migration zone of plumes. Estimates of the net currents were derived by combining predictions of the drift currents, available from a mesoscale ocean model, with estimates of the tidal currents generated by an RPS model set up for the study area. These estimates are considered representative of the oceanographic currents that influence the Crux development area. Shell has also collected 12 months of metocean data in the Crux development area, with this data being used to validate the hydrodynamic model used in this modelling study. Refer to Section 2.2.5.4 for further discussion of the tidal and current model validation.

A composite modelled ocean current data product was derived by combining predictions of mesoscale circulation currents, available at daily resolution from global ocean models, with predictions of the hourly tidal

currents generated by the RPS HYDROMAP model. By combining a drift current model with a tidal model, the influences of inter-annual and seasonal drift patterns, and the more regular variations in tide, were included.

2.2.5.2 Mesoscale Circulation

Large-scale and mesoscale ocean circulation (also referred to as drift currents) will be the dominant driver of long-term (> several days) transport of effluent plumes. Mesoscale ocean processes are generally defined as having horizontal spatial scales of 10-500 km, and periods of 10-200 days, and processes with scales greater than this are referred to as large-scale. The major persistent large-scale and mesoscale surface currents off Western Australia are presented in Figure 2.3. They are characterised as follows:

- **Buoyancy driven circulation**. The main buoyancy-driven feature in the region is the Indonesian Throughflow (ITF) which conducts warm water from the equator into the Indian Ocean. Buoyancy gradients across the continental shelf due to differential heating and cooling and/or surface runoff may also drive three-dimensional circulation patterns.
- **Wind (Ekman) driven circulation**. The Australian North West Shelf has an annual wind cycle (easterly winds during winter, south-westerly winds during summer) which drives seasonal variability in surface circulation patterns.
- **Eddies and jets**. These non-linear features evolve from the large-scale and mesoscale flow field interacting with the bathymetry. These are random features and it is generally hard to predict their exact timing and location.

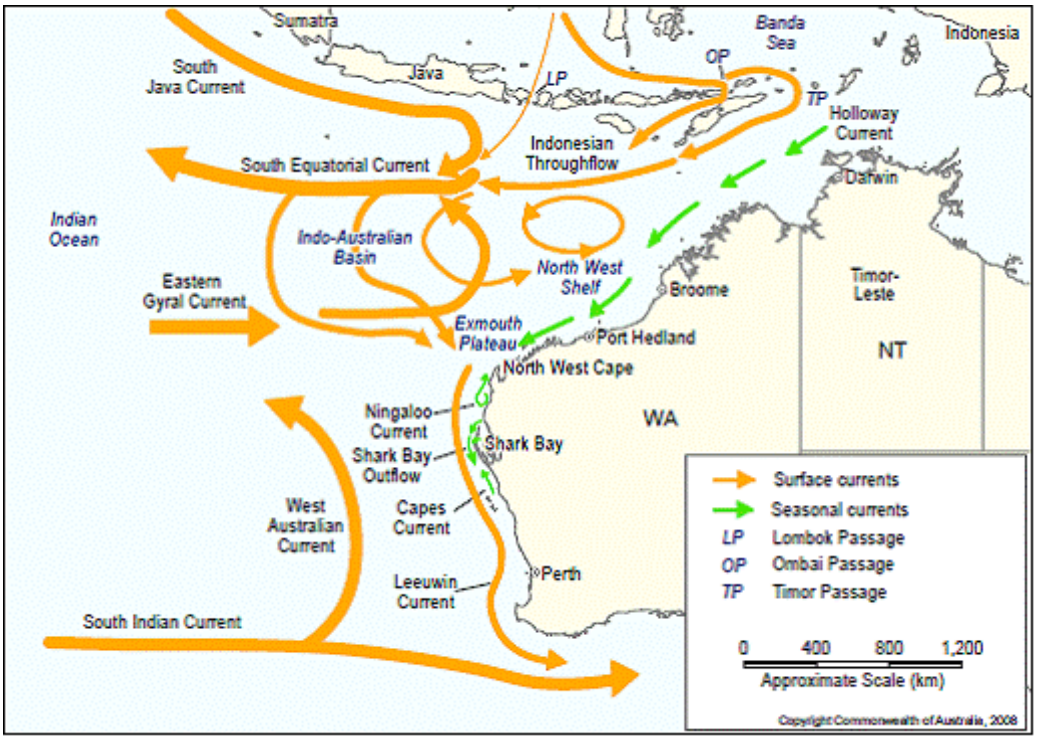


Figure 2.3 A map of the major currents off the West Australian coast (DEWHA, 2008).

RPS

2.2.5.2.1 Description of Mesoscale Model: HYCOM

Representation of the drift currents was available from the output of the global circulation model the Hybrid Coordinate Ocean Model (HYCOM; Bleck, 2002; Chassignet *et al.*, 2007, 2009), created by the National Ocean Partnership Program (NOPP), as part of the US Global Ocean Data Assimilation Experiment (GODAE). The HYCOM model is a three-dimensional model that assimilates ocean observations of sea surface temperature, sea surface salinity and surface height, obtained by satellite observations, along with atmospheric forcing conditions from atmospheric models to predict drift currents generated by such forces as wind shear, density and sea height variations and the rotation of the earth.

The HYCOM model is configured to combine the three vertical coordinate types currently in use in ocean models: depth (*z*-levels), density (isopycnal layers), and terrain-following (σ-levels). HYCOM uses isopycnal layers in the open, stratified ocean, but uses the layered continuity equation to make a dynamically smooth transition to a terrain-following coordinate in shallow coastal regions, and to *z*-level coordinates in the mixed layer and/or unstratified seas. Thus, this hybrid coordinate system allows for the extension of the geographic range of applicability to shallow coastal seas and unstratified parts of the world ocean. It maintains the significant advantages of an isopycnal model in stratified regions while allowing more vertical resolution near the surface and in shallow coastal areas, hence providing a better representation of the upper ocean physics. The model has global coverage with a horizontal resolution of 1/12th of a degree (approximately 7 km at mid-latitudes) and a temporal resolution of one day.

A hindcast data set of HYCOM currents was obtained for a ten-year period spanning 2008 to 2017 (inclusive).

Figure 2.4 shows the seasonal near-seabed current roses near the proposed Crux platform. The data shows that the near-seabed current speeds and directions vary between seasons. In general, during summer (December to February) currents have the strongest average speed (<0.1 m/s with a maximum of 0.32 m/s) and tend to flow east-southeast. During winter (April to August), currents flow mostly toward the west-southwest. During transitional conditions (March and September to November), currents flow mostly towards the south-southeast.

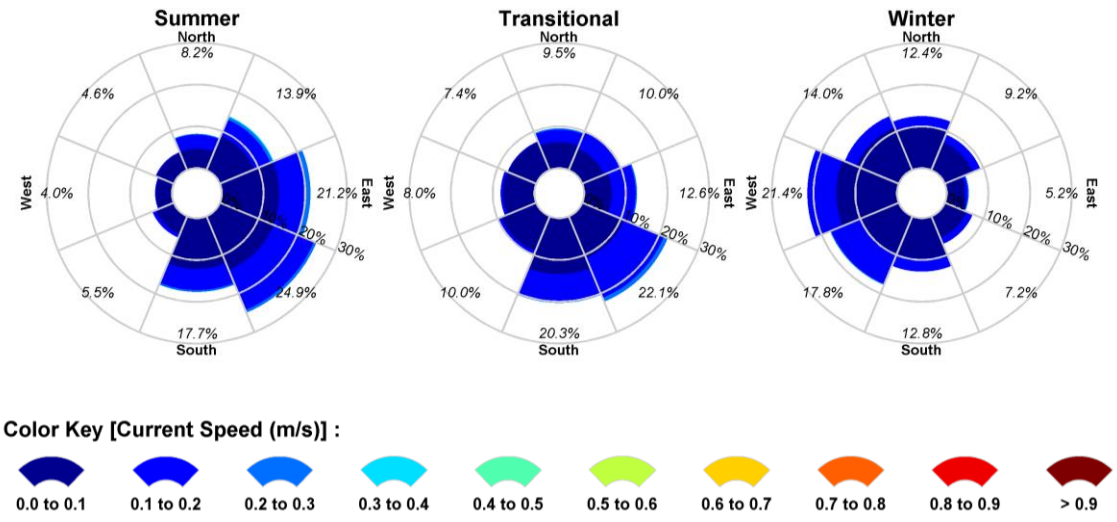


Figure 2.4 Seasonal current distribution (2008-2017, inclusive) derived from the HYCOM database near to the proposed Crux platform. The colour key shows the current magnitude, the compass

direction provides the direction towards which the current is flowing, and the size of the wedge gives the percentage of the record.

2.2.5.3 Tidal Currents

2.2.5.3.1 Description of Tidal Model: HYDROMAP

As the HYCOM model does not include tidal forcing, and because the data is only available at a daily frequency, a tidal model was developed for the study region using RPS' three-dimensional hydrodynamic model, HYDROMAP.

The model formulations and output (current speed, direction and sea level) of this model have been validated through field measurements around the world for more than 25 years (Isaji & Spaulding, 1984, 1986; Isaji *et al.*, 2001; Zigic *et al.*, 2003). HYDROMAP current data has also been widely used as input to forecasts and hindcasts of oil spill migrations in Australian waters. This modelling system forms part of the National Marine Oil Spill Contingency Plan for the Australian Maritime Safety Authority (AMSA) (AMSA, 2002).

HYDROMAP simulates the flow of ocean currents within a model region due to forcing by astronomical tides, wind stress and bottom friction. The model employs a sophisticated dynamically nested-gridding strategy, supporting up to six levels of spatial resolution within a single domain. This allows for higher resolution of currents within areas of greater bathymetric and coastline complexity, or of particular interest to a study.

The numerical solution methodology of HYDROMAP follows that of Davies (1977a, 1977b) with further developments for model efficiency by Owen (1980) and Gordon (1982). A more detailed presentation of the model can be found in Isaji & Spaulding (1984).

2.2.5.3.2 Tidal Grid Setup

A HYDROMAP model was established over a domain that extended approximately 3,300 km east-west by 3,100 km north-south over the eastern Indian Ocean. The grid extends beyond Eucla in the south and beyond Bathurst Island in the north (Figure 2.5).

Four layers of sub-gridding were applied to provide variable resolution throughout the domain. The resolution at the primary level was 15 km. The finer levels were defined by subdividing these cells into 4, 16 and 64 cells, resulting in resolutions of 7.5 km, 3.75 km and 1.88 km. The finer grids were allocated in a step-wise fashion to areas where higher resolution of circulation patterns was required to resolve flows through channels, around shorelines or over more complex bathymetry. Approximately 98,600 cells were used to define the region.

Bathymetric data used to define the three-dimensional shape of the study domain was extracted from the CMAP electronic chart database and supplemented where necessary with manual digitisation of chart data supplied by the Australian Hydrographic Office. Depths in the domain ranged from shallow intertidal areas through to approximately 7,200 m.

2.2.5.3.3 Tidal Boundary Conditions

Ocean boundary data for the HYDROMAP model was obtained from the TOPEX/Poseidon global tidal database (TPXO7.2) of satellite-measured altimetry data, which provided estimates of tidal amplitudes and phases for the eight dominant tidal constituents (designated as K_2, S_2, M_2, N_2, K_1, P_1, O_1 and Q_1) at a horizontal scale of approximately 0.25°. Using the tidal data, sea surface heights are firstly calculated along the open boundaries at each time step in the model.

The TOPEX/Poseidon satellite data is produced, and quality controlled by the US National Atmospheric and Space Agency (NASA). The satellites, equipped with two highly accurate altimeters capable of taking sea level measurements accurate to less than ±5 cm, measured oceanic surface elevations (and the resultant tides) for over 13 years (1992–2005). In total, these satellites carried out more than 62,000 orbits of the planet. The TOPEX/Poseidon tidal data has been widely used amongst the oceanographic community, being the subject of more than 2,100 research publications (e.g. Andersen, 1995; Ludicone *et al.*, 1998; Matsumoto *et al.*, 2000;

Kostianoy *et al.*, 2003; Yaremchuk & Tangdong, 2004; Qiu & Chen, 2010). As such, the TOPEX/Poseidon tidal data is considered suitably accurate for this study.

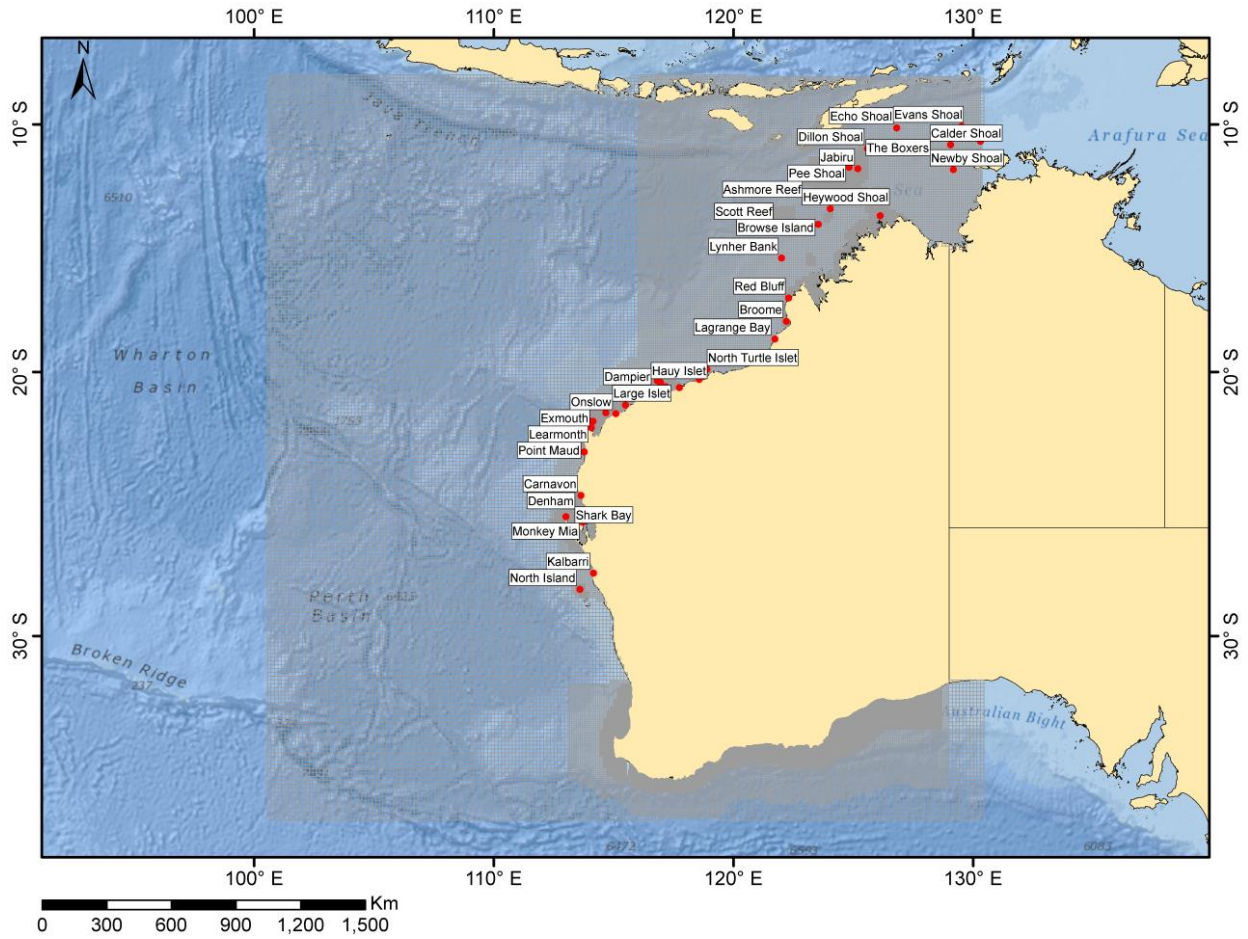


Figure 2.5 Hydrodynamic model grid (grey wire mesh) used to generate the tidal currents, showing the full domain in context with the continental land mass and the locations available for tidal comparisons (red labelled dots). Higher-resolution areas are indicated by the denser mesh zones.

2.2.5.4 Tidal and Current Model Validation

The suitability of the modelled tidal and drift current data products was evaluated by comparing the predicted currents to those measured at the Crux development area. The following sections describe the sources of both the modelled and measured data, the comparison methodology, and the outcomes of the comparisons for both the tidal and drift current components.

2.2.5.4.1 Data Sources

A tidal model was developed for the study region using RPS' three-dimensional hydrodynamic model, HYDROMAP. HYDROMAP simulates the flow of ocean currents within a model region due to forcing by astronomical tides, wind stress and bottom friction. This model is described in Section 2.2.5.3.

A mesoscale ocean current data sets was selected for the study: HYCOM (Hybrid Coordinate Ocean Model) Consortium's global ocean model, HYCOM. This model is described in Section 2.2.5.2.

A data set of measured currents was collected by RPS at the Crux development area between April 2016 and May 2017 (RPS, 2017). This data set includes a series of point current measurements made at six depths through the water column using CM04 current meters mounted on a floating mooring. The measurement depths are approximately 20 m, 70 m, 110 m, 150 m, 165 m and 167 m below the water surface. The temporal resolution of the data is 1 minute. The raw data was quality-controlled by RPS and only data identified as high-quality was used for comparison to model data. For the measurements at a 20 m water depth, there is approximately a 7-week gap in the data between early September and late October 2016.

2.2.5.4.2 Model Validation Skills

Overview

The mesoscale and tidal current models were validated through quantitative and visual comparisons of measured and modelled data.

Statistics

A quantitative analysis of a model's skill at replicating the environmental conditions was conducted using the Index of Agreement (IOA), presented in Willmott (1981), and the Mean Absolute Error (MAE), discussed in Willmott (1982) and Willmott & Matsuura (2005). Other traditional error estimates, such as the correlation coefficient and the root mean square error (RMSE) are problematic and prone to ambiguities and bias (Willmott & Matsuura, 2005; Willmott, 1982). Consequently, they are not reported in isolation here.

The MAE is simply the average of the absolute values of the differences between the observed and modelled values. MAE is a more natural measure of average error (Willmott & Matsuura, 2005) and more readily understood. The IOA is determined using the following formula:

$$\mathrm{IOA} = 1 - \frac{\sum |X_{\mathrm{model}} - X_{\mathrm{obs}}|^2}{\sum \left(|X_{\mathrm{model}} - \overline{X_{\mathrm{obs}}}| + |X_{\mathrm{obs}} - \overline{X_{\mathrm{obs}}}| \right)^2}$$

In this equation, X represents the variable being compared and $\bar{X}$ represents the mean of that variable over time.

A perfect agreement can be said to exist between the model and field observations if the IOA gives a measure of one, and complete disagreement will produce an IOA measure of zero (Wilmott, 1981). Although it is difficult to find guidelines for what values of the IOA might represent a good agreement, Willmott *et al.* (1985) suggests that values meaningfully larger than 0.5 represent good model performance. Clearly, the higher the IOA and the lower the MAE, the better the model performance.

An important point to note regarding both, and in fact most, measures of model performance, is that slight phase differences in the series can result in a seemingly poor statistical comparison, particularly in rapidly changing series such as tidal direction or water elevation where the tidal range is large. It is therefore always important to consider both the statistics and the visual representation of the comparison (Willmott *et al.*, 1985). Statistical comparison of current direction can be misleading; skill measures of direction can become biased where the directional fluctuations are near 0-360°. Therefore, we have based the quantitative assessment on the U and V current components and not magnitude and direction.

Time Series

In addition to bulk statistical measures, model performance for the measurement period was assessed visually with the aid of scatterplots and rose plots. The scatterplots show the correlation between the x- and y-components of the measured and modelled data. The rose plots show the frequency of current direction by sector, and magnitude by colour, to allow comparison of current direction between modelled and measured data.

The model performance was also evaluated against time series plots of water level, U (east-west) velocity component, V (north/south) velocity component, current speed and current direction data. This approach is valuable because statistical measures of model skill can heavily penalise errors in phase (i.e. time lags) even when the dynamics of flow are broadly reproduced.

2.2.5.4.3 Tidal Elevation Validation

For verification of the tidal elevation predictions, the model output was compared against independent predictions of tides using the XTide database (Flater, 1998). The XTide database contains harmonic tidal constituents derived from measured water level data at locations around the world. Of more than 80 tidal stations within the HYDROMAP model domain, 18 sites near the Crux development area were used for comparison.

Time series comparisons were completed for a six-month period from January to June 2010. The statistics are summarised in Table 2.6, and indicate excellent model performance in this region. Water level time series for these locations are shown in Figure 2.6, Figure 2.7 and Figure 2.8 for a one-month period (March 2010). All comparisons show that the model produces a very good match to the known tidal behaviour for a wide range of tidal amplitudes and clearly represents the varying diurnal and semi-diurnal nature of the tidal signal.

For the purposes of understanding the limitations in accuracy of the tidal predictions, the RMSE and MAE in Table 2.6 should be noted. On average, the model predictions are within 0.1-0.3 m of XTide predictions based on known constituent data at any point in time. Often the error is mostly attributable to errors of phase in the tidal signal, with the magnitude of the tidal rise and fall over each tide well represented. However, in the application of the data predictions to operational circumstances, the potential errors should be considered.

The model skill was further evaluated through a comparison of the predicted and observed tidal constituents, derived from an analysis of model-predicted time-series at each location. A scatter plot of the observed and modelled amplitude (top) and phase (bottom) of the five dominant tidal constituents (S_2, M_2, N_2, K_1 and O_1) is presented in Figure 2.9. The red line on each plot shows the 1:1 line, which would indicate a perfect match between the modelled and observed data. Note that the data is generally closely aligned to the 1:1 line demonstrating the high quality of the model performance.

Table 2.6 Statistical comparison of predicted surface elevation data from HYDROMAP and XTide at 18 locations in the tidal model domain (January to July 2010).

Tide Station	Longitude (°E)	Latitude (°S)	IOA	CC	MAE (m)	RMSE (m)
Ashmore Reef	123.02	12.22	0.99	0.99	0.14	0.18
Browse Island	123.55	14.10	0.97	0.97	0.36	0.45
Calder Shoal	129.07	10.85	0.97	0.97	0.17	0.21
Cape Legendre	116.83	20.35	0.99	0.99	0.12	0.14
Dillon Shoal	125.60	11.00	0.97	0.95	0.18	0.22
Echo Shoal	126.82	10.15	0.97	0.94	0.17	0.21
Evans Shoal	129.53	10.08	0.98	0.98	0.11	0.14
Goodrich Bank	130.32	10.70	0.99	0.97	0.13	0.16
Heywood Shoal	124.05	13.47	0.98	0.96	0.27	0.33
Jabiru	125.20	11.83	097	0.95	0.22	0.27
Loxton Shoal	128.72	09.60	0.99	0.98	0.10	0.13
Lynedoch Bank	130.82	10.03	0.98	0.98	0.12	0.15
Lynher Bank	122.02	15.47	0.98	0.97	0.26	0.31
Newby Shoal	129.18	11.87	0.98	0.96	0.23	0.27
Pee Shoal	124.83	11.77	0.97	0.94	0.23	0.27
Scott Reef	121.80	14.05	0.99	0.98	0.16	0.19
The Boxers	128.35	11.45	0.97	0.96	0.16	0.20
Troughton Island	126.13	13.75	0.97	0.95	0.27	0.33

Notes: *IOA Index of Agreement – values close to 1 represent a high level of agreement.*
CC Correlation Coefficient – values close to 1 represent very good correlation.
MAE Mean Absolute Error – the lower the value, the smaller the error.
RMSE Root Mean Square Error – the lower the value, the smaller the error.

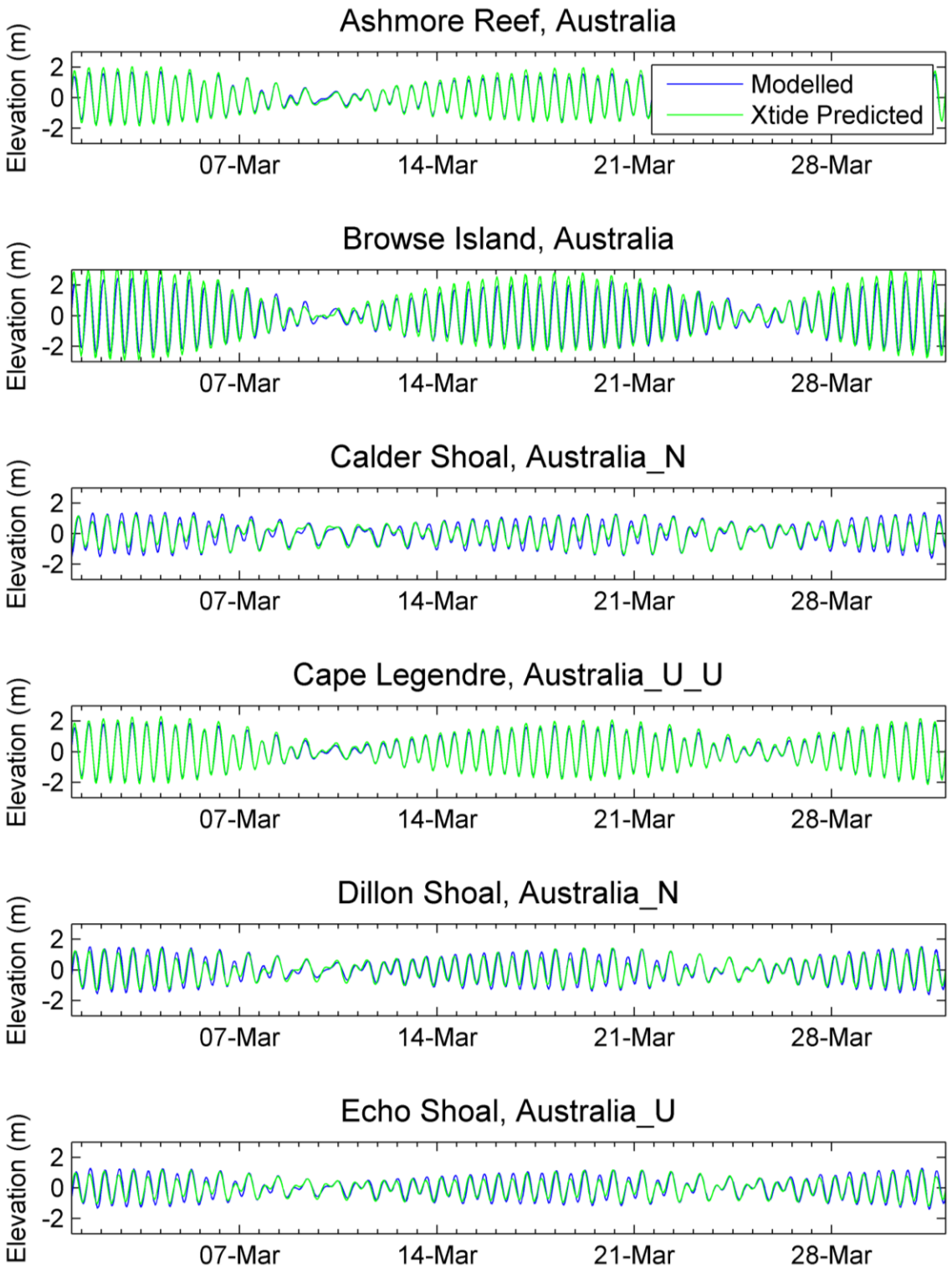


Figure 2.6 Time series comparisons between predicted surface elevation data from HYDROMAP (blue line) and XTide (green line) at six locations in the tidal model domain (March 2010).

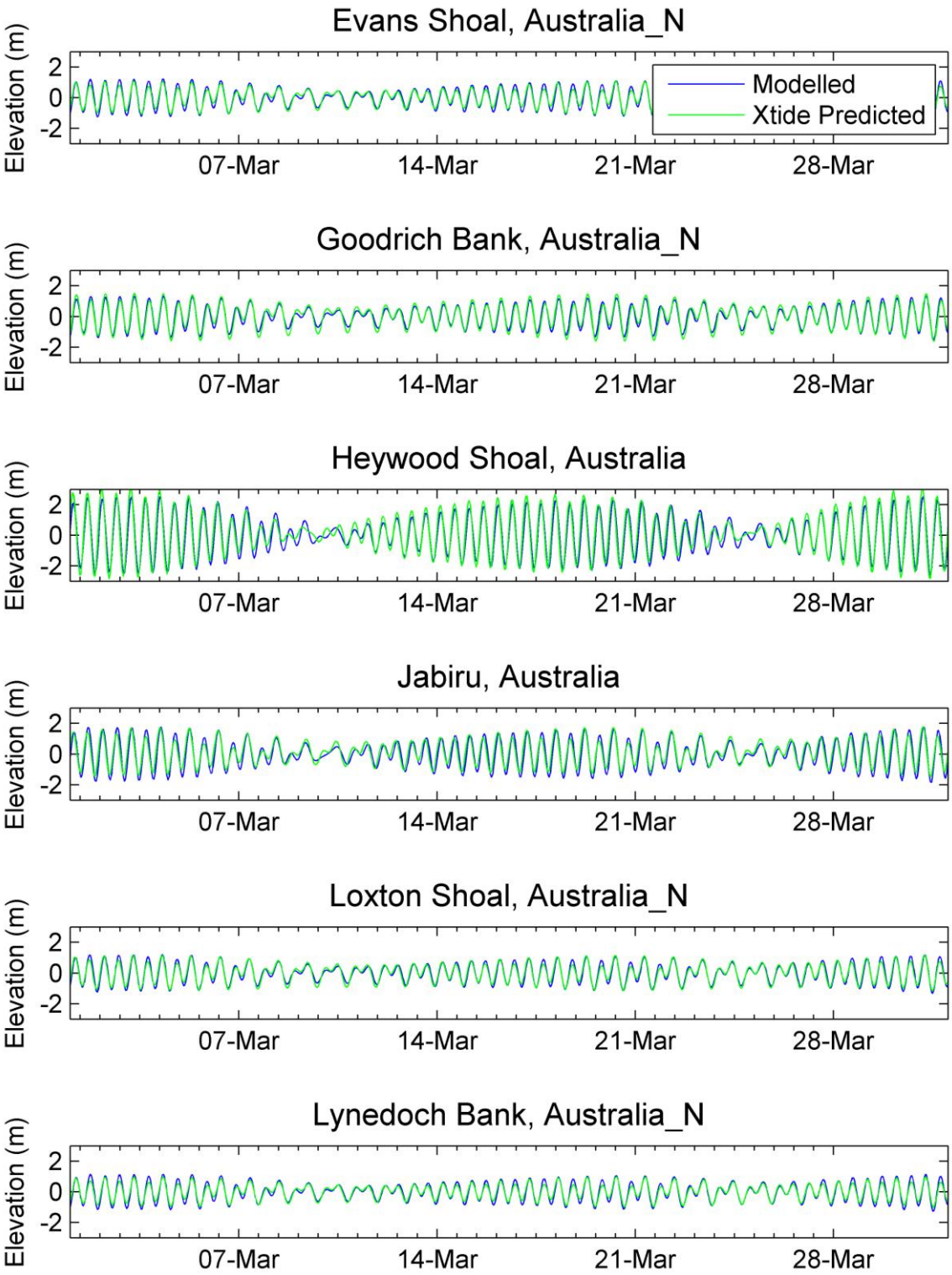


Figure 2.7 Time series comparisons between predicted surface elevation data from HYDROMAP (blue line) and XTide (green line) at six locations in the tidal model domain (March 2010).

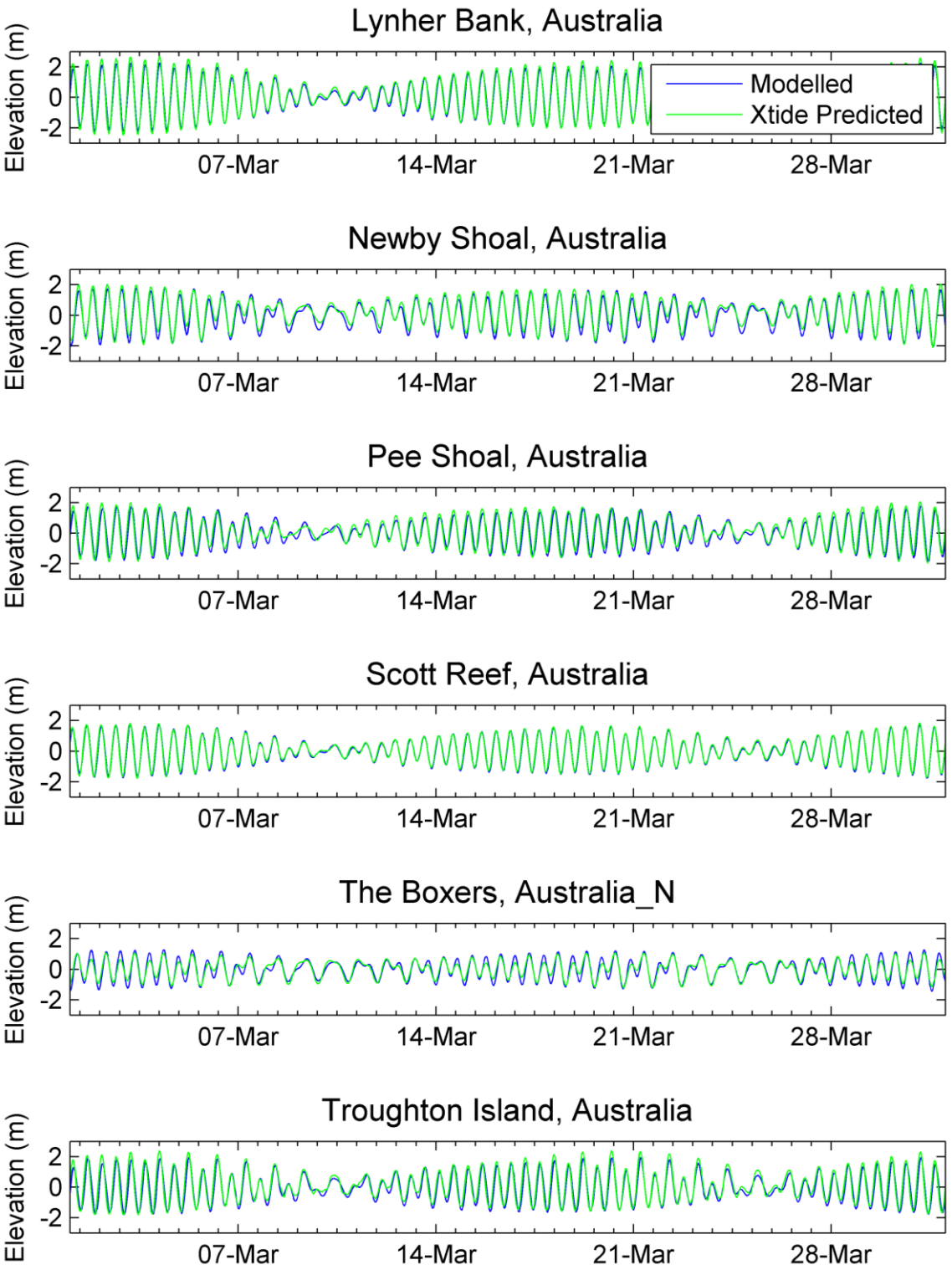


Figure 2.8 Time series comparisons between predicted surface elevation data from HYDROMAP (blue line) and XTide (green line) at six locations in the tidal model domain (March 2010).

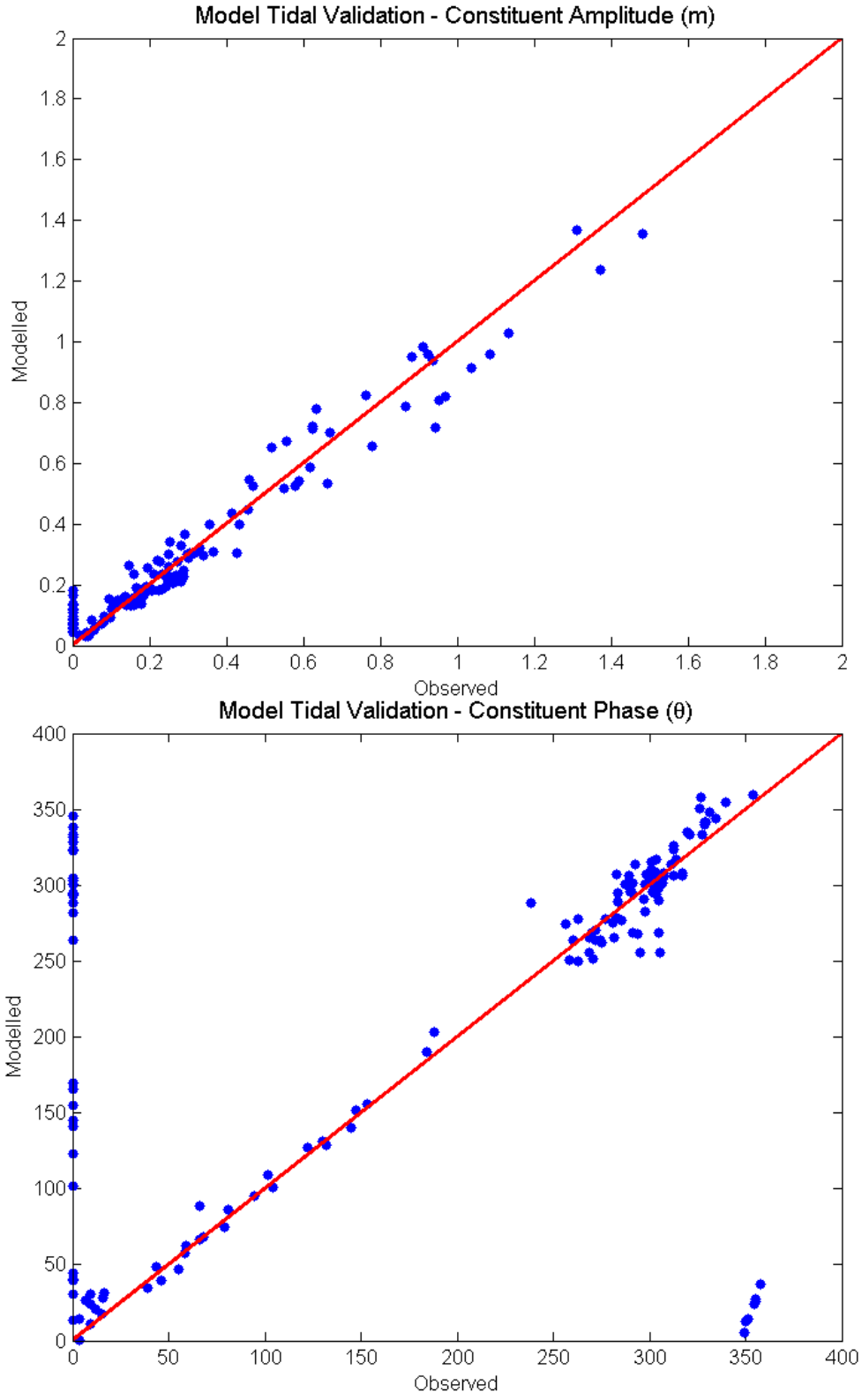


Figure 2.9 Comparisons between predicted tidal constituent amplitudes (top) and phases (bottom) from HYDROMAP and XTide at all stations in the tidal model domain. The red line indicates a 1:1 correlation between the respective data sets.

2.2.5.4.4 Composite Current Data Set Validation: HYDROMAP + HYCOM

A composite modelled ocean current data product was derived by combining predictions of mesoscale circulation currents, available at daily resolution from the HYCOM ocean model, with predictions of the hourly tidal currents generated by the RPS HYDROMAP model.

To verify the modelled current predictions, the composite model outputs at the Crux development area were compared against the unfiltered site-specific current measurements. The model results were validated through both quantitative and visual comparisons between measured and modelled data at each depth where both data sets were available.

Time series comparison of composite model outputs and measured current magnitude, direction, and U/V velocity components at water depths of 20 m, 70 m and 110 m are presented in Figure 2.10, Figure 2.11 and Figure 2.12, respectively, for one month during winter (June 2016) and summer (December 2016). The time series comparisons reveal that the composite model offers a good match with the measured U/V velocity components at all water depths in both winter and summer, with the magnitudes and timings of the peaks and troughs matching well.

The IOA and MAE values derived from comparisons of the U/V velocity components at water depths of 20 m, 70 m and 110 m over the full measurement period are presented in Table 2.7. The IOA for each velocity component is high at all water depths, reflecting the good match in the magnitudes and timings of the peaks and troughs in the composite model data and measured data. The MAE for the U/V velocity components is relatively low at approximately 0.1 m/s for all water depths, indicating that the magnitude and range of the velocity components match well; however, a slight overprediction of the current magnitude is evident at times.

To compare directionality, roses for the composite model outputs and measured currents at 20 m, 70 m and 110 m water depths over the full measurement period are shown in Figure 2.12. The roses show that the composite model current direction is a good match with the measured direction. A shift in the dominant current direction from a north/south alignment in the measured data set to a northwest/southeast alignment in the composite model data set is evident at the 20 m water depth, and to a lesser extent also at the 70 m water depth. However, the range and variability in the measured current direction is captured by the composite model data, which matches best with the measured data at the water depth of 110 m.

Based on the validation performance, the composite model data set is a good model of standard conditions at the Crux development area and will adequately resolve local and regional circulation patterns. As such, the model is considered suitable for use in the numerical modelling studies conducted as part of the Crux project.

Table 2.7 Statistical comparison of predicted (HYDROMAP+HYCOM) and observed current speeds along orthogonal component axes at the Crux development area (2016-2017).

Skill Measure	Index of Agreement (IOA)			Mean Absolute Error (MAE) (m/s)		
Depth (m)	20	70	110	20	70	110
U Component	0.72	0.75	0.76	0.11	0.11	0.11
V Component	0.82	0.80	0.78	0.11	0.10	0.10

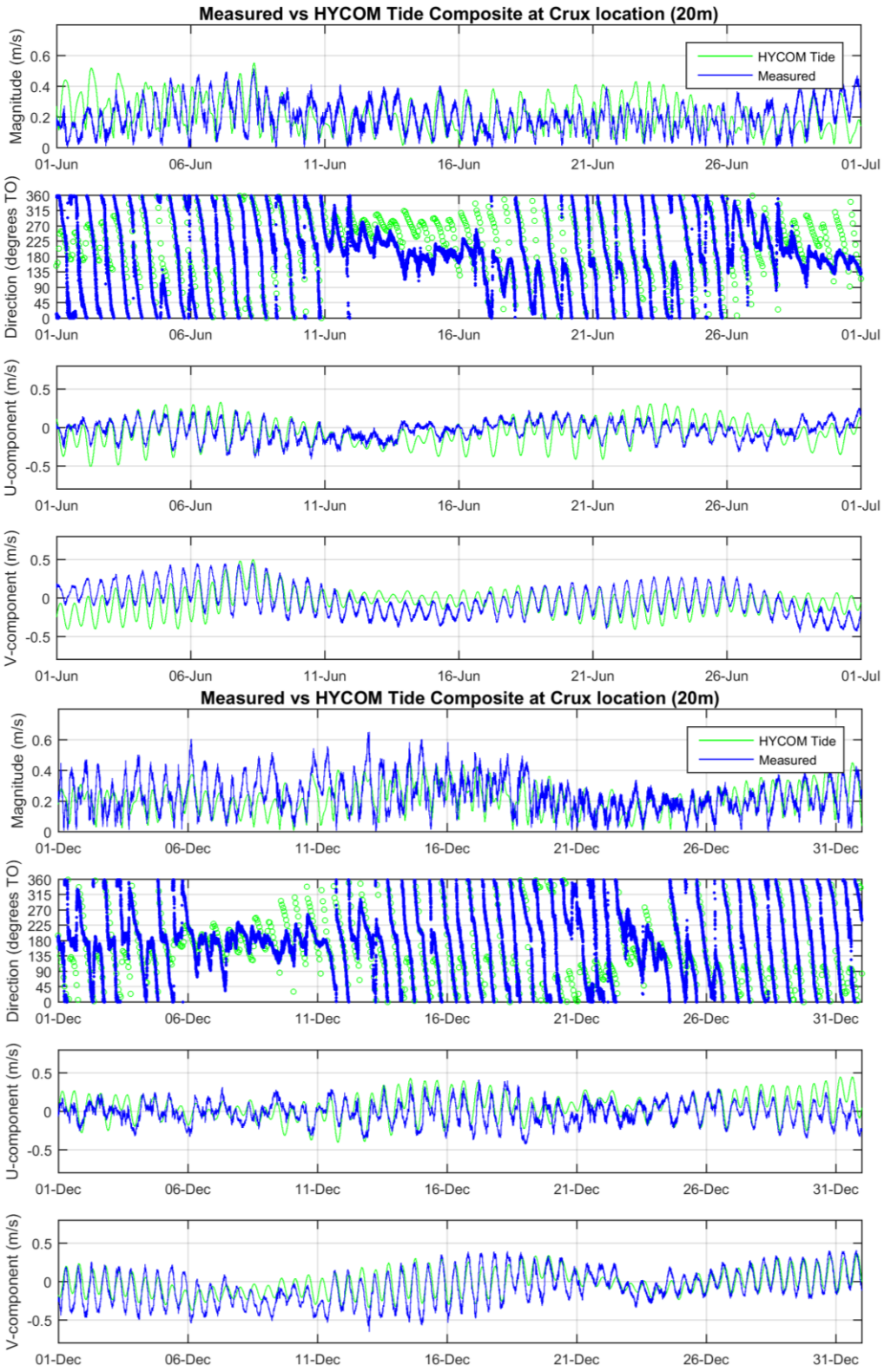


Figure 2.10 Time series comparisons between predicted (HYDROMAP+HYCOM, green line) and measured (blue line) current data at the Crux development area at a depth of approximately 20 m for June 2016 (top panel) and December 2016 (bottom panel).

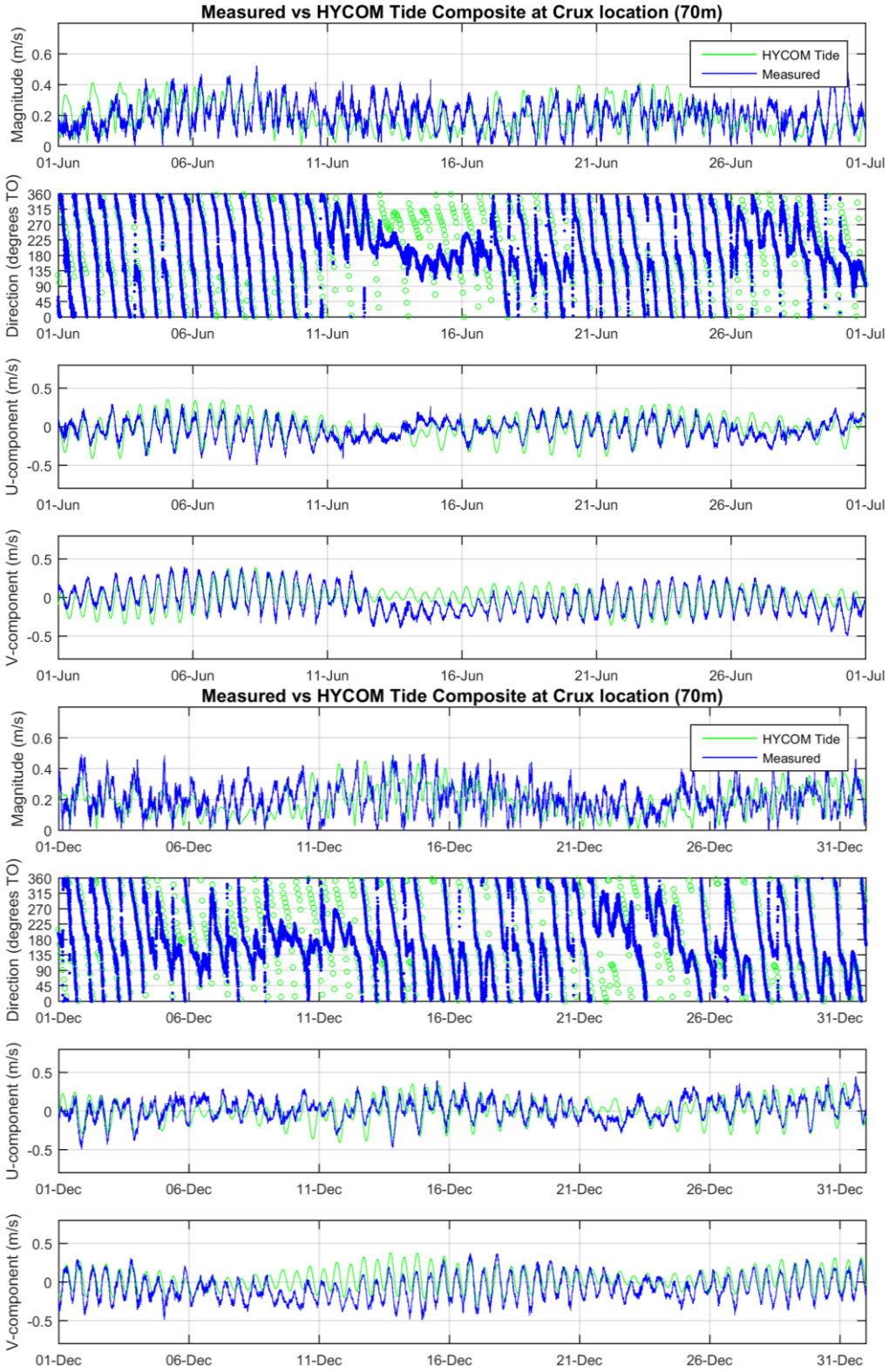


Figure 2.11 Time series comparisons between predicted (HYDROMAP+HYCOM, green line) and measured (blue line) current data at the Crux development area at a depth of approximately 70 m for June 2016 (top panel) and December 2016 (bottom panel).

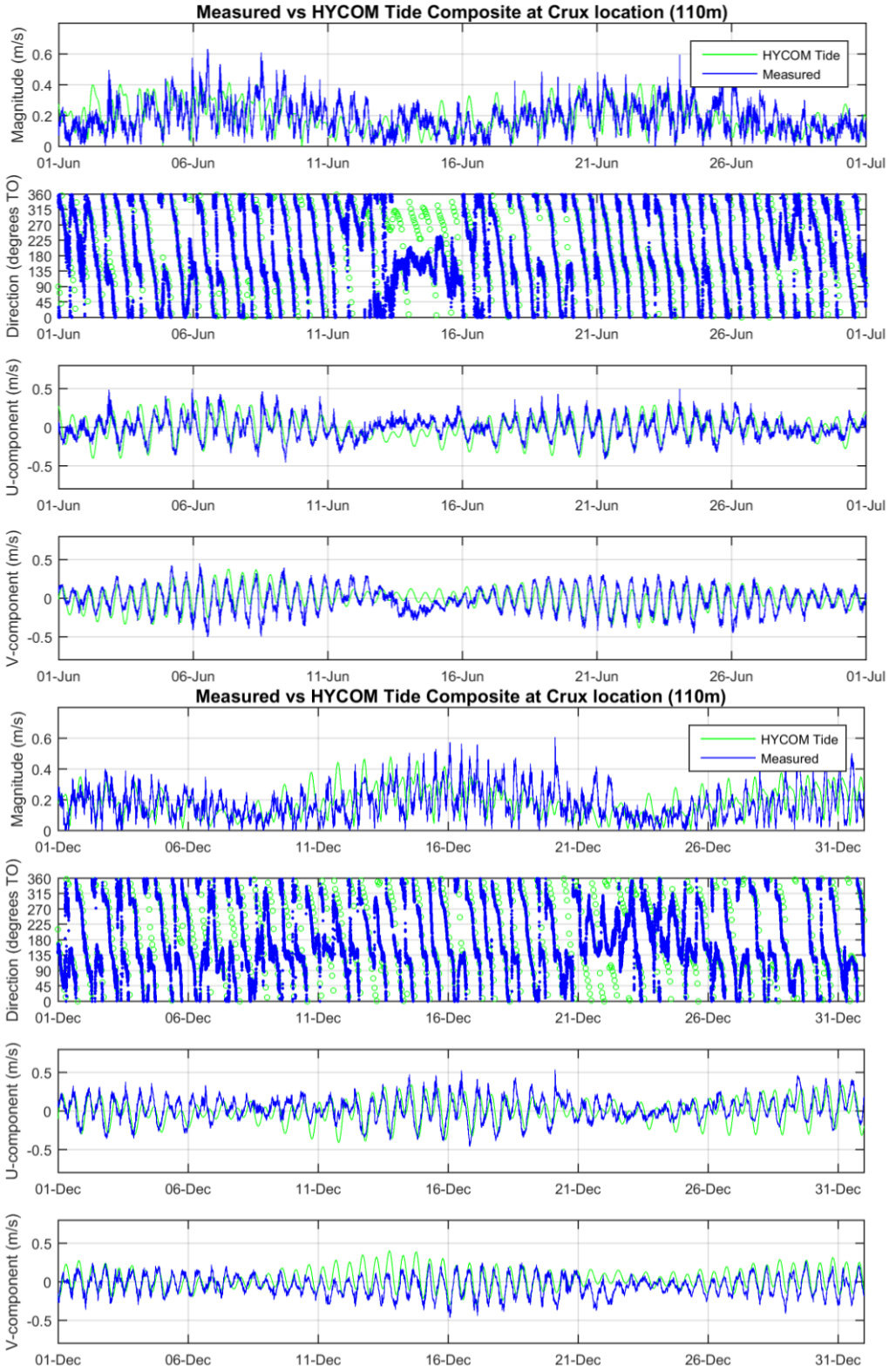


Figure 2.12 Time series comparisons between predicted (HYDROMAP+HYCOM, green line) and measured (blue line) current data at the Crux development area at a depth of approximately 110 m for June 2016 (top panel) and December 2016 (bottom panel).

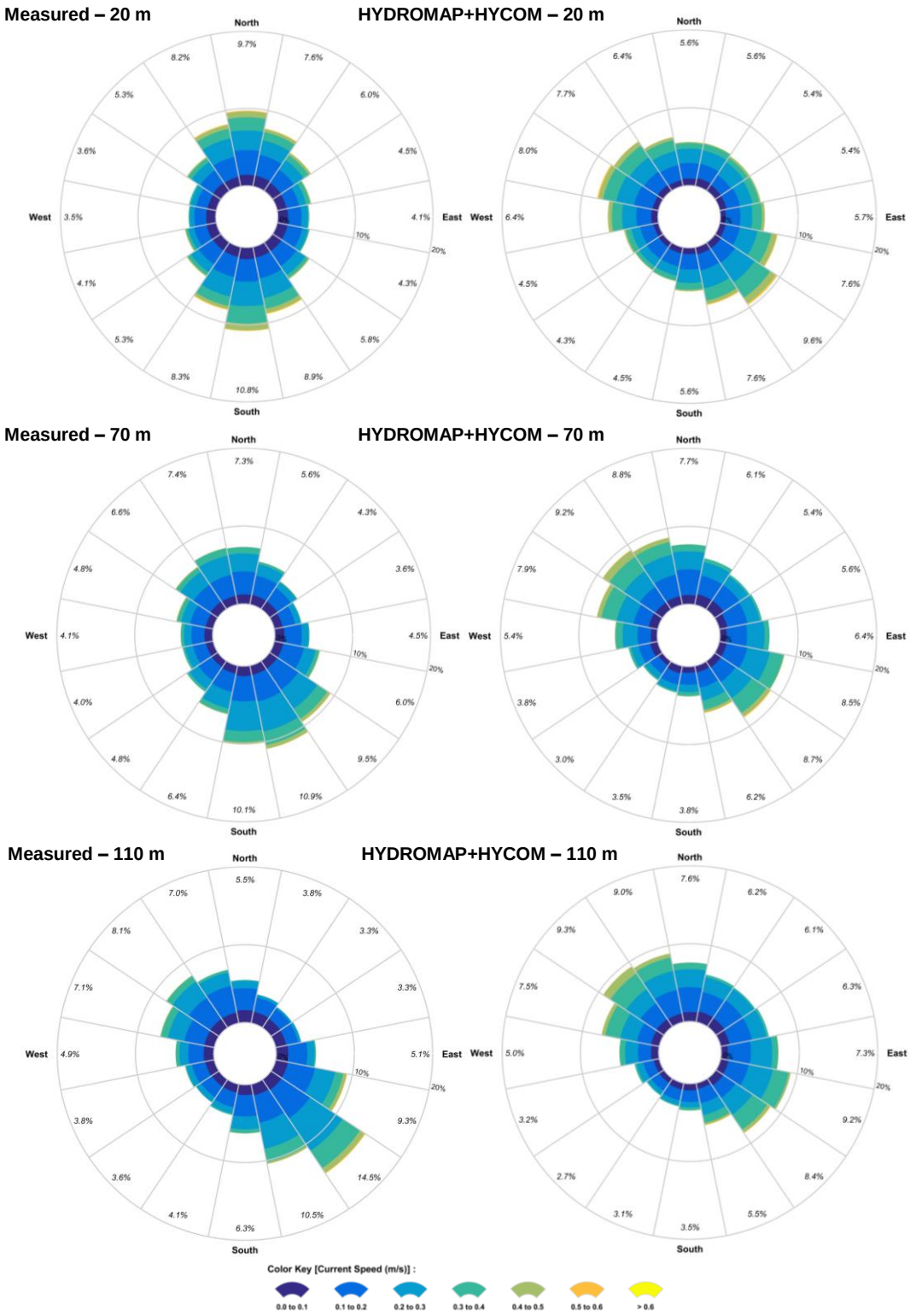


Figure 2.13 Comparative distributions for measured (left column) and predicted (HYDROMAP+HYCOM, right column) current data at the Crux development area (2016-2017) at depths of approximately 20 m (top row), 70 m (middle row) and 110 m (bottom row). The colour key shows the current magnitude, the compass direction provides the direction towards which the current is flowing, and the size of the wedge gives the percentage of the record.

3 Modelling Results

3.1 Near-Field Modelling

3.1.1 Overview

In the following sections, two sets of tables are presented. The first table summarises the predicted plume characteristics in the near-field mixing zone under varying current speeds. The second set of tables summarises the concentration of biocide at the end of the near-field mixing zone and the amount of dilution.

Figure 3.1 to Figure 3.3 (note the differing x-axis and y-axis aspect ratios) show the change in average temperature and dilution of the plume under varying seasonal conditions (summer, transitional and winter) and current speeds (weak, medium and strong). The figures show the predicted horizontal distances travelled by the plume before it contacts the seabed.

The results show that due to the momentum of the discharge a turbulent mixing zone is created in the immediate vicinity of the discharge point (1-2 m). Following this initial mixing, the marginally-negatively buoyant plume is predicted to sink slightly in the water column before reaching the seabed. Increases in ambient current speed are shown to increase the horizontal distance travelled by the plume from the discharge point.

Table 3.1 shows the predicted plume characteristics for the varying seasonal conditions and current speeds. A maximum horizontal distance of 19.1 m from the discharge point is achieved in the transitional season. The diameter of the plume at the end of the near-field mixing zone ranges from 2.9 m to 3.4 m. Increases in current speed serve to restrict the diameter of the plume.

In all cases, the temperature is predicted to be within 0.6 °C of the ambient temperature within 20 m of the discharge location.

For all seasons, the primary factor influencing dilution of the plume is the strength of the ambient current. Weak currents allow the plume to reach the seabed closer to the discharge point, which slows the rate of dilution (Table 3.1). The worst-case average dilution levels of the plume upon reaching the seabed under weak, medium and strong currents are predicted to be 1:5.9, 1:7.5 and 1:9.6, respectively, under summer and winter conditions. Additionally, the worst-case minimum dilution levels of the plume (i.e. dilution of the plume centreline) upon reaching the seabed under weak, medium and strong currents are predicted to be 1:2.7, 1:2.7 and 1:2.8, respectively, under summer and winter conditions. Note that these predictions rely on the persistence of current speed and direction over time and do not account for any build-up of plume concentrations due to weak currents or current reversals.

The results indicate that the biocide constituent of the hydrotest discharge is not expected to reach a 1:500 dilution in the near-field mixing zone. This occurs under all current conditions (Table 3.2 to Table 3.4).

Table 3.1 Predicted plume characteristics at the end of the near-field mixing zone for the specified flow rate (0.3 m^3/s) for each season and current speed.

Season	Near-Seabed Current Speed (m/s)	Plume Diameter (m)	Plume Temperature (°C)	Plume-Ambient Temperature Difference (°C)	Plume Dilution (1:x)		Maximum Horizontal Distance (m)
					Minimum	Average	
Summer	Weak (0.06)	3.2	19.9	0.58	2.7	5.9	7.2
	Medium (0.19)	3.1	20.0	0.46	2.7	7.5	9.9
	Strong (0.38)	2.9	20.1	0.35	2.8	9.6	15.7
Transitional	Weak (0.05)	3.4	18.8	0.33	2.8	6.3	7.8
	Medium (0.20)	3.3	18.9	0.24	3.0	8.8	12.1
	Strong (0.38)	3.0	18.9	0.19	3.1	10.6	19.1
Winter	Weak (0.05)	3.2	19.7	0.54	2.7	5.9	7.2
	Medium (0.19)	3.1	19.8	0.42	2.7	7.5	9.9
	Strong (0.39)	2.9	19.9	0.32	2.8	9.6	15.7

Table 3.2 Concentrations of biocide at the end of the near-field stage, and the required concentration thresholds and number of dilutions for the summer season. Note from Table 3.1 that dilutions at the 5th, 50th and 95th percentile current speeds were 5.9, 7.5 and 9.6, respectively.

Constituent	Source Concentration (ppm)	End of Near-Field Concentration (ppm)		
		5th %ile	50th %ile	95th %ile
		5.9x dilution	7.5x dilution	9.6x dilution
Biocide	500	84.7	66.7	52.1

Table 3.3 Concentrations of biocide at the end of the near-field stage, and the required concentration thresholds and number of dilutions for the transitional season. Note from Table 3.1 that dilutions at the 5th, 50th and 95th percentile current speeds were 6.3, 8.8 and 10.6, respectively.

Constituent	Source Concentration (ppm)	End of Near-Field Concentration (ppm)		
		5th %ile	50th %ile	95th %ile
		6.3x dilution	8.8x dilution	10.6x dilution
Biocide	500	79.4	56.8	47.2

Table 3.4 Concentrations of biocide at the end of the near-field stage, and the required concentration thresholds and number of dilutions for the winter season. Note from Table 3.1 that dilutions at the 5th, 50th and 95th percentile current speeds were 5.9, 7.5 and 9.6, respectively.

Constituent	Source Concentration (ppm)	End of Near-Field Concentration (ppm)		
		5th %ile	50th %ile	95th %ile
		5.9x dilution	7.5x dilution	9.6x dilution
Biocide	500	84.7	66.7	52.1

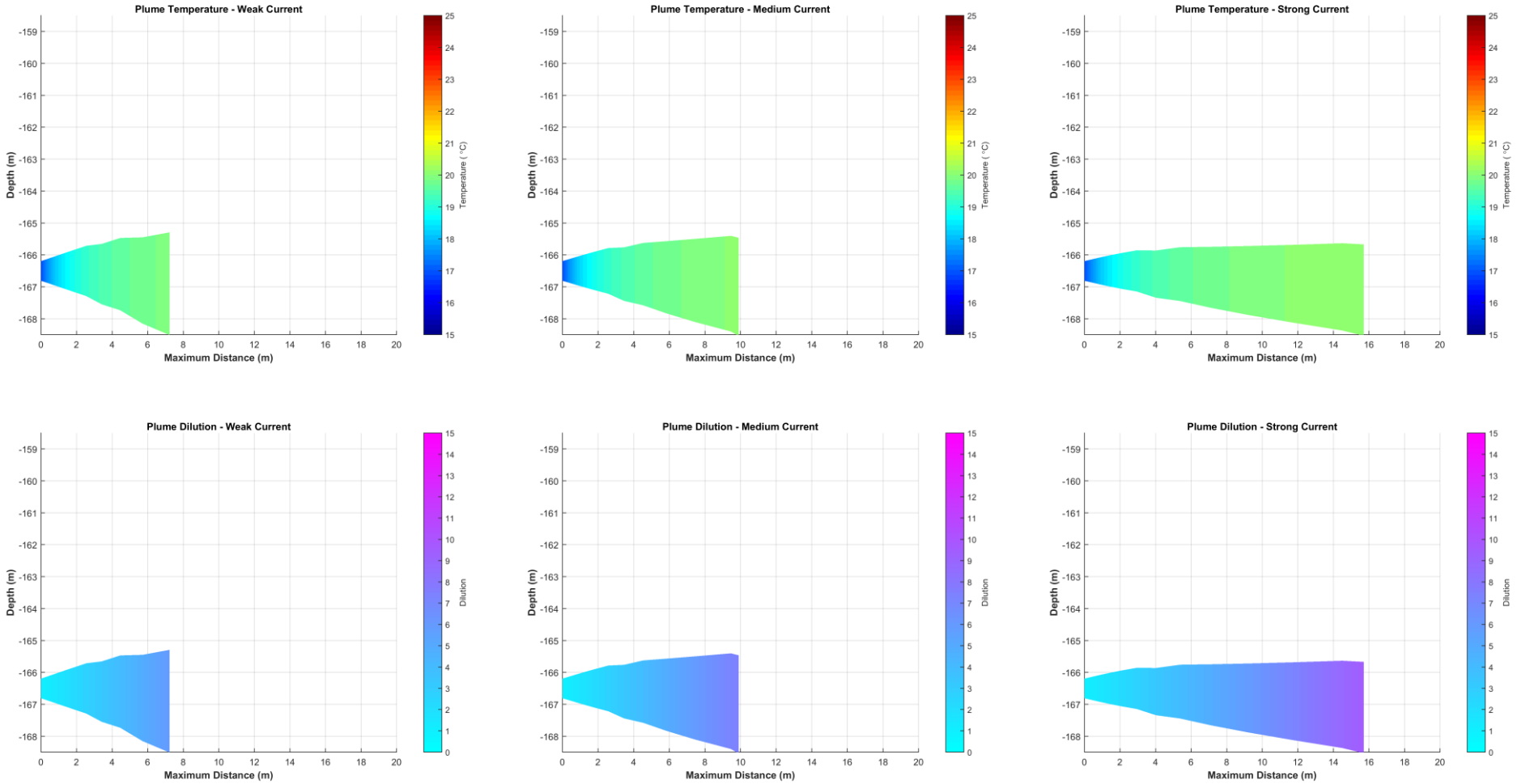


Figure 3.1 Near-field average temperature and dilution results for constant weak, medium and strong summer currents (0.3 m^3/s flow rate).

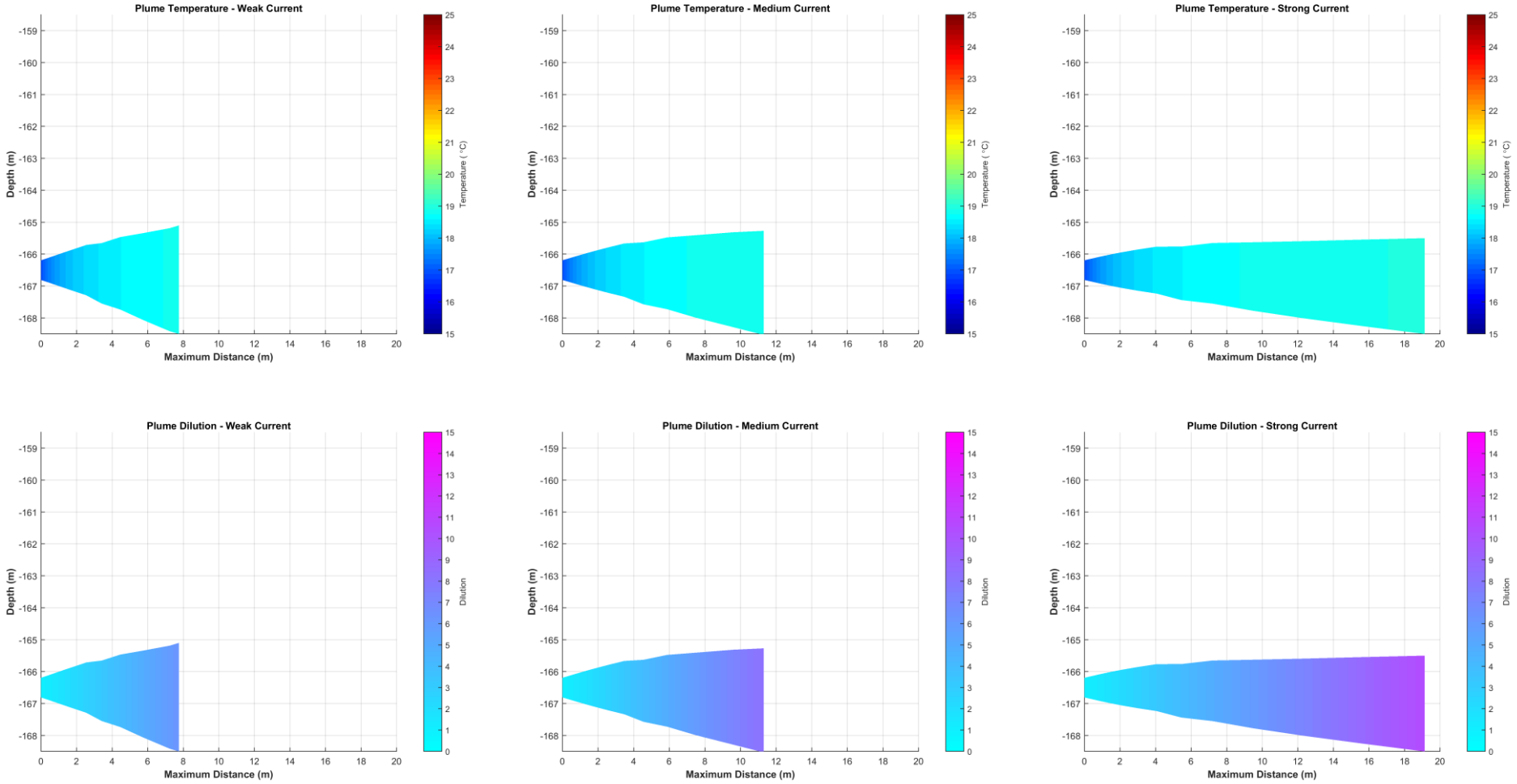


Figure 3.2 Near-field average temperature and dilution results for constant weak, medium and strong transitional currents (0.3 m^3/s flow rate).

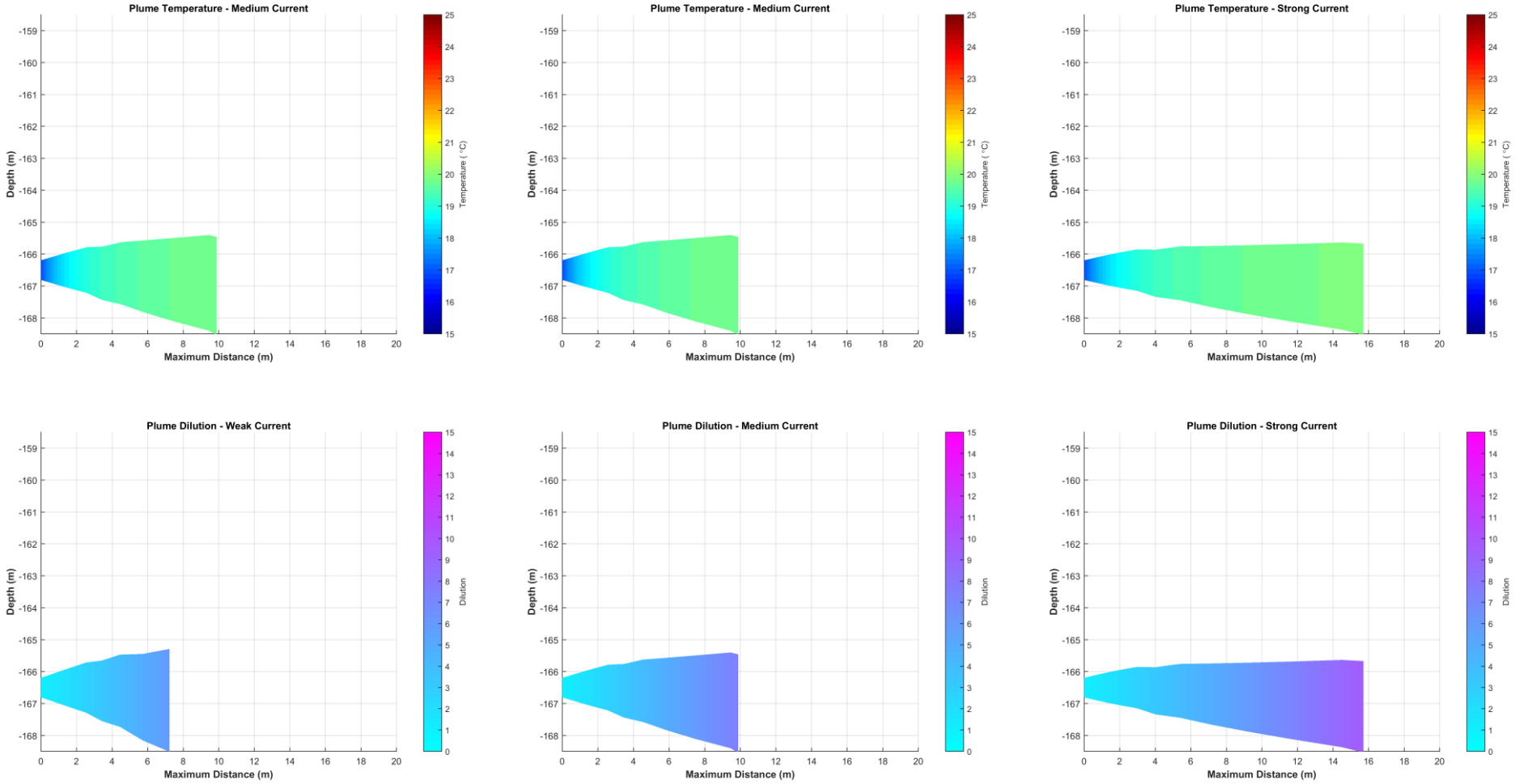


Figure 3.3 Near-field average temperature and dilution results for constant weak, medium and strong winter currents (0.3 m^3/s flow rate).

3.2 Far-Field Modelling

3.2.1 Overview

It is important to note that near-field and far-field modelling are used to describe different processes and scales of effect, and therefore the far-field modelling results will not necessarily correspond to the outcomes at the end of the near-field mixing zone for any given discharge scenario. The far-field results included episodes of pooling of the discharge plume under weak currents, which caused lower dilutions (higher concentrations) further from the discharge location when the pooled plume was advected away. Episodes of recirculation – where the plume moved back under the discharge at some later time due to the oscillatory nature of the tide – were also observed, compounding the pooling effect and further lowering the dilution values.

The results of the far-field modelling were statistically analysed to develop the distribution of outcomes based on time and event. These are presented as contours of minimum dilution. Note that the aggregated dilution contours presented in Section 3.2.2 do not represent the location of the plume at any point in time but are a statistical summary of the range of outcomes across all replicate simulations and time steps.

3.2.2 Seasonal Analysis

The model outputs over the ten-year hindcast period (2008-2017) were combined and analysed on a seasonal basis (summer, transitional and winter). This approach assists with identifying the potential exposure to the shoals nearest to the proposed Crux platform (Vulcan Shoal, Goeree Shoal and Eugene McDermott Shoal) on a seasonal basis whilst considering interannual variability in ocean current conditions.

Table 3.5 provides a summary of the minimum and maximum distances for the discharge location to achieve a given dilution for each season. Dilutions of 1:500 – equivalent to 1 ppm, which represents the impact threshold defined in Section 2.1.3.1 – are predicted to occur between 5,209 m and 5,727 m from the discharge point. The 1:500 dilution contour is predicted to remain at a minimum distance of more than 8 km from the nearest shoal (Goeree Shoal) in any season, therefore no exposure to harmful contaminant levels is expected for non-transient species.

Table 3.6 provides a summary of the total area of coverage for a given dilution for each season. The area of exposure for the 1:500 dilution level is predicted to be largest during summer conditions (52.9 km^2) and smallest during transitional conditions (48.3 km^2).

Figure 3.4 to Figure 3.6 show the aggregated spatial extents of the minimum dilutions for each season. Note that the contours represent the lowest predicted dilution (highest concentration) at any given time-step through the water column and do not consider frequency or duration.

The results presented are conservative and assume that no processes other than dilution (i.e. no biodegradation over the relatively short duration of the dispersion process) would reduce the source concentrations over time.

Table 3.5 Minimum, average and maximum distance from the hydrotest discharge location to achieve a given dilution for each season.

Flow rate (m^3/s)	Season	Minimum/average/maximum distance (m) from discharge location to achieve given dilution								
		1:50 dilution			1:100 dilution			1:500 dilution		
		Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum
0.3	Summer	825	960	1,063	3,622	3,811	3,980	5,332	5,589	5,727
	Transitional	911	1,112	1,242	2,863	2,925	2,985	4,875	5,077	5,209
	Winter	872	1,095	1,201	2,968	3,152	3,254	4,641	5,125	5,343

Table 3.6 Total area of coverage for a given dilution for each season.

Flow rate (m^3/s)	Season	Total area (km^2) of coverage for given dilution		
		1:50 dilution	1:100 dilution	1:500 dilution
0.3	Summer	1.2	7.8	52.9
	Transitional	1.3	7.6	48.3
	Winter	1.3	8.3	51.3

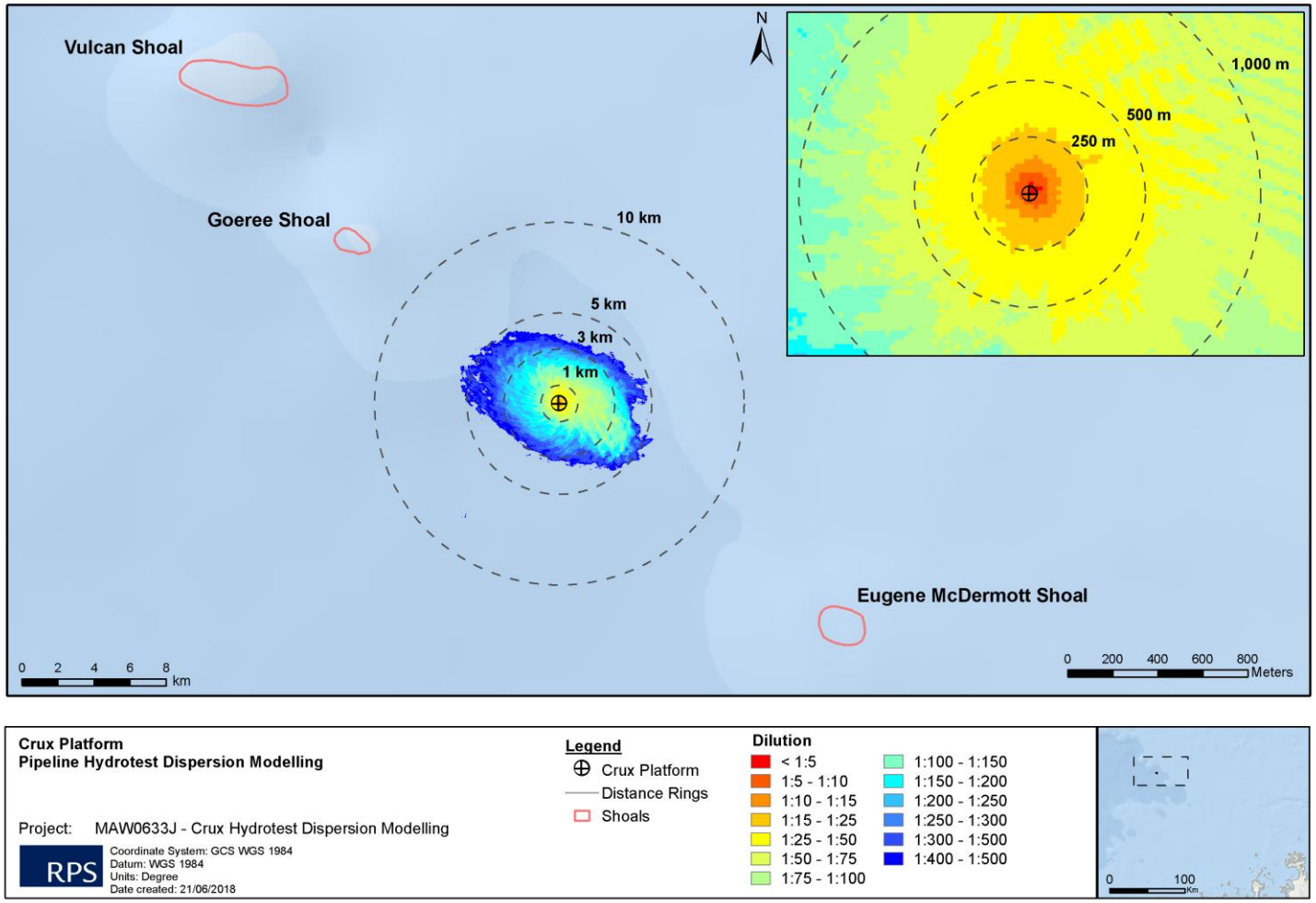


Figure 3.4 Predicted dilutions under summer conditions for the specified flow rate (0.3 m^3/s).

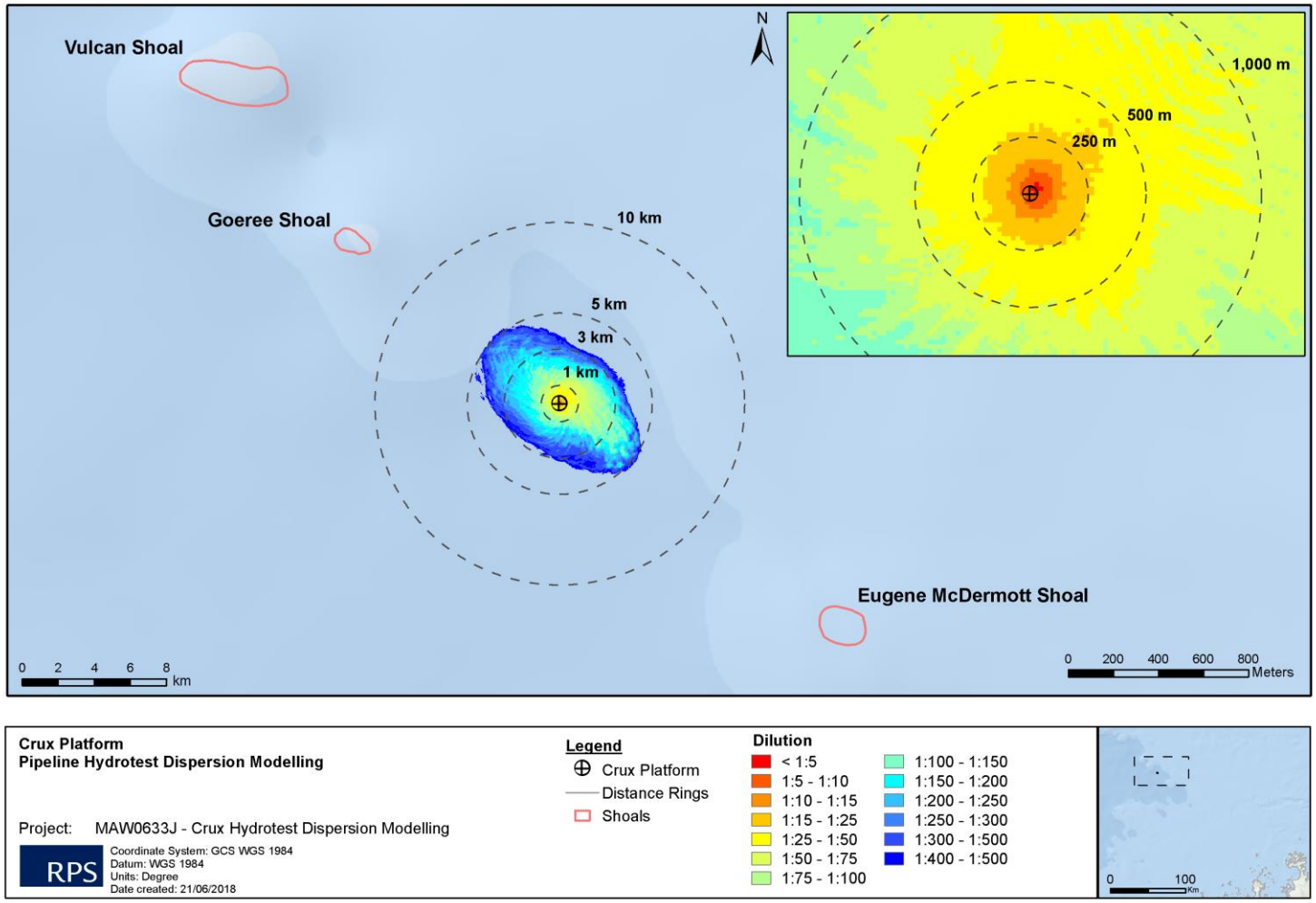


Figure 3.5 Predicted dilutions under transitional conditions for the specified flow rate (0.3 m^3/s).

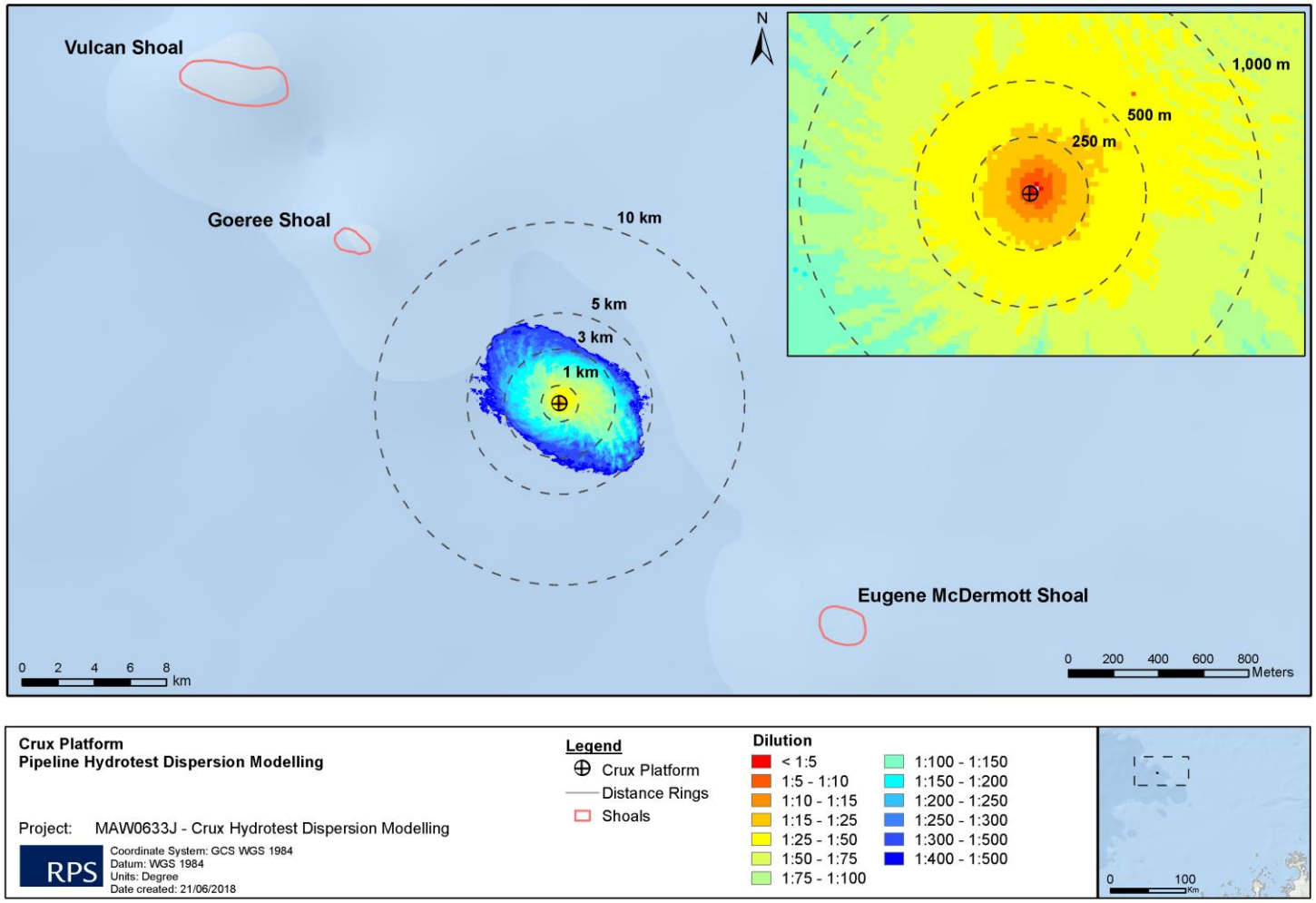


Figure 3.6 Predicted dilutions under winter conditions for the specified flow rate (0.3 m^3/s).

3.2.3 Combined Analysis

The model outputs for each season (summer, transitional and winter) over the ten-year hindcast period (2008-2017) were combined and analysed on an annualised basis.

Table 3.7 provides a summary of the minimum and maximum distances for the discharge location to achieve a given dilution for each season. Dilutions of 1:500 – equivalent to 1 ppm, which represents the impact threshold defined in Section 2.1.3.1 – are predicted to occur between 5,209 m and 5,727 m from the discharge point.

Table 3.8 provides a summary of the total area of coverage for a given dilution. The area of exposure for the 1:500 dilution level is predicted to be 57.0 km^2 for a flow rate of 0.3 m^2/s.

Figure 3.7 show the aggregated spatial extents of the minimum dilutions.

Note that the contours represent the lowest predicted dilution (highest concentration) at any given time-step through the water column and do not consider frequency or duration.

The results presented are conservative and assume that no processes other than dilution (i.e. no biodegradation over the relatively short duration of the dispersion process) would reduce the source concentrations over time.

Table 3.7 Minimum, average and maximum distance from the hydrotest discharge location to achieve a given dilution for each season.

Flow rate (m^3/s)	Season	Minimum/average/maximum distance (m) from discharge location to achieve given dilution								
		1:50 dilution			1:100 dilution			1:500 dilution		
		Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum
0.3	Annualised	825	1,055	1,242	2,863	3,296	3,980	4,641	5,263	5,727

Table 3.8 Total area of coverage for a given dilution.

Flow rate (m^3/s)	Season	Total area (km^2) of coverage for given dilution		
		1:50 dilution	1:100 dilution	1:500 dilution
0.3	Annualised	1.5	9.5	57.0

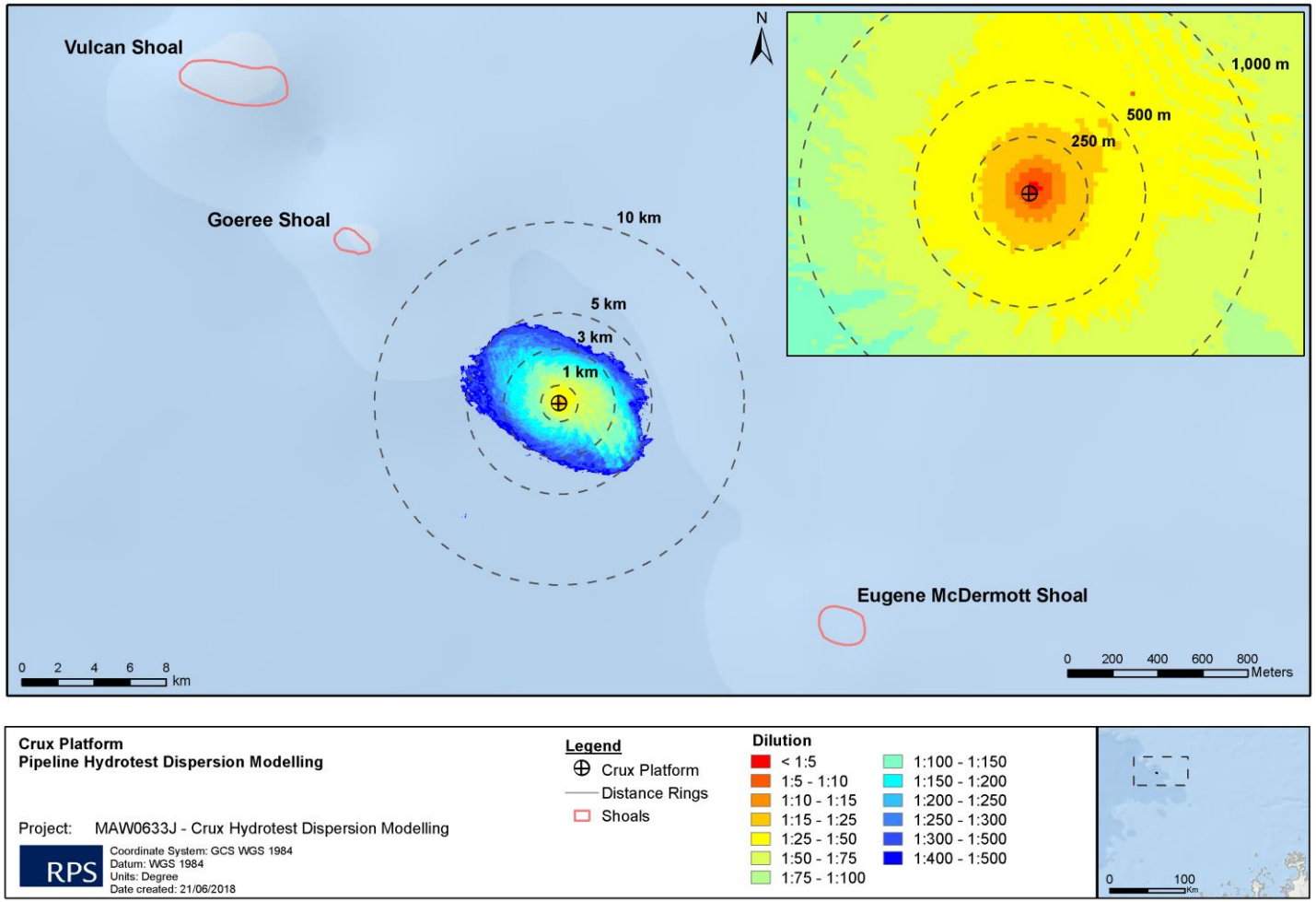


Figure 3.7 Predicted annualised minimum dilutions for the specified flow rate (0.3 m^3/s).

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Appendix G: Oil Spill Modelling Study (RPS 2018d)

REPORT

Crux Project

Oil Spill Modelling

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1 Introduction

1.1 Background

RPS has been commissioned by CDM Smith Australia Pty Ltd (CDM Smith), on behalf of Shell Australia Pty Ltd (Shell), to undertake a quantitative spill risk assessment of hypothetical hydrocarbon spill scenarios at the proposed Crux platform (Crux platform) and related components of the project (Table 1.1). The Crux platform is located in the northern Browse Basin in offshore Commonwealth marine waters, approximately 190 km offshore north-west Australia and 620 km north-north-east of Broome.

The main objectives of the study were to provide an assessment, through stochastic spill modelling, of the probabilities of hydrocarbon contact (at greater than defined concentrations), and quantify the effects on both the surface waters and within the water column (i.e. entrained and dissolved aromatic hydrocarbons) at key environmental values and sensitivities (e.g. shoals/banks, offshore reefs and islands, Australian Marine Parks etc.).

Shell identified four maximum credible hydrocarbon spill scenarios that may be associated with the Crux project, including a subsea well blowout, a loss of condensate inventory at the platform, a subsea pipeline rupture, and a loss of fuel from a support vessel. Each scenario was modelled and assessed over defined seasonal periods: summer (December to February), winter (April to August) and transitional (March and September to November).

The details of the scenarios assessed in this study are as follows:

- Scenario 1: A long-term (80-day) uncontrolled subsurface blowout of 206,225 m^3 (2,578 m^3/day) of Crux condensate at a development well location;
- Scenario 2: A short-term (instantaneous) surface release of 88 m^3 of Crux condensate at the platform location following an inventory integrity failure;
- Scenario 3: A short-term (5.6-hour) subsurface release of 2,037 m^3 of Crux condensate from the export pipeline at the closest point to Heywood Shoal following a rupture; and
- Scenario 4: A short-term (1-hour) surface release of 1,000 m^3 of Intermediate Fuel Oil (IFO-180) at the Crux end of the export pipeline following a pipelay vessel collision.

The release locations modelled are shown in Table 1.1 and Figure 1.1.

Oil spill modelling was undertaken using a three-dimensional oil spill trajectory and weathering model, SIMAP (Spill Impact Mapping and Analysis Program), which is designed to simulate the transport, spreading and weathering of specific oil types under the influence of changing meteorological and oceanographic forces.

Near-field subsurface discharge modelling was undertaken using OILMAP, which predicts the droplet sizes that are generated by the turbulence of the discharge as well as the centreline velocity, buoyancy, width and trapping depth (if any) of the rising gas and oil plumes.

The modelling outcomes provide a conservative understanding of where a large-scale hydrocarbon release could travel in any condition, plotted all in one figure. The modelling does not take into consideration any of the spill prevention, mitigation and response capabilities that would be implemented in response to the spill. Therefore, the modelling results represent the maximum extent that may be influenced by the released hydrocarbons.

The hydrocarbon spill model, and the methodology and analysis applied herein, uses modelling algorithms which have been anonymously peer-reviewed and published in international journals. Further, RPS warrants

that this work meets and exceeds the American Society for Testing and Materials (ASTM) Standard F2067-13 "*Standard Practice for Development and Use of Oil Spill Models*".

Table 1.1 Locations of the proposed Crux platform and the pipeline rupture point used as the release sites for the hydrocarbon spill modelling assessment.

Release Site	Latitude (°S)	Longitude (°E)	Water Depth (m)
Crux Development Well/Not Normally Manned platform	12° 57' 52.46"	124° 26' 33.21"	168.5
Pipeline route location closest to Heywood Shoal	13° 15' 29.00"	123° 54' 39.00"	199.0

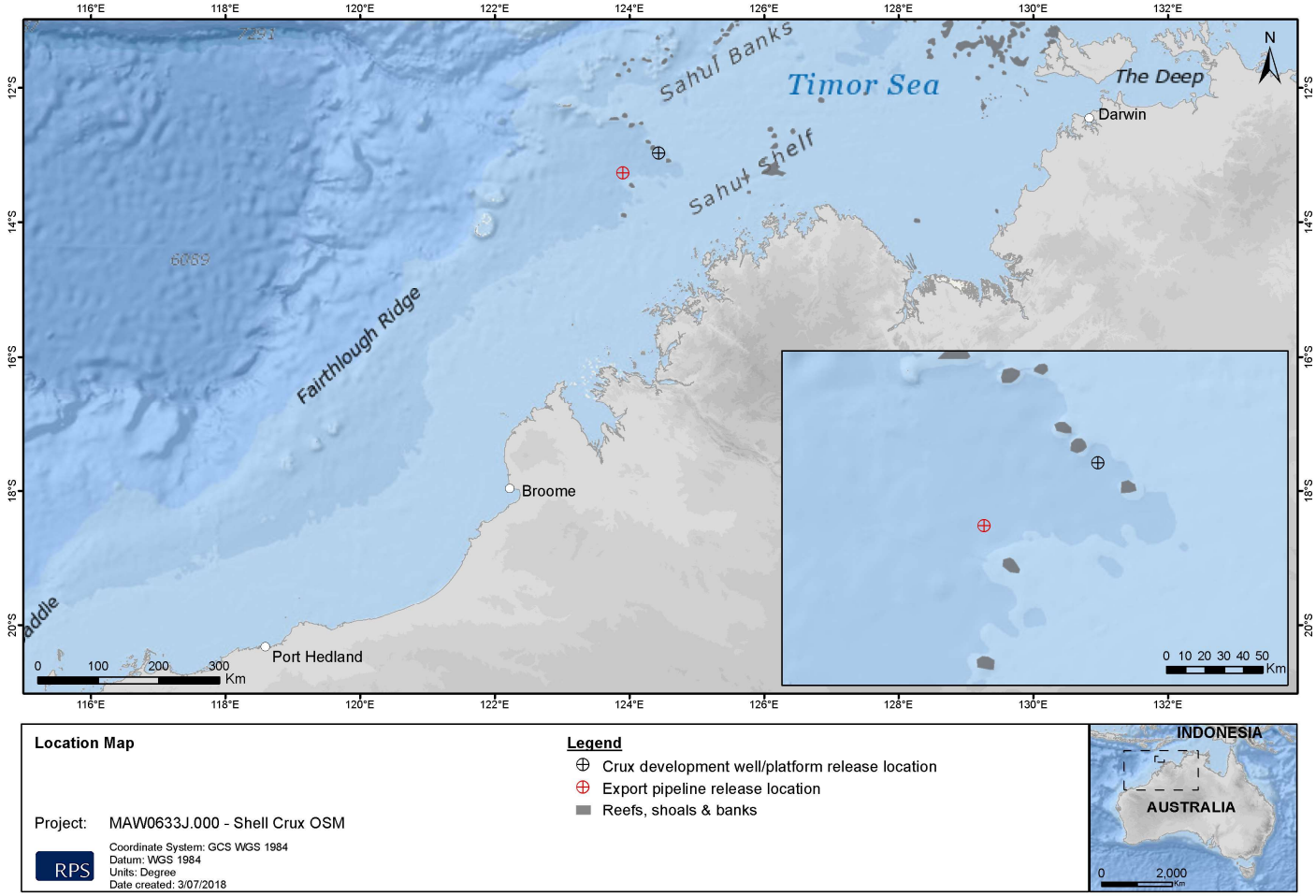


Figure 1.1 Location of the modelled hydrocarbon spill scenario release sites.

1.2 What is Oil Spill Modelling?

Oil spill modelling is a valuable tool widely used for risk assessment, emergency response and contingency planning where it can be particularly helpful to proponents and decision makers. By modelling a series of the most likely oil spill scenarios, decisions concerning suitable response measures and strategic locations for deploying equipment and materials can be made, and the locations at most risk can be identified. The two types of oil spill modelling often used are stochastic and deterministic modelling.

1.2.1 Stochastic Modelling (Multiple Spill Simulations)

Stochastic oil spill modelling is created by overlaying a great number (often hundreds) of individual, computer-simulated hypothetical spills (NOPSEMA, 2018; Figure 1.2).

Stochastic modelling is a common means of assessing the potential risks from oil spills related to new projects and facilities. Stochastic modelling typically utilises hydrodynamic data for the location in combination with historic wind data. Typically, 100-250 iterations of the model will be run utilising the data that is most relevant to the season or timing of the project.

The outcomes are often presented as a probability of exposure which is primarily used for risk assessment purposes and to understand the range of environments that could be influenced or impacted by a spill. Elements of the stochastic modelling can also be used in oil spill preparedness and planning.

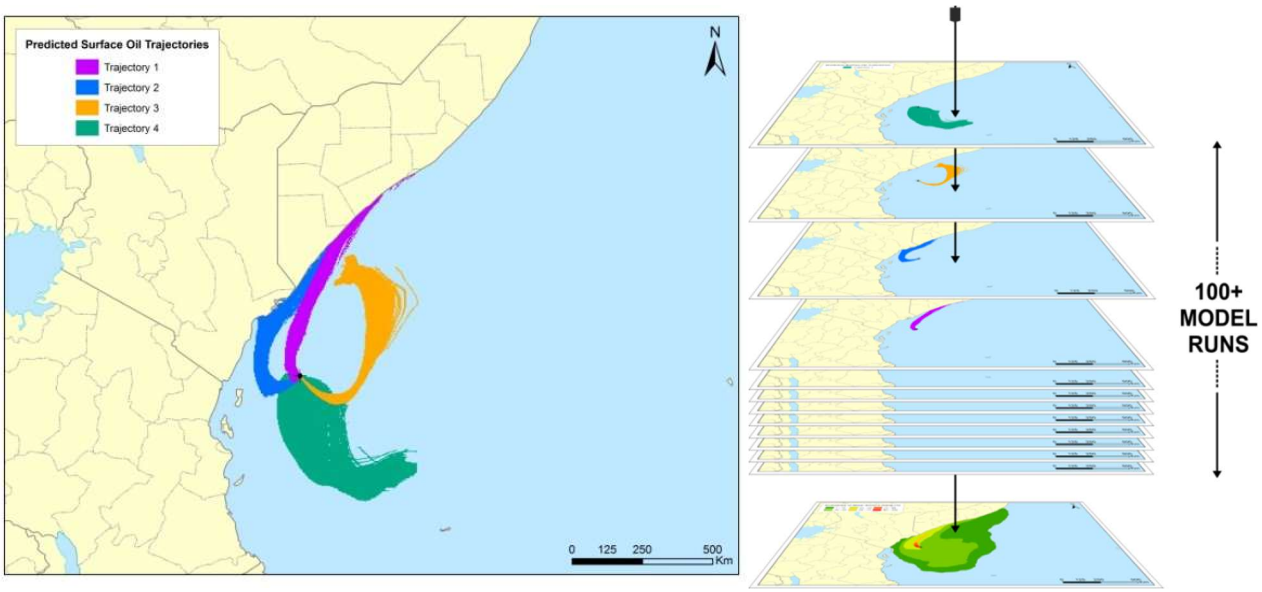


Figure 1.2 Examples of four individual spill trajectories (four replicate simulations) predicted by SIMAP for a spill scenario. The frequency of contact with given locations is used to calculate the probability of impacts during a spill. Essentially, all model runs are overlain (shown as the stacked runs on the right) and the number of times that trajectories contact a given location at a concentration is used to calculate the probability.

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1.2.2 Deterministic Modelling (Single Spill Simulation)

Deterministic modelling is the predictive modelling of a single incident subject to a single sample of wind and weather conditions over time (NOPSEMA, 2018; Figure 1.3).

Deterministic modelling is often paired with stochastic modelling to place the large stochastic footprint into perspective. This deterministic analysis is generally a single run selected from the stochastic analysis and serves as the basis for developing the plans and equipment needs for a realistic spill response.

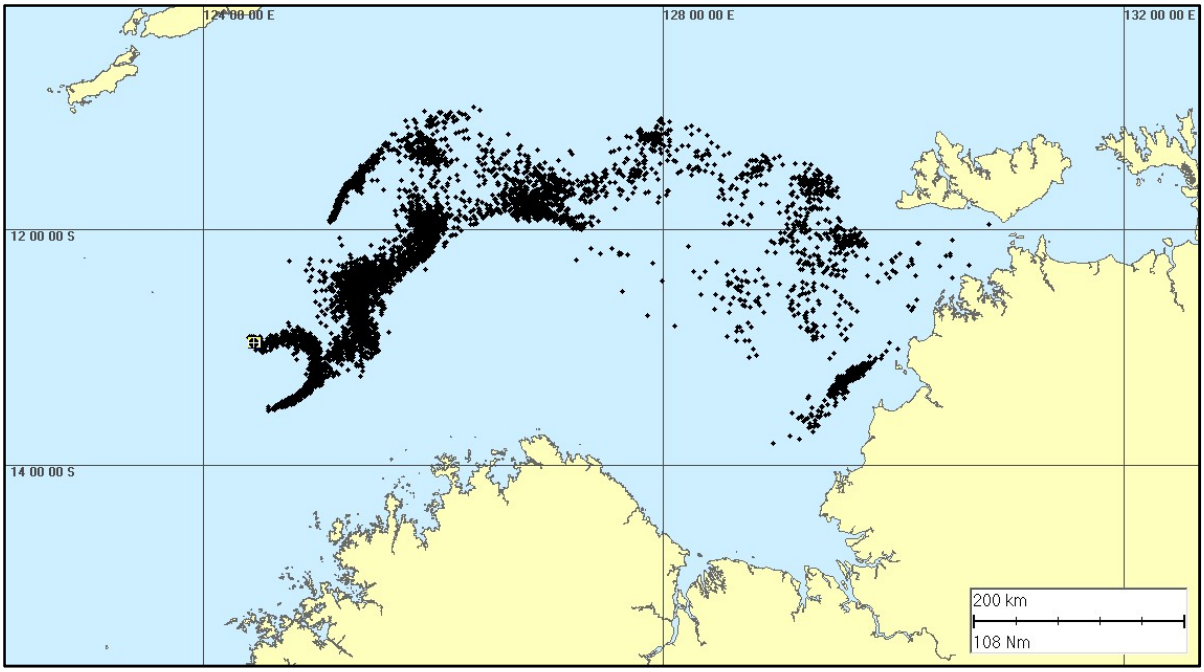


Figure 1.3 Example of an individual spill trajectory predicted by SIMAP for a spill scenario.

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2 Modelling Methodology

2.1 Description of the Models

2.1.1 SIMAP

The spill modelling was carried out using a purpose-developed oil spill trajectory and fates model, SIMAP (Spill Impact Mapping and Assessment Program). This model is designed to simulate the transport and weathering processes that affect the outcomes of hydrocarbon spills to the sea, accounting for the specific oil type, spill scenario, and prevailing wind and current patterns.

SIMAP is an evolution of the US EPA Natural Resource Damage Assessment model (French & Rines, 1997; French, 1998; French *et al.*, 1999) and is designed to simulate the fate and effects of spilled oils and fuels for both the surface and three-dimensional plume that is generated in the water column. SIMAP includes algorithms to account for both physical transport and weathering processes. The latter are important for accounting for the partitioning of the spilled mass over time between the water surface (surface hydrocarbons), water column (entrained oil and dissolved compounds), atmosphere (evaporated compounds) and land (stranded oil). The model also accounts for the interaction between weathering and transport processes.

The physical transport algorithms calculate transport and spreading by physical forces, including surface tension, gravity and wind and current forces for both hydrocarbons on the sea surface and within the water column. The fates algorithms calculate all of the weathering processes known to be important for oil spilled to marine waters. These include droplet and slick formation, entrainment by wave action, emulsification, dissolution of soluble components, sedimentation, evaporation, bacterial and photo-chemical decay and shoreline interactions. These algorithms account for the specific oil type being considered.

Entrainment is the physical process where globules of oil are transported from the sea surface into the water column by breaking waves. It has been observed that entrained oil is broken into droplets of varying sizes. Small droplets spread and diffuse in the water column, while larger ones rise rapidly back to the surface (Delvigne & Sweeney, 1988; Delvigne, 1991).

Dissolution is the process by which soluble hydrocarbons enter the water from a surface slick or from entrained droplets. The lower molecular weight hydrocarbons tend to be both more volatile and more soluble than those of higher molecular weight.

The formation of water-in-oil emulsions, or mousse, which is termed ‘emulsification’, depends on oil composition and sea state. Emulsified oil can contain as much as 80% water in the form of micrometre-sized droplets dispersed within a continuous phase of oil (Wheeler, 1978; Daling & Brandvik, 1991; Bobra, 1991; Daling *et al.*, 1997; Fingas, 1995; Fingas, 1997).

Evaporation can result in the transfer of large proportions of spilled oil from the sea surface to the atmosphere, depending on the type of oil (Gundlach & Boehm, 1981).

Evaporation rates vary over space and time, and are dependent on the prevailing sea temperatures, wind and current speeds, the surface area of the droplets (sea surface and entrained) that are exposed to the atmosphere as well as the state of weathering of the oil. Evaporation rates will decrease over time, depending on the calculated rate of loss of the more volatile compounds. By this process, the model can differentiate between the fates of different oil types.

Entrainment, dissolution and emulsification rates are correlated to wave energy, which is accounted for by estimating wave heights from the sustained wind speed, direction and fetch (i.e. distance downwind from land barriers) at different locations in the domain. Dissolution rates are dependent upon the proportion of soluble, short-chained hydrocarbon compounds, and the surface area at the oil/water interface. Dissolution rates are

also strongly affected by the level of turbulence. For example, dissolution rates will be relatively high at the site of the release for a deep-sea discharge at high pressure.

In contrast, the release of hydrocarbons onto the water surface will not generate high concentrations of soluble compounds. However, subsequent exposure of hydrocarbons on the sea surface to breaking waves will enhance entrainment of oil into the upper water column as oil droplets, which will enhance dissolution of the soluble components. Because the compounds that have high solubility also have high volatility, the processes of evaporation and dissolution will be in dynamic competition with the balance dictated by the nature of the release and the weather conditions that affect the oil after release. The SIMAP weathering algorithms include terms to represent these dynamic processes. Technical descriptions of the algorithms used in SIMAP and validations against real spill events are provided in French (1998), French *et al.* (1999) and French-McCay (2004).

Input specifications for oil types include the density, viscosity, pour-point, distillation curve (volume of oil distilled off versus temperature) and the aromatic/aliphatic component ratios within given boiling point ranges. The model calculates a distribution of the oil by mass into the following components:

- Surface-bound or floating oil;
- Entrained oil (non-dissolved oil droplets that are physically entrained by wave action);
- Dissolved hydrocarbons (principally the aromatic and short-chained aliphatic compounds);
- Evaporated hydrocarbons;
- Sedimented hydrocarbons; and
- Decayed hydrocarbons.

2.1.2 OILMAP

SIMAP uses specifications of the depth of release to represent spills onto the water surface or into the water column. For subsurface release scenarios, where oil will initially be entrained in the water column as droplets of oil in suspension, it is necessary to define the size-distribution of the droplets and their initial vertical distribution following the initial (within minutes) discharge processes. These processes include the jet induced by the discharge and the dynamic evolution of any associated gas plume. This size distribution will regulate the time for oil droplets to rise to near the sea surface and affect their ability to surface and become floating oil.

High pressure releases (such as a subsea pipeline rupture or gas/oil blowout) tend to generate a distribution with a small to median size (300 µm or less; Johansen, 2003). Due to their larger surface area to volume ratio, droplets of decreasing size will rise under buoyancy at a quadratically slower rate due to viscous resistance exerted by the surrounding water, which can be theoretically derived using Stokes' Law.

If oil is discharged with little or no gas, the oil droplets must rise to the surface under their own buoyancy (resisted by water viscosity) after the dissipation of a relatively short (approximately 1-2 m) discharge jet. However, if gas is discharged with the oil, it will rapidly expand on exiting the pressurised reservoir and continue to expand as it rises and water pressure reduces. As the discharge moves upward, the density difference between the expanding gas bubbles in the plume and the receiving water results in a buoyant force which drives the plume of gas, oil and water towards the surface.

Oil in the release is rapidly mixed by the turbulence in the rising plume. These droplets (typically a few micrometres to millimetres in diameter) are rapidly transported upward by the rising plume; their individual rise velocities contributing little to their upward motion. As the plume rises, it continues to entrain ambient water, which reduces the buoyancy of the mixture and increases the radius of the plume (Chen & Yapa, 2007; Spaulding *et al.*, 2000).

In shallow water (<200 m), which is representative of the depth profiles in the Crux development area, the rising plume of gas, oil and water will tend to reach the sea surface before deflecting as a radial, surface flow zone which will spread the oil droplets rapidly away from the centre of the plume (Spaulding *et al.*, 2000). The velocity and oil concentrations in this surface flow zone decrease while the depth of the zone increases. Finally, in the far field where the plume buoyancy has been dissipated, ambient currents and the turbulence generated by wind generated waves will determine the subsequent transport and dispersion of the oil droplets.

OILMAP is an oil spill trajectory and fates model extended for the prediction of oil from subsurface oil/gas blowouts, (Spaulding *et al.*, 2000). The blowout model predicts the droplet sizes that are generated by the turbulence of the discharge as well as the centreline velocity, buoyancy, width and trapping depth (if any) of the rising gas plume. Inputs to the model include the depth (hence water pressure); discharge rate; hole size; oil density and viscosity, and the vertical temperature/salinity profile of the receiving water. This model was applied to supply the droplet size distribution and the plume dimensions to the SIMAP model, for the long-term discharge simulations.

The current, wind and water column profile data used as input to the modelling are discussed in Sections 2.2, 2.3 and 2.4, respectively.

2.2 Regional Ocean Currents

2.2.1 Overview

The area of interest for this study is typified by strong tidal flows over the shallower regions, particularly along the inshore region of the Kimberley Coast. However, the offshore regions with water depths exceeding 100-200 m experience significant large-scale drift currents. These drift currents can be relatively strong (1-2 knots) and complex, manifesting as a series of eddies, meandering currents and connecting flows. These offshore drift currents also tend to persist longer (days to weeks) than tidal current flows (hours between reversals) and thus will have greater influence upon the net trajectory of hydrocarbon plumes over time scales exceeding a few hours.

Wind shear on the water surface also generates local-scale currents that can persist for extended periods (hours to days) and result in long trajectories. Hence, the current-induced transport of plumes can be variably affected by combinations of tidal, wind-induced and density-induced drift currents. Depending on their local influence, it is important to consider all these potential advective mechanisms to rigorously understand patterns of potential transport from a given discharge location.

To appropriately allow for temporal and spatial variation in the current field, dispersion modelling requires the current speed and direction over a spatial grid covering the potential migration zone of plumes. As long-term measured current data is not available at the Crux development area, the analysis relied upon hindcasts of the circulation generated by numerical modelling. Estimates of the net currents were derived by combining predictions of the drift currents, available from a mesoscale ocean model, with estimates of the tidal currents generated by an RPS model set up for the study area. These estimates are considered representative of the oceanographic currents that influence the Crux development area.

A composite modelled ocean current data product was derived by combining predictions of mesoscale circulation currents, available at daily resolution from global ocean models, with predictions of the hourly tidal currents generated by the RPS HYDROMAP model. By combining a drift current model with a tidal model, the influences of inter-annual and seasonal drift patterns, and the more regular variations in tide, were included.

2.2.2 Mesoscale Circulation

Large-scale and mesoscale ocean circulation (also referred to as drift currents) will be the dominant driver of long-term (> several days) transport of effluent plumes. Mesoscale ocean processes are generally defined as

having horizontal spatial scales of 10-500 km, and periods of 10-200 days, and processes with scales greater than this are referred to as large-scale. The major persistent large-scale and mesoscale surface currents off Western Australia are presented in Figure 2.1. They are characterised as follows:

- **Buoyancy driven circulation**. The main buoyancy-driven feature in the region is the Indonesian Throughflow (ITF) which conducts warm water from the equator into the Indian Ocean. Buoyancy gradients across the continental shelf due to differential heating and cooling and/or surface runoff may also drive three-dimensional circulation patterns.
- **Wind (Ekman) driven circulation**. The Australian North West Shelf has an annual wind cycle (easterly winds during winter, south-westerly winds during summer) which drives seasonal variability in surface circulation patterns.
- **Eddies and jets**. These non-linear features evolve from the large-scale and mesoscale flow field interacting with the bathymetry. These are random features and it is generally hard to predict their exact timing and location.

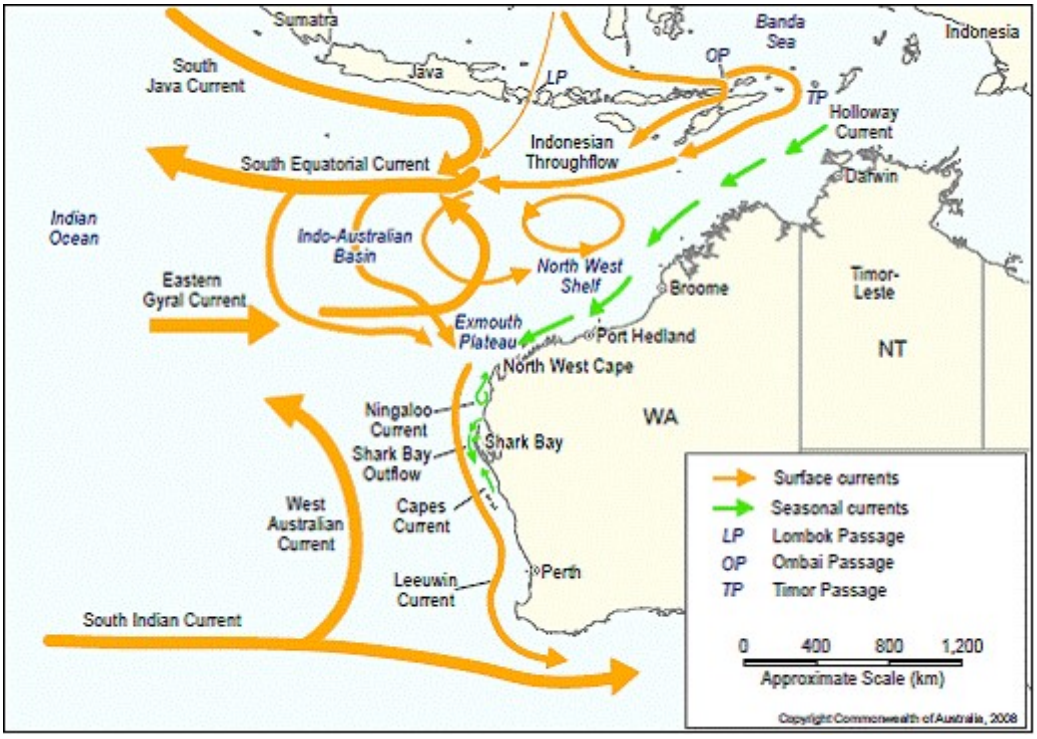


Figure 2.1 A map of the major currents off the West Australian coast (DEWHA, 2008).

2.2.2.1 Description of Mesoscale Model: HYCOM

Representation of the drift currents was available from the output of the global circulation model the Hybrid Coordinate Ocean Model (HYCOM; Bleck, 2002; Chassignet *et al.*, 2007, 2009), created by the National Ocean Partnership Program (NOPP), as part of the US Global Ocean Data Assimilation Experiment (GODAE). The HYCOM model is a three-dimensional model that assimilates ocean observations of sea surface temperature, sea surface salinity and surface height, obtained by satellite observations, along with atmospheric forcing

conditions from atmospheric models to predict drift currents generated by such forces as wind shear, density and sea height variations and the rotation of the earth.

The HYCOM model is configured to combine the three vertical coordinate types currently in use in ocean models: depth (*z*-levels), density (isopycnal layers), and terrain-following (*σ*-levels). HYCOM uses isopycnal layers in the open, stratified ocean, but uses the layered continuity equation to make a dynamically smooth transition to a terrain-following coordinate in shallow coastal regions, and to *z*-level coordinates in the mixed layer and/or unstratified seas. Thus, this hybrid coordinate system allows for the extension of the geographic range of applicability to shallow coastal seas and unstratified parts of the world ocean. It maintains the significant advantages of an isopycnal model in stratified regions while allowing more vertical resolution near the surface and in shallow coastal areas, hence providing a better representation of the upper ocean physics. The model has global coverage with a horizontal resolution of 1/12th of a degree (approximately 7 km at mid-latitudes) and a temporal resolution of one day.

A hindcast data set of HYCOM currents was obtained for a ten-year period spanning 2008 to 2017 (inclusive).

Figure 2.2 shows the seasonal surface current roses near the Crux platform. The data shows that the surface current speeds and directions vary between seasons. In general, during summer (December to February) currents have the strongest average speed (0.25 m/s with a maximum of 0.65 m/s) and tend to flow west-southwest. During winter (April to August), current flow conditions are more variable and flow mostly toward the west-southwest and east-northeast. During transitional conditions (March and September to November), the current flow is less variable and predominantly toward the west.

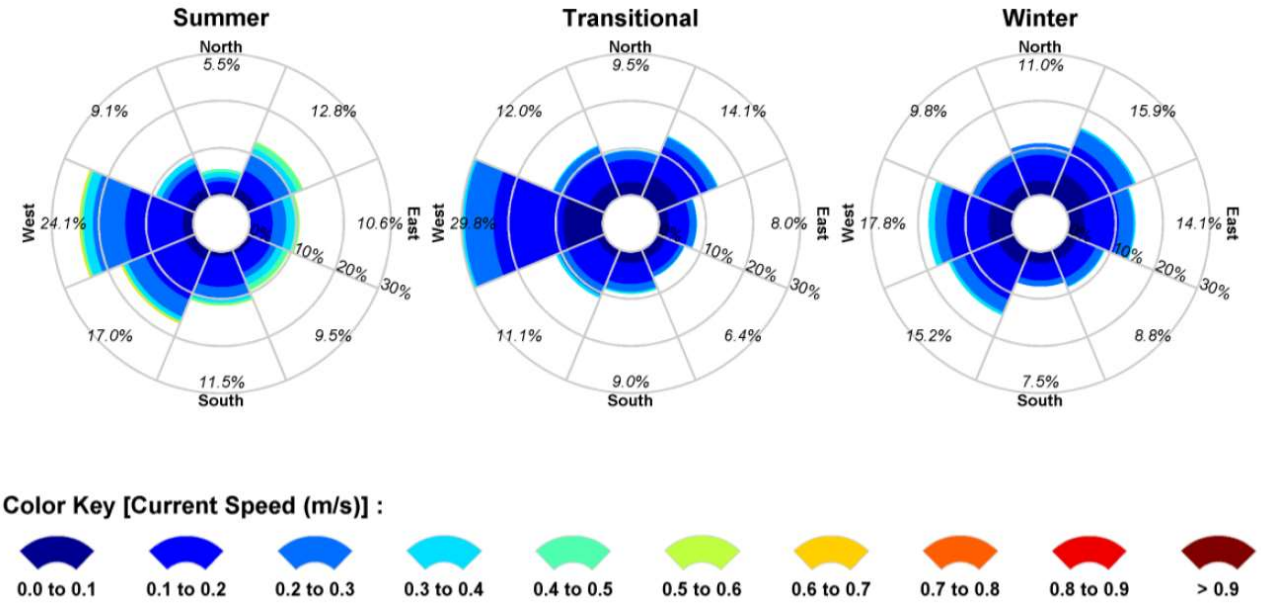


Figure 2.2 Seasonal current distribution (2008-2017, inclusive) derived from the HYCOM database near to the proposed Crux platform. The colour key shows the current magnitude, the compass direction provides the direction towards which the current is flowing, and the size of the wedge gives the percentage of the record.

RPS

2.2.3 Tidal Currents

2.2.3.1 Description of Tidal Model: HYDROMAP

As the HYCOM model does not include tidal forcing, and because the data is only available at a daily frequency, a tidal model was developed for the study region using RPS' three-dimensional hydrodynamic model, HYDROMAP.

The model formulations and output (current speed, direction and sea level) of this model have been validated through field measurements around the world for more than 25 years (Isaji & Spaulding, 1984, 1986; Isaji *et al.*, 2001; Zigic *et al.*, 2003). HYDROMAP current data has also been widely used as input to forecasts and hindcasts of oil spill migrations in Australian waters. This modelling system forms part of the National Marine Oil Spill Contingency Plan for the Australian Maritime Safety Authority (AMSA) (AMSA, 2002).

HYDROMAP simulates the flow of ocean currents within a model region due to forcing by astronomical tides, wind stress and bottom friction. The model employs a sophisticated dynamically nested-gridding strategy, supporting up to six levels of spatial resolution within a single domain. This allows for higher resolution of currents within areas of greater bathymetric and coastline complexity, or of particular interest to a study.

The numerical solution methodology of HYDROMAP follows that of Davies (1977a, 1977b) with further developments for model efficiency by Owen (1980) and Gordon (1982). A more detailed presentation of the model can be found in Isaji & Spaulding (1984).

2.2.3.2 Tidal Grid Setup

A HYDROMAP model was established over a domain that extended approximately 4,800 km east-west by 4,200 km north-south over the eastern Indian Ocean. The grid extends beyond Eucla in the south and beyond Indonesia in the north (Figure 2.3).

Four layers of sub-gridding were applied to provide variable resolution throughout the domain. The resolution at the primary level was 15 km. The finer levels were defined by subdividing these cells into 4, 16 and 64 cells, resulting in resolutions of 7.5 km, 3.75 km and 1.88 km. The finer grids were allocated in a step-wise fashion to areas where higher resolution of circulation patterns was required to resolve flows through channels, around shorelines or over more complex bathymetry. Approximately 156,000 cells were used to define the region.

Bathymetric data used to define the three-dimensional shape of the study domain was extracted from the CMAP electronic chart database and supplemented where necessary with manual digitisation of chart data supplied by the Australian Hydrographic Office. Depths in the domain ranged from shallow intertidal areas through to approximately 7,200 m.

2.2.3.3 Tidal Boundary Conditions

Ocean boundary data for the HYDROMAP model was obtained from the TOPEX/Poseidon global tidal database (TPXO7.2) of satellite-measured altimetry data, which provided estimates of tidal amplitudes and phases for the eight dominant tidal constituents (designated as K_2, S_2, M_2, N_2, K_1, P_1, O_1 and Q_1) at a horizontal scale of approximately 0.25°. Using the tidal data, sea surface heights are firstly calculated along the open boundaries at each time step in the model.

The TOPEX/Poseidon satellite data is produced, and quality controlled by the US National Atmospheric and Space Agency (NASA). The satellites, equipped with two highly accurate altimeters capable of taking sea level measurements accurate to less than ±5 cm, measured oceanic surface elevations (and the resultant tides) for over 13 years (1992–2005). In total, these satellites carried out more than 62,000 orbits of the planet. The TOPEX/Poseidon tidal data has been widely used amongst the oceanographic community, being the subject of more than 2,100 research publications (e.g. Andersen, 1995; Ludicone *et al.*, 1998; Matsumoto *et al.*, 2000;

Kostianoy *et al.*, 2003; Yaremchuk & Tangdong, 2004; Qiu & Chen, 2010). As such, the TOPEX/Poseidon tidal data is considered suitably accurate for this study.

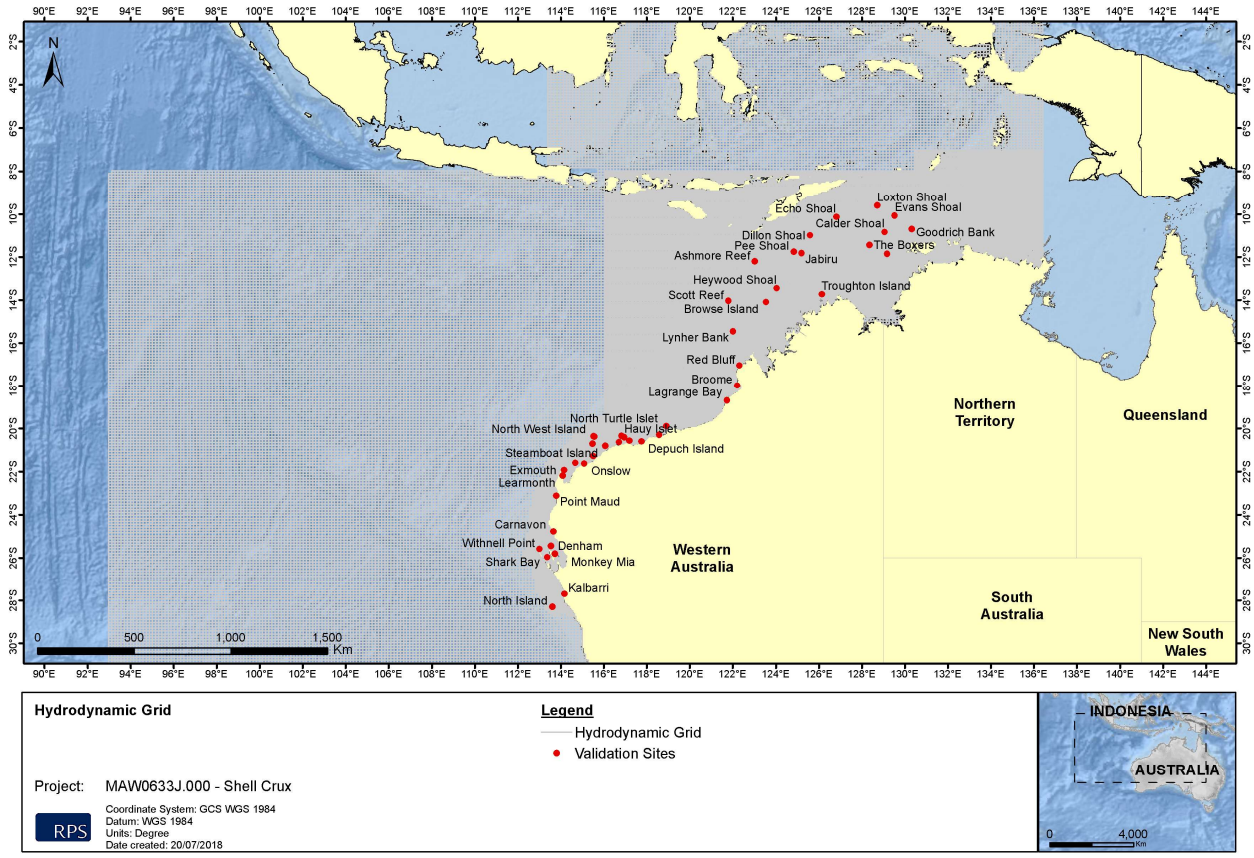


Figure 2.3 Hydrodynamic model grid (grey wire mesh) used to generate the tidal currents, showing the full domain in context with the continental land mass and the locations available for tidal comparisons (red labelled dots). Higher-resolution areas are indicated by the denser mesh zones.

2.2.4 Tidal and Current Model Validation

The suitability of the modelled tidal and drift current data products was evaluated by comparing the predicted currents to those measured at the Crux development area. The following sections describe the sources of both the modelled and measured data, the comparison methodology, and the outcomes of the comparisons for both the tidal and drift current components.

2.2.4.1 Data Sources

A tidal model was developed for the study region using RPS' three-dimensional hydrodynamic model, HYDROMAP. HYDROMAP simulates the flow of ocean currents within a model region due to forcing by astronomical tides, wind stress and bottom friction. This model is described in Section 2.2.3.

A mesoscale ocean current data sets was selected for the study: HYCOM (Hybrid Coordinate Ocean Model) Consortium's global ocean model, HYCOM. This model is described in Section 2.2.2.

A data set of measured currents was collected by RPS at the Crux development area between April 2016 and May 2017 (RPS, 2017). This data set includes a series of point current measurements made at six depths through the water column using CM04 current meters mounted on a floating mooring. The measurement depths are approximately 20 m, 70 m, 110 m, 150 m, 165 m and 167 m below the water surface. The temporal resolution of the data is 1 minute. The raw data was quality-controlled by RPS and only data identified as high-quality was used for comparison to model data. For the measurements at a 20 m water depth, there is approximately a 7-week gap in the data between early September and late October 2016.

2.2.4.2 Model Validation Skills

2.2.4.2.1 Overview

The mesoscale and tidal current models were validated through quantitative and visual comparisons of measured and modelled data.

2.2.4.2.2 Statistics

A quantitative analysis of a model's skill at replicating the environmental conditions was conducted using the Index of Agreement (IOA), presented in Willmott (1981), and the Mean Absolute Error (MAE), discussed in Willmott (1982) and Willmott & Matsuura (2005). Other traditional error estimates, such as the correlation coefficient and the root mean square error (RMSE) are problematic and prone to ambiguities and bias (Willmott & Matsuura, 2005; Willmott, 1982). Consequently, they are not reported in isolation here.

The MAE is simply the average of the absolute values of the differences between the observed and modelled values. MAE is a more natural measure of average error (Willmott & Matsuura, 2005) and more readily understood. The IOA is determined using the following formula:

$$\mathrm{IOA} = 1 - \frac{\sum |X_{\mathrm{model}} - X_{\mathrm{obs}}|^2}{\sum \left(|X_{\mathrm{model}} - \overline{X_{\mathrm{obs}}}| + |X_{\mathrm{obs}} - \overline{X_{\mathrm{obs}}}| \right)^2}$$

In this equation, X represents the variable being compared and $\bar{X}$ represents the mean of that variable over time.

A perfect agreement can be said to exist between the model and field observations if the IOA gives a measure of one, and complete disagreement will produce an IOA measure of zero (Wilmott, 1981). Although it is difficult to find guidelines for what values of the IOA might represent a good agreement, Willmott *et al.* (1985) suggests that values meaningfully larger than 0.5 represent good model performance. Clearly, the higher the IOA and the lower the MAE, the better the model performance.

An important point to note regarding both, and in fact most, measures of model performance, is that slight phase differences in the series can result in a seemingly poor statistical comparison, particularly in rapidly changing series such as tidal direction or water elevation where the tidal range is large. It is therefore always important to consider both the statistics and the visual representation of the comparison (Willmott *et al.*, 1985). Statistical comparison of current direction can be misleading; skill measures of direction can become biased where the directional fluctuations are near 0-360°. Therefore, we have based the quantitative assessment on the U and V current components and not magnitude and direction.

2.2.4.2.3 Time Series

In addition to bulk statistical measures, model performance for the measurement period was assessed visually with the aid of scatterplots and rose plots. The scatterplots show the correlation between the x- and y-components of the measured and modelled data. The rose plots show the frequency of current direction by sector, and magnitude by colour, to allow comparison of current direction between modelled and measured data.

The model performance was also evaluated against time series plots of water level, U (east-west) velocity component, V (north/south) velocity component, current speed and current direction data. This approach is valuable because statistical measures of model skill can heavily penalise errors in phase (i.e. time lags) even when the dynamics of flow are broadly reproduced.

2.2.4.3 Tidal Elevation Validation

For verification of the tidal elevation predictions, the model output was compared against independent predictions of tides using the XTide database (Flater, 1998). The XTide database contains harmonic tidal constituents derived from measured water level data at locations around the world. Of more than 80 tidal stations within the HYDROMAP model domain, 18 sites near the Crux development area were used for comparison.

Time series comparisons were completed for a six-month period from January to June 2010. The statistics are summarised in Table 2.1, and indicate excellent model performance in this region. Water level time series for these locations are shown in Figure 2.4, Figure 2.5 and Figure 2.6 for a one-month period (March 2010). All comparisons show that the model produces a very good match to the known tidal behaviour for a wide range of tidal amplitudes and clearly represents the varying diurnal and semi-diurnal nature of the tidal signal.

For the purposes of understanding the limitations in accuracy of the tidal predictions, the RMSE and MAE in Table 2.1 should be noted. On average, the model predictions are within 0.1-0.3 m of XTide predictions based on known constituent data at any point in time. Often the error is mostly attributable to errors of phase in the tidal signal, with the magnitude of the tidal rise and fall over each tide well represented. However, in the application of the data predictions to operational circumstances, the potential errors should be considered.

The model skill was further evaluated through a comparison of the predicted and observed tidal constituents, derived from an analysis of model-predicted time-series at each location. A scatter plot of the observed and modelled amplitude (top) and phase (bottom) of the five dominant tidal constituents (S_2, M_2, N_2, K_1 and O_1) is presented in Figure 2.7. The red line on each plot shows the 1:1 line, which would indicate a perfect match between the modelled and observed data. Note that the data is generally closely aligned to the 1:1 line demonstrating the high quality of the model performance.

RPS

Table 2.1 Statistical comparison of predicted surface elevation data from HYDROMAP and XTide at 18 locations in the tidal model domain (January to July 2010).

Tide Station	Longitude (°E)	Latitude (°S)	IOA	CC	MAE (m)	RMSE (m)
Ashmore Reef	123.02	12.22	0.99	0.99	0.14	0.18
Browse Island	123.55	14.10	0.97	0.97	0.36	0.45
Calder Shoal	129.07	10.85	0.97	0.97	0.17	0.21
Cape Legendre	116.83	20.35	0.99	0.99	0.12	0.14
Dillon Shoal	125.60	11.00	0.97	0.95	0.18	0.22
Echo Shoal	126.82	10.15	0.97	0.94	0.17	0.21
Evans Shoal	129.53	10.08	0.98	0.98	0.11	0.14
Goodrich Bank	130.32	10.70	0.99	0.97	0.13	0.16
Heywood Shoal	124.05	13.47	0.98	0.96	0.27	0.33
Jabiru	125.20	11.83	097	0.95	0.22	0.27
Loxton Shoal	128.72	09.60	0.99	0.98	0.10	0.13
Lynedoch Bank	130.82	10.03	0.98	0.98	0.12	0.15
Lynher Bank	122.02	15.47	0.98	0.97	0.26	0.31
Newby Shoal	129.18	11.87	0.98	0.96	0.23	0.27
Pee Shoal	124.83	11.77	0.97	0.94	0.23	0.27
Scott Reef	121.80	14.05	0.99	0.98	0.16	0.19
The Boxers	128.35	11.45	0.97	0.96	0.16	0.20
Troughton Island	126.13	13.75	0.97	0.95	0.27	0.33

Notes: *IOA Index of Agreement – values close to 1 represent a high level of agreement.*
CC Correlation Coefficient – values close to 1 represent very good correlation.
MAE Mean Absolute Error – the lower the value, the smaller the error.
RMSE Root Mean Square Error – the lower the value, the smaller the error.

RPS

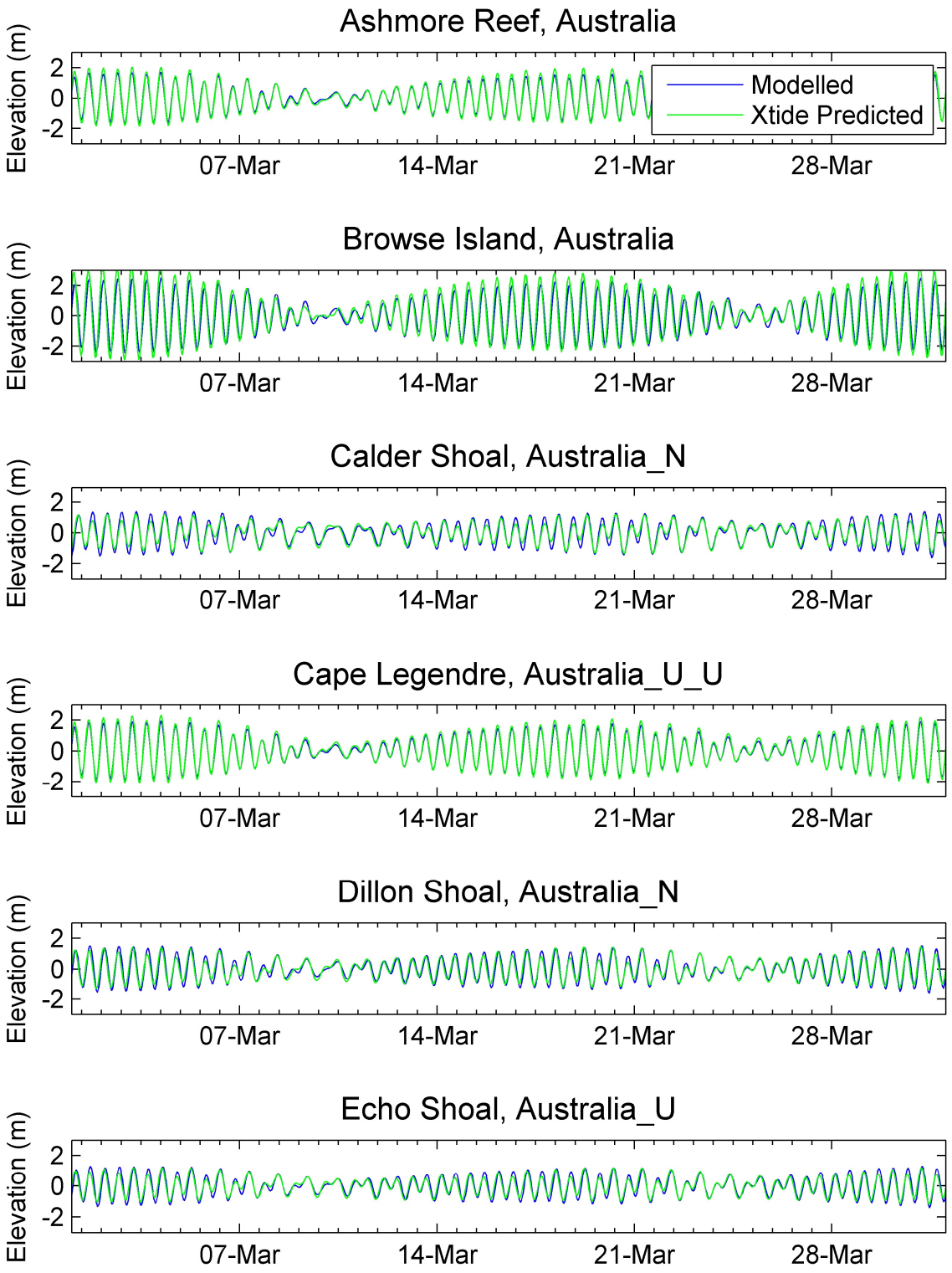


Figure 2.4 Time series comparisons between predicted surface elevation data from HYDROMAP (blue line) and XTide (green line) at six locations in the tidal model domain (March 2010).

RPS

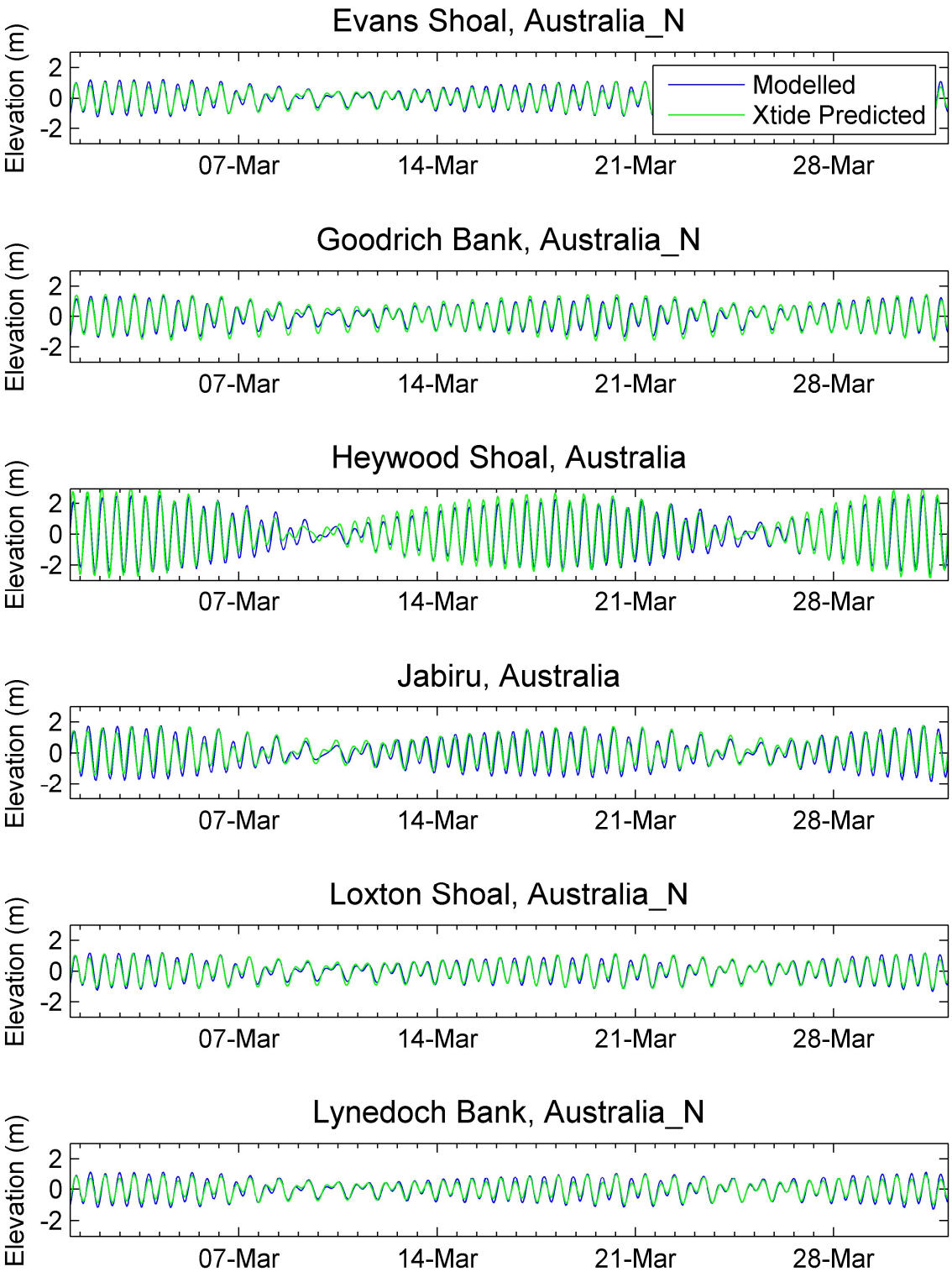


Figure 2.5 Time series comparisons between predicted surface elevation data from HYDROMAP (blue line) and XTide (green line) at six locations in the tidal model domain (March 2010).

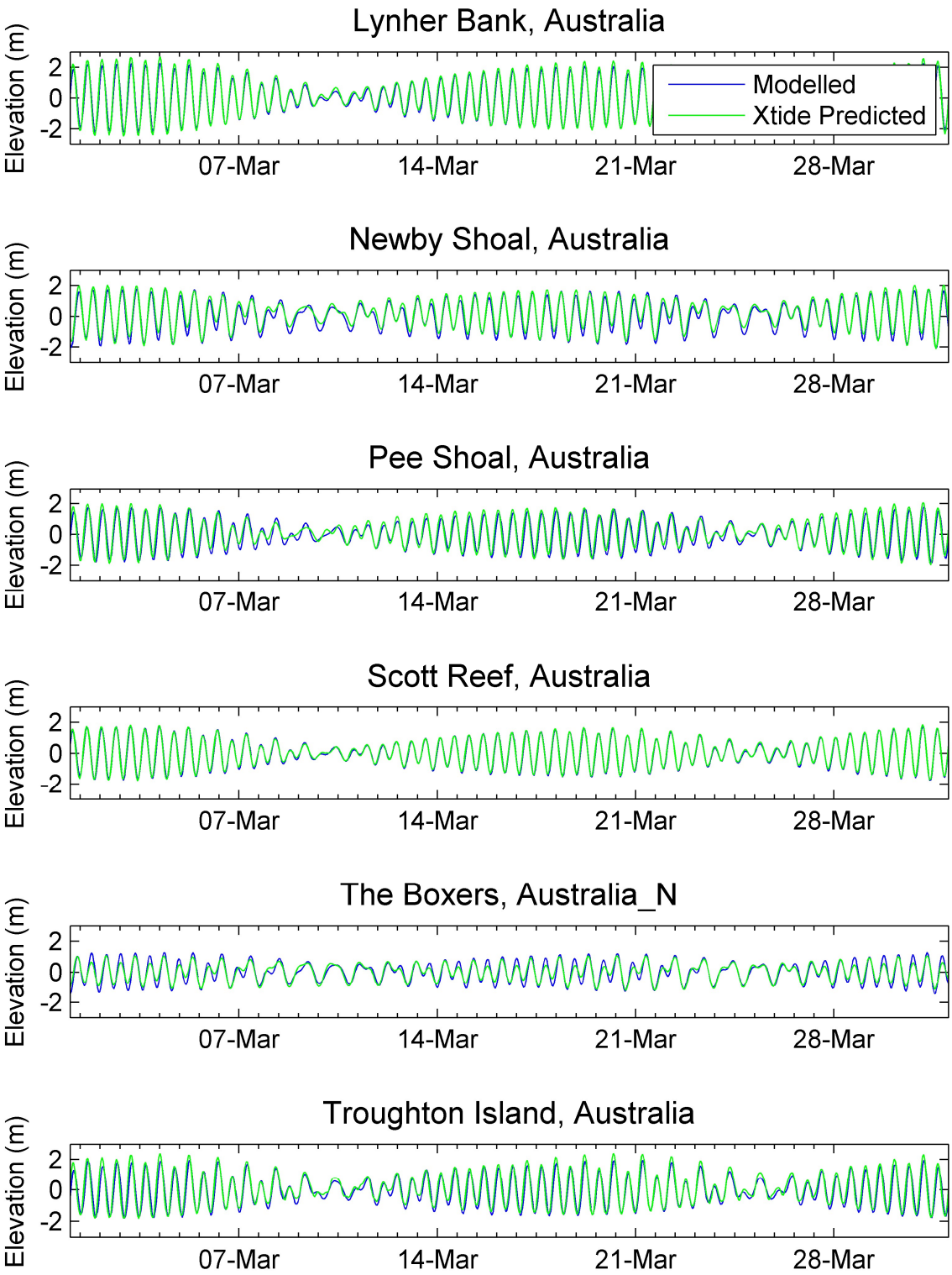


Figure 2.6 Time series comparisons between predicted surface elevation data from HYDROMAP (blue line) and XTide (green line) at six locations in the tidal model domain (March 2010).

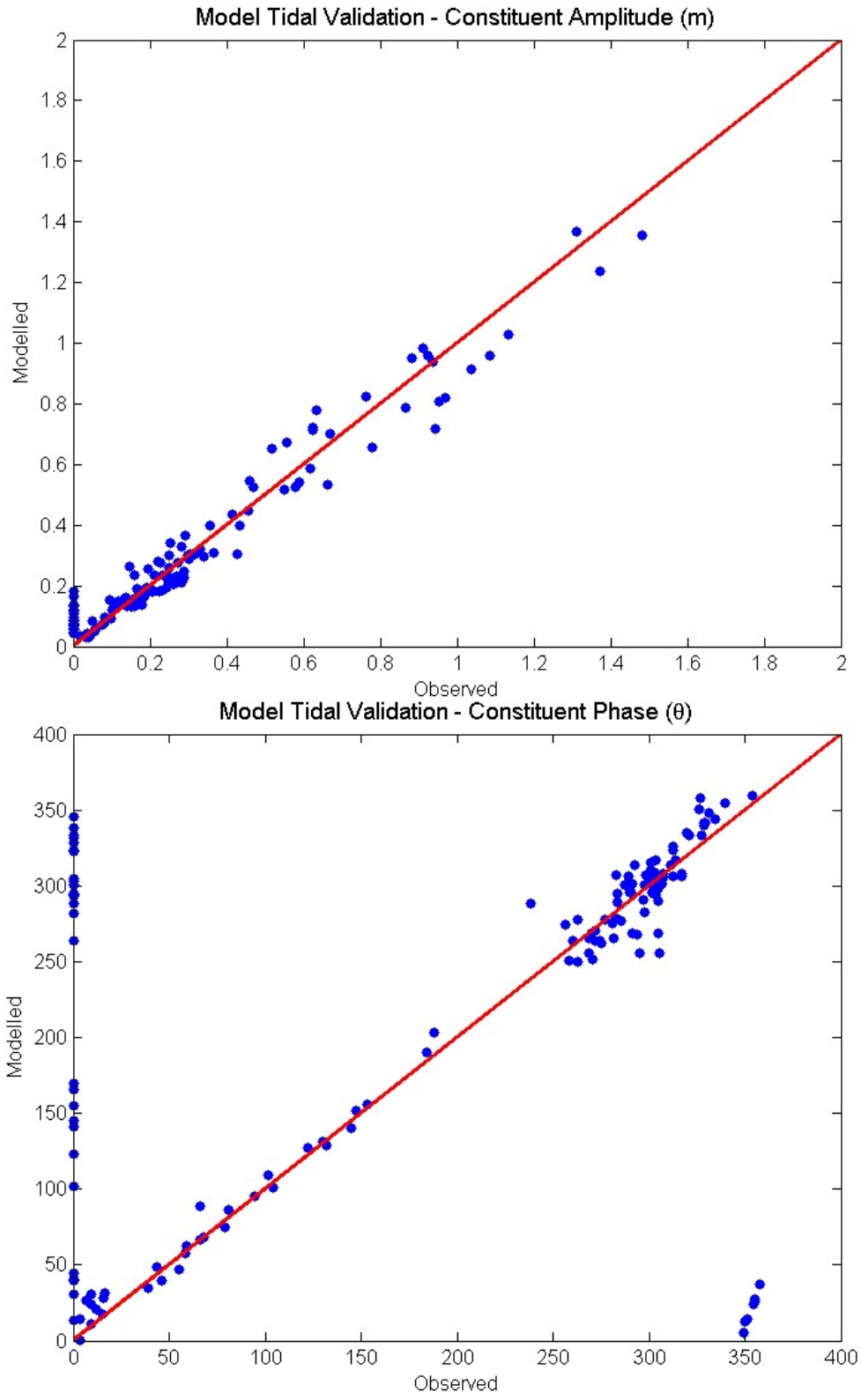


Figure 2.7 Comparisons between predicted tidal constituent amplitudes (top) and phases (bottom) from HYDROMAP and XTide at all stations in the tidal model domain. The red line indicates a 1:1 correlation between the respective data sets.

RPS

2.2.4.4 Composite Current Data Set Validation: HYDROMAP + HYCOM

A composite modelled ocean current data product was derived by combining predictions of mesoscale circulation currents, available at daily resolution from the HYCOM ocean model, with predictions of the hourly tidal currents generated by the RPS HYDROMAP model.

To verify the modelled current predictions, the composite model outputs at the Crux development area were compared against the unfiltered site-specific current measurements. The model results were validated through both quantitative and visual comparisons between measured and modelled data at each depth where both data sets were available.

Time series comparison of composite model outputs and measured current magnitude, direction, and U/V velocity components at water depths of 20 m, 70 m and 110 m are presented in Figure 2.8, Figure 2.9 and Figure 2.10, respectively, for one month during winter (June 2016) and summer (December 2016). The time series comparisons reveal that the composite model offers a good match with the measured U/V velocity components at all water depths in both winter and summer, with the magnitudes and timings of the peaks and troughs matching well.

The IOA and MAE values derived from comparisons of the U/V velocity components at water depths of 20 m, 70 m and 110 m over the full measurement period are presented in Table 2.2. The IOA for each velocity component is high at all water depths, reflecting the good match in the magnitudes and timings of the peaks and troughs in the composite model data and measured data. The MAE for the U/V velocity components is relatively low at approximately 0.1 m/s for all water depths, indicating that the magnitude and range of the velocity components match well; however, a slight overprediction of the current magnitude is evident at times.

To compare directionality, roses for the composite model outputs and measured currents at 20 m, 70 m and 110 m water depths over the full measurement period are shown in Figure 2.10. The roses show that the composite model current direction is a good match with the measured direction. A shift in the dominant current direction from a north/south alignment in the measured data set to a northwest/southeast alignment in the composite model data set is evident at the 20 m water depth, and to a lesser extent also at the 70 m water depth. However, the range and variability in the measured current direction is captured by the composite model data, which matches best with the measured data at the water depth of 110 m.

Based on the validation performance, the composite model data set is a good model of standard conditions at the Crux development area and will adequately resolve local and regional circulation patterns. As such, the model is considered suitable for use in the numerical modelling studies conducted as part of the Crux project.

Table 2.2 Statistical comparison of predicted (HYDROMAP+HYCOM) and observed current speeds along orthogonal component axes at the Crux development area (2016-2017).

Skill Measure	Index of Agreement (IOA)			Mean Absolute Error (MAE) (m/s)		
Depth (m)	20	70	110	20	70	110
U Component	0.72	0.75	0.76	0.11	0.11	0.11
V Component	0.82	0.80	0.78	0.11	0.10	0.10

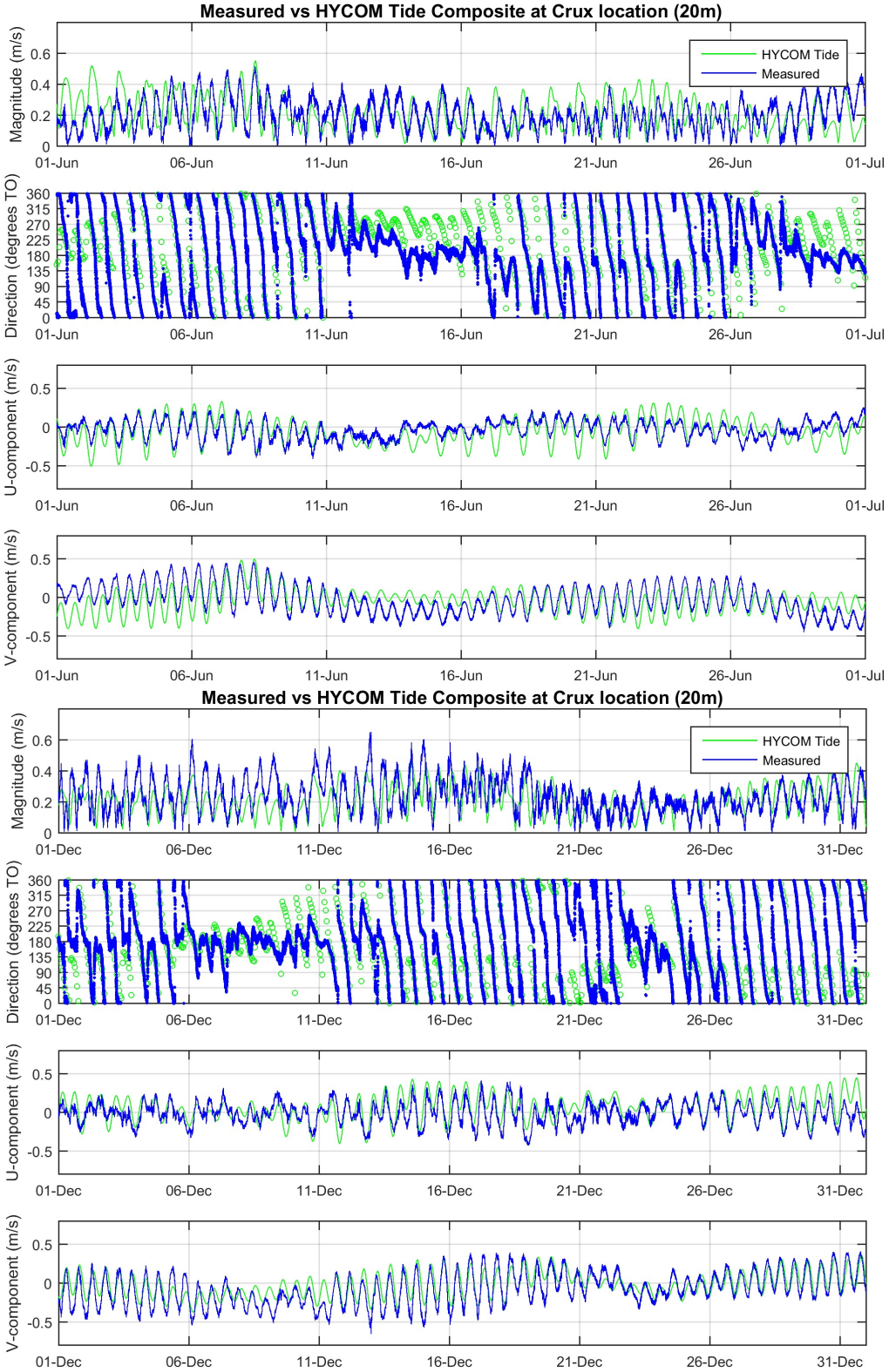


Figure 2.8 Time series comparisons between predicted (HYDROMAP+HYCOM, green line) and measured (blue line) current data at the Crux development area at a depth of approximately 20 m for June 2016 (top panel) and December 2016 (bottom panel).

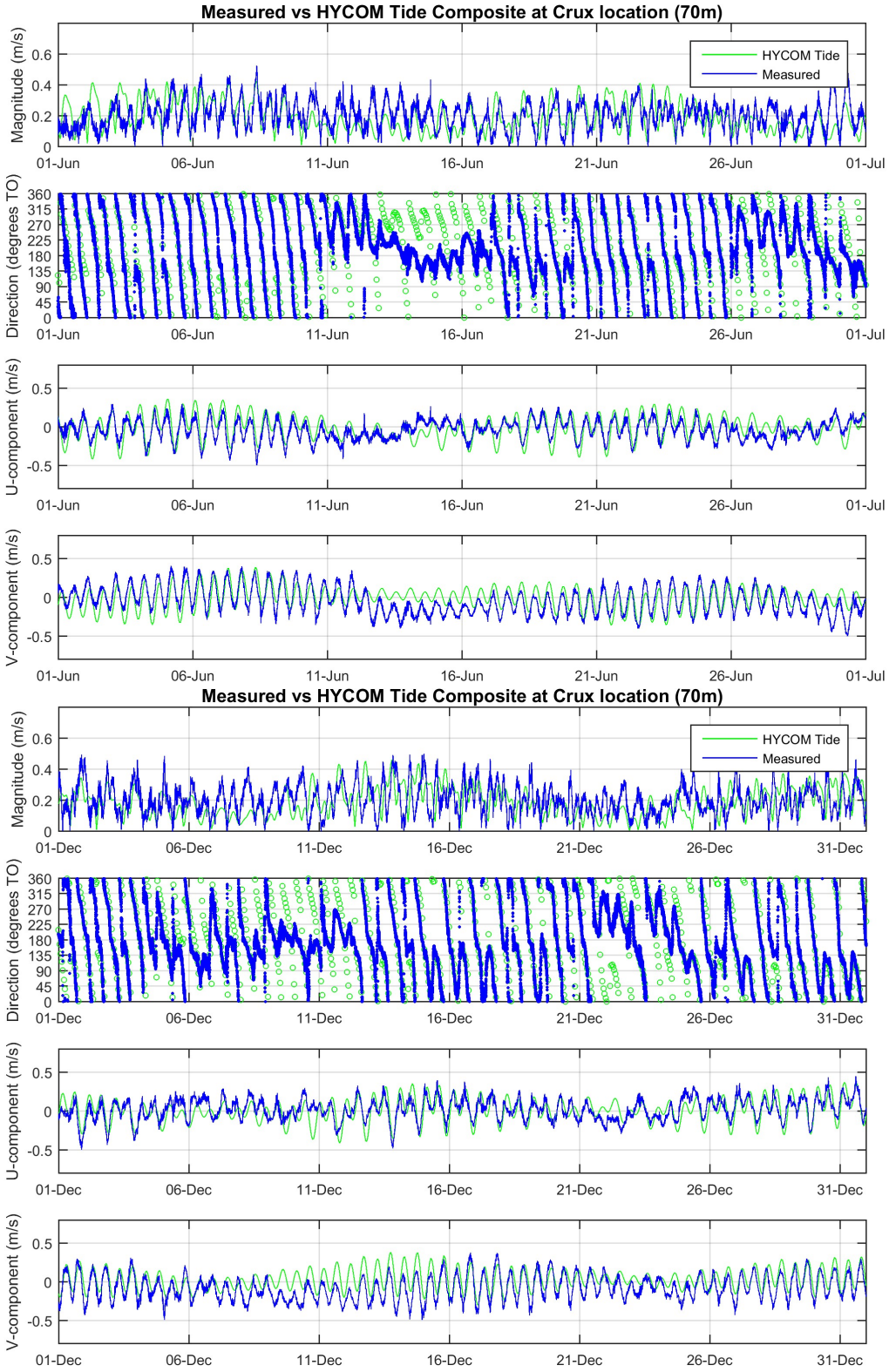


Figure 2.9 Time series comparisons between predicted (HYDROMAP+HYCOM, green line) and measured (blue line) current data at the Crux development area at a depth of approximately 70 m for June 2016 (top panel) and December 2016 (bottom panel).

RPS

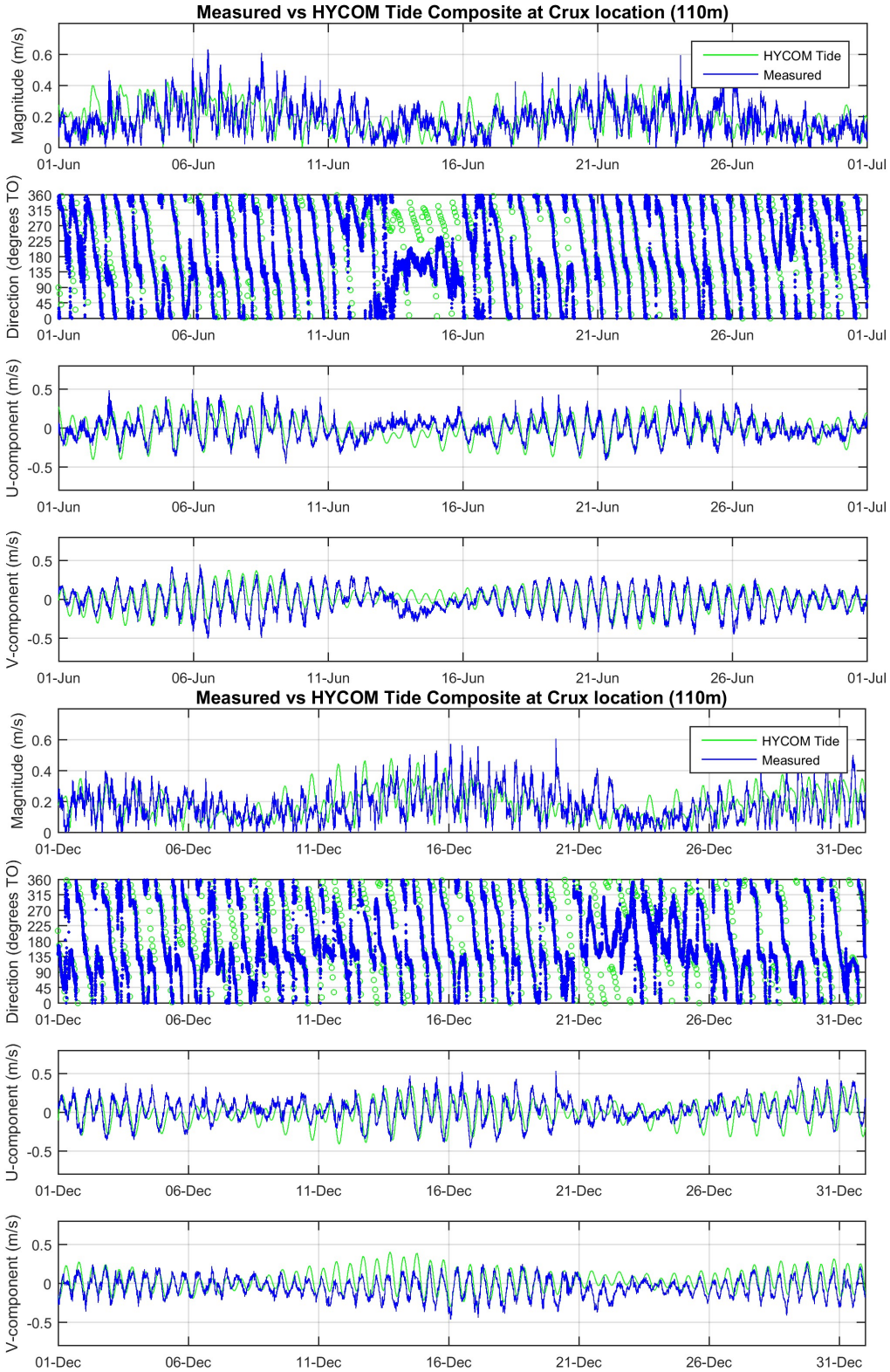


Figure 2.10 Time series comparisons between predicted (HYDROMAP+HYCOM, green line) and measured (blue line) current data at the Crux development area at a depth of approximately 110 m for June 2016 (top panel) and December 2016 (bottom panel).

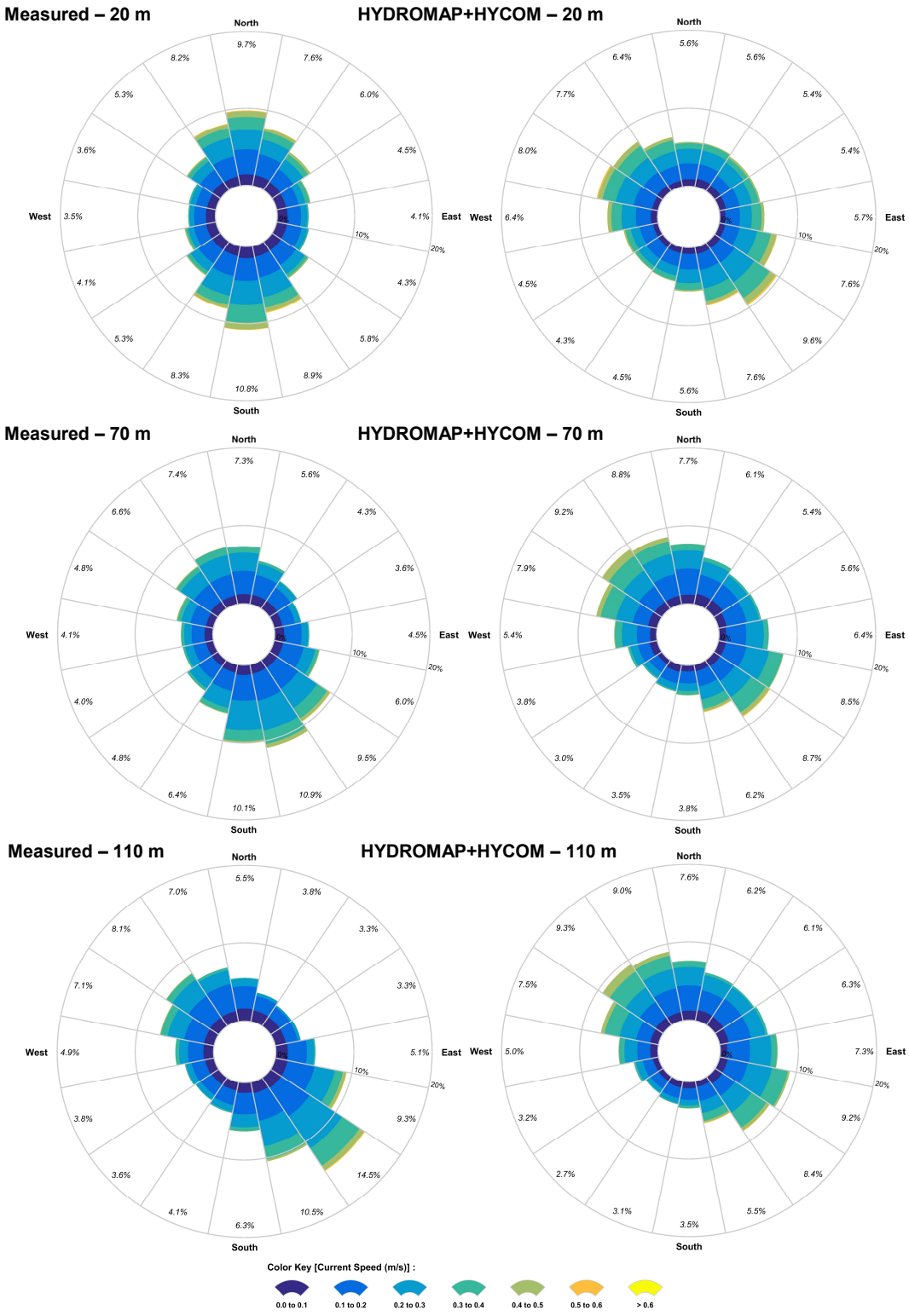


Figure 2.11 Comparative distributions for measured (left column) and predicted (HYDROMAP+HYCOM, right column) current data at the Crux development area (2016-2017) at depths of approximately 20 m (top row), 70 m (middle row) and 110 m (bottom row). The colour key shows the current magnitude, the compass direction provides the direction towards which the current is flowing, and the size of the wedge gives the percentage of the record.

2.3 Wind Data

To account for the influence of the wind on surface-bound hydrocarbons, representation of the wind conditions was provided by spatial wind fields sourced from the National Center for Environmental Prediction (NCEP), National Oceanic and Atmospheric Administration (NOAA) Cooperative Institute for Research in Environmental Sciences (CIRES) Climate Diagnostics Center in Boulder, Colorado, United States of America (USA). The NCEP Climate Forecast System Reanalysis (CFSR; Saha *et al.*, 2010) is a fully-coupled, data-assimilative hindcast model representing the interaction between the Earth's oceans, land and atmosphere. The gridded data output, including surface winds, is available at 0.25° resolution and 1-hourly time intervals.

Time series of wind speed and direction were extracted from the CFSR database for all nodes in the model domain for the same temporal coverage as the current data (2008-2017, inclusive). The data was assumed to be a suitably representative sample of the wind conditions over the study area for future years.

Figure 2.12 shows the seasonal wind roses near the Crux platform. The data shows that the wind speeds and directions vary between seasons. During summer (December to February), the winds blow predominantly from the west, and in winter (April to August) the winds blow predominantly from the east. During transitional conditions, wind directionality is more variable and wind speeds are generally lower than in the other seasons. Peak wind speeds of around 20 m/s are most commonly observed in summer and winter.

The extracted wind data near the release location suggests that, in the absence of any current effects, the wind acting on hydrocarbons on the sea surface will tend to result in initial trajectories that will most frequently be towards the east during summer period and towards the west during winter period. Note that the actual trajectories of the hydrocarbons on the sea surface will be the net result of a combination of the prevailing wind and current vectors acting at a given time and location. For long duration spills which may span multiple "periods" of the year, the net outcomes may be a blend between the major seasonal outcomes.

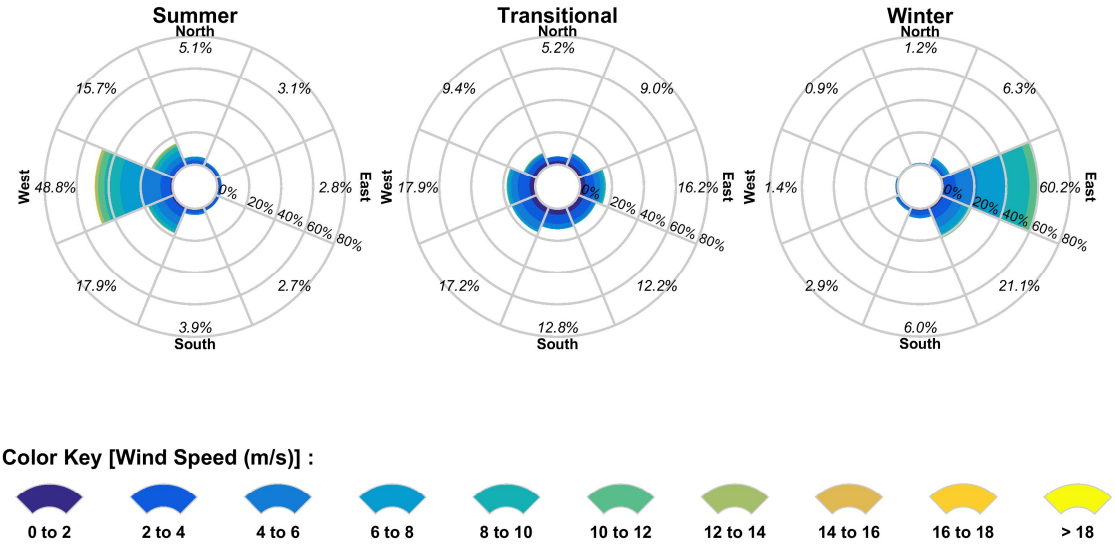


Figure 2.12 Seasonal wind distribution (2008-2017, inclusive) derived from the CFSR database near to the proposed Crux platform. The colour key shows the wind magnitude, the compass direction provides the direction from which the wind is blowing, and the size of the wedge gives the percentage of the record.

2.4 Temperature and Salinity Data

Temperature and salinity data based on one year of measurements carried out at the Crux development area by RPS between April 2016 and May 2017 (RPS, 2017) was supplied for the study.

Temperature and salinity data applied to the near-field modelling was sourced from the World Ocean Atlas 2013 (WOA13) database produced by the National Oceanographic Data Centre (National Oceanic and Atmospheric Administration) and its co-located World Data Center for Oceanography (Levitus *et al.*, 2013).

For both data sets, annualised mean temperature profiles were calculated. Figure 2.13 presents a comparison of the WOA13 and RPS-measured annualised temperature profiles. From the profiles, it is evident that the WOA13 temperature structure offer a good match with the measured data and can be considered representative of the conditions in the Crux development area.

Table 2.3 shows the average seasonal water temperature and salinity levels at varying depths from 0 to 170 m. This data can be considered representative of seasonal conditions in the Crux development area.

The seasonal temperature profiles exhibit a reasonably consistent reduction in temperature with increasing depth. Salinity levels are generally more consistent and exhibit a vertically well-mixed water body (34.19 – 34.59 practical salinity unit, PSU), irrespective of season or depth.

Table 2.3 Average temperature and salinity levels adjacent to the proposed Crux platform.

Season	Depth (m)	Temperature (°C)	Salinity (PSU)
Summer	0	29.62	34.58
	10	29.54	34.57
	30	28.89	34.55
Transitional	0	27.34	34.19
	10	27.33	34.21
	30	27.18	34.23
Winter	0	28.49	34.34
	10	28.39	34.35
	30	27.48	34.39

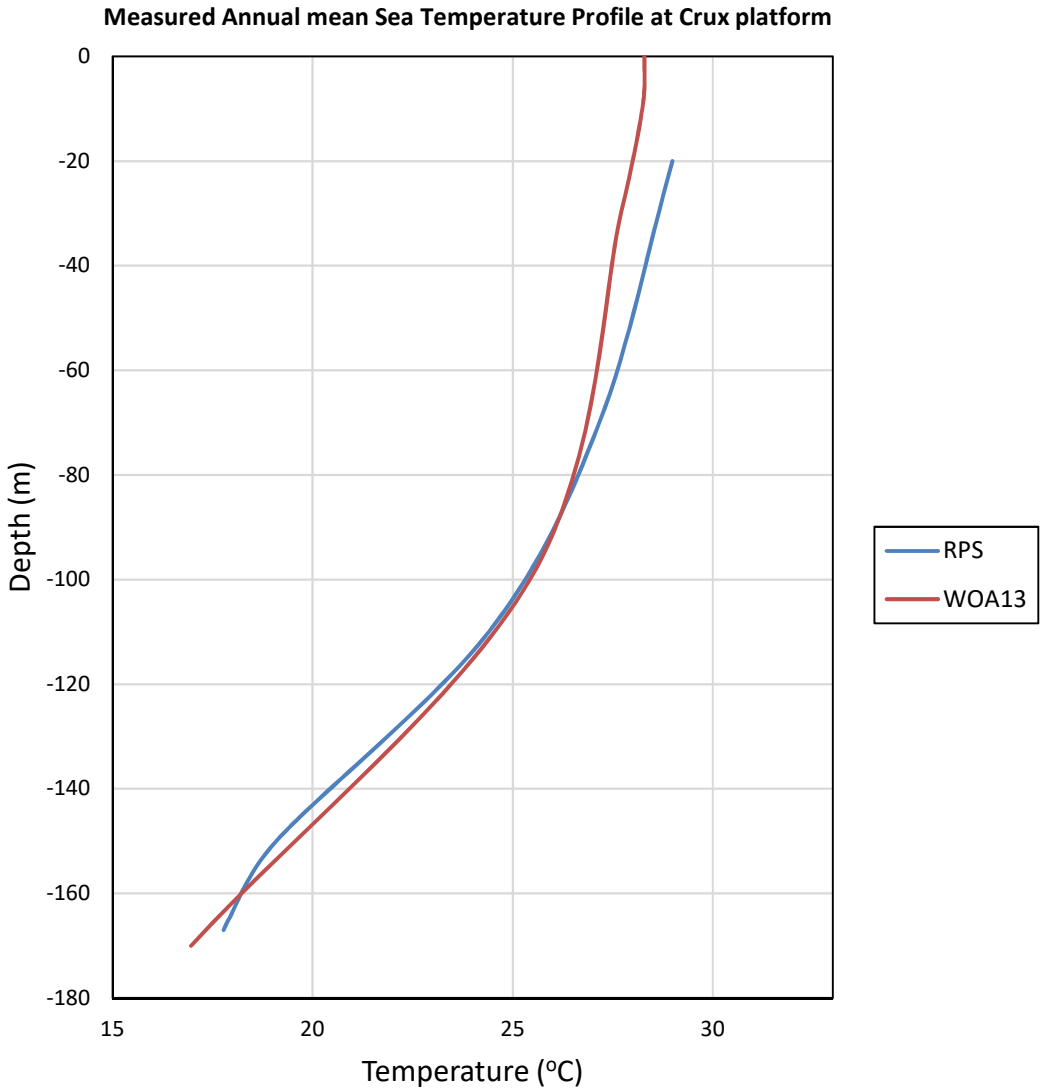


Figure 2.13 Comparison of World Ocean Atlas 2013 and RPS measured annual temperature profiles at Crux platform location.

2.5 Stochastic Modelling

Oil spill modelling was undertaken using a three-dimensional oil spill trajectory and weathering model, SIMAP (Spill Impact Mapping and Analysis Program), which is designed to simulate the transport, spreading and weathering of specific oil types under the influence of changing meteorological and oceanographic forces. Near-field subsurface discharge modelling was undertaken using OILMAP, which predicts the droplet sizes that are generated by the turbulence of the discharge as well as the centreline velocity, buoyancy, width and trapping depth (if any) of the rising gas and oil plumes.

The SIMAP model simulates both surface and subsurface releases and uses the unique physical and chemical properties of an oil type to calculate rates of evaporation and viscosity change, including the tendency to form oil-in-water emulsions. Moreover, the unique transport and dispersion of surface hydrocarbons and in-water components (entrained and dissolved) are modelled separately. Thus, the model can be used to understand the wider potential consequences of a spill, including direct contact to oil on the sea surface for surface features and exposure to entrained and dissolved oil for organisms in the water column.

To define trends and variations in the potential outcomes of a given scenario, a stochastic modelling scheme was followed in this study, whereby SIMAP was applied to repeatedly simulate the defined spill scenarios using different samples of current and wind data selected randomly from an historic time series of wind and current data representative of the study area. To ensure seasonal representation, a fixed number of replicate simulations were performed using start times from each seasonal period. Results of the replicate simulations were then statistically analysed and mapped to define contours of risk around the release point.

For this purpose, a long-term archive of spatially-variable wind and current data covering northern Australia and spanning 10 years (2008-2017, inclusive) was assembled. Current patterns accounted for temporal and spatial variations in large-scale drift currents over the outer shelf waters (typically >200 m depth) together with tidal and wind-driven currents. Modelling was carried out using current and wind data sampled from the data archive for periods corresponding to the nominated seasons to quantify seasonal risks of contact at surrounding locations.

Note that the duration of the simulations requires that they may extend beyond the period in which the simulated spill occurred. Each simulation was run for the duration of the specified spill, plus a further period after the cessation of discharge to allow for oil concentrations to decrease below the low threshold concentrations applied in the analysis. It is expected that remnant floating oil, which may be present at low thresholds at the end of each simulation, would represent highly weathered and degraded products. This assumption of an extended duration period beyond the simulated spill event provides for a conservative modelling outcome and contributes to a worst-case outer extent of influence.

It is important to note that the modelling results presented in this report relate to the predicted outcomes once defined spill events have occurred. The probability of the spill scenarios occurring is not considered. Furthermore, the results are presented in terms of statistical probability maps, based on many simulations under different conditions. Different locations within the potential zone of influence would be affected under each different time series of environmental forces. Consequently, these contours for the potential zone of influence will cover a larger area than the area that could be affected during any one single spill event (see Figure 1.2). The contours should therefore be judged as contours of probability and not representations of the area swept by individual releases.

In performing stochastic analyses, it is important to understand the significance of the stochastic footprints relative to the footprint of one individual spill. Readers unfamiliar with modelling methodologies may misinterpret the model outcomes. To prevent misinterpretation, the stochastic results are often paired with a single deterministic trajectory for comparison.

2.6 Deterministic Modelling

From the stochastic set of replicate simulations for each scenario, deterministic model runs of interest were selected according to the following criteria:

- Maximum oil volume accumulated across all shoreline receptors;
- Minimum time to commencement of oil accumulation at any shoreline receptor (at a threshold of 10 g/m^2);
- Maximum length of oiled shoreline (at a threshold of 10 g/m^2).

2.7 Hydrocarbon Properties

2.7.1 Overview

Two different hydrocarbons were modelled as part of the study: Crux condensate and Intermediate Fuel Oil (IFO) 180. The different hydrocarbons have varying physical and chemical properties which determine the way they will behave in the marine environment.

Table 2.4 and Table 2.5 show the physical characteristics and boiling point ranges for each hydrocarbon, respectively. The hydrocarbon property category and hydrocarbon persistence classification were derived from AMSA (AMSA, 2015a) guidelines. The classification is based on a hydrocarbon's specific gravity in combination with relevant boiling point ranges.

Table 2.4 Physical properties of the hydrocarbons used in the modelling.

Physical Properties	Crux Condensate	IFO-180
Density (kg/m^3)	783.6 (at 15 °C)	967.0 (at 25 °C)
API	49.0	14.8
Dynamic viscosity (cP)	1.052 (at 20 °C)	2,324 (at 15 °C)
Pour point (°C)	9.0	-10.0
Hydrocarbon property category	Group I	Group IV
Hydrocarbon persistence classification	Non-persistent	Persistent (heavy)

Table 2.5 Boiling-point breakdown of the hydrocarbons used in the modelling.

Oil Type	Volatiles (%)	Semi-Volatiles (%)	Low Volatiles (%)	Residual (%)	Aromatics (%)
Boiling point (°C)	**<180 C4 to C10**	**180 - 265 C11 to C15**	**265 - 380 C16 to C20**	**>380 >C20**	**Of whole oil <380 BP**
	Non-persistent			**Persistent**	-
Crux condensate	54.8	22.8	14.6	7.8	12.3
IFO-180	1.0	14.4	20.8	63.8	5.9

The boiling points are dictated by the length of the carbon chains, with the longer and more complex compounds having a higher boiling point, and therefore lower volatility and evaporation rate.

In the above, the typical evaporation times once the hydrocarbons reach the surface and is exposed to the atmosphere are around:

- Up to 12 hours for the C4 to C10 compounds (or less than 180 °C BP);
- Up to 24 hours for the C11 to C15 compounds (180-265 °C BP);
- Several days for the C16 to C20 compounds (265-380 °C BP); and
- N/A for the residual compounds, which will resist evaporation, persist in the marine environment for longer periods, and be subject to relatively slow degradation.

The actual fate of the released hydrocarbon in the marine environment will depend greatly on the amount of the hydrocarbon that reaches the surface, either through the initial release or by rising after discharge in the water column.

2.7.2 Crux Condensate

Crux condensate (API 49.0) contains a low proportion (approximately 7.8% by mass) of hydrocarbon compounds (mostly non-toxic inert waxes) that will not evaporate at atmospheric temperatures. These compounds will persist in the marine environment.

The unweathered hydrocarbon has a dynamic viscosity of 1.052 cP. The pour point of the whole condensate (9 °C) ensures that the unweathered hydrocarbon will remain in a liquid state over the annual temperature range observed in northern Australian waters.

The condensate is composed of hydrocarbons that have a wide range of boiling points and volatilities at atmospheric temperatures, and which will begin to evaporate at different rates on exposure to the atmosphere. Evaporation rates will increase with temperature, but in general about 54.8% of the hydrocarbon mass should evaporate within the first 12 hours (BP < 180 °C); a further 22.8% should evaporate within the first 24 hours (180 °C < BP < 265 °C); and a further 14.6% should evaporate over several days (265 °C < BP < 380 °C).

Selective evaporation of the lower boiling-point components will lead to a shift in the physical properties of the remaining Crux condensate, including an increase in the viscosity and pour point. Although removal of the most volatile compounds through evaporation and dissolution will result in an increase in density of the remaining Crux condensate, the mixture will not solidify or sink as it weathers.

The whole condensate has low asphaltene content (<0.05%), indicating a low tendency for the hydrocarbon to take up water to form water-in-oil emulsion over the weathering cycle.

Soluble aromatic hydrocarbons contribute approximately 12.3% by mass of the whole condensate, with a large proportion (9.8%) in the C4-C10 range of hydrocarbons. These compounds will evaporate rapidly, reducing the potential for dissolution of a proportion of them into the water.

A series of model weather tests were conducted to illustrate the potential behaviour of Crux condensate when exposed to idealised environmental conditions. The predicted weathering of hydrocarbons when simulations are conducted under constant wind speeds of 5, 10 and 15 knots is shown in Figure 2.14, Figure 2.15 and Figure 2.16 for Scenarios 1, 2 and 3, respectively.

For Scenarios 2 and 3, the figures show that as wind speed increases a larger volume of hydrocarbons becomes entrained in the water column; consequently, less oil is available on the water surface for evaporation to occur. For Scenario 1, increases in wind speed are observed to have a minimal effect on levels of entrainment because the subsurface discharge characteristics dictate that the vast majority of the oil mass will remain entrained after release, as opposed to being present on the sea surface.

RPS

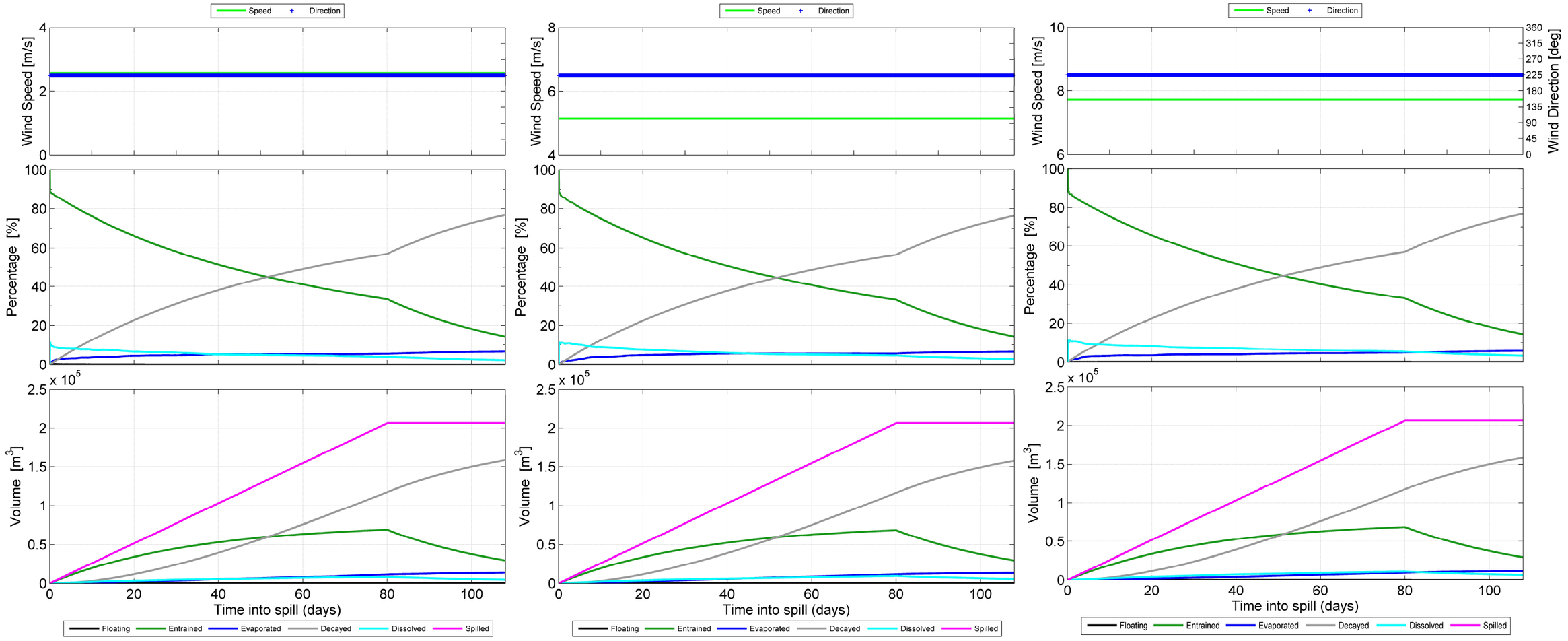


Figure 2.14 Mass balance plot representing, as proportion (middle row) and volume (bottom row), the weathering of an 80-day subsurface release of Crux condensate at a Development Well (Scenario 1) subject to constant wind speeds (top row) of 5 knots (left column), 10 knots (middle column) and 15 knots (right column).

RPS

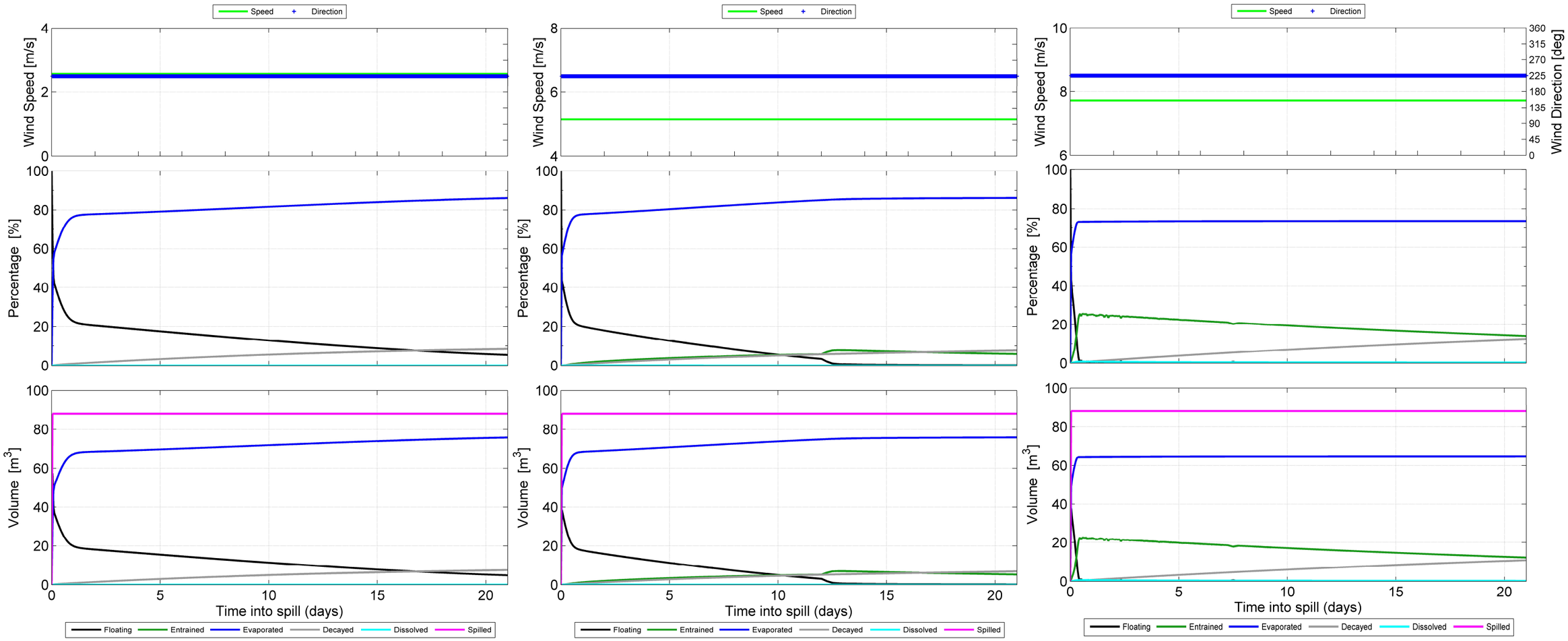


Figure 2.15 Mass balance plot representing, as proportion (middle row) and volume (bottom row), the weathering of an instantaneous surface release of Crux condensate at the Crux platform (Scenario 2) subject to constant wind speeds (top row) of 5 knots (left column), 10 knots (middle column) and 15 knots (right column).

RPS

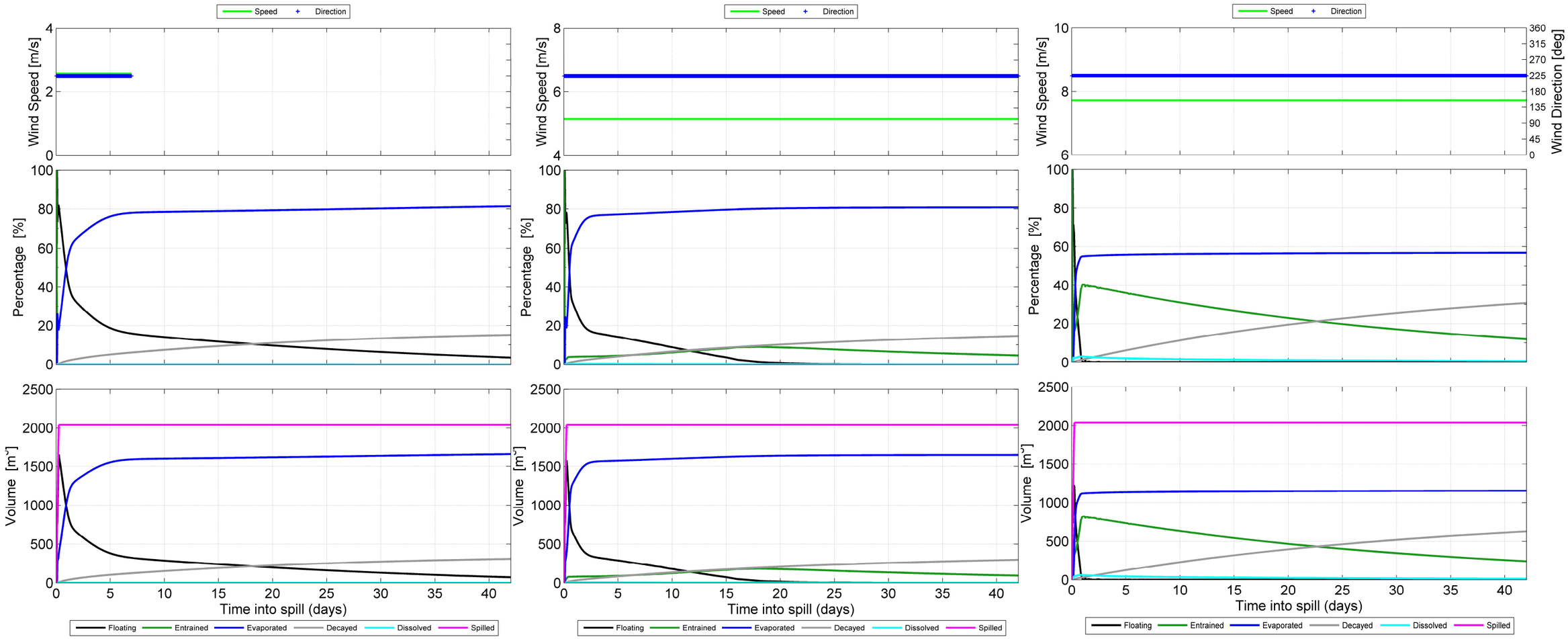


Figure 2.16 Mass balance plot representing, as proportion (middle row) and volume (bottom row), the weathering of a 5.6-hour subsurface release of Crux condensate from a pipeline (Scenario 3) subject to constant wind speeds (top row) of 5 knots (left column), 10 knots (middle column) and 15 knots (right column).

2.7.3 IFO-180

IFO-180 (API 14.8) has a high density (967 kg/m^3) and a high viscosity (2,324 cP). It consists mainly of low volatiles (20.8%) and persistent hydrocarbons (63.8%). If released to the marine environment, the light volatiles (1%) are rapidly lost via evaporation while the residual component is expected to become semi-solid to solid at ambient temperatures. IFO-180 does not tend to entrain in the upper water column based on the hydrocarbon characteristics.

Depending on the environmental conditions and its state of weathering, IFO-180 can form stable or mesostable water-in-oil emulsions (emulsions) in which seawater droplets become suspended into the oil matrix (Fingas & Fieldhouse, 2004). This process requires physical mixing (i.e. wave action) with the stability of the emulsion influenced by the properties of the hydrocarbon product, including viscosities and asphaltene/resin content. Emulsions generally have an average water content of approximately 80% after 24 hours and have been shown to remain stable for up to four weeks under laboratory and test tank conditions (Fingas & Fieldhouse, 2004). Emulsions have an average water content of around 70% after 24 hours which decreases to approximately 30% after one week (Fingas & Fieldhouse, 2004). Emulsions generally become unstable within three days, as shown under laboratory conditions. Emulsification of IFO-180 will affect the spreading and weathering of the oil and increase the volume of oily material. If not within an emulsion state, the decay of IFO-180 is more rapid in comparison to condensates and marine diesel as microbial decay is generally faster for hydrocarbons with higher viscosity.

The toxic potential of IFO-180 is largely dependent on the properties of the blend, but generally contains <10% distillate with the remaining 90% composed of Heavy Fuel Oils (HFOs). The volatile and soluble components include those that are responsible for producing most of the aquatic toxicity due to its bioavailability to marine organisms. Thus, Crux condensate is considered to have a higher aquatic toxicity potential in comparison to IFO-180. However, these volatile, non-persistent components are short-lived and susceptible to evaporation and degradation. The weathered portion of IFO would behave similarly to HFO. The residual components would eventually become insoluble in seawater and end up adhered to sediment or biota, reducing the risk of acute toxicity.

A series of model weather tests were conducted to illustrate the potential behaviour of IFO-180 when exposed to idealised environmental conditions. The predicted weathering of hydrocarbons when simulations are conducted under constant wind speeds of 5, 10 and 15 knots is shown in Figure 2.17 for Scenario 4.

The figure demonstrates the highly persistent and viscous nature of the oil, with a similar evaporative loss rate and negligible levels of entrainment for all wind speeds.

RPS

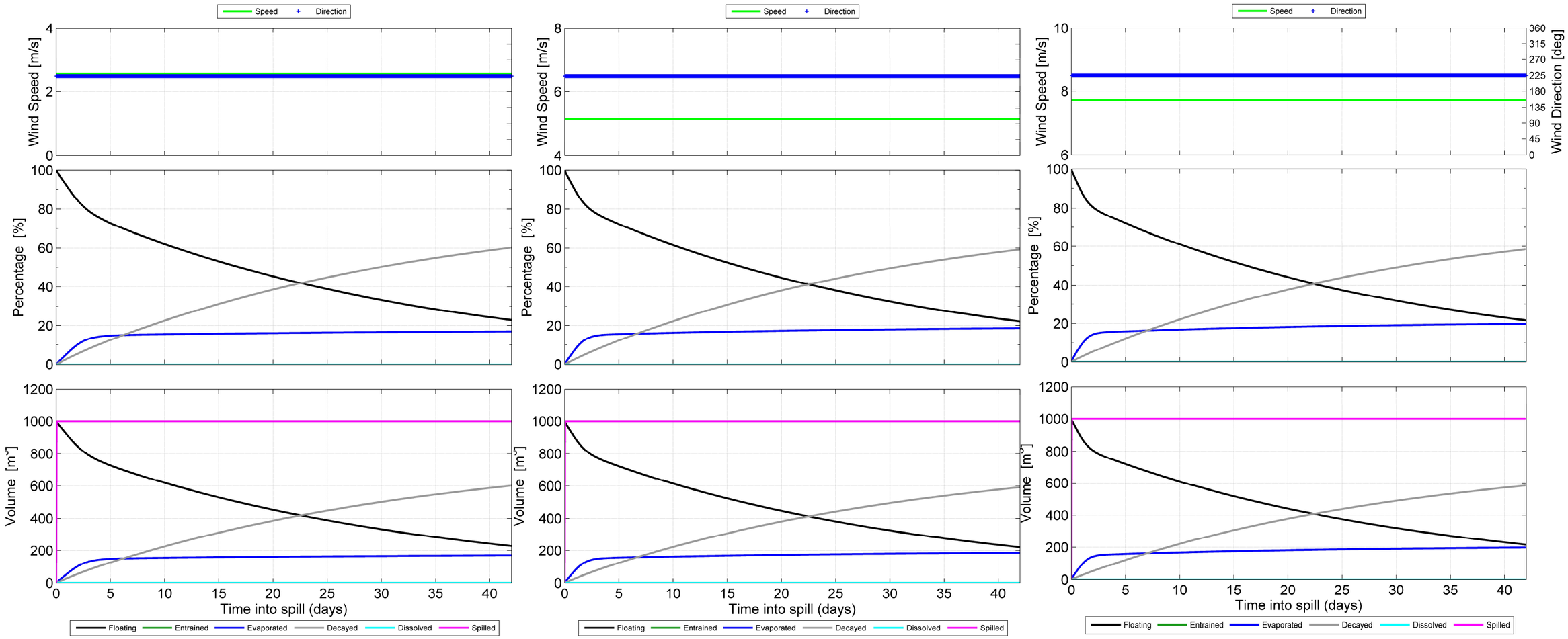


Figure 2.17 Mass balance plot representing, as proportion (middle row) and volume (bottom row), the weathering of a 1-hour surface release of IFO-180 at the Crux end of the export pipeline (Scenario 4) subject to constant wind speeds (top row) of 5 knots (left column), 10 knots (middle column) and 15 knots (right column).

2.8 Subsurface Discharge Characteristics

2.8.1 Overview

High-pressure releases that involve mixed gas and hydrocarbon will tend to generate relatively small droplet sizes that have slow rise rates, due to viscous resistance imparted by the surrounding seawater, and may become trapped by density layers in the water column (Chen & Yapa, 2002). The buoyancy of the gas cloud may lift entrained oil droplets towards the surface and, in the case of blowouts in relatively shallow water (<100-200 m), the rising column of gas and entrained water can lift the hydrocarbon to the surface at a substantially faster rate than would occur from the relative buoyancy of the hydrocarbon alone, opposed by the viscosity of the water column.

For deeper releases (200-500 m), the gas will expand to entrain oil droplets towards the surface, but the gas and hydrocarbon will then tend to separate before the hydrocarbon surfaces because the gas either goes into solution or accelerates away from the hydrocarbon droplets. The height at which the gas lift ceases is referred to as the trapping height. The rate at which hydrocarbon rises from the trapping height will be determined by a number of factors, including the relative buoyancy of the hydrocarbon versus local water density, the size of the droplets (increased viscous resistance for smaller sizes), the presence of density barriers in the water column and the action of shear currents that might be present in the water column.

The OILMAP model was used in this study to predict the behaviour of the rising plume of gas-oil-water and the oil droplet distribution resulting from subsurface discharge scenarios. These comprised one subsea well blowout and one subsea pipeline rupture (Scenarios 1 and 3).

Inputs to the OILMAP model included specification of the discharge rate, hole size, gas-to-oil ratio, and the temperature of the hydrocarbon on exiting and before subsequent cooling by the ambient water. The model input also included temperature and salinity profiles representative of the location. Summaries of the inputs to and outputs of the OILMAP simulations for each of these scenarios are presented in the following sections.

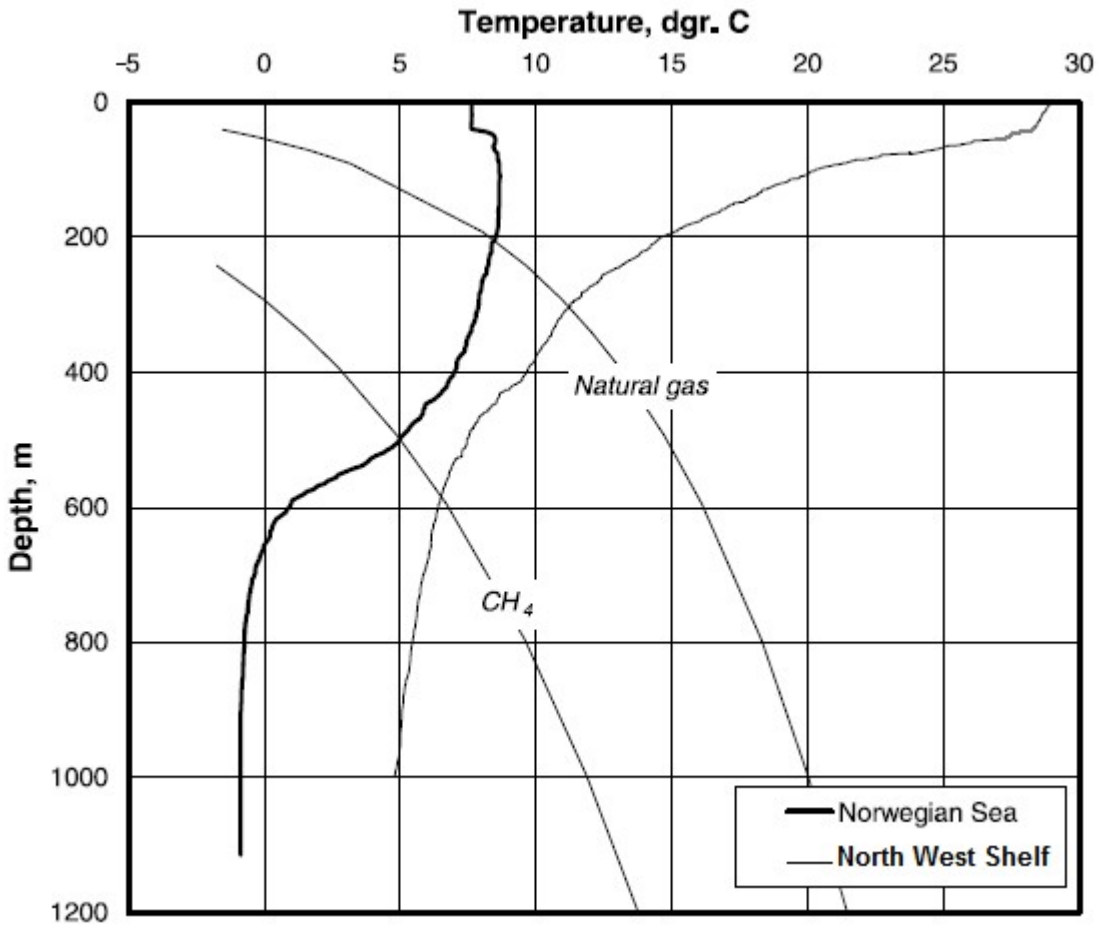


Figure 2.18 Theoretical equilibrium lines for hydrate formation based on the temperature and pressure at the release point. The line for "natural gas" assumes 80% methane, 10% ethane and 10% propane. Typical indicative sea temperature profiles with depth are indicated (Johansen, 2003).

2.8.2 Scenario 1: Subsurface Blowout at a Development Well

For the release of Crux condensate following a subsurface blowout from a development well, the OILMAP input parameters and the resulting output parameters that were used as input into SIMAP are presented in Table 2.6. The model input also included temperature and salinity profiles representative of the location.

The results of the OILMAP simulation predict that the discharge will generate a cone of rising gas that will entrain the hydrocarbon droplets and ambient sea water up to the water surface. The mixed plume is initially forecast to jet towards the water surface with a vertical velocity of around 12.2 m/s, gradually slowing and increasing in plume diameter as more ambient water is entrained. The diameter of the central cone of rising water and hydrocarbon at the neutral-buoyancy point is predicted to be 21.8 m.

The high discharge velocity and turbulence generated by the expanding gas plume is predicted to generate very small oil droplets (<30 µm) that will have very low rise velocities (<0.005 cm/s). These droplets will be subject to mixing due to turbulence generated by the lateral displacement of the rising plume, as well as vertical mixing induced by wind and breaking waves. Therefore, despite reaching the surface due to the lift produced by the rising plume, the droplets will then initially remain within the wave-mixed layer of the water column (3-

10 m deep, depending on the conditions), where they can resist surfacing due to their weak buoyancy relative to other mixing processes. While most of the oil droplets will tend to remain in the upper water column (where the most elevated concentrations will usually be found as a result), turbulent mixing and dispersion processes will distribute oil throughout the whole water column at lower concentrations.

The ongoing nature of the release combined with the potential for the plume to breach the water surface may present other hazards, including conditions that may lead to high local concentrations of atmospheric volatiles. The results suggest that beyond the immediate vicinity of the blowout the majority of the released hydrocarbons will be present in the upper layers of the ocean (with lower concentrations deeper in the water column), with the potential for hydrocarbons to form localised floating films under sufficiently calm local wind conditions.

2.8.3 Scenario 3: Subsurface Rupture of the Crux Export Pipeline

For the release of Crux condensate following a rupture of the export pipeline, the OILMAP input parameters and the resulting output parameters that were used as input into SIMAP are presented in Table 2.6. The model input also included temperature and salinity profiles representative of the Crux project area.

The results of the OILMAP simulation predict that the discharge will generate a cone of rising gas that will entrain the hydrocarbon droplets and ambient sea water up to the water surface. The mixed plume is initially forecast to jet towards the water surface with a vertical velocity of around 4.3 m/s, gradually slowing and increasing in plume diameter as more ambient water is entrained. The diameter of the central cone of rising water and oil at the neutral-buoyancy point is predicted to be 24.9 m.

The discharge velocity and turbulence generated by the expanding gas plume is predicted to generate relatively large hydrocarbon droplets (approximately 500-2,500 µm) that will have relatively high rise velocities (approximately 1.6-10 cm/s). These droplets will be subject to mixing due to turbulence generated by the lateral displacement of the rising plume, as well as vertical mixing induced by wind and breaking waves. Floating oil films are likely to be formed under typical wind conditions.

The ongoing nature of the release combined with the potential for the plume to breach the water surface may present other hazards, including conditions that may lead to high local concentrations of atmospheric volatiles. The results suggest that beyond the immediate vicinity of the rupture the majority of the released hydrocarbons will be present in the upper layers of the ocean, with the potential for hydrocarbons to form localised floating films under sufficiently calm conditions. While most of the entrained oil droplets will tend to remain in the upper water column (where the most elevated concentrations will usually be found as a result), turbulent mixing and dispersion processes will distribute oil throughout the whole water column at lower concentrations.

Table 2.6 Near-field subsurface discharge plume dynamics for Scenarios 1 and 3.

Variable	Scenario 1 – Well Blowout	Scenario 3 – Pipeline Rupture
Initial plume rise velocity (m/s)	12.2	4.3
Terminal plume rise velocity (m/s)	9.8	2.9
Plume rise time (s)	28.6	116.5
Maximum plume core diameter (m)	21.8	24.9
Plume trapping depth (m below mean sea level)	0 (surface)	0 (surface)

2.9 Model Settings and Assumptions

Table 2.7 provides a summary of the hydrocarbon spill model settings and assumptions. The simulation durations were carefully selected for each scenario based on extensive sensitivity testing. During the sensitivity testing process, sample spill simulations are run for longer than the intended durations for each scenario. Upon completion of the spill simulations, the results are carefully assessed to examine the persistence of the hydrocarbon (i.e. whether the maximum evaporative loss has been achieved for the period of time modelled; and whether a substantial volume of hydrocarbons – if any – remain in the water column) in conjunction with the extent of sea surface exposure based on reporting thresholds. The persistence of the hydrocarbons on the sea surface and entrained within the water column is based on several factors, including the nature of release (duration, volume and type), residual properties of the hydrocarbon type, and weathering. Once there is agreement between the two factors (i.e. the final fate of hydrocarbon is accounted for and the full exposure area is identified) the simulation duration is deemed appropriate.

Table 2.7 Summary of the hydrocarbon spill model settings.

Parameter	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Scenario description	Subsurface blowout after loss of well control	Surface storage tank rupture after inventory integrity failure	Subsurface pipeline rupture	Surface fuel tank rupture after pipelay vessel collision
Location	Development well	Crux platform	Pipeline route at closest point to Heywood Shoal	Crux end of the export pipeline
Number of randomly-selected spill start times per season	100	100	100	100
Hydrocarbon type	Crux condensate	Crux condensate	Crux condensate	IFO-180
Spill volume (m^3)	206,225 (2,578 m^3/day)	88	2,037	1,000
Release type	Subsurface	Surface	Subsurface	Surface
Release duration	80 days	Instantaneous	5.6 hours	1 hour
Simulation duration	108 days	21 days	42 days	42 days
Seasons assessed	Summer (December to February) Transitional (March and September to November) Winter (April to August)			
Sea surface (floating) hydrocarbon exposure thresholds	1 g/m^2 (low exposure) 10 g/m^2 (moderate exposure) 25 g/m^2 (high exposure)			
Shoreline hydrocarbon exposure thresholds	10 g/m^2 (low exposure) 100 g/m^2 (moderate exposure) 1,000 g/m^2 (high exposure)			
Subsurface: Entrained hydrocarbon exposure thresholds	10 ppb (low exposure) 100 ppb (moderate exposure) 500 ppb (high exposure)			
Subsurface: Dissolved aromatic hydrocarbon exposure thresholds	6 ppb (low exposure) 50 ppb (moderate exposure) 400 ppb (high exposure)			

2.10 Sea Surface, Shoreline and Subsurface Thresholds

The SIMAP model can track hydrocarbon concentrations to levels lower than those biologically significant or visible to the naked eye. Therefore, it is useful to define meaningful threshold concentrations (based on scientific literature) to account for exposure and contact by oil components.

The judgement of meaningful levels is complex and is influenced by the mode of action, sensitivity of the biota contacted, the duration of the contact and the particular toxicity of the compounds that are represented in the hydrocarbon. For the latter factor, further consideration must be given to the change in the composition of a hydrocarbon type over time due to weathering processes which in general terms becomes less toxic as the oil weathers.

For this study, thresholds for sea surface (i.e. floating) hydrocarbons, shoreline hydrocarbons, entrained oil and dissolved aromatic hydrocarbons were specified for use in defining the potential zone of influence of the spill event. These thresholds are summarised in Table 2.8, along with supporting justification and additional context relating to the area of influence.

Table 2.8 Summary of the zones of exposure and thresholds applied in this study.

Exposure Zone	Threshold	Justification
Floating Hydrocarbon Threshold		
Exposure zone Low exposure (1 g/m^2-10 g/m^2)	1 g/m^2	The 1 g/m^2 threshold represents the practical limit of observing hydrocarbon sheens in the marine environment and therefore has been used to define the outer boundary of the low exposure zone. This threshold is considered below levels which would cause environmental harm and is more indicative of the areas perceived to be affected due to its visibility on the sea-surface. This exposure zone is not considered to be of significant biological impact but may be visible to the human eye. This exposure zone represents the area contacted by the spill and defines the conservative outer boundary of the area of influence from a hydrocarbon spill. For context, <15 ppm is an allowable discharge limit from ships and 30 ppm is a typical discharge limit from an offshore oil and gas facility. Above 30 ppm, a visible sheen is observable at the sea surface.
Adverse exposure zone Moderate exposure (10 g/m^2-25 g/m^2)	10 g/m^2	Ecological impact has been estimated to occur at 10 g/m^2 as this level of oiling has been observed to mortally impact birds and other wildlife associated with the water surface (French *et al.*, 1996; French-McCay, 2009). The 10 g/m^2 threshold has been selected to define the moderate exposure zone. Contact within this exposure zone may result in impacts to the marine environment.
Adverse exposure zone High exposure (>25 g/m^2)	25 g/m^2	The 25 g/m^2 threshold is above the minimum threshold observed to cause ecological impact. Studies have indicated that a concentration of surface oil 25 g/m^2 or greater would be harmful for the majority of birds that contact the hydrocarbon at this concentration (Scholten *et al.*, 1996; Koops *et al.*, 2004). Exposure above this threshold is used to define the high exposure zone.
Shoreline Hydrocarbon Threshold		
Exposure zone Low exposure (10 g/m^2-100 g/m^2)	10 g/m^2	In previous risk assessment studies by French-McCay *et al.* (2005a, 2005b), a threshold of 1 g/m^2 was used to assess the potential for shoreline contact (by oil stranding on shorelines/beaches). It is a conservative threshold used to define regions of socio-economic impact, such as the triggering of temporary closures of fisheries, or the need for shore clean-up on man-made concrete/stone walls or on amenity beaches. A less conservative threshold of 10 g/m^2 has been defined as the zone of potential 'low' exposure. This exposure zone represents the area visibly contacted by the spill and defines the outer boundary of the area of influence from a hydrocarbon spill.
Adverse exposure zone Moderate exposure (100 g/m^2-1,000 g/m^2)	100 g/m^2	French *et al.* (1996) and French-McCay (2009) have defined an oil exposure threshold of 100 g/m^2 for shorebirds and wildlife (furbearing aquatic mammals and marine reptiles) on or along the shore, which is based on studies for sub-lethal and lethal impacts. The 100 g/m^2 threshold has been used in previous environmental risk assessment studies (French-McCay *et al.*, 2004, 2011, 2012; French-McCay, 2003; NOAA, 2013). This threshold is also recommended in AMSA's foreshore assessment guide as the acceptable minimum thickness that does not inhibit the potential for recovery and is best remediated by natural coastal processes alone (AMSA, 2015b). Thresholds of 100 g/m^2 and 1,000 g/m^2
Adverse exposure zone High exposure (>1,000 g/m^2)	1,000 g/m^2	

Exposure Zone	Threshold	Justification
		will define the zones of potential 'moderate' and 'high' exposure on shorelines, respectively. Contact within these exposure zones may result in impacts to the marine environment.
Entrained Hydrocarbon Threshold		
Exposure zone Low exposure (10 ppb-100 ppb)	10 ppb	The 10 ppb threshold represents the lowest concentration and corresponds generally with the lowest trigger levels for chronic exposure for entrained hydrocarbons in the Australian and New Zealand Environment and Conservation Council (ANZECC) and Agricultural and Resource Management Council of Australia and New Zealand (ARMCANZ) (ANZECC & ARMCANZ, 2000) water quality guidelines. Due to the requirement for relatively long exposure times (>24 hours) for these concentrations to be significant, they are likely to be more meaningful for juvenile fish, larvae and planktonic organisms that might be entrained (or otherwise moving) within the entrained plumes, or when entrained hydrocarbons adhere to organisms or is trapped against a shoreline for periods of several days or more. This exposure zone is not considered to be of significant biological impact. This exposure zone represents the area contacted by the spill and conservatively defines the outer boundary of the area of influence from a hydrocarbon spill.
Adverse exposure zone Moderate exposure (100 ppb-500 ppb)	100 ppb	The 100 ppb threshold is considered conservative in terms of potential for toxic effects leading to mortality for sensitive mature individuals and early life stages of species. This threshold has been defined to indicate a potential zone of acute exposure, which is more meaningful over shorter exposure durations. The 100 ppb threshold has been selected to define the moderate exposure zone. Contact within this exposure zone may result in impacts to the marine environment.
Adverse exposure zone High exposure (>500 ppb)	500 ppb	The 500 ppb threshold is considered conservative high exposure level in terms of potential for toxic effects leading to mortality for more tolerant species or habitats. This threshold has been defined to indicate a potential zone of acute exposure, which is more meaningful over shorter exposure durations. The 500 ppb threshold has been selected to define the high exposure zone.
Dissolved Aromatic Hydrocarbon Threshold		
Exposure zone Low exposure (6 ppb-50 ppb)	6 ppb	The threshold value for species toxicity in the water column is based on global data from French *et al.* (1999) and French-McCay (2002, 2003), which showed that species sensitivity (fish and invertebrates) to dissolved aromatics exposure >4 days (96-hour LC_{50}) under different environmental conditions varied from 6 ppb-400 ppb, with an average of 50 ppb. This range covered 95% of aquatic organisms tested, which included species during sensitive life stages (eggs and larvae). Based on scientific literature, a minimum threshold of 6 ppb used to define the low exposure zones (Engelhardt, 1983; Clark, 1984; Geraci & St. Aubin, 1988; Jenssen, 1994; Tsvetnenko, 1998). This exposure zone is not considered to be of significant biological impact. This exposure zone represents the area contacted by the spill and conservatively defines the outer boundary of the area of influence from a hydrocarbon spill.
Adverse exposure zone Moderate exposure (50 ppb-400 ppb)	50 ppb	A conservative threshold of 50 ppb was chosen as it is more likely to be indicative of potentially harmful exposure to fixed habitats over short exposure durations (French-McCay 2002). French-McCay (2002) indicates that an average 96-hour LC_{50} of 50 ppb could serve as an acute lethal threshold to 5% of biota.

Exposure Zone	Threshold	Justification
		The 50 ppb threshold has been selected to define the moderate exposure zone. Contact within this exposure zone may result in impacts to the marine environment.
Adverse exposure zone High exposure (>400 ppb)	400 ppb	A conservative threshold of 400 ppb was chosen as it is more likely to be indicative of potentially harmful exposure to fixed habitats over short exposure durations (French-McCay 2002). French-McCay (2002) indicates that an average 96-hour LC_{50} of 400 ppb could serve as an acute lethal threshold to 50% of biota. The 400 ppb threshold has been selected to define the high exposure zone.

LC_{50}: Median lethal dose required for mortality of 50% of a tested population after a specified test duration.

2.11 Receptors Overview

The key sensitive receptors assessed in this study are shown in Figure 2.19 to Figure 2.28. These include Australian Marine Parks (AMPs), State/Territory Marine Parks, mainland and island coastlines (emergent receptors), Key Ecological Features (KEFs), reefs, shoals and banks (submerged receptors) and biologically important areas (BIAs) for turtles.

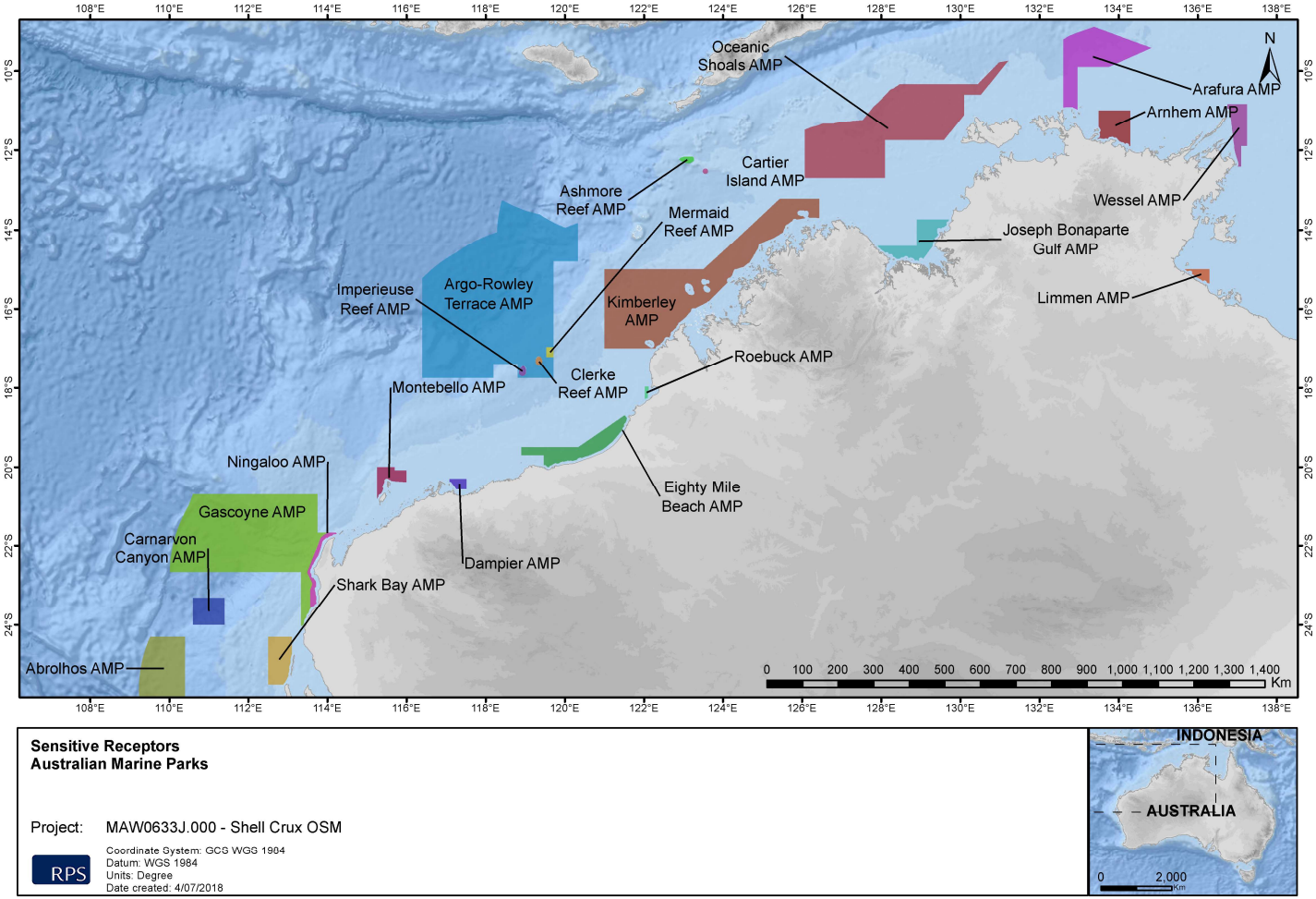


Figure 2.19 Locations of Australian Marine Parks (AMPs) in the study region.

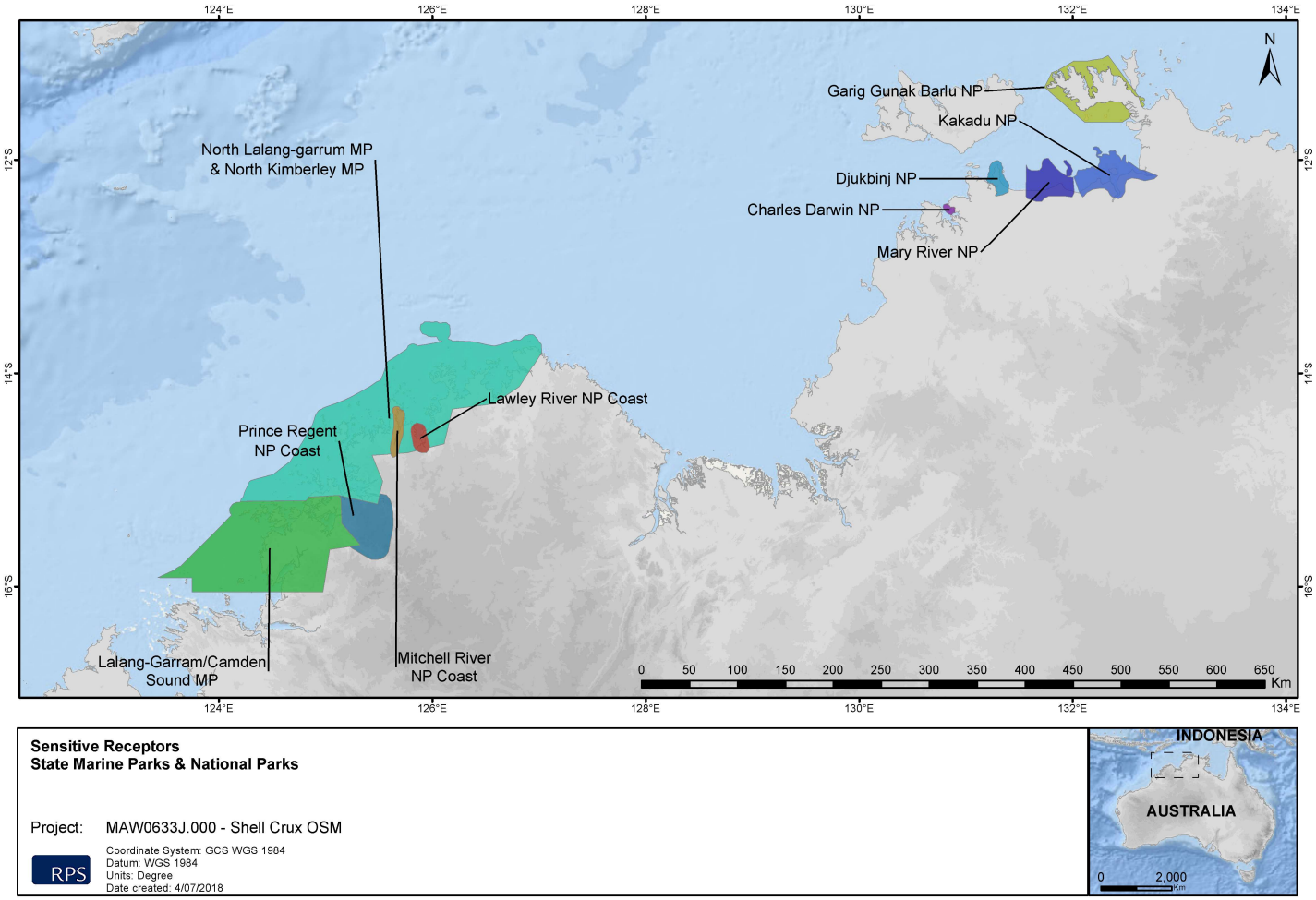


Figure 2.20 Locations of State Marine Parks (MPs) and National Parks (NPs) in the study region.

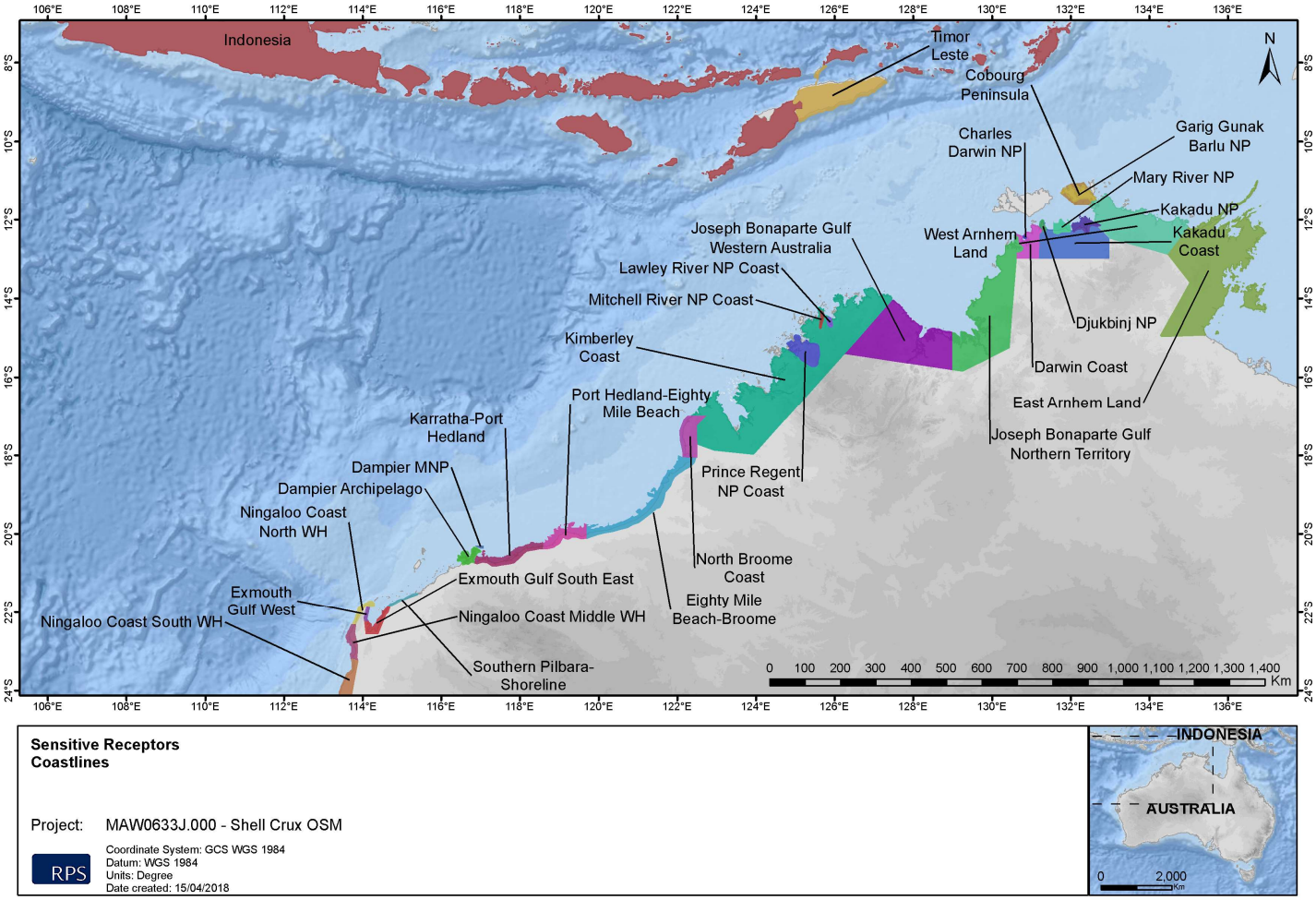


Figure 2.21 Locations of mainland coastlines (emergent receptors) in the study region.

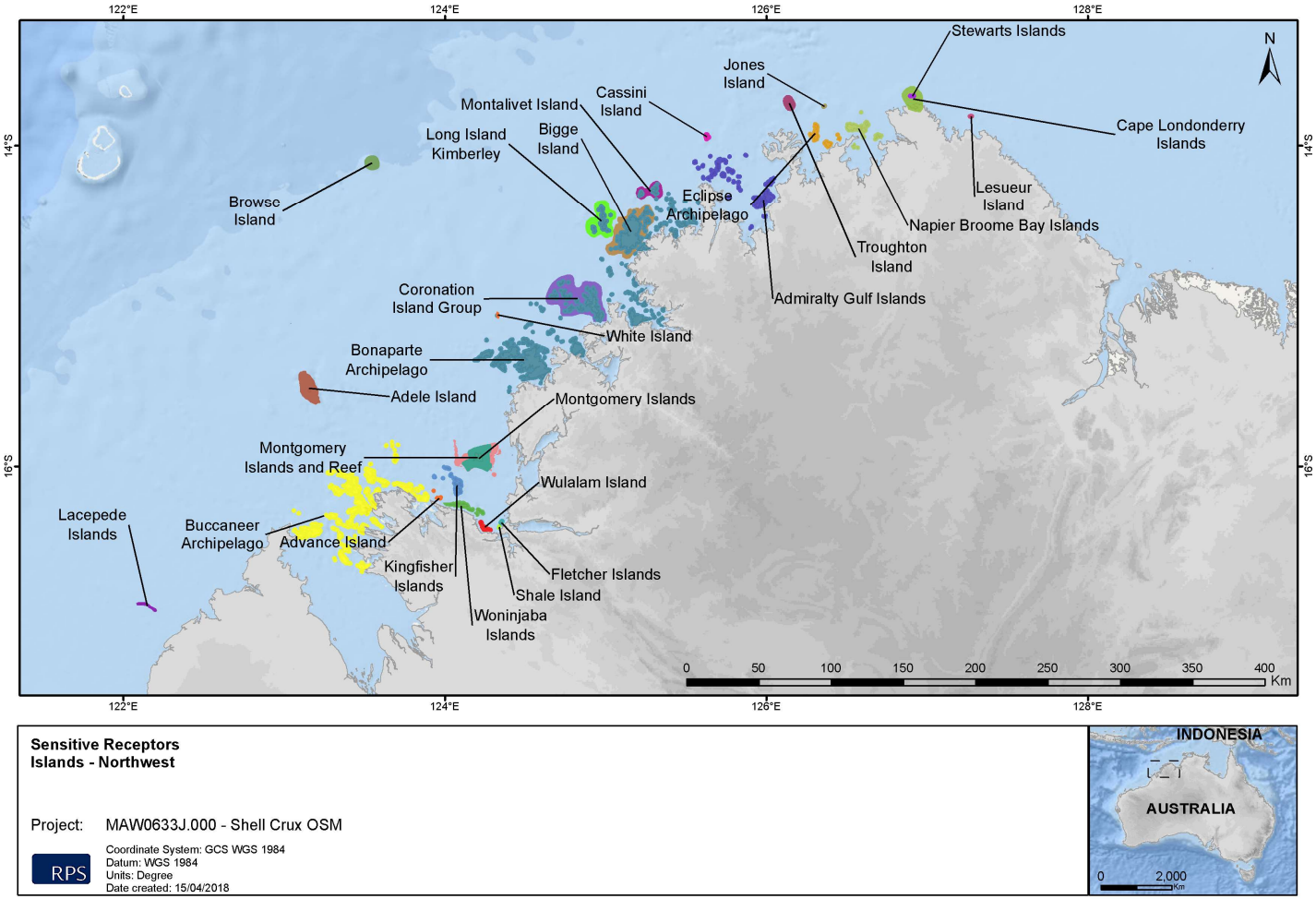


Figure 2.22 Locations of north-western island coastlines (emergent receptors) in the study region.

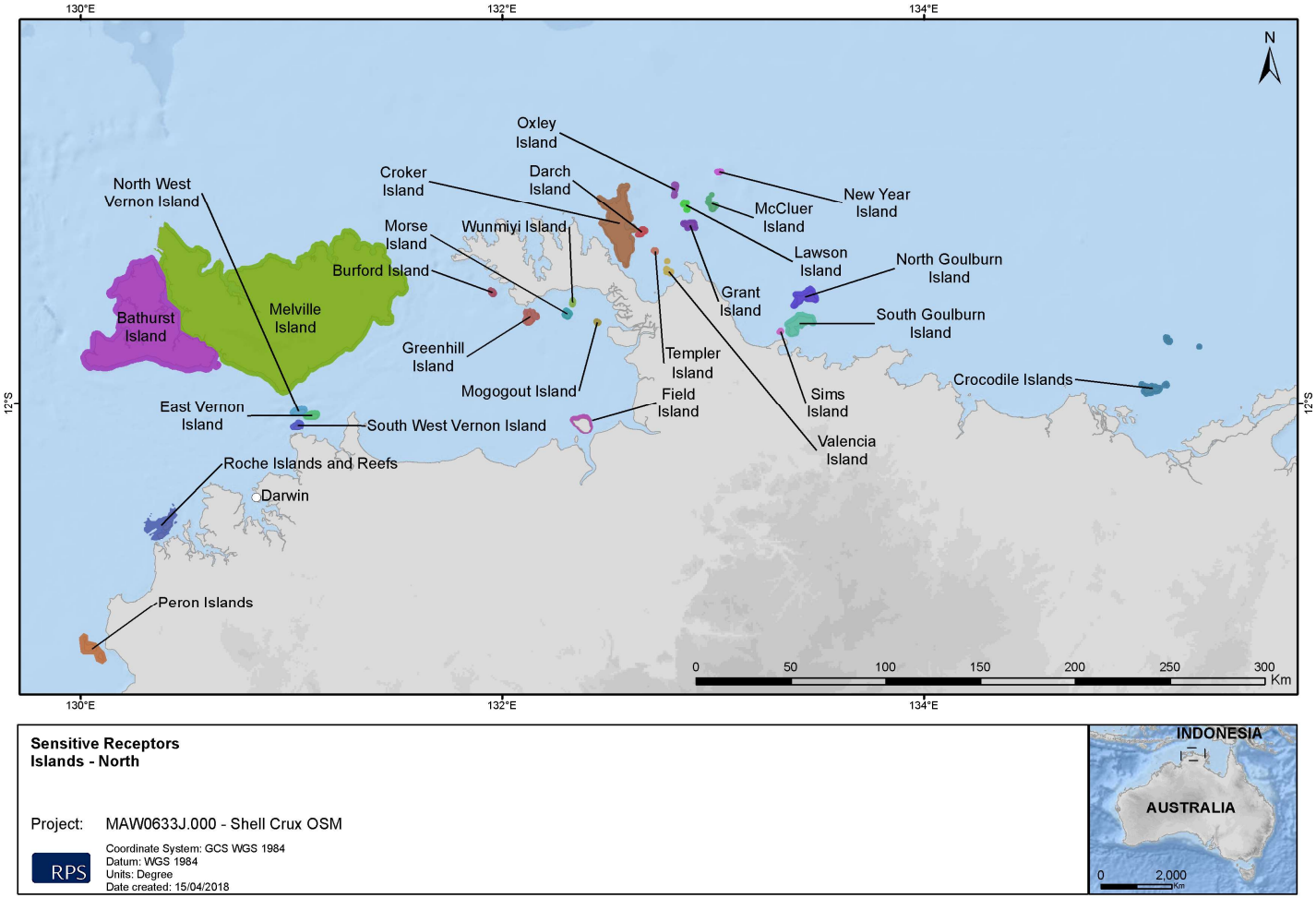


Figure 2.23 Locations of northern island coastlines (emergent receptors) in the study region.

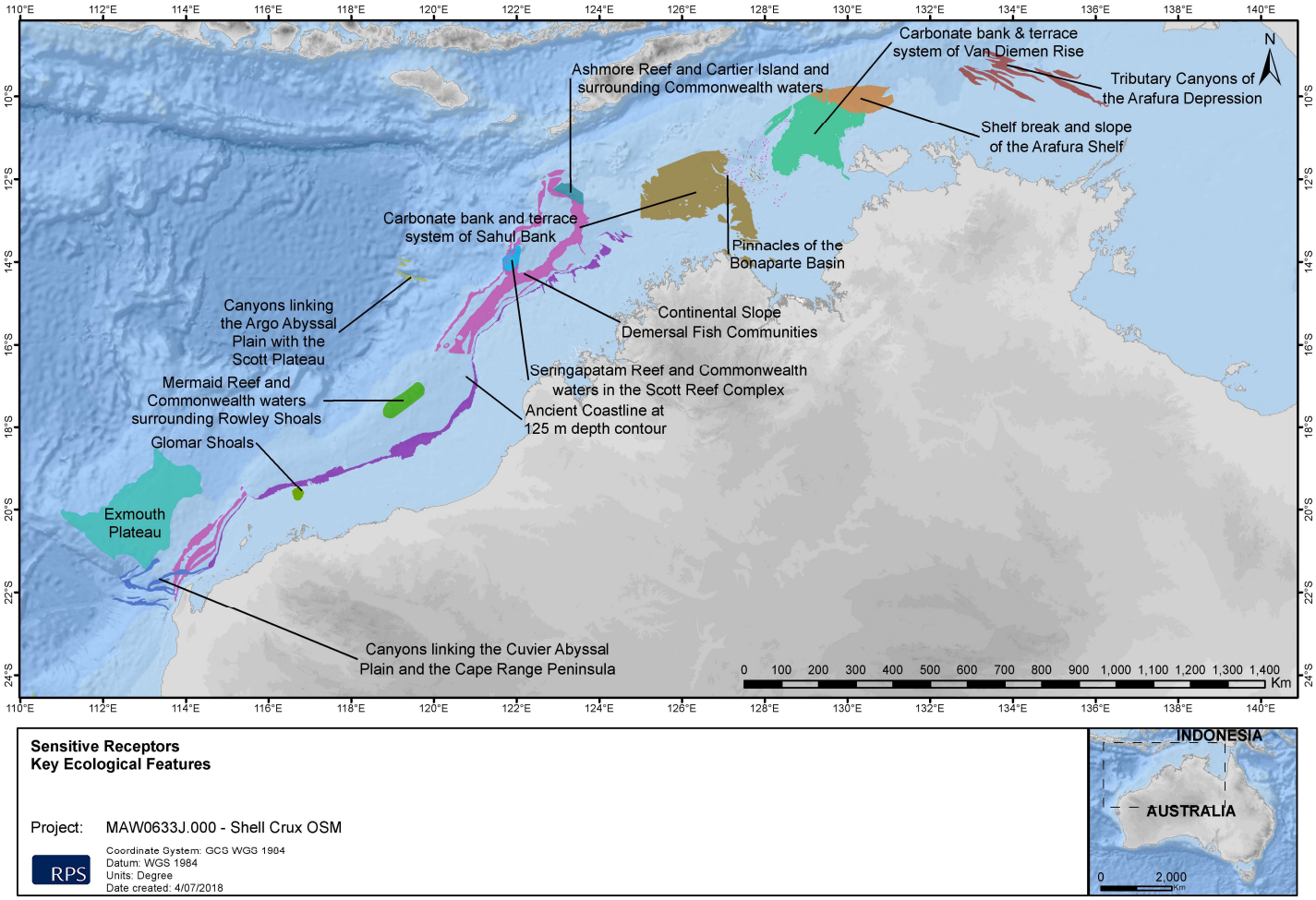


Figure 2.24 Locations of Key Ecological Features (KEFs) in the study region.

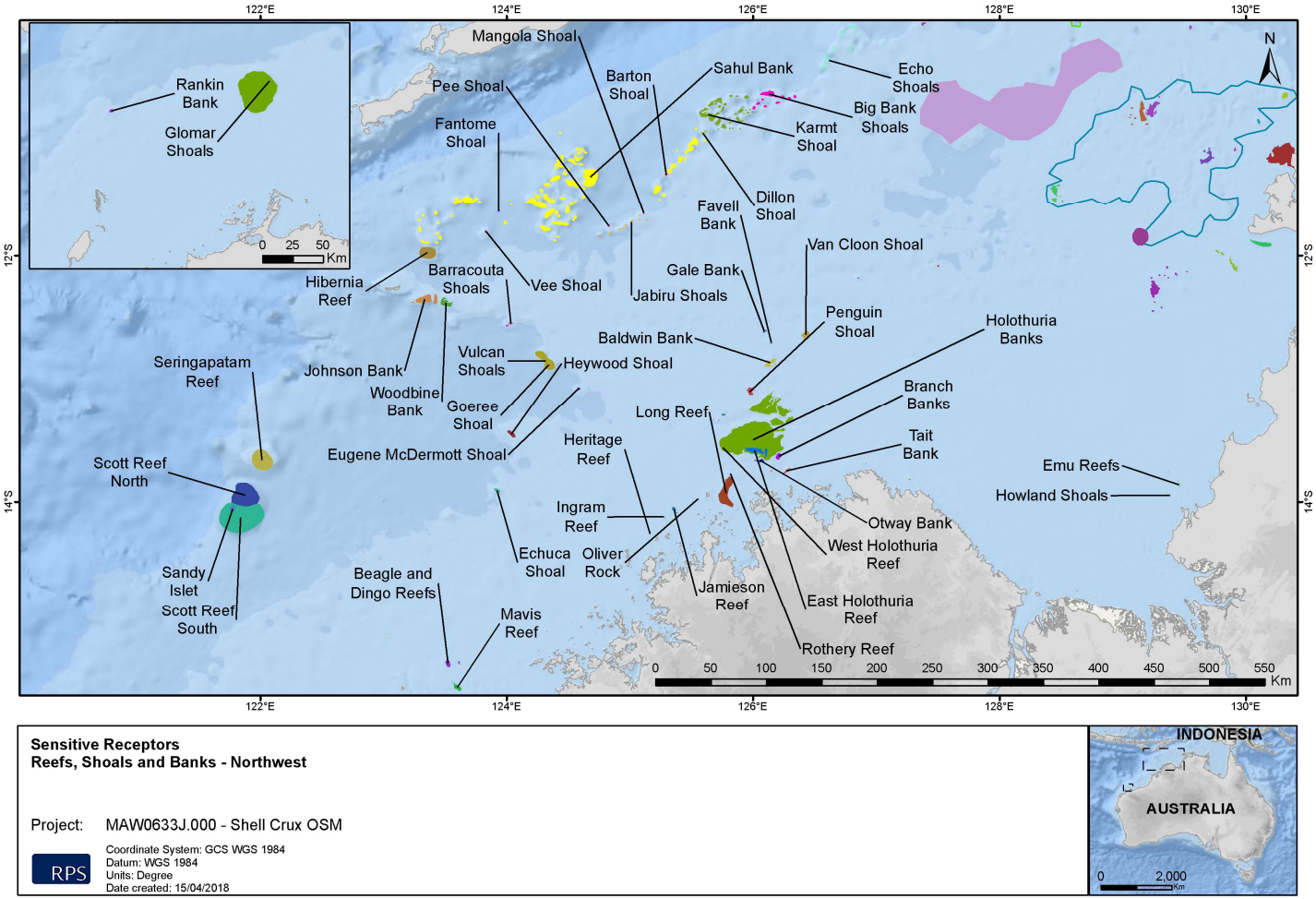


Figure 2.25 Locations of north-western reefs, shoals and banks (submerged receptors) in the study region.

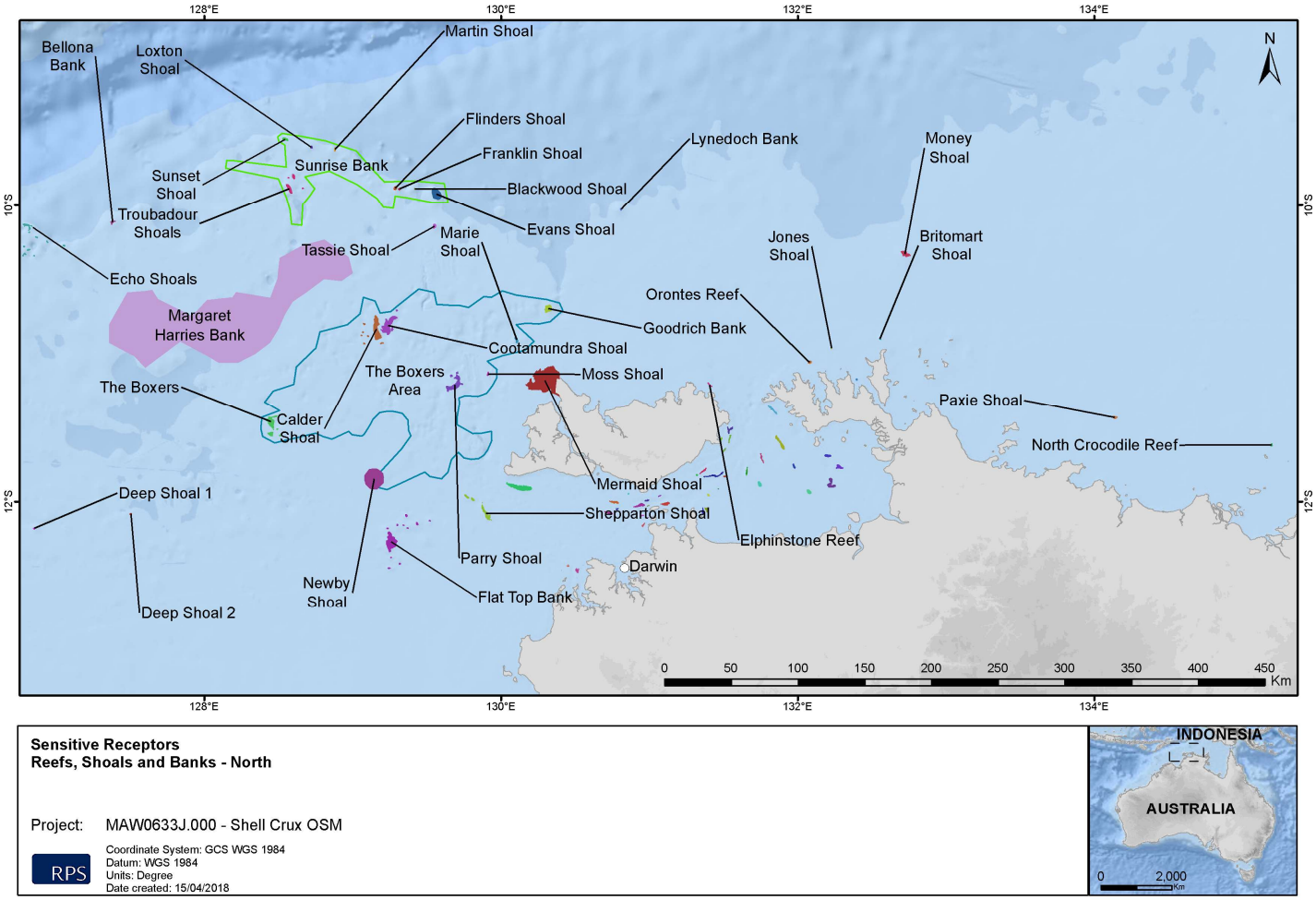


Figure 2.26 Locations of northern reefs, shoals and banks (submerged receptors) in the study region.

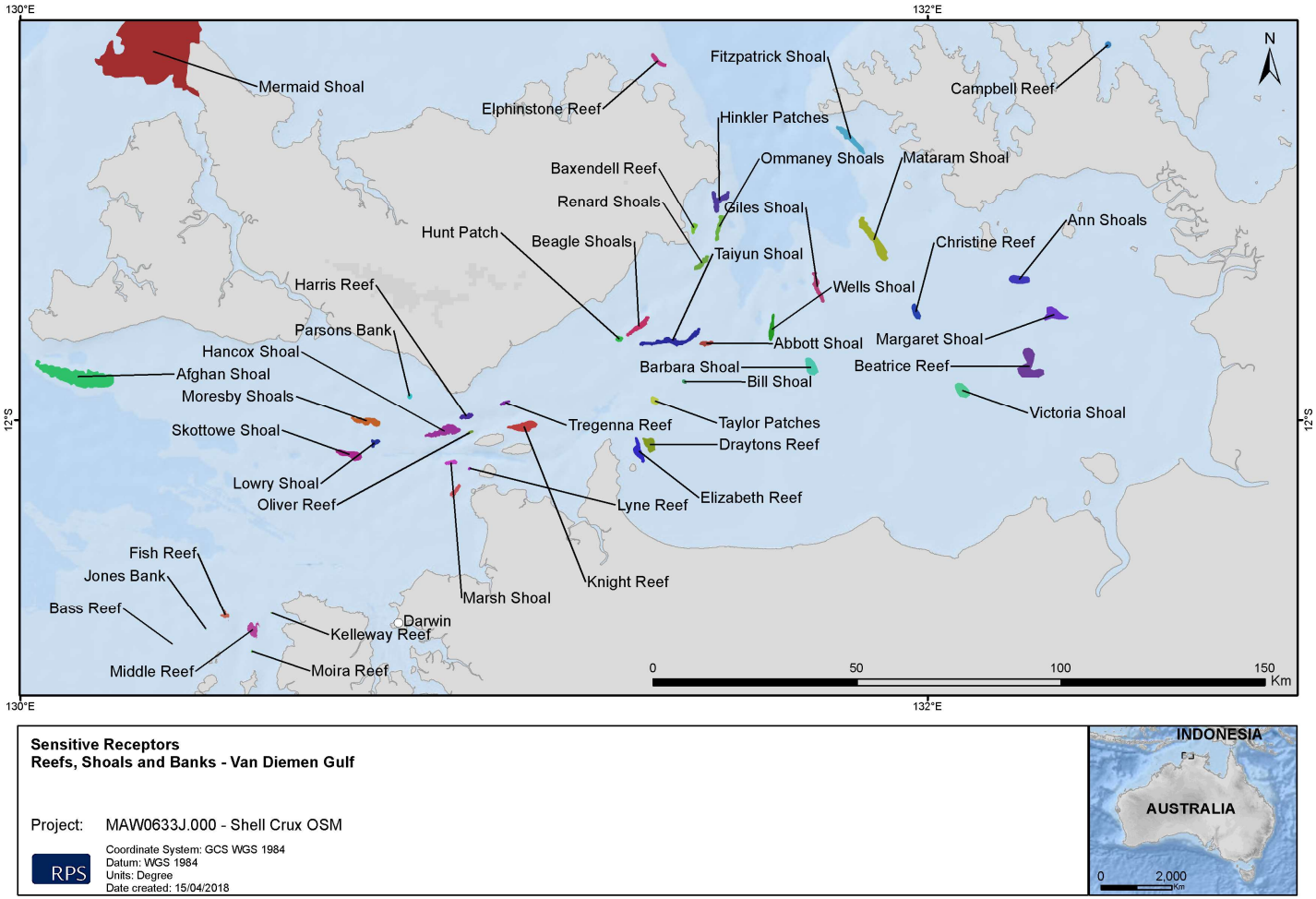


Figure 2.27 Locations of reefs, shoals and banks (submerged receptors) in the Van Diemen Gulf.

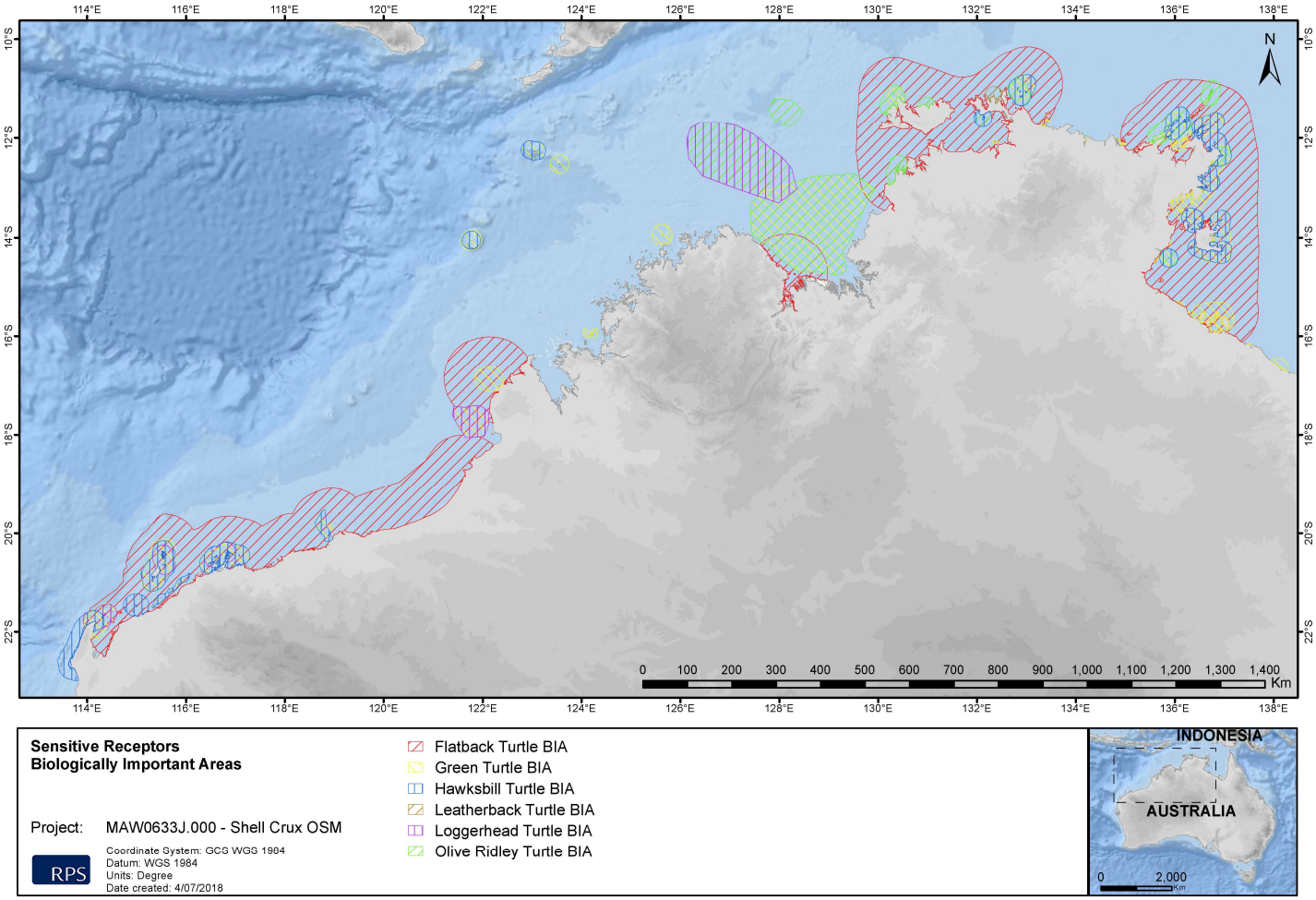


Figure 2.28 Locations of BIAs for turtles in the study region.

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3 Modelling Results

3.1 Overview

If readers are not fully familiar with how to interpret stochastic modelling outputs, please refer to the following NOPSEMA factsheet before reading this report section:

https://www.nopsema.gov.au/assets/Publications/A626200.pdf

Predictions for the probability of contact and time to contact by hydrocarbon concentrations equalling or exceeding defined thresholds for floating and shoreline hydrocarbons, entrained hydrocarbons and dissolved aromatic hydrocarbons are provided in the following sections to summarise the results of the seasonal stochastic modelling.

Contour maps present estimates for the seasonal probability of contact by instantaneous concentrations of at least the defined minimum threshold concentrations (≥1 g/m^2, ≥10 g/m^2 and ≥25 g/m^2 for floating hydrocarbons; ≥10 g/m^2, ≥100 g/m^2 and ≥1,000 g/m^2 for shoreline hydrocarbons, ≥10 ppb, ≥100 ppb and ≥500 ppb for entrained hydrocarbons, and ≥6 ppb, ≥50 ppb and ≥400 ppb for dissolved aromatic hydrocarbons) for at least one time step (1 hour). These contours summarise the outcomes for **all replicate simulations** commencing across each seasonal period – 100 replicate simulations for each season giving a **total of 300 replicate simulations for each scenario**.

Readers should note that the contour maps presented in this report (in Appendices) do not represent the predicted coverage of any one hydrocarbon spill or a depiction of a film or plume at any particular instant in time. Rather, the contours are a composite of a large number of theoretical paths, integrated over the full duration of the simulations relevant to each scenario. The contour maps should be treated as indications of the probability of exposure at defined concentrations, for individual locations, at some point in time after the defined spill commences, given the trends and variations in metocean conditions that occur around the study area.

Locations with higher probability ratings were predicted to be exposed during a greater number of spill simulations, indicating that the combination of the prevailing wind and current conditions are more likely to result in contact to these locations if a hypothetical spill scenario were to occur. The areas outside of the lowest-percentage contour indicate that contact will be less likely under the range of prevailing conditions for this region than areas falling within higher probability contours. It is important to note that the probabilities are derived from the samples of data used in the modelling. Therefore, locations that are not calculated to receive exposure at threshold concentrations or greater in any of the replicate simulations might possibly be contacted if very unusual conditions were to occur. Hence, probabilities of nil are not attributed to areas beyond the lowest probability contour but are referred to as <0.3%. While noting this, the results are considered to provide an appropriate representation of the potential probability for locations to be contacted given the large number of replicate simulations run (300 per scenario).

Tables are presented to summarise estimates of contact risk for key sensitive receptors (Section 2.11).

The probability estimates for contact by floating hydrocarbons that are presented in the tables summarise the probability that hydrocarbons will arrive at shorelines as floating films at the specified threshold concentration or greater for at least one hour. The tables show the seasonal probabilities determined from the results for each season.

The minimum time estimates shown in the tables present the shortest time for any hydrocarbons to drift from the release location to any part of the sensitive receptor, relative to the commencement of the spill. These times then indicate the minimum weathering time for hydrocarbons that might make contact with the receptor.

The mean and maximum shoreline concentrations indicate the concentrations forecast to potentially accumulate over time on any discrete part of a shoreline (calculated for individual portions of approximately 1 km length). Accumulated concentrations are calculated by summing the mass of hydrocarbons that arrives at any concentration (including < threshold) over time at a model cell and subtracting any mass lost through evaporation and washing off, where relevant.

The maximum local accumulated concentration in the worst replicate spill is the greatest accumulation predicted for any point on the shoreline during any replicate simulation, and thus represents an overly conservative estimate of the potential impact to a shoreline. The maximum local accumulated concentration averaged over all replicate spills is the greatest concentration calculated for any point on the shoreline after averaging over all replicate simulations, and is more appropriate for assessing the potential impact to shorelines.

Note that it is possible that hydrocarbons arriving at concentrations that are less than the threshold may accumulate over the course of a spill event to result in concentrations that may exceed the threshold. Hence, the mean expected, and maximum concentrations of accumulated hydrocarbons can exceed the threshold applied to the probability calculations for the arrival of floating hydrocarbons even where no instantaneous exceedances above threshold are predicted. While noting this, the results are considered to provide an appropriate representation of the potential accumulation of hydrocarbons on shorelines given the large number of replicate simulations run (300 per scenario). It is important to understand that the two parameters (floating concentration and shoreline concentration) are quite distinct, calculated in different ways and representative of alternative outcomes. The floating probability estimates and the shoreline accumulative estimates should therefore be treated as independent estimators of different exposure outcomes, and not directly compared.

For the entrained and dissolved components, the tabulated results summarise interrogations of cells representing the water surrounding the sensitive receptor shorelines (or submerged features), with individual buffer zones as illustrated in Figure 2.19 to Figure 2.28. Buffer zones were defined with consideration of the bathymetry bordering each receptor, natural boundaries, or sensible legislative boundaries.

The modelling for each scenario assumed no spill response efforts are undertaken to collect or otherwise affect the natural transport and weathering of the hydrocarbons.

The predicted outcomes based on the modelling results are discussed in the following sections in terms of floating and shoreline, entrained and dissolved aromatic hydrocarbons. The discussion is also predominantly focused on the outcomes of stochastic risk contours.

Plots of the annualised Zones of Potential Exposure (ZoPEs) are presented for each scenario.

From the stochastic set of replicate simulations, three replicate simulations were identified as yielding the worst-case or best oil spill response planning outcomes for Scenarios 1, 2, 3 and 4. This section summarises the risk of contact estimates calculated for the replicate simulations selected according to the following criteria:

- Maximum oil volume accumulated across all shoreline receptors;
- Minimum time to commencement of oil accumulation at any shoreline receptor (at a threshold of 10 g/m^2);
- Maximum length of oiled shoreline (at a threshold of 10 g/m^2).

The worst-case replicates identified for each scenario are summarised in Table 3.1 to Table 3.3.

A time series compilation of figures from the replicate deterministic simulation (i.e. a single spill event) yielding the maximum oil volume accumulated across all shoreline receptors for each scenario is presented in Appendix E. Each of the time series figure compilations presented in Appendix E includes areal exposure at discrete time intervals during each deterministic scenario, along with snapshots of the vertical distribution of dissolved aromatic hydrocarbons in the water column at the corresponding time intervals. Where a vertical distribution

figure is not presented, this means that no plume of hydrocarbons intersected the defined transect line at that particular time interval.

Table 3.1 Identified replicate simulations meeting the maximum accumulated shoreline oil volume criterion.

Scenario	Maximum Volume Ashore Criterion		
	Worst-Affected Receptor	**Volume (m^3)**	**Season**
1	Djukbinj NP	9.3	Summer
2	Ashmore Reef and Cartier Island and Surrounding Commonwealth Waters KEF	2.0	Winter
3	Hawksbill Turtle BIA Green Turtle BIA Ashmore Reef and Cartier Island and Surrounding Commonwealth Waters KEF	116.0	Transitional
4	Bonaparte Archipelago (Bigge Island)	624.3	Summer

Table 3.2 Identified replicate simulations meeting the minimum time to shoreline accumulation criterion.

Scenario	Minimum Time to Shoreline Contact Criterion		
	Worst-Affected Receptor	**Time (d)**	**Season**
1	Hawksbill Turtle BIA Green Turtle BIA Ashmore Reef and Cartier Island and Surrounding Commonwealth Waters KEF	10.3	Winter
2	Ashmore Reef and Cartier Island and Surrounding Commonwealth Waters KEF	11.9	Winter
3	Hawksbill Turtle BIA Green Turtle BIA Ashmore Reef and Cartier Island and Surrounding Commonwealth Waters KEF	6.0	Transitional
4	Hawksbill Turtle BIA Green Turtle BIA Ashmore Reef and Cartier Island and Surrounding Commonwealth Waters KEF	5.1	Winter

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Table 3.3 Identified replicate simulations meeting the maximum length of oiled shoreline criterion.

Scenario	Maximum Length of Shoreline Contact Criterion		
	Worst-Affected Receptor	**Length (km)**	**Season**
1	Darwin Coast	11.0	Transitional
2	Ashmore Reef and Cartier Island and Surrounding Commonwealth Waters KEF	2.0	Winter
3	Green Turtle BIA Ashmore Reef and Cartier Island and Surrounding Commonwealth Waters KEF	10.0	Transitional
4	North Lalang-garram MP & North Kimberley MP	117.0	Transitional

3.2 Scenario 1 – 80-Day Subsurface Blowout of Crux Condensate at a Development Well

3.2.1 Discussion of Results

3.2.1.1 Overview

This scenario investigated the probability of exposure to key sensitive receptors by hydrocarbons resulting from an 80-day uncontrolled subsurface blowout, discharging 206,225 m^3 (2,578 m^3/day) of Crux condensate from a development well at any time of year, with no spill response mitigation measures applied.

Considering the discharge characteristics, the properties of the hydrocarbon and its expected weathering behaviour, the bulk of the condensate, which is predicted to form relatively small oil droplets due to the large gas/oil ratio, will remain entrained in the water column, with a relatively small proportion (the largest oil droplets, i.e. >80 µm) rising to the surface to form floating films under typical to calm wind conditions. Once at the surface given the low viscosity of the condensate, re-entrainment into the water column is highly likely to occur under all but relatively calm wind conditions. On reaching the surface, it is likely that the majority of the hydrocarbon mass will be found in the surface mixed layer (3-10 m deep, depending on the conditions), with a small proportion on the water surface. Evaporation rates will be high, given the large proportion of volatile (55%) and semi-volatile (23%) compounds within the condensate, with the residual fraction (8%) persisting in the environment until degradation processes occur (over periods of weeks to months). Considering the spill volume and the relatively high likelihood of entrainment occurring, there is a high potential for dissolution of soluble aromatic compounds.

Figure 3.1 to Figure 3.3 show a summary of the areal extent for all hydrocarbon phases at the low, moderate and high thresholds, respectively.

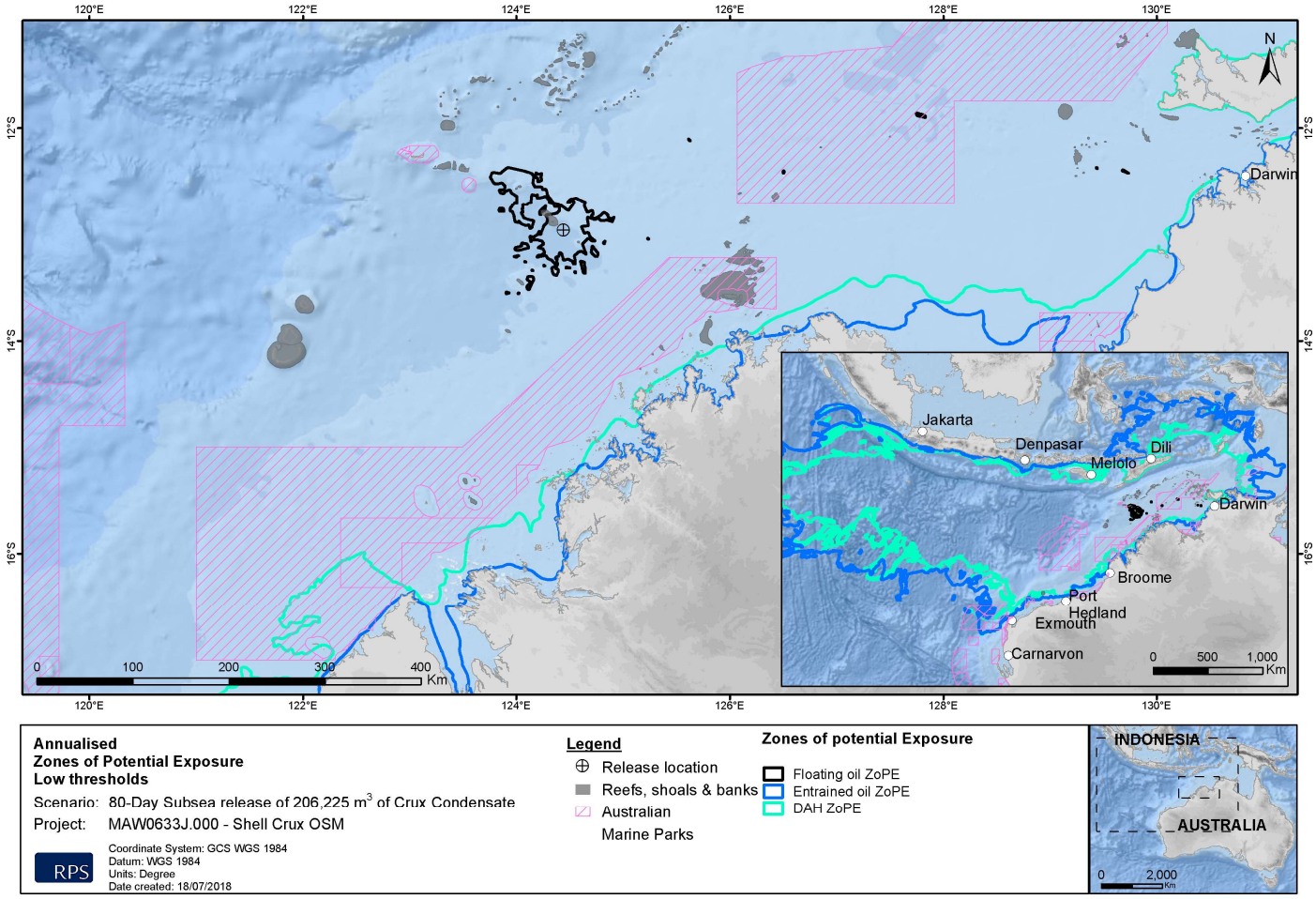


Figure 3.1 Surface and Subsurface Hydrocarbons | Blowout Scenario | Stochastic Outcomes. Areal extent of potential exposure at the low thresholds resulting from an 80-day subsurface release of Crux condensate at a development well.

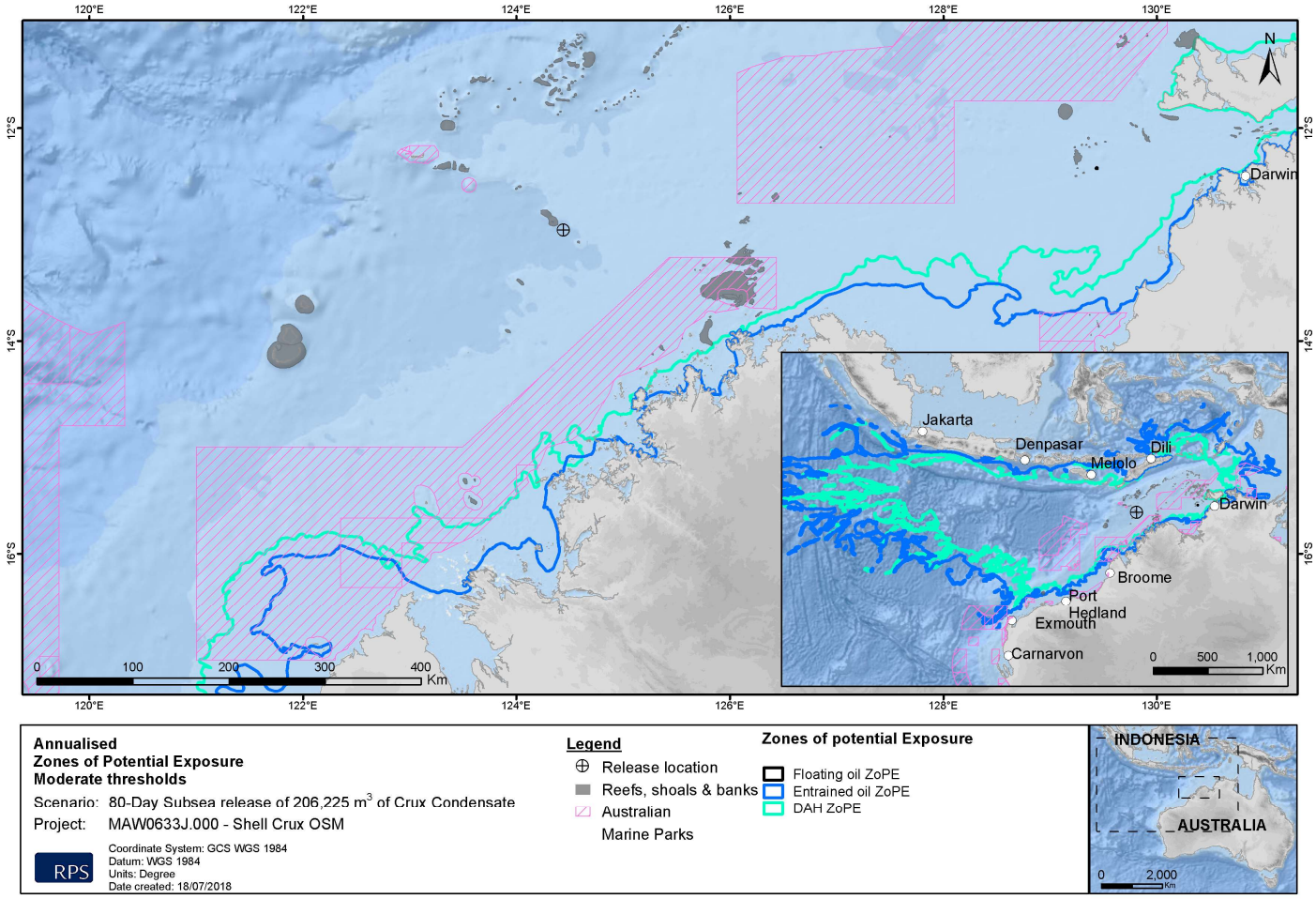


Figure 3.2 Surface and Subsurface Hydrocarbons | Blowout Scenario | Stochastic Outcomes. Areal extent of potential exposure at the moderate thresholds resulting from an 80-day subsurface release of Crux condensate at a development well.

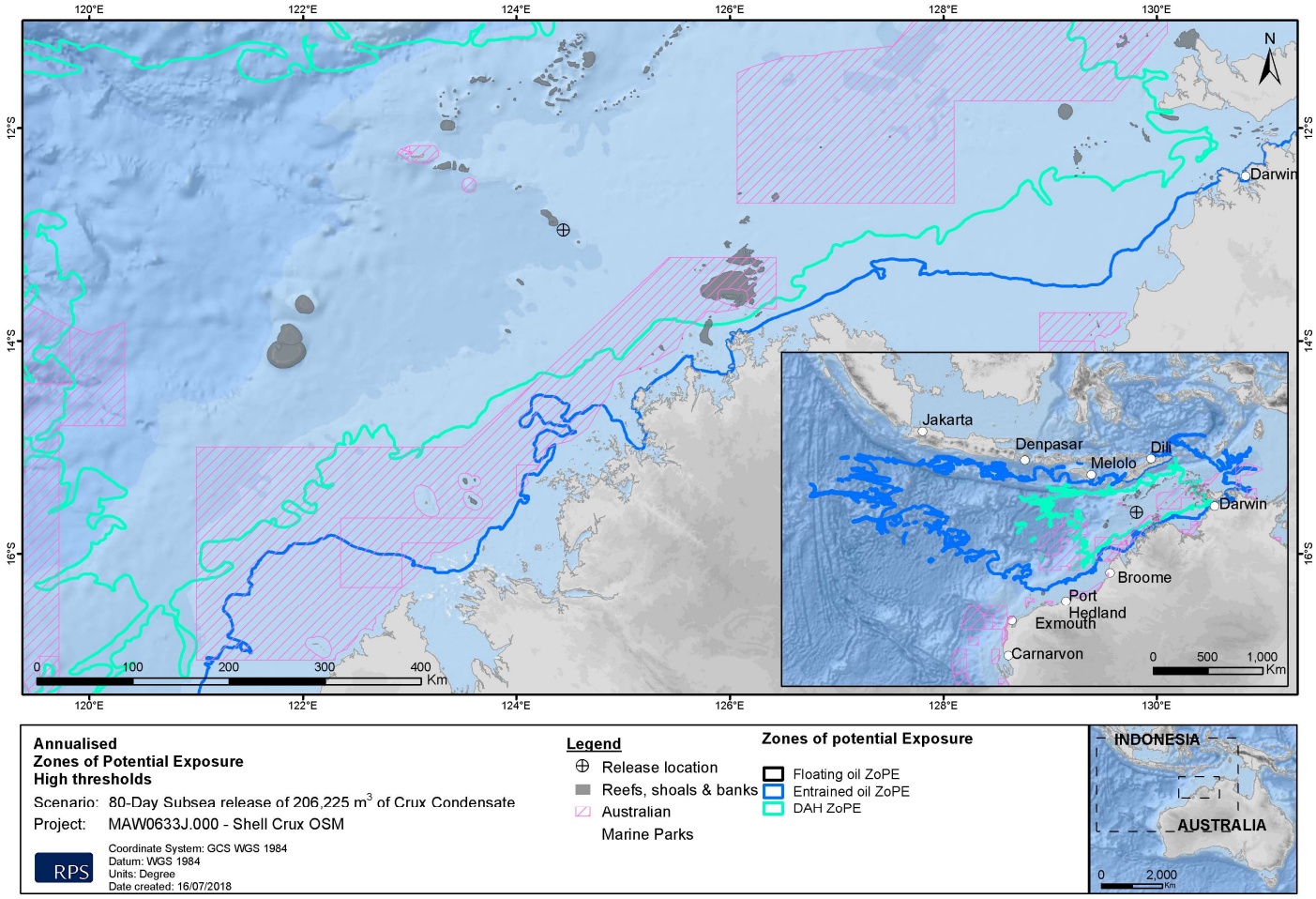


Figure 3.3 Surface and Subsurface Hydrocarbons | Blowout Scenario | Stochastic Outcomes. Areal extent of potential exposure at the high thresholds resulting from an 80-day subsurface release of Crux condensate at a development well.

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3.2.1.2 Floating and Shoreline Hydrocarbons

The annualised probability contour figures (Appendix A) indicate that hydrocarbons on the sea surface at or greater than the threshold concentrations are predicted to remain relatively localised around the release location, with very low probability of contact to the nearest shoreline receptors. The maximum distances to the outer extents of the low and moderate floating oil thresholds (1 g/m^2 and 10 g/m^2, respectively) are predicted to be 577 km and 548 km, respectively (Table 3.4). Floating oil concentrations are not predicted to exceed the high threshold (25 g/m^2).

The Southern Bluefin Tuna Fishery, Western Skipjack Fishery and Western Tuna and Billfish Fishery receptors have the highest predicted probability of contact at the low threshold being 58% (Table 3.5). Only a small number of Fisheries receptors are predicted to receive floating oil at moderate threshold concentrations with probabilities of approximately 0.6%.

The minimum time to contact with any receptor by floating oil at the low threshold is forecast at approximately 2-3 hours over all seasons at the Southern Bluefin Tuna Fishery, Western Skipjack Fishery and Western Tuna and Billfish Fishery receptors. The minimum time to contact with these receptors at the moderate threshold is forecast at approximately 103 days.

Potential for accumulation of hydrocarbons on shorelines is predicted to be low (<1% probability at the moderate threshold of 100 g/m^2), with a maximum accumulated volume forecast at Melville Island (9 m^3), Darwin Coast (6 m^3), Kakadu Coast (10 m^3), and Djukbinj NP (NT) (10 m^3), and maximum local accumulated concentration on shorelines of 473 g/m^2 forecast at Melville Island (Table 3.5).

Table 3.4 Maximum distances from the release location to zones of floating oil exposure for Scenario 1 (206,225 m^3 Crux condensate).

	Floating Oil Exposure Threshold		
	Low (1-10 g/m^2)	**Moderate (10-25 g/m^2)**	**High (>25 g/m^2)**
Maximum distance travelled (km) by a spill trajectory	577	548	-

3.2.1.3 Subsurface – Entrained Hydrocarbons

The annualised probability contour figures (Figure 3.7 and Appendix A) indicate that entrained oil concentrations at or greater than the threshold concentrations travel up to 3,292 km (10 ppb) from the release location. The maximum extents are forecast to be slightly reduced for the moderate (100 ppb; 3,279 km) and high (500 ppb; 3,239 km) thresholds.

Stochastic modelling shows that the entrained hydrocarbon concentrations greater that the conservative thresholds can potentially occur at most of the environmental sensitivities. Southern Bluefin Tuna Fishery, Western Skipjack Fishery, Western Tuna and Billfish Fishery, North-West Slope Trawl Fishery, Eugene McDermott Shoal, Vulcan Shoals and Goeree Shoal receptors are predicted to be contacted at the high threshold with probabilities >90% (Table 3.6).

Receptors with the highest probability of receiving entrained oil at low threshold concentrations are waters above Key Ecological Features including Ancient Coastline at 125 m Depth Contour (96%), Continental Slope Demersal Fish Communities (95%), and Ashmore Reef and Cartier Island and Surrounding Commonwealth Waters KEF (91%). Biologically Important Areas for Green Turtle and Hawksbill Turtle are forecast to receive

entrained oil at the low threshold with probabilities of 95% and 84%, respectively. High probabilities of contact at this threshold are also forecast at the closest AMPs (Cartier Island AMP, 91%; Ashmore Reef AMP, 82%) and at the waters above the nearest shoals and banks (Barracouta Shoals, 89%; Heywood Shoal, 89%; Johnson Bank, 84%; Woodbine Bank, 80%). These sensitive receptors are also contacted at the moderate threshold with lower probabilities.

The minimum time to contact with any receptor by entrained oil at the low, moderate and high thresholds is forecast at Southern Bluefin Tuna Fishery, Western Skipjack Fishery and Western Tuna and Billfish Fishery, at approximately 1 hour.

3.2.1.4 Subsurface – Dissolved Aromatic Hydrocarbons

The annualised probability contour figures (Figure 3.9 to Figure 3.11) indicate that dissolved aromatic hydrocarbons at or greater than the threshold concentrations travel up to 3,280 km (6 ppb) from the release location. The maximum extents are forecast to be slightly reduced for the moderate (50 ppb; 3,181 km) and high (400 ppb; 2,946 km) thresholds.

A number of receptors are predicted to receive dissolved aromatic hydrocarbons at high threshold concentrations. Southern Bluefin Tuna Fishery, Western Skipjack Fishery, Western Tuna and Billfish Fishery and Vulcan Shoals receptors are predicted to be contacted at the high threshold with probabilities >90% (Table 3.7).

Receptors with the highest probability of receiving dissolved aromatic hydrocarbons at low threshold concentrations include Goeree Shoal (98%), Eugene McDermott Shoal (98%) and Heywood Shoal (85%). Key Ecological Features are forecast to receive dissolved aromatic hydrocarbons at the low threshold with highest probabilities forecast at Ancient Coastline at 125 m Depth Contour (95%), Seringapatam Reef and Commonwealth Waters in the Scott Reef Complex KEF (91%), Continental Slope Demersal Fish Communities (89%), and Ashmore Reef and Cartier Island and Surrounding Commonwealth Waters (82%). High annualised probabilities of contact at the low threshold are also forecast at North-West Slope Trawl Fishery (98%) and Green Turtle BIAs (86%). These sensitive receptors are also contacted at the moderate threshold with lower probabilities.

3.2.1.5 Deterministic Cases

A replicate simulation during the summer season (spill starting at 10:00 18th December 2013) has been identified as the worst-case replicate according to the maximum oil volume accumulated across all shoreline receptors criteria for Scenario 1 (9.3 m^3 at Djukbinj NP). Figures showing the evolution of this spill simulation are contained in Appendix E. Hydrocarbons on the sea surface mainly drifted southwest of the release location. The potential floating oil exposure zones (low threshold) was limited to within 15 km of the release location, with the moderate and high thresholds not exceeded. The entrained oil and dissolved aromatic hydrocarbons were shown to move east and northeast of the release location. Low, moderate and high entrained hydrocarbons were observed up to 1,155 km, 1,048 km and 890 km, respectively, from the release location. Low, moderate and high dissolved aromatic hydrocarbons were observed up to 1,071 km, 597 km and 364 km, respectively, from the release location.

A replicate simulation during the winter season (spill starting at 09:00 21st July 2016) has been identified as the worst-case replicate according to the minimum time to commencement of oil accumulation at any shoreline receptor criteria for Scenario 1 (10.3 days at Ashmore Reef and Cartier Island and Surrounding Commonwealth Waters KEF). Hydrocarbons on the sea surface mainly drifted northwest of the release location. The potential floating oil exposure zones (low threshold) was limited to within 30 km of the release location, with the moderate and high thresholds not exceeded. The entrained oil and dissolved aromatic hydrocarbons were shown to move west of the release location. Low, moderate and high entrained hydrocarbons were recorded up to 3,211 km, 3,211 km and 3,207 km, respectively, from the release location.

Low, moderate and high dissolved aromatic hydrocarbons were observed up to 3,209 km, 3,190 km and 2,946 km, respectively, from the release location.

A replicate simulation during the transitional season (spill starting at 19:00 30th November 2010) has been identified as the worst-case replicate according to the maximum length of oiled shoreline criteria for Scenario 1 (11 km at Darwin Coast). Hydrocarbons on the sea surface mainly drifted northeast of the release location. The potential floating oil exposure zones (low threshold) was limited to within 17 km of the release location, with the moderate and high thresholds not exceeded. The entrained oil and dissolved aromatic hydrocarbons were shown to move east and northeast of the release location. Low, moderate and high entrained hydrocarbons were recorded up to 1,206 km, 1,199 km and 972 km, respectively, from the release location. Low, moderate and high dissolved aromatic hydrocarbons were observed up to 960 km, 917 km and 700 km, respectively, from the release location.

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3.2.2 Floating and Shoreline Hydrocarbons

Table 3.5 Expected annualised floating and shoreline oil outcomes at sensitive receptors resulting from an 80-day subsurface release of Crux condensate at a development well.

	Receptor	Probability (%) of films arriving at receptors at			Minimum time to receptor (hours) for films at			Probability (%) of shoreline oil on receptors at			Minimum time to receptor (hours) for shoreline oil at			Maximum local accumulated concentration (g/m²)		Maximum accumulated volume (m³) along this shoreline		Maximum length of shoreline (km) with concentrations ≥10.0 g/m²	
		≥1 g/m²	≥10 g/m²	≥25 g/m²	≥1 g/m²	≥10 g/m²	≥25 g/m²	≥10 g/m²	≥100 g/m²	≥1,000 g/m²	≥10 g/m²	≥100 g/m²	≥1,000 g/m²	averaged over all replicate simulations	worst replicate simulation	averaged over all replicate simulations	worst replicate simulation	averaged over all replicate simulations	worst replicate simulation
Coastlines	Cobourg Peninsula	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	0.4	<1	<1	NC	NC
	Darwin Coast	<0.3	<0.3	<0.3	NC	NC	NC	0.6	<0.3	<0.3	2,251	NC	NC	0.3	93	<1	6	<1	11
	Indonesia	<0.3	<0.3	<0.3	NC	NC	NC	1.2	0.6	<0.3	945	1,022	NC	1.3	357	<1	3	<1	3
	Joseph Bonaparte Gulf Northern Territory	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	3.4	<1	<1	NC	NC
	Kakadu Coast	<0.3	<0.3	<0.3	NC	NC	NC	0.9	0.6	<0.3	2,222	2,356	NC	1.1	243	<1	10	<1	4
	Kakadu National Park	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	<0.1	<1	<1	NC	NC
	Kimberley Coast	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	2.1	<1	<1	NC	NC
	North Broome Coast	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	<0.1	<1	<1	NC	NC
	Port Hedland-Eighty Mile Beach	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	<0.1	<1	<1	NC	NC
	Timor Leste	<0.3	<0.3	<0.3	NC	NC	NC	0.6	<0.3	<0.3	953	NC	NC	0.1	31	<1	<1	<1	1
	West Arnhem Land	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	<0.1	<1	<1	NC	NC
Islands	Adele Island	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	<0.1	<1	<1	NC	NC
	Admiralty Gulf Islands	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	1.3	<1	<1	NC	NC
	Advance Island	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	NC	NC	NC	NC	NC	NC
	Bathurst Island	<0.3	<0.3	<0.3	NC	NC	NC	0.6	0.6	<0.3	1,719	2,373	NC	0.6	190	<1	3	<1	1
	Bigge Island	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	0.4	<1	<1	NC	NC
	Bonaparte Archipelago	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	0.6	<1	<1	NC	NC
	Browse Island	<0.3	<0.3	<0.3	NC	NC	NC	6.6	0.9	<0.3	337	1,677	NC	3.7	167	<1	3	<1	1
	Buccaneer Archipelago	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	<0.1	<1	<1	NC	NC
	Burford Island	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	<0.1	<1	<1	NC	NC
	Cape Londonderry Islands	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	<0.1	<1	<1	NC	NC
	Cassini Island	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	0.8	<1	<1	NC	NC
	Coronation Island Group	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	<0.1	<1	<1	NC	NC
	Crocodile Islands	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	NC	NC	NC	NC	NC	NC
	Croker Island	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	0.2	<1	<1	NC	NC
	Darch Island	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	<0.1	<1	<1	NC	NC
	East Vernon Island	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	0.1	<1	<1	NC	NC
	Eclipse Archipelago	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	0.2	<1	<1	NC	NC

RPS

Receptor	Probability (%) of films arriving at receptors at			Minimum time to receptor (hours) for films at			Probability (%) of shoreline oil on receptors at			Minimum time to receptor (hours) for shoreline oil at			Maximum local accumulated concentration (g/m²)		Maximum accumulated volume (m³) along this shoreline		Maximum length of shoreline (km) with concentrations ≥10.0 g/m²	
	≥1 g/m²	≥10 g/m²	≥25 g/m²	≥1 g/m²	≥10 g/m²	≥25 g/m²	≥10 g/m²	≥100 g/m²	≥1,000 g/m²	≥10 g/m²	≥100 g/m²	≥1,000 g/m²	averaged over all replicate simulations	worst replicate simulation	averaged over all replicate simulations	worst replicate simulation	averaged over all replicate simulations	worst replicate simulation
Field Island	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	<0.1	<1	<1	NC	NC
Grant Island	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	<0.1	<1	<1	NC	NC
Greenhill Island	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	0.1	<1	<1	NC	NC
Jones Island	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	2.5	<1	<1	NC	NC
Kingfisher Islands	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	NC	NC	NC	NC	NC	NC
Lacepede Islands	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	<0.1	<1	<1	NC	NC
Lawson Island	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	<0.1	<1	<1	NC	NC
Lesueur Island	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	<0.1	<1	<1	NC	NC
Long Island Kimberley	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	0.6	<1	<1	NC	NC
McCluer Island	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	<0.1	<1	<1	NC	NC
Melville Island	<0.3	<0.3	<0.3	NC	NC	NC	0.6	0.6	<0.3	2,096	2,109	NC	1.6	473	<1	9	<1	5
Montalivet Island	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	<0.1	<1	<1	NC	NC
Montgomery Islands	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	NC	NC	NC	NC	NC	NC
Montgomery Islands and Reef	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	NC	NC	NC	NC	NC	NC
Napier Broome Bay Islands	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	<0.1	<1	<1	NC	NC
New Year Island	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	<0.1	<1	<1	NC	NC
North Goulburn Island	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	<0.1	<1	<1	NC	NC
North West Vernon Island	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	1.5	<1	<1	NC	NC
Oxley Island	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	0.2	<1	<1	NC	NC
Peron Islands	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	0.1	<1	<1	NC	NC
Roche Islands and Reefs	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	0.2	<1	<1	NC	NC
South West Vernon Island	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	<0.1	<1	<1	NC	NC
Stewarts Islands	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	<0.1	<1	<1	NC	NC
Templer Island	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	<0.1	<1	<1	NC	NC
Troughton Island	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	2.5	<1	<1	NC	NC
Valencia Island	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	NC	NC	NC	NC	NC	NC
White Island*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Reefs Baxendell Reef*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Beagle and Dingo Reefs*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Beatrice Reef*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Campbell Reef*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

RPS

Receptor	Probability (%) of films arriving at receptors at			Minimum time to receptor (hours) for films at			Probability (%) of shoreline oil on receptors at			Minimum time to receptor (hours) for shoreline oil at			Maximum local accumulated concentration (g/m²)		Maximum accumulated volume (m³) along this shoreline		Maximum length of shoreline (km) with concentrations ≥10.0 g/m²	
	≥1 g/m²	≥10 g/m²	≥25 g/m²	≥1 g/m²	≥10 g/m²	≥25 g/m²	≥10 g/m²	≥100 g/m²	≥1,000 g/m²	≥10 g/m²	≥100 g/m²	≥1,000 g/m²	averaged over all replicate simulations	worst replicate simulation	averaged over all replicate simulations	worst replicate simulation	averaged over all replicate simulations	worst replicate simulation
Christine Reef*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Draytons Reef*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
East Holothuria Reef*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Elizabeth Reef*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Elphinstone Reef*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Emu Reefs*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Fish Reef*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Harris Reef*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Heritage Reef*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Hibernia Reef*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Hinkler Patches*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Hunt Patch*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Ingram Reef*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Jamieson Reef*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Knight Reef*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Long Reef	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	1.2	<1	<1	NC	NC
Lyne Reef*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Mavis Reef*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Middle Reef*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
North Crocodile Reef*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Oliver Reef*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Oliver Rock*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Orontes Reef*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Rothery Reef*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Sandy Islet	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	0.2	9.2	<1	<1	NC	NC
Scott Reef North*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Scott Reef South	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	0.2	9.2	<1	<1	NC	NC
Seringapatam Reef*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Taylor Patches*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
The Boxers*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
The Boxers Area*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

RPS

	Receptor	Probability (%) of films arriving at receptors at			Minimum time to receptor (hours) for films at			Probability (%) of shoreline oil on receptors at			Minimum time to receptor (hours) for shoreline oil at			Maximum local accumulated concentration (g/m²)		Maximum accumulated volume (m³) along this shoreline		Maximum length of shoreline (km) with concentrations ≥10.0 g/m²	
		≥1 g/m²	≥10 g/m²	≥25 g/m²	≥1 g/m²	≥10 g/m²	≥25 g/m²	≥10 g/m²	≥100 g/m²	≥1,000 g/m²	≥10 g/m²	≥100 g/m²	≥1,000 g/m²	averaged over all replicate simulations	worst replicate simulation	averaged over all replicate simulations	worst replicate simulation	averaged over all replicate simulations	worst replicate simulation
Shoals	Tregenna Reef*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	West Holothuria Reef*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Abbott Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Afghan Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Ann Shoals*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Barbara Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Barracouta Shoals*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Barton Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Bassett-Smith Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Beagle Shoals*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Big Bank Shoals*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Bill Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Britomart Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Calder Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Cootamundra Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Deep Shoal 1*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Deep Shoal 2*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Dillon Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Echo Shoals*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Echuca Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Eugene McDermott Shoal*	0.9	<0.3	<0.3	1,033	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Evans Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Fantome Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Fitzpatrick Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Flinders Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Franklin Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Giles Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Goeree Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Hancox Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Heywood Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Jabiru Shoals*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

RPS

Receptor	Probability (%) of films arriving at receptors at			Minimum time to receptor (hours) for films at			Probability (%) of shoreline oil on receptors at			Minimum time to receptor (hours) for shoreline oil at			Maximum local accumulated concentration (g/m²)		Maximum accumulated volume (m³) along this shoreline		Maximum length of shoreline (km) with concentrations ≥10.0 g/m²	
	≥1 g/m²	≥10 g/m²	≥25 g/m²	≥1 g/m²	≥10 g/m²	≥25 g/m²	≥10 g/m²	≥100 g/m²	≥1,000 g/m²	≥10 g/m²	≥100 g/m²	≥1,000 g/m²	averaged over all replicate simulations	worst replicate simulation	averaged over all replicate simulations	worst replicate simulation	averaged over all replicate simulations	worst replicate simulation
Jones Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Karmt Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Lowry Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Loxton Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Mangola Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Margaret Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Marie Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Marsh Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Martin Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Mataram Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Mermaid Shoal	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	<0.1	<1	<1	NC	NC
Money Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Moresby Shoals*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Moss Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Newby Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Ommaney Shoals*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Parry Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Paxie Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Pee Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Penguin Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Penguin Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Renard Shoals*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Shepparton Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Skottowe Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Sunset Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Taiyun Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Tassie Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Troubadour Shoals*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Van Cloon Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Vee Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Victoria Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

RPS

	Receptor	Probability (%) of films arriving at receptors at			Minimum time to receptor (hours) for films at			Probability (%) of shoreline oil on receptors at			Minimum time to receptor (hours) for shoreline oil at			Maximum local accumulated concentration (g/m²)		Maximum accumulated volume (m³) along this shoreline		Maximum length of shoreline (km) with concentrations ≥10.0 g/m²	
		≥1 g/m²	≥10 g/m²	≥25 g/m²	≥1 g/m²	≥10 g/m²	≥25 g/m²	≥10 g/m²	≥100 g/m²	≥1,000 g/m²	≥10 g/m²	≥100 g/m²	≥1,000 g/m²	averaged over all replicate simulations	worst replicate simulation	averaged over all replicate simulations	worst replicate simulation	averaged over all replicate simulations	worst replicate simulation
	Vulcan Shoals*	1.8	<0.3	<0.3	103	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Wells Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Banks	Baldwin Bank*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Bellona Bank*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Branch Banks*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Favell Bank*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Flat Top Bank*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Foelsche Bank*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Gale Bank*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Goodrich Bank*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Holothuria Banks*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Johnson Bank*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Lynedoch Bank*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Margaret Harries Bank*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Otway Bank*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Parsons Bank*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Rankin Bank*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Sahul Bank*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Sunrise Bank*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Tait Bank*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Woodbine Bank*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Marine Parks	Arafura AMP*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Arnhem AMP*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Ashmore Reef AMP	<0.3	<0.3	<0.3	NC	NC	NC	3	<0.3	<0.3	246	NC	NC	1.3	38	<1	2	<1	5
	Lalang-garram/Camden Sound MP	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	<0.1	<1	<1	NC	NC
	Carnarvon Canyon AMP*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Cartier Island AMP	<0.3	<0.3	<0.3	NC	NC	NC	12.3	0.6	<0.3	272	418	NC	5	104	<1	2	<1	3
	Charles Darwin NP	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	0.2	<1	<1	NC	NC
	Djukbinj NP	<0.3	<0.3	<0.3	NC	NC	NC	0.9	0.6	<0.3	2,222	2,356	NC	1.1	243	<1	10	<1	4
	Eighty Mile Beach AMP	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	NC	NC	NC	NC	NC	NC
	Garig Gunak Barlu NP	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	0.1	<1	<1	NC	NC

RPS

	Receptor	Probability (%) of films arriving at receptors at			Minimum time to receptor (hours) for films at			Probability (%) of shoreline oil on receptors at			Minimum time to receptor (hours) for shoreline oil at			Maximum local accumulated concentration (g/m²)		Maximum accumulated volume (m³) along this shoreline		Maximum length of shoreline (km) with concentrations ≥10.0 g/m²	
		≥1 g/m²	≥10 g/m²	≥25 g/m²	≥1 g/m²	≥10 g/m²	≥25 g/m²	≥10 g/m²	≥100 g/m²	≥1,000 g/m²	≥10 g/m²	≥100 g/m²	≥1,000 g/m²	averaged over all replicate simulations	worst replicate simulation	averaged over all replicate simulations	worst replicate simulation	averaged over all replicate simulations	worst replicate simulation
	Gascoyne AMP*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Kakadu NP	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	<0.1	<1	<1	NC	NC
	Kimberley AMP	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	<0.1	<1	<1	NC	NC
	North Lalang-garram MP & North Kimberley MP	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	2.5	<1	<1	NC	NC
	Lawley River NP Coast	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	NC	NC	NC	NC	NC	NC
	Mary River NP	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	0.1	<1	<1	NC	NC
	Mermaid Reef AMP	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	0.1	<1	<1	NC	NC
	Mitchell River NP Coast	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	NC	NC	NC	NC	NC	NC
	Montebello AMP*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Ningaloo AMP*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Oceanic Shoals AMP*	0.6	<0.3	<0.3	991	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Prince Regent NP Coast	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	NC	NC	NC	NC	NC	NC
Key Ecological Features	Ancient Coastline at 125 m depth contour*	0.9	<0.3	<0.3	497	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Ashmore Reef and Cartier Island and surrounding Commonwealth Waters	<0.3	<0.3	<0.3	NC	NC	NC	12.3	0.6	<0.3	246	418	NC	5	104	<1	3	<1	7
	Canyons linking the Argo Abyssal Plain with the Scott Plateau*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Canyons linking the Cuvier Abyssal Plain and the Cape Range Peninsula*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Carbonate bank & terrace system of Van Diemen Rise*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Carbonate bank and terrace system of Sahul Shelf	0.6	<0.3	<0.3	392	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	<0.1	<1	<1	NC	NC
	Continental Slope Demersal Fish Communities*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Exmouth Plateau*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Glomar Shoals*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Mermaid Reef and Commonwealth Waters surrounding Rowley Shoals	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	0.4	<1	<1	NC	NC
	Pinnacles of the Bonaparte Basin*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Seringapatam Reef and Commonwealth Waters in the Scott Reef Complex	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	0.2	9.2	<1	<1	NC	NC

	Receptor	Probability (%) of films arriving at receptors at			Minimum time to receptor (hours) for films at			Probability (%) of shoreline oil on receptors at			Minimum time to receptor (hours) for shoreline oil at			Maximum local accumulated concentration (g/m²)		Maximum accumulated volume (m³) along this shoreline		Maximum length of shoreline (km) with concentrations ≥10.0 g/m²	
		≥1 g/m²	≥10 g/m²	≥25 g/m²	≥1 g/m²	≥10 g/m²	≥25 g/m²	≥10 g/m²	≥100 g/m²	≥1,000 g/m²	≥10 g/m²	≥100 g/m²	≥1,000 g/m²	averaged over all replicate simulations	worst replicate simulation	averaged over all replicate simulations	worst replicate simulation	averaged over all replicate simulations	worst replicate simulation
	Shelf break and slope of the Arafura Shelf*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Tributary Canyons of the Arafura Depression*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Fisheries	Northern Prawn Fishery	0.6	0.6	<0.3	1,991	2,474	NC	0.6	0.6	<0.3	1,719	2,109	NC	1.6	473	NC	NC	NC	NC
Fisheries	North-West Slope Trawl Fishery*	0.9	<0.3	<0.3	237	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Fisheries	Southern Bluefin Tuna Fishery	58.2	0.6	<0.3	2	2,474	NC	12.3	0.6	<0.3	246	418	NC	5	473	NC	NC	NC	NC
Fisheries	Timor Reef Fishery (NT Managed)*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Fisheries	Western Skipjack Fishery	58.2	0.6	<0.3	2	2,474	NC	12.3	0.6	<0.3	246	418	NC	5	473	NC	NC	NC	NC
Fisheries	Western Tuna and Billfish Fishery	58.2	0.6	<0.3	2	2,474	NC	12.3	0.6	<0.3	246	418	NC	5	473	NC	NC	NC	NC
Biologically Important Areas	Flatback Turtle BIA	0.6	<0.3	<0.3	991	NC	NC	0.6	0.6	<0.3	1,719	2,109	NC	1.6	473	<1	9	NC	NC
Biologically Important Areas	Green Turtle BIA	<0.3	<0.3	<0.3	NC	NC	NC	12.3	0.6	<0.3	246	418	NC	5	104	<1	3	<1	7
Biologically Important Areas	Hawksbill Turtle BIA	<0.3	<0.3	<0.3	NC	NC	NC	3	<0.3	<0.3	246	NC	NC	1.3	38	<1	2	<1	5
Biologically Important Areas	Leatherback Turtle BIA	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	<0.1	<1	<1	NC	NC
Biologically Important Areas	Loggerhead Turtle BIA	0.6	<0.3	<0.3	991	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	NC	NC	NC	NC	NC	NC
Biologically Important Areas	Olive Ridley Turtle BIA	0.6	<0.3	<0.3	991	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	0.7	<1	<1	NC	NC

NC: No contact to receptor predicted for specified threshold. NA: Not applicable.

** Floating oil will not accumulate on submerged features and at open ocean locations.*

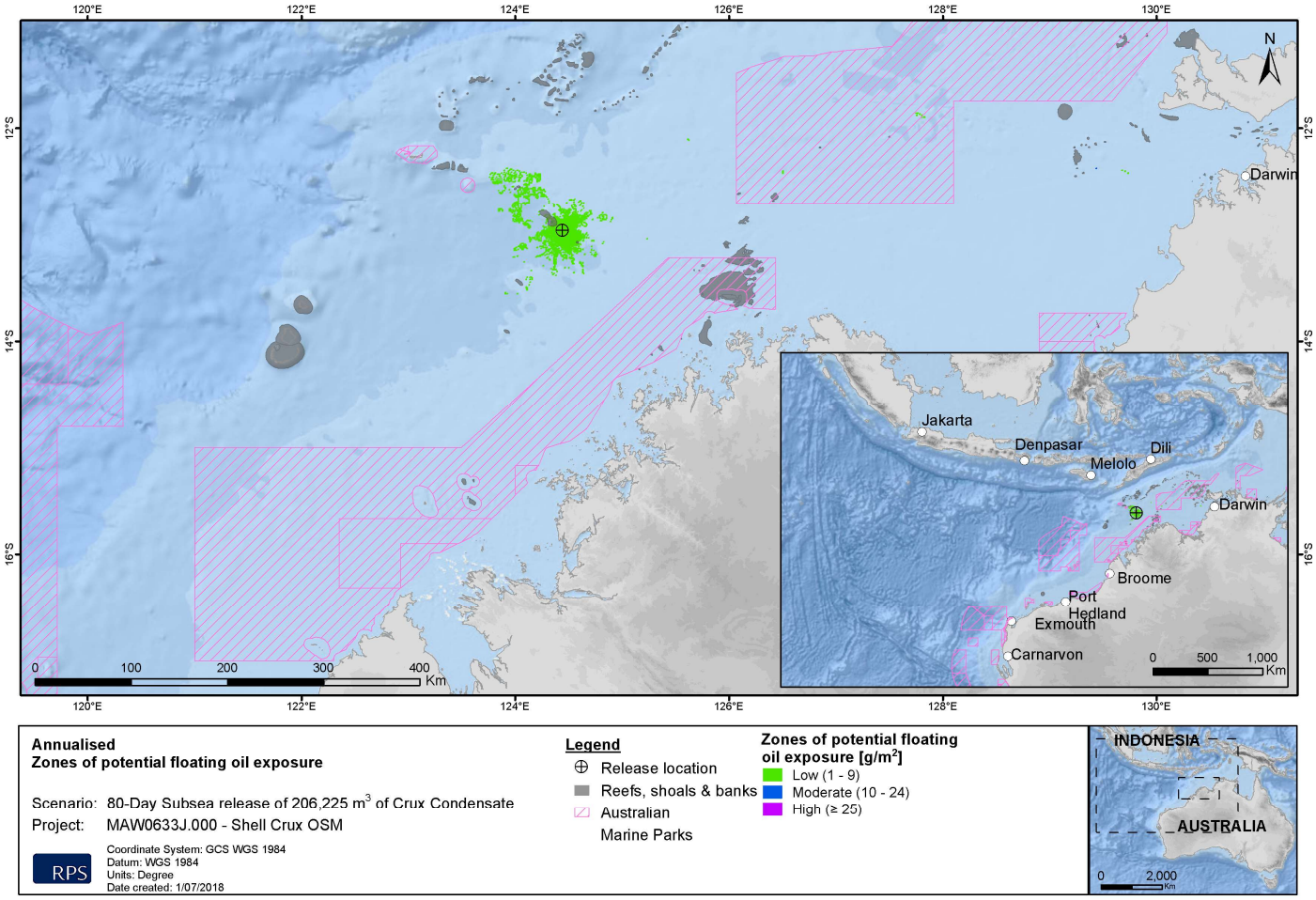


Figure 3.4 Surface Hydrocarbons | Blowout Scenario | Stochastic Outcomes. Areal extent of potential exposure at defined floating oil threshold concentrations resulting from an 80-day subsurface release of Crux condensate at a development well.

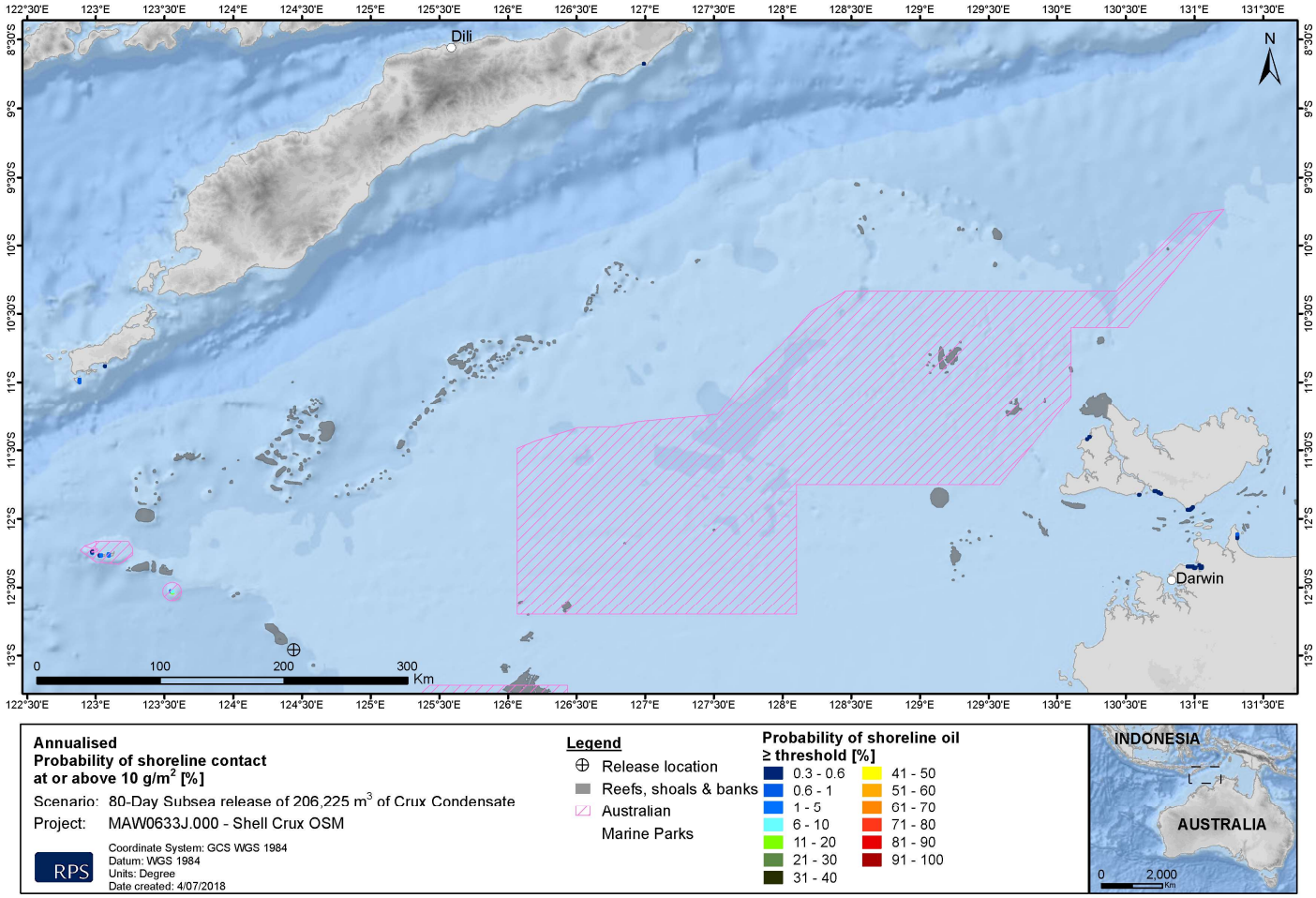


Figure 3.5 Shoreline Hydrocarbons | Blowout Scenario | Stochastic Outcomes. Predicted annualised probability of shoreline oil concentrations at or above 10 g/m^2 resulting from an 80-day subsurface release of Crux condensate at a development well.

RPS

3.2.3 Entrained Hydrocarbons

Table 3.6 Expected annualised entrained oil outcomes at sensitive receptors resulting from an 80-day subsurface release of Crux condensate at a development well.

	Receptor	Probability (%) of entrained hydrocarbon concentration contact at specific receptor depth			Minimum time to receptor waters (hours)		
		≥10 ppb	≥100 ppb	≥500 ppb	≥10 ppb	≥100 ppb	≥500 ppb
Coastlines	Cobourg Peninsula	6	4.2	1.5	1,177	1,187	1,220
	Darwin Coast	7.2	5.1	2.4	1,078	1,109	1,129
	Indonesia	30.6	17.1	5.4	672	677	738
	Joseph Bonaparte Gulf Northern Territory	7.2	4.5	2.1	1,075	1,129	1,138
	Kakadu Coast	9.6	7.5	4.8	1,313	1,351	1,370
	Kakadu National Park	1.8	0.9	<0.3	1,798	2,072	NC
	Kimberley Coast	4.5	3.9	3	589	592	817
	North Broome Coast	2.1	<0.3	<0.3	2,051	NC	NC
	Port Hedland-Eighty Mile Beach	0.6	<0.3	<0.3	2,175	NC	NC
	Timor Leste	20.4	14.7	5.4	706	739	1,028
	West Arnhem Land	1.2	0.6	<0.3	1,482	1,611	NC
Islands	Adele Island	8.1	5.7	2.4	1,032	1,496	1,509
	Admiralty Gulf Islands	4.5	3.6	2.4	576	697	722
	Advance Island	<0.3	<0.3	<0.3	NC	NC	NC
	Bathurst Island	17.4	15.6	10.8	971	1,009	1,016
	Bigge Island	4.8	3.9	3	673	675	687
	Bonaparte Archipelago	5.7	4.2	3	647	649	662
	Browse Island	79.8	74.7	54.6	278	290	338
	Buccaneer Archipelago	4.8	3	1.8	1,618	1,656	2,261
	Burford Island	4.2	0.9	<0.3	2,139	2,345	NC
	Cape Londonderry Islands	1.2	0.6	<0.3	930	2,556	NC
	Cassini Island	6.6	3.9	3.6	528	564	699
	Coronation Island Group	5.4	2.1	0.9	1,320	1,352	1,628
	Crocodile Islands	0.9	0.6	0.6	2,101	2,104	2,113
	Croker Island	4.5	2.7	1.8	1,266	1,297	1,328
	Darch Island	2.4	1.2	0.6	1,445	1,458	2,078
	East Vernon Island	9.9	7.5	5.4	1,123	1,151	1,348
	Eclipse Archipelago	3.9	2.7	<0.3	764	990	NC

RPS

	Receptor	Probability (%) of entrained hydrocarbon concentration contact at specific receptor depth			Minimum time to receptor waters (hours)		
		≥10 ppb	≥100 ppb	≥500 ppb	≥10 ppb	≥100 ppb	≥500 ppb
	Field Island	1.8	0.9	<0.3	1,858	2,072	NC
	Grant Island	2.4	1.5	0.6	1,472	1,672	1,782
	Greenhill Island	1.2	<0.3	<0.3	2,193	NC	NC
	Jones Island	4.2	3.6	3	579	670	728
	Kingfisher Islands	1.5	<0.3	<0.3	2,275	NC	NC
	Lacepede Islands	2.7	1.2	<0.3	2,040	2,256	NC
	Lawson Island	2.4	2.1	0.9	1,383	1,497	1,775
	Lesueur Island	0.9	<0.3	<0.3	2,266	NC	NC
	Long Island Kimberley	6	4.2	3	637	648	650
	McCluer Island	2.4	2.4	0.6	1,416	1,425	1,860
	Melville Island	13.2	10.5	7.5	980	985	1,131
	Montalivet Island	5.4	3.6	2.7	650	660	663
	Montgomery Islands	2.4	1.2	0.6	2,279	2,280	2,368
	Montgomery Islands and Reef	2.4	1.2	0.6	2,268	2,280	2,368
	Napier Broome Bay Islands	1.2	0.6	<0.3	2,118	2,556	NC
	New Year Island	3.9	2.1	0.9	1,420	1,606	1,891
	North Goulburn Island	1.2	0.6	<0.3	1,687	1,860	NC
	North West Vernon Island	9.9	8.4	6	1,111	1,120	1,285
	Oxley Island	3.9	2.4	1.2	1,368	1,391	1,852
	Peron Islands	3.9	1.8	0.6	1,468	2,023	2,543
	Roche Islands and Reefs	5.7	4.2	1.8	1,144	1,275	1,280
	South West Vernon Island	9	6.6	4.5	1,193	1,255	1,349
	Stewarts Islands	0.9	<0.3	<0.3	2,396	NC	NC
	Templer Island	0.9	<0.3	<0.3	1,472	NC	NC
	Troughton Island	8.1	3.9	3.6	252	263	263
	Valencia Island	0.6	<0.3	<0.3	1,593	NC	NC
	White Island	5.1	2.1	0.6	1,465	1,802	2,461
Reefs	Baxendell Reef	5.4	4.2	1.5	1,753	1,774	1,901
	Beagle and Dingo Reefs	6.9	2.7	1.5	1,118	1,743	1,953
	Beatrice Reef	2.1	1.8	1.2	1,742	1,758	1,799
	Campbell Reef	2.1	<0.3	<0.3	1,364	NC	NC
	Christine Reef	4.2	1.8	<0.3	1,570	1,576	NC

RPS

Receptor	Probability (%) of entrained hydrocarbon concentration contact at specific receptor depth			Minimum time to receptor waters (hours)		
	≥10 ppb	≥100 ppb	≥500 ppb	≥10 ppb	≥100 ppb	≥500 ppb
Draytons Reef	9	6	4.2	1,339	1,369	1,440
East Holothuria Reef	15.6	9.6	6.9	228	228	238
Elizabeth Reef	9	6	4.2	1,335	1,379	1,435
Elphinstone Reef	10.5	7.8	2.1	1,144	1,190	1,273
Emu Reefs	0.9	<0.3	<0.3	2,216	NC	NC
Fish Reef	7.5	5.1	2.1	1,131	1,194	1,297
Harris Reef	9.6	8.7	7.2	1,091	1,112	1,303
Heritage Reef	5.1	3	2.7	649	651	669
Hibernia Reef	67.2	49.5	27.9	296	304	328
Hinkler Patches	5.4	3.6	1.5	1,760	1,802	1,879
Hunt Patch	7.8	6.6	4.2	1,427	1,480	1,536
Ingram Reef	8.4	4.8	3.6	648	649	971
Jamieson Reef	8.1	5.7	3.9	527	651	652
Knight Reef	9.9	8.4	5.4	1,128	1,144	1,318
Long Reef	7.5	4.2	3.9	527	527	528
Lyne Reef	8.1	6.6	3.9	1,205	1,322	1,484
Mavis Reef	4.8	1.8	0.9	1,127	1,581	2,243
Middle Reef	6.6	3.9	1.8	1,246	1,260	1,299
North Crocodile Reef	0.9	0.6	<0.3	2,086	2,114	NC
Oliver Reef	9.6	8.4	5.1	1,103	1,115	1,320
Oliver Rock	5.7	3.6	3	551	684	958
Orontes Reef	5.7	2.7	1.2	1,195	1,211	1,357
Rothery Reef	7.8	4.8	3.6	236	527	528
Sandy Islet	78.6	64.8	44.4	437	445	472
Scott Reef North	79.5	66.6	48.9	422	427	461
Scott Reef South	79.8	66.3	45.6	435	438	456
Seringapatam Reef	80.7	68.4	52.2	397	400	401
Taylor Patches	8.1	7.5	5.4	1,350	1,375	1,385
The Boxers	35.4	30.3	19.2	503	527	529
The Boxers Area	35.7	30.3	20.4	498	517	519
Tregenna Reef	8.7	8.1	5.4	1,112	1,125	1,326
West Holothuria Reef	19.5	13.8	8.4	198	226	228

RPS

	Receptor	Probability (%) of entrained hydrocarbon concentration contact at specific receptor depth			Minimum time to receptor waters (hours)		
		≥10 ppb	≥100 ppb	≥500 ppb	≥10 ppb	≥100 ppb	≥500 ppb
Shoals	Abbott Shoal	7.5	6.6	3.9	1,399	1,404	1,670
	Afghan Shoal	16.2	14.4	12.3	958	985	1,021
	Ann Shoals	1.2	<0.3	<0.3	2,206	NC	NC
	Barbara Shoal	6.9	6	2.4	1,459	1,462	1,472
	Barracouta Shoals	89.1	84.9	66.6	89	90	104
	Barton Shoal	50.1	44.1	28.8	349	353	451
	Bassett-Smith Shoal	38.1	32.7	24.9	152	162	241
	Beagle Shoals	7.5	6.6	3.9	1,446	1,472	1,555
	Big Bank Shoals	41.1	35.7	23.1	399	399	403
	Bill Shoal	7.8	6.6	4.2	1,391	1,397	1,413
	Britomart Shoal	5.7	2.4	0.9	1,324	1,550	1,569
	Calder Shoal	25.2	18.9	9.6	698	701	811
	Cootamundra Shoal	23.4	17.1	7.8	721	722	907
	Deep Shoal 1	54.6	53.1	43.8	160	164	175
	Deep Shoal 2	46.2	43.5	32.7	252	253	277
	Dillon Shoal	45.9	39.3	29.1	344	348	475
	Echo Shoals	35.1	29.1	16.5	455	464	479
	Echuca Shoal	71.7	64.5	51.9	261	263	353
	Eugene McDermott Shoal	98.7	98.7	97.5	16	17	17
	Evans Shoal	13.8	10.5	5.1	1,026	1,029	1,172
	Fantome Shoal	53.4	39.3	19.8	376	390	399
	Fitzpatrick Shoal	4.8	2.7	0.6	1,246	1,364	1,387
	Flinders Shoal	14.7	8.4	2.7	1,018	1,026	1,334
	Franklin Shoal	14.1	8.7	3	1,019	1,022	1,269
	Giles Shoal	7.2	4.8	2.1	1,521	1,524	1,776
	Goeree Shoal	100	99.6	97.5	18	18	19
	Hancox Shoal	9.9	8.7	6	1,090	1,101	1,291
	Heywood Shoal	88.8	84.9	76.8	91	118	126
	Jabiru Shoals	56.4	49.8	39.9	146	155	208
	Jones Shoal	7.2	4.2	0.6	1,240	1,306	1,936
	Karmt Shoal	46.5	38.1	28.5	328	333	367
	Lowry Shoal	10.5	8.7	5.4	1,040	1,075	1,153

RPS

	Receptor	Probability (%) of entrained hydrocarbon concentration contact at specific receptor depth			Minimum time to receptor waters (hours)		
		≥10 ppb	≥100 ppb	≥500 ppb	≥10 ppb	≥100 ppb	≥500 ppb
	Loxton Shoal	15.6	8.4	4.2	1,037	1,040	1,063
	Mangola Shoal	54.3	48.6	37.2	268	268	290
	Margaret Shoal	1.5	1.2	0.6	1,932	1,941	2,439
	Marie Shoal	16.2	13.8	7.8	965	989	1,020
	Marsh Shoal	9.6	6.6	5.4	1,200	1,283	1,435
	Martin Shoal	14.1	8.1	3.6	1,058	1,085	1,110
	Mataram Shoal	6	4.2	1.2	1,657	1,685	2,262
	Mermaid Shoal	17.1	13.8	9	962	966	970
	Money Shoal	5.4	1.8	0.6	1,344	1,346	2,155
	Moresby Shoals	10.2	8.4	7.5	1,034	1,061	1,107
	Moss Shoal	18.6	16.5	9	951	958	1,006
	Newby Shoal	27.6	23.7	17.4	576	721	767
	Ommaney Shoals	5.4	4.2	1.8	1,698	1,746	1,855
	Parry Shoal	21.3	17.4	12.6	931	934	976
	Paxie Shoal	0.6	<0.3	<0.3	1,914	NC	NC
	Pee Shoal	52.8	44.7	30.9	207	215	244
	Penguin Shoal	42.6	37.2	26.7	166	166	232
	Penguin Shoal	42.6	37.2	26.7	166	166	232
	Renard Shoals	5.4	4.5	2.1	1,559	1,726	1,758
	Shepparton Shoal	19.2	15.9	12.6	664	695	703
	Skottowe Shoal	11.1	9.6	5.7	1,027	1,044	1,079
	Sunset Shoal	16.5	13.5	4.2	1,023	1,027	1,031
	Taiyun Shoal	7.8	6.9	4.2	1,405	1,430	1,548
	Tassie Shoal	13.5	10.8	5.7	973	1,008	1,107
	Troubadour Shoals	13.5	10.8	3.9	967	1,149	1,311
	Van Cloon Shoal	53.1	47.1	34.5	174	175	176
	Vee Shoal	59.1	44.7	21.3	234	243	245
	Victoria Shoal	2.7	1.8	1.2	1,688	1,695	1,712
	Vulcan Shoals	100	100	100	7	7	8
	Wells Shoal	7.2	6	2.4	1,438	1,446	1,591
Banks	Baldwin Bank	49.5	42.3	35.1	219	226	232
Banks	Bellona Bank	32.4	26.1	13.2	680	770	779

RPS

	Receptor	Probability (%) of entrained hydrocarbon concentration contact at specific receptor depth			Minimum time to receptor waters (hours)		
		≥10 ppb	≥100 ppb	≥500 ppb	≥10 ppb	≥100 ppb	≥500 ppb
	Branch Banks	8.7	4.5	3.6	264	264	264
	Favell Bank	53.4	47.7	42.3	167	170	171
	Flat Top Bank	22.8	19.8	16.2	450	451	452
	Foelsche Bank	7.2	6	3.6	1,195	1,207	1,429
	Gale Bank	57.6	54.3	46.5	92	93	96
	Goodrich Bank	13.2	9.9	3.9	1,033	1,062	1,067
	Holothuria Banks	34.2	30.9	24.6	186	187	197
	Johnson Bank	83.7	73.8	44.1	168	169	192
	Lynedoch Bank	10.2	6.9	1.2	1,068	1,184	1,580
	Margaret Harries Bank	37.2	32.7	21.3	532	536	540
	Otway Bank	10.5	6.9	4.2	240	240	250
	Parsons Bank	8.7	7.8	7.5	1,078	1,090	1,182
	Rankin Bank	1.8	0.6	<0.3	2,203	2,209	NC
	Sahul Bank	61.8	49.2	37.8	128	128	129
	Sunrise Bank	17.1	13.5	6.6	906	964	977
	Tait Bank	4.5	3.6	3	558	567	569
	Woodbine Bank	80.4	73.2	48.3	145	146	158
Marine Parks	Arafura AMP	7.2	3.9	1.5	1,282	1,283	1,493
	Arnhem AMP	2.4	2.4	0.9	1,474	1,476	1,868
	Ashmore Reef AMP	81.9	72.3	47.4	177	188	193
	Lalang-garram/Camden Sound MP	4.5	2.4	1.8	1,336	1,350	2,234
	Carnarvon Canyon AMP	0.6	<0.3	<0.3	2,273	NC	NC
	Cartier Island AMP	90.6	85.2	64.5	89	95	98
	Charles Darwin NP	2.4	1.5	1.5	1,186	1,186	1,298
	Djukbinj NP	9.6	7.8	5.4	1,304	1,320	1,368
	Eighty Mile Beach AMP	1.2	0.6	<0.3	2,161	2,460	NC
	Garig Gunak Barlu NP	6.6	4.2	1.8	1,177	1,185	1,197
	Gascoyne AMP	1.8	0.9	0.6	1,680	2,208	2,230
	Kakadu NP	2.7	2.4	1.5	1,688	1,707	1,772
	Kimberley AMP	75.6	57.3	45.3	81	82	82
	North Lalang-garram MP & North Kimberley MP	16.5	10.8	7.5	226	227	227

RPS

	Receptor	Probability (%) of entrained hydrocarbon concentration contact at specific receptor depth			Minimum time to receptor waters (hours)		
		≥10 ppb	≥100 ppb	≥500 ppb	≥10 ppb	≥100 ppb	≥500 ppb
	Lawley River NP Coast	0.6	0.6	<0.3	1,743	2,041	NC
	Mary River NP	5.7	3.6	2.4	1,402	1,417	1,493
	Mermaid Reef AMP	41.4	26.4	11.1	892	924	1,082
	Mitchell River NP Coast	1.5	0.9	<0.3	1,601	1,838	NC
	Montebello AMP	2.1	0.6	<0.3	1,981	2,241	NC
	Ningaloo AMP	0.6	<0.3	<0.3	1,735	NC	NC
	Oceanic Shoals AMP	63.3	60.3	53.7	85	86	87
	Prince Regent NP Coast	2.4	2.1	1.2	1,133	1,464	1,831
Key Ecological Features	Ancient Coastline at 125 m depth contour	95.7	94.8	91.8	28	29	30
	Ashmore Reef and Cartier Island and surrounding Commonwealth Waters	90.6	85.2	64.5	89	95	98
	Canyons linking the Argo Abyssal Plain with the Scott Plateau	47.4	32.4	17.1	578	581	670
	Canyons linking the Cuvier Abyssal Plain and the Cape Range Peninsula	1.5	0.9	0.6	1,685	2,266	2,304
	Carbonate bank & terrace system of Van Diemen Rise	39.6	36.3	29.1	356	358	367
	Carbonate bank and terrace system of Sahul Shelf	74.7	72.6	68.4	30	30	31
	Continental Slope Demersal Fish Communities	95.4	90.6	75.9	53	55	60
	Exmouth Plateau	6.9	2.4	0.6	1,570	1,575	1,590
	Glomar Shoals	2.4	1.2	0.6	1,656	2,103	2,129
	Mermaid Reef and Commonwealth Waters surrounding Rowley Shoals	43.2	26.4	11.1	886	924	1,018
	Pinnacles of the Bonaparte Basin	50.4	45.9	34.5	226	227	231
	Seringapatam Reef and Commonwealth Waters in the Scott Reef Complex	80.7	68.1	52.2	396	399	401
	Shelf break and slope of the Arafura Shelf	15.9	11.7	7.2	929	937	944
	Tributary Canyons of the Arafura Depression	4.5	2.4	1.2	1,488	1,531	1,917
Fisheries	Northern Prawn Fishery	54.6	51.9	42.3	180	185	201
	North-West Slope Trawl Fishery	99.9	98.7	97.2	11	11	11

RPS

	Receptor	Probability (%) of entrained hydrocarbon concentration contact at specific receptor depth			Minimum time to receptor waters (hours)		
		≥10 ppb	≥100 ppb	≥500 ppb	≥10 ppb	≥100 ppb	≥500 ppb
	Southern Bluefin Tuna Fishery	100	100	100	1	1	1
	Timor Reef Fishery (NT Managed)	34.8	32.7	19.5	555	582	601
	Western Skipjack Fishery	100	100	100	1	1	1
	Western Tuna and Billfish Fishery	100	100	100	1	1	1
Biologically Important Areas	Flatback Turtle BIA	61.5	59.4	52.5	101	103	106
	Green Turtle BIA	94.5	90.3	68.4	68	70	71
	Hawksbill Turtle BIA	84.3	75.6	51.3	155	157	163
	Leatherback Turtle BIA	6.6	3.6	1.8	1,214	1,225	1,239
	Loggerhead Turtle BIA	61.5	59.4	52.5	101	103	106
	Olive Ridley Turtle BIA	61.5	59.4	52.5	101	103	106

NC: No contact to receptor predicted for specified threshold.

** Probabilities and maximum concentrations calculated at depth of submerged feature.*

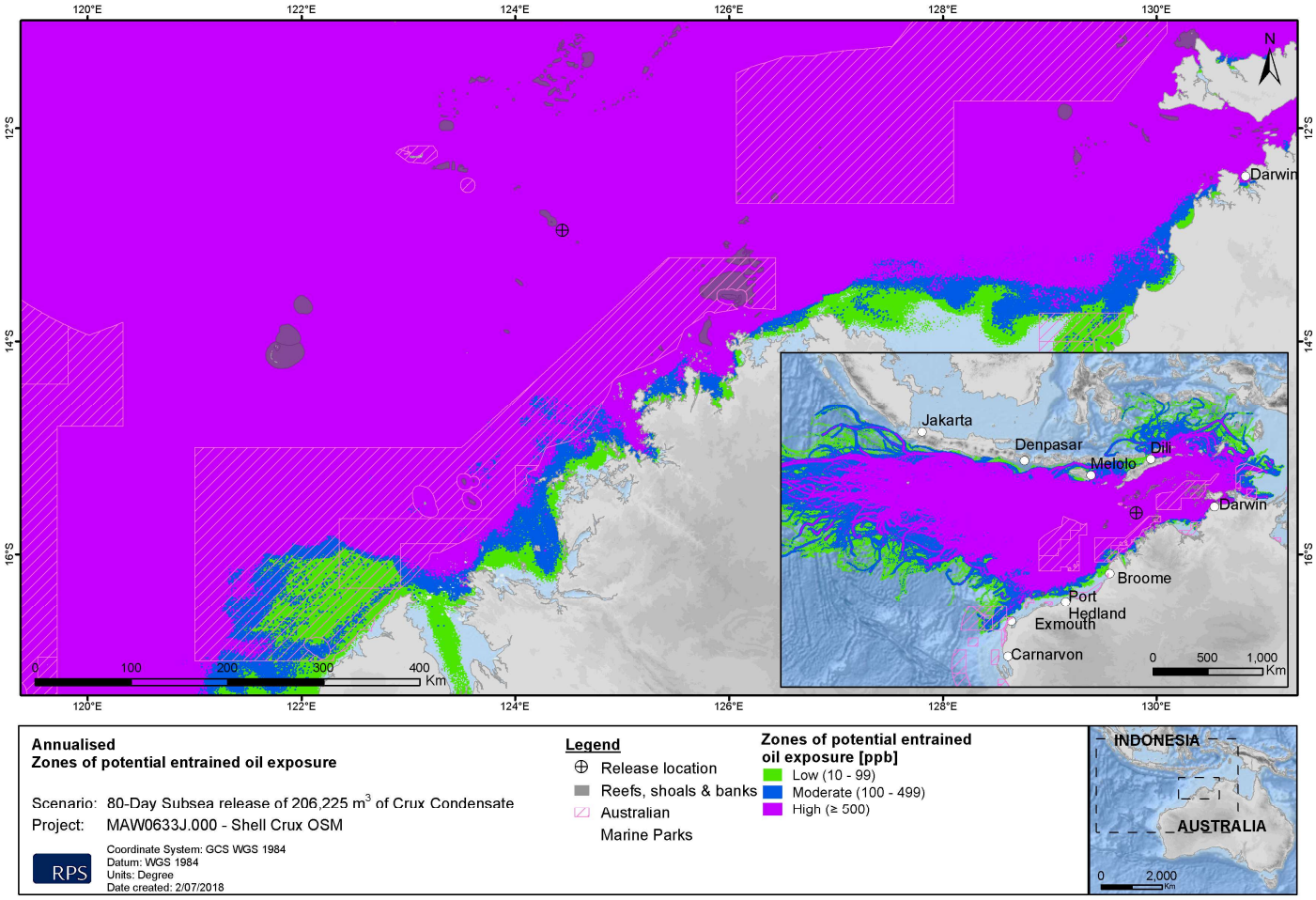


Figure 3.6 Subsurface Hydrocarbons | Entrained | Blowout Scenario | Stochastic Outcomes. Areal extent of potential exposure at defined entrained oil threshold concentrations resulting from an 80-day subsurface release of Crux condensate at a development well.

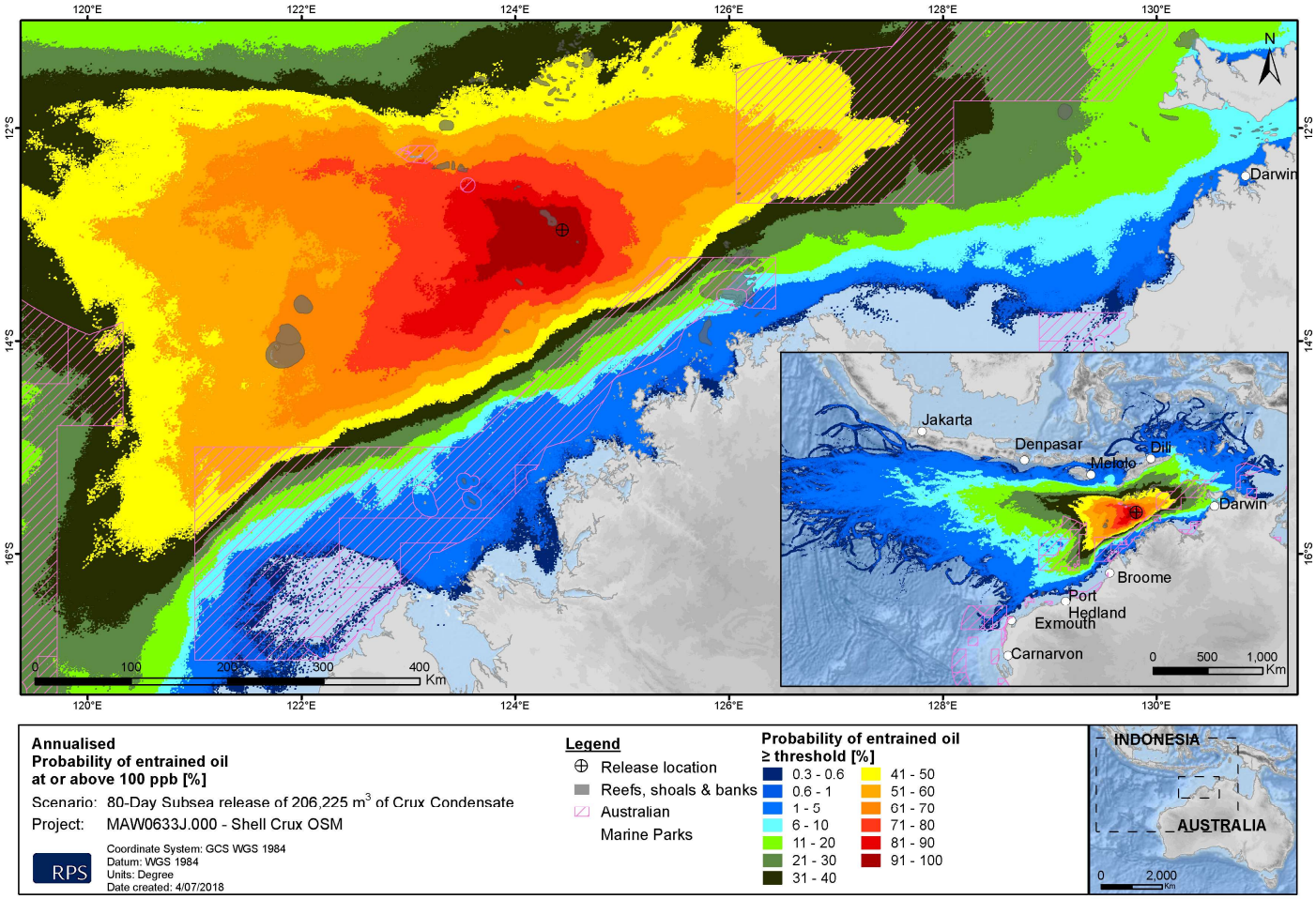


Figure 3.7 Subsurface Hydrocarbons | Entrained | Blowout Scenario | Stochastic Outcomes. Predicted annualised probability of entrained oil concentrations at or above 100 ppb resulting from an 80-day subsurface release of Crux condensate at a development well.

RPS

3.2.4 Dissolved Aromatic Hydrocarbons

Table 3.7 Expected annualised dissolved aromatic hydrocarbon outcomes at sensitive receptors resulting from an 80-day subsurface release of Crux condensate at a development well.

	Receptor	Probability (%) of dissolved aromatic hydrocarbon concentration at specific receptor depth		
		≥6 ppb	≥50 ppb	≥400 ppb
Coastlines	Cobourg Peninsula	1.8	0.6	<0.3
	Darwin Coast	2.1	1.2	<0.3
	Indonesia	13.2	4.2	0.9
	Joseph Bonaparte Gulf Northern Territory	2.4	1.5	<0.3
	Kakadu Coast	5.1	0.6	<0.3
	Kakadu National Park	<0.3	<0.3	<0.3
	Kimberley Coast	3	0.9	<0.3
	North Broome Coast	0.9	<0.3	<0.3
	Port Hedland-Eighty Mile Beach	<0.3	<0.3	<0.3
	Timor Leste	11.1	2.1	0.6
	West Arnhem Land	<0.3	<0.3	<0.3
Islands	Adele Island	6	1.8	0.6
	Admiralty Gulf Islands	2.7	1.8	<0.3
	Advance Island	<0.3	<0.3	<0.3
	Bathurst Island	14.1	6.6	0.6
	Bigge Island	3	2.7	0.6
	Bonaparte Archipelago	3.6	2.7	0.6
	Browse Island	73.2	48.6	3.9
	Buccaneer Archipelago	2.7	0.6	<0.3
	Burford Island	<0.3	<0.3	<0.3
	Cape Londonderry Islands	<0.3	<0.3	<0.3
	Cassini Island	3.6	1.8	<0.3
	Coronation Island Group	1.8	0.6	0.6
	Crocodile Islands	<0.3	<0.3	<0.3
	Croker Island	1.8	0.9	<0.3
	Darch Island	<0.3	<0.3	<0.3
	East Vernon Island	6	1.2	<0.3
	Eclipse Archipelago	1.2	<0.3	<0.3
	Field Island	<0.3	<0.3	<0.3

RPS

	Receptor	Probability (%) of dissolved aromatic hydrocarbon concentration at specific receptor depth		
		≥6 ppb	≥50 ppb	≥400 ppb
	Grant Island	0.6	<0.3	<0.3
	Greenhill Island	<0.3	<0.3	<0.3
	Jones Island	3	0.6	<0.3
	Kingfisher Islands	<0.3	<0.3	<0.3
	Lacepede Islands	0.9	<0.3	<0.3
	Lawson Island	0.9	0.6	<0.3
	Lesueur Island	<0.3	<0.3	<0.3
	Long Island Kimberley	3.6	2.7	0.6
	McCluer Island	1.5	0.6	<0.3
	Melville Island	6.6	2.4	<0.3
	Montalivet Island	3	2.7	0.6
	Montgomery Islands	<0.3	<0.3	<0.3
	Montgomery Islands and Reef	0.6	<0.3	<0.3
	Napier Broome Bay Islands	<0.3	<0.3	<0.3
	New Year Island	1.2	<0.3	<0.3
	North Goulburn Island	<0.3	<0.3	<0.3
	North West Vernon Island	6.6	2.4	<0.3
	Oxley Island	1.8	0.6	<0.3
	Peron Islands	1.2	<0.3	<0.3
	Roche Islands and Reefs	2.1	<0.3	<0.3
	South West Vernon Island	5.7	<0.3	<0.3
	Stewarts Islands	<0.3	<0.3	<0.3
	Templer Island	<0.3	<0.3	<0.3
	Troughton Island	4.2	3.6	2.7
	Valencia Island	<0.3	<0.3	<0.3
	White Island	2.1	<0.3	<0.3
Reefs	Baxendell Reef	0.9	0.6	<0.3
	Beagle and Dingo Reefs	4.8	0.9	<0.3
	Beatrice Reef	<0.3	<0.3	<0.3
	Campbell Reef	<0.3	<0.3	<0.3
	Christine Reef	<0.3	<0.3	<0.3
	Draytons Reef	3.9	<0.3	<0.3
	East Holothuria Reef	9.6	5.4	2.4

RPS

	Receptor	Probability (%) of dissolved aromatic hydrocarbon concentration at specific receptor depth		
		≥6 ppb	≥50 ppb	≥400 ppb
	Elizabeth Reef	3.9	<0.3	<0.3
	Elphinstone Reef	1.5	<0.3	<0.3
	Emu Reefs	<0.3	<0.3	<0.3
	Fish Reef	2.4	0.9	<0.3
	Harris Reef	7.2	2.7	<0.3
	Heritage Reef	3	2.4	<0.3
	Hibernia Reef	45.3	24.6	2.1
	Hinkler Patches	1.2	<0.3	<0.3
	Hunt Patch	2.1	<0.3	<0.3
	Ingram Reef	3.9	1.8	<0.3
	Jamieson Reef	5.1	1.8	<0.3
	Knight Reef	5.4	2.1	<0.3
	Long Reef	4.2	3.6	2.7
	Lyne Reef	4.5	<0.3	<0.3
	Mavis Reef	1.2	0.9	<0.3
	Middle Reef	1.5	<0.3	<0.3
	North Crocodile Reef	<0.3	<0.3	<0.3
	Oliver Reef	6.6	2.7	<0.3
	Oliver Rock	3	0.9	<0.3
	Orontes Reef	1.8	0.9	<0.3
	Rothery Reef	4.8	3.6	3
	Sandy Islet	61.5	35.7	2.7
	Scott Reef North	65.7	42.9	6.9
	Scott Reef South	63.9	37.8	4.2
	Seringapatam Reef	65.7	46.8	6.6
	Taylor Patches	5.4	0.9	<0.3
	The Boxers	28.5	17.7	2.4
	The Boxers Area	28.5	18.6	2.4
	Tregenna Reef	5.4	2.1	<0.3
	West Holothuria Reef	13.2	6.9	2.4
Shoals	Abbott Shoal	2.7	0.9	<0.3
	Afghan Shoal	14.4	8.7	0.6
	Ann Shoals	<0.3	<0.3	<0.3

Receptor	Probability (%) of dissolved aromatic hydrocarbon concentration at specific receptor depth		
	≥6 ppb	≥50 ppb	≥400 ppb
Barbara Shoal	1.2	<0.3	<0.3
Barracouta Shoals	82.5	66.6	22.8
Barton Shoal	41.4	27.6	3.6
Bassett-Smith Shoal	33.9	24.3	2.4
Beagle Shoals	2.1	<0.3	<0.3
Big Bank Shoals	33.6	19.8	1.2
Bill Shoal	3.9	<0.3	<0.3
Britomart Shoal	0.6	<0.3	<0.3
Calder Shoal	18.3	6.6	0.6
Cootamundra Shoal	15.6	4.8	<0.3
Deep Shoal 1	52.2	39.3	3.6
Deep Shoal 2	38.7	29.7	5.4
Dillon Shoal	37.5	23.4	1.2
Echo Shoals	26.4	10.2	0.6
Echuca Shoal	63.6	46.5	5.1
Eugene McDermott Shoal	97.5	96.3	86.4
Evans Shoal	8.7	3.6	<0.3
Fantome Shoal	38.1	16.5	1.2
Fitzpatrick Shoal	<0.3	<0.3	<0.3
Flinders Shoal	6.6	1.8	<0.3
Franklin Shoal	7.8	1.8	<0.3
Giles Shoal	0.9	<0.3	<0.3
Goeree Shoal	98.4	96.9	88.8
Hancox Shoal	6.6	3.6	<0.3
Heywood Shoal	84.9	79.2	30.9
Jabiru Shoals	48.9	38.1	9
Jones Shoal	1.2	<0.3	<0.3
Karmt Shoal	37.2	23.4	2.7
Lowry Shoal	7.2	3	<0.3
Loxton Shoal	8.1	1.8	<0.3
Mangola Shoal	47.1	36.6	6.6
Margaret Shoal	<0.3	<0.3	<0.3
Marie Shoal	10.2	2.4	<0.3

	Receptor	Probability (%) of dissolved aromatic hydrocarbon concentration at specific receptor depth		
		≥6 ppb	≥50 ppb	≥400 ppb
	Marsh Shoal	5.7	0.6	<0.3
	Martin Shoal	6.6	2.1	<0.3
	Mataram Shoal	0.6	<0.3	<0.3
	Mermaid Shoal	10.5	3	<0.3
	Money Shoal	0.9	<0.3	<0.3
	Moresby Shoals	7.2	3.9	<0.3
	Moss Shoal	13.5	4.2	<0.3
	Newby Shoal	23.1	16.8	1.5
	Ommaney Shoals	0.9	0.6	<0.3
	Parry Shoal	16.8	8.4	<0.3
	Paxie Shoal	<0.3	<0.3	<0.3
	Pee Shoal	44.1	28.8	5.1
	Penguin Shoal	38.1	26.1	2.7
	Penguin Shoal	38.1	26.1	2.7
	Renard Shoals	1.2	<0.3	<0.3
	Shepparton Shoal	14.1	9.6	0.6
	Skottowe Shoal	7.5	4.2	<0.3
	Sunset Shoal	10.2	2.1	<0.3
	Taiyun Shoal	2.7	0.9	<0.3
	Tassie Shoal	7.8	3	<0.3
	Troubadour Shoals	7.5	2.4	<0.3
	Van Cloon Shoal	46.5	31.8	6
	Vee Shoal	39.3	19.8	2.7
	Victoria Shoal	<0.3	<0.3	<0.3
	Vulcan Shoals	100	99.9	97.2
	Wells Shoal	1.8	<0.3	<0.3
Banks	Baldwin Bank	42.6	32.7	8.1
	Bellona Bank	21.6	6	0.9
	Branch Banks	4.5	3.9	1.2
	Favell Bank	47.1	40.2	6.6
	Flat Top Bank	18.6	12.9	1.5
	Foelsche Bank	2.7	0.6	<0.3
	Gale Bank	52.8	44.4	6.6

RPS

	Receptor	Probability (%) of dissolved aromatic hydrocarbon concentration at specific receptor depth		
		≥6 ppb	≥50 ppb	≥400 ppb
	Goodrich Bank	6.6	1.2	<0.3
	Holothuria Banks	31.5	23.1	5.7
	Johnson Bank	70.5	46.2	8.1
	Lynedoch Bank	4.5	0.6	<0.3
	Margaret Harries Bank	32.1	16.5	1.5
	Otway Bank	5.1	3.9	2.1
	Parsons Bank	7.2	2.1	<0.3
	Rankin Bank	0.6	<0.3	<0.3
	Sahul Bank	46.8	37.5	7.2
	Sunrise Bank	10.8	4.8	1.2
	Tait Bank	3	3	<0.3
	Woodbine Bank	72.6	50.4	10.8
Marine Parks	Arafura AMP	2.1	0.6	<0.3
	Arnhem AMP	1.5	0.6	<0.3
	Ashmore Reef AMP	68.4	40.8	9.3
	Lalang-garram/Camden Sound MP	2.1	0.6	<0.3
	Carnarvon Canyon AMP	<0.3	<0.3	<0.3
	Cartier Island AMP	82.2	63.9	18.6
	Charles Darwin NP	1.5	<0.3	<0.3
	Djukbinj NP	5.1	0.6	<0.3
	Eighty Mile Beach AMP	0.6	<0.3	<0.3
	Garig Gunak Barlu NP	2.1	1.2	<0.3
	Gascoyne AMP	1.2	<0.3	<0.3
	Kakadu NP	<0.3	<0.3	<0.3
	Kimberley AMP	57.3	46.2	12.6
	North Lalang-garram MP & North Kimberley MP	11.4	6	3
	Lawley River NP Coast	<0.3	<0.3	<0.3
	Mary River NP	1.8	<0.3	<0.3
	Mermaid Reef AMP	27.3	9	0.6
	Mitchell River NP Coast	<0.3	<0.3	<0.3
	Montebello AMP	0.9	0.6	<0.3
	Ningaloo AMP	<0.3	<0.3	<0.3
	Oceanic Shoals AMP	60.6	53.1	12.9

RPS

	Receptor	Probability (%) of dissolved aromatic hydrocarbon concentration at specific receptor depth		
		≥6 ppb	≥50 ppb	≥400 ppb
	Prince Regent NP Coast	<0.3	<0.3	<0.3
Key Ecological Features	Ancient Coastline at 125 m depth contour	94.8	93.6	67.5
	Ashmore Reef and Cartier Island and surrounding Commonwealth Waters	82.2	64.2	18.6
	Canyons linking the Argo Abyssal Plain with the Scott Plateau	30.6	9.6	0.9
	Canyons linking the Cuvier Abyssal Plain and the Cape Range Peninsula	0.9	<0.3	<0.3
	Carbonate bank & terrace system of Van Diemen Rise	35.1	24.6	2.4
	Carbonate bank and terrace system of Sahul Shelf	72.6	66.9	42.6
	Continental Slope Demersal Fish Communities	88.8	72.6	28.5
	Exmouth Plateau	2.1	0.6	<0.3
	Glomar Shoals	1.2	<0.3	<0.3
	Mermaid Reef and Commonwealth Waters surrounding Rowley Shoals	27.3	9	0.9
	Pinnacles of the Bonaparte Basin	43.2	31.2	5.1
	Seringapatam Reef and Commonwealth Waters in the Scott Reef Complex	65.7	46.8	6.9
	Shelf break and slope of the Arafura Shelf	9.9	4.5	0.6
	Tributary Canyons of the Arafura Depression	1.2	<0.3	<0.3
Fisheries	Northern Prawn Fishery	51.6	39.9	7.2
	North-West Slope Trawl Fishery	98.1	97.5	84.9
	Southern Bluefin Tuna Fishery	100	100	100
	Timor Reef Fishery (NT Managed)	30.9	14.7	1.8
	Western Skipjack Fishery	100	100	100
	Western Tuna and Billfish Fishery	100	100	100
Biologically Important Areas	Flatback Turtle BIA	59.7	52.5	12.9
	Green Turtle BIA	85.5	68.1	20.4
	Hawksbill Turtle BIA	71.4	44.7	10.8
	Leatherback Turtle BIA	2.1	1.2	<0.3
	Loggerhead Turtle BIA	59.7	52.5	12.9
	Olive Ridley Turtle BIA	59.7	52.5	12.9

** Probabilities and maximum concentrations calculated at depth of submerged feature.*

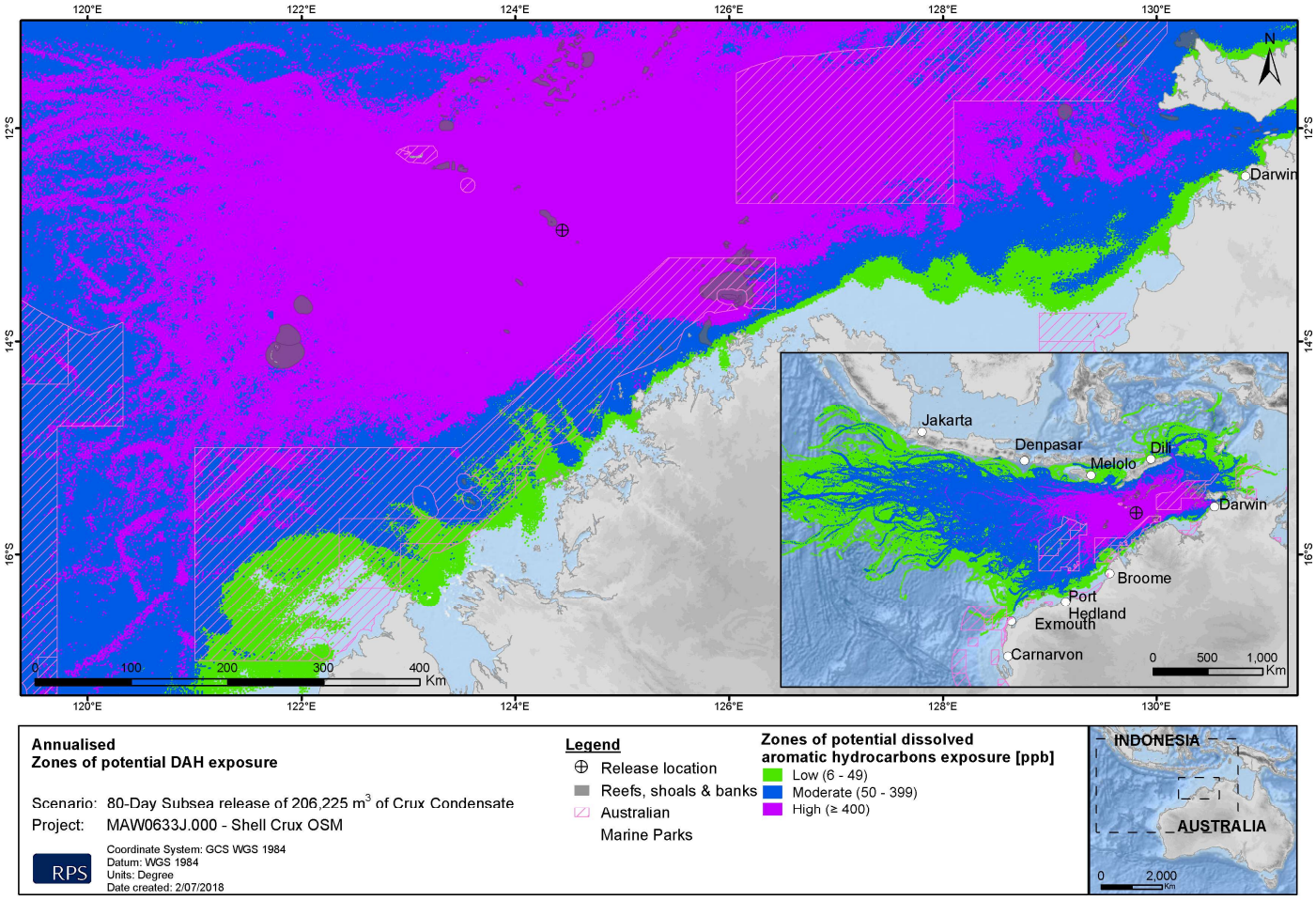


Figure 3.8 Subsurface Hydrocarbons | Dissolved | Blowout Scenario | Stochastic Outcomes. Areal extent of potential exposure at defined dissolved aromatic hydrocarbon threshold concentrations resulting from an 80-day subsurface release of Crux condensate at a development well.

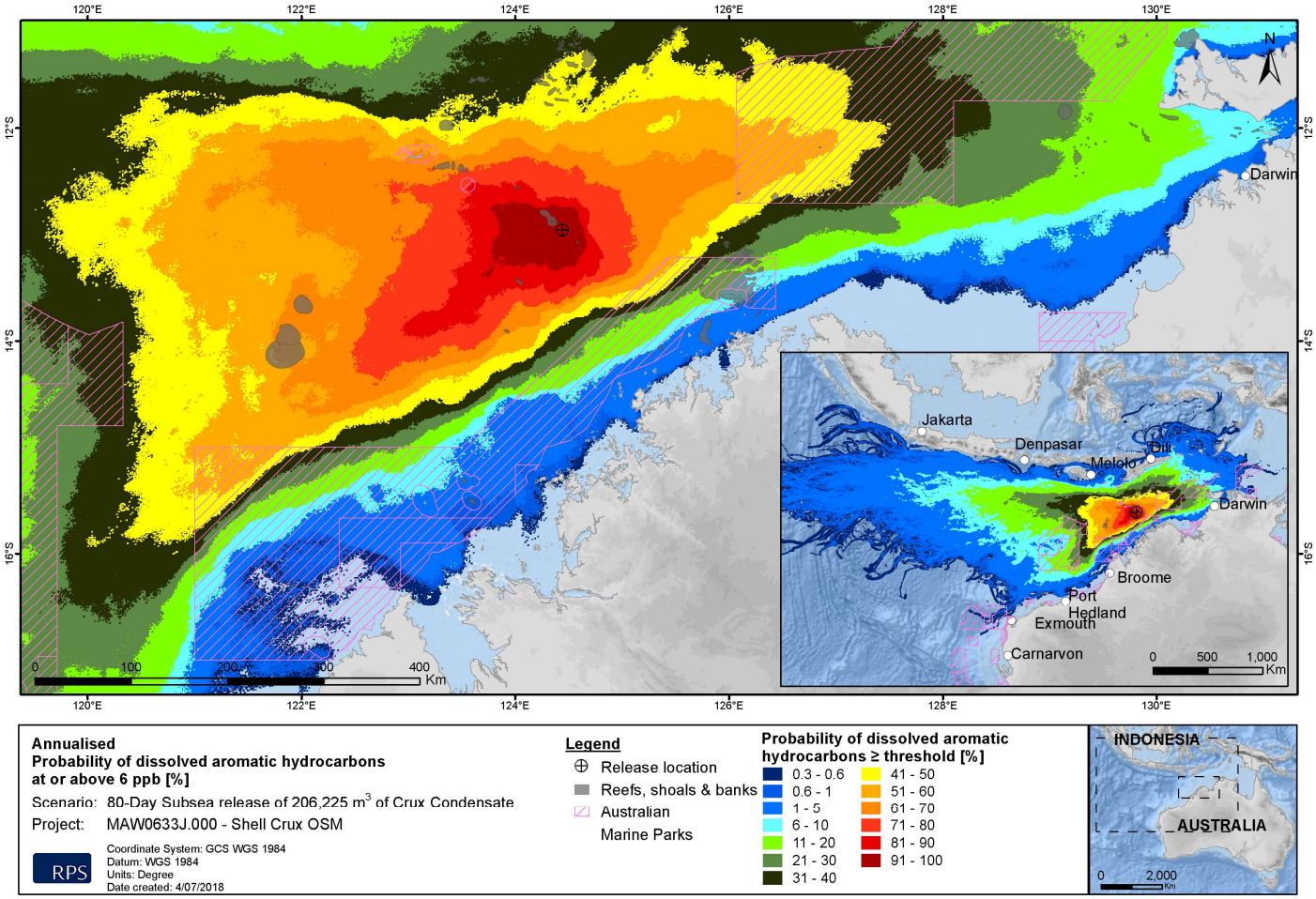


Figure 3.9 Subsurface Hydrocarbons | Dissolved | Blowout Scenario | Stochastic Outcomes. Predicted annualised probability of dissolved aromatic hydrocarbon concentrations at or above 6 ppb resulting from an 80-day subsurface release of Crux condensate at a development well.

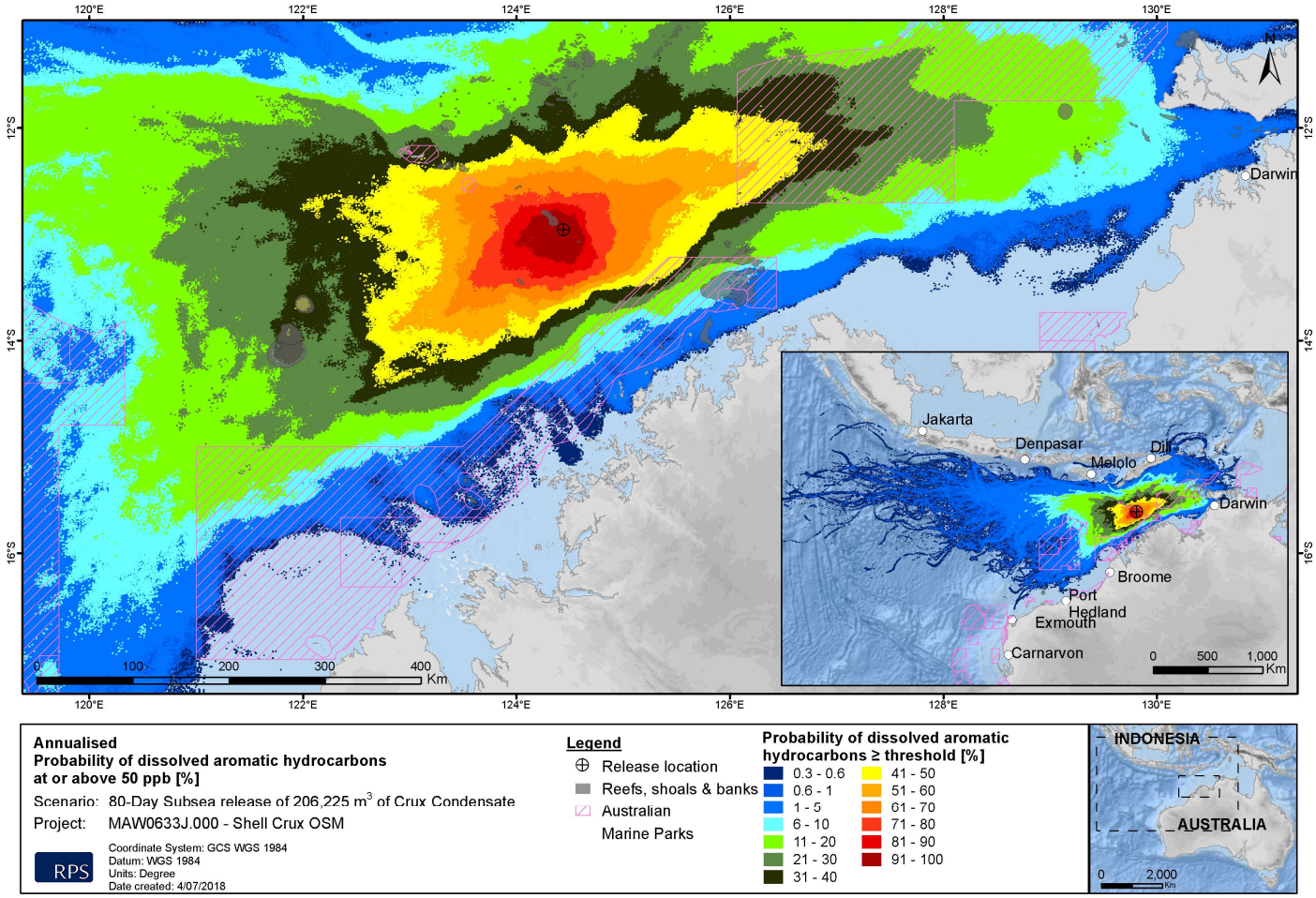


Figure 3.10 Subsurface Hydrocarbons | Dissolved | Blowout Scenario | Stochastic Outcomes. Predicted annualised probability of dissolved aromatic hydrocarbon concentrations at or above 50 ppb resulting from an 80-day subsurface release of Crux condensate at a development well.

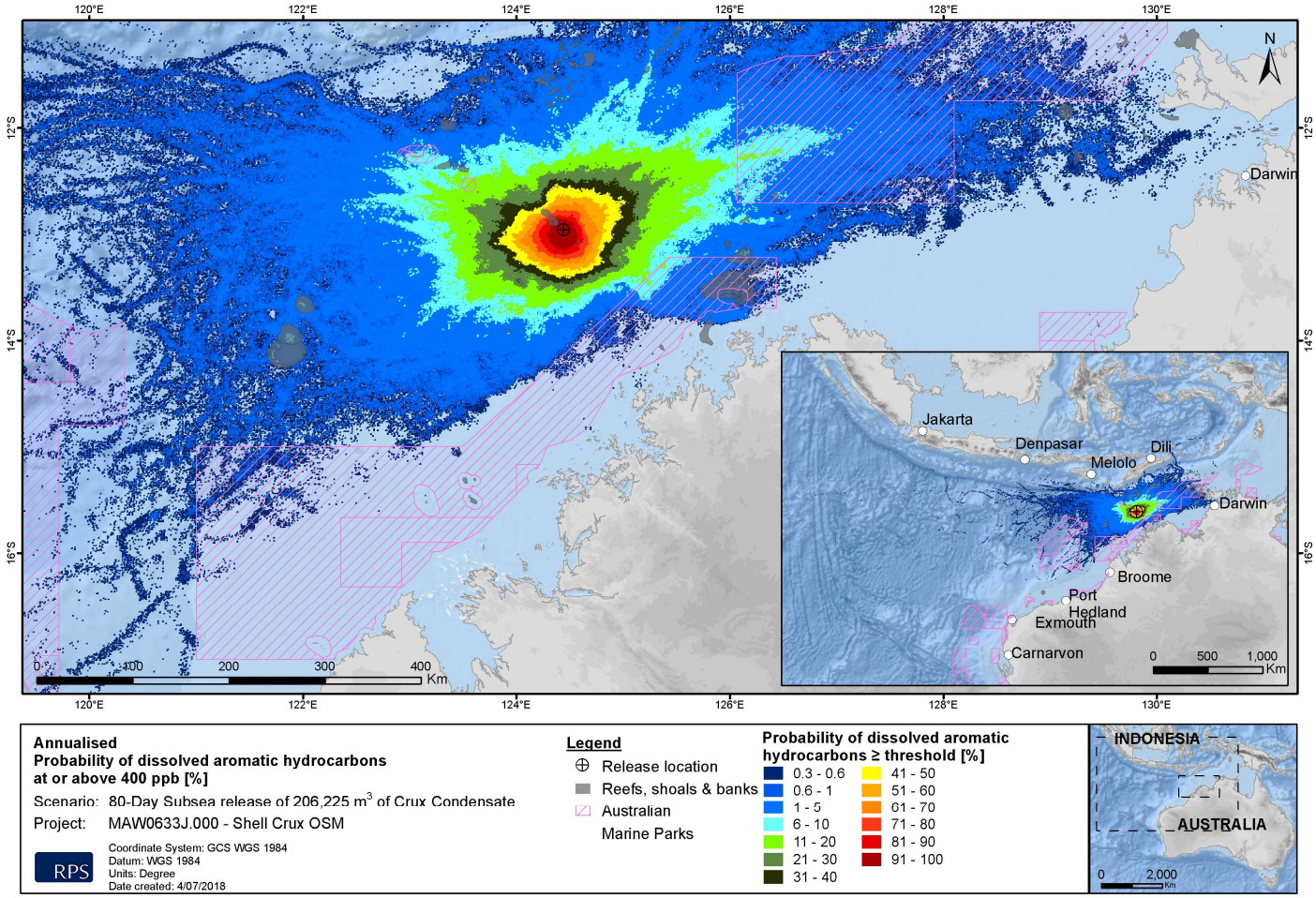


Figure 3.11 Subsurface Hydrocarbons | Dissolved | Blowout Scenario | Stochastic Outcomes. Predicted annualised probability of dissolved aromatic hydrocarbon concentrations at or above 400 ppb resulting from an 80-day subsurface release of Crux condensate at a development well.

3.3 Scenario 2 – Short-Term Surface Release of Crux Condensate at the Crux Platform

3.3.1 Discussion of Results

3.3.1.1 Overview

This scenario investigated the probability of exposure to key sensitive receptors by hydrocarbons resulting from a short-term (instantaneous) surface release following an inventory integrity failure, discharging 88 m^3 of Crux condensate at the Crux platform location at any time of year, with no spill response mitigation measures applied.

Considering the discharge characteristics, the properties of the condensate and its expected weathering behaviour, floating films are likely to be formed under typical to calm wind conditions. Given the low viscosity of the condensate, entrainment into the water column is highly likely to occur under all but relatively calm wind conditions. It is likely that the bulk of the oil mass at any time will be found in the surface mixed layer and on the water surface. Evaporation rates will be high, given the large proportion of volatile (54%) and semi-volatile (22%) compounds within the condensate, with the residual fraction (8%) persisting in the environment until degradation processes occur (over periods of weeks to months). Considering the relatively high likelihood of entrainment occurring, there is a high potential for dissolution of soluble aromatic compounds.

Figure 3.12 to Figure 3.14 show a summary of the areal extent for all hydrocarbon phases at the low, moderate and high thresholds, respectively.

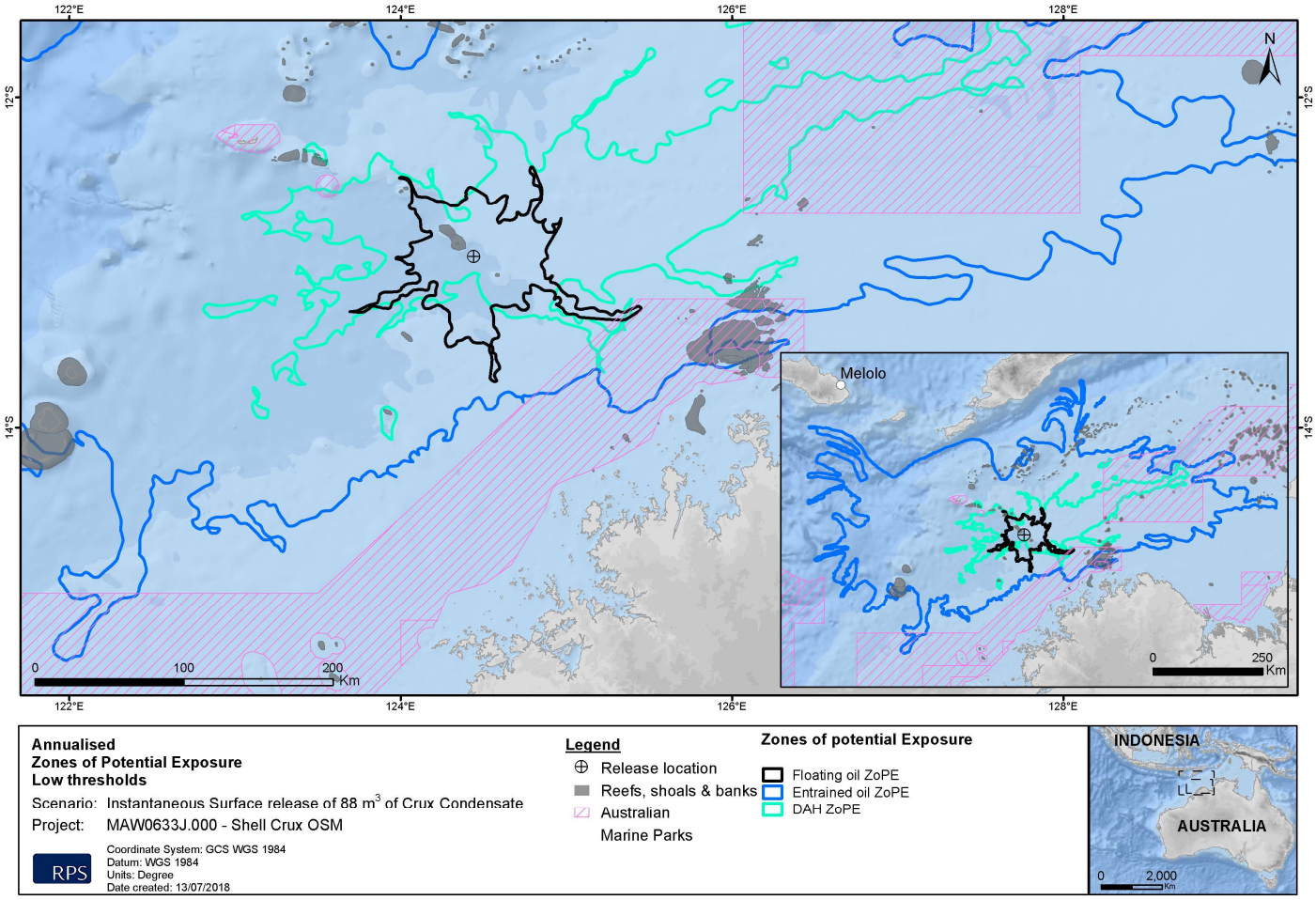


Figure 3.12 Surface and Subsurface Hydrocarbons | Inventory Scenario | Stochastic Outcomes. Areal extent of potential exposure at the low thresholds resulting from an instantaneous surface release of Crux condensate at the Crux platform.

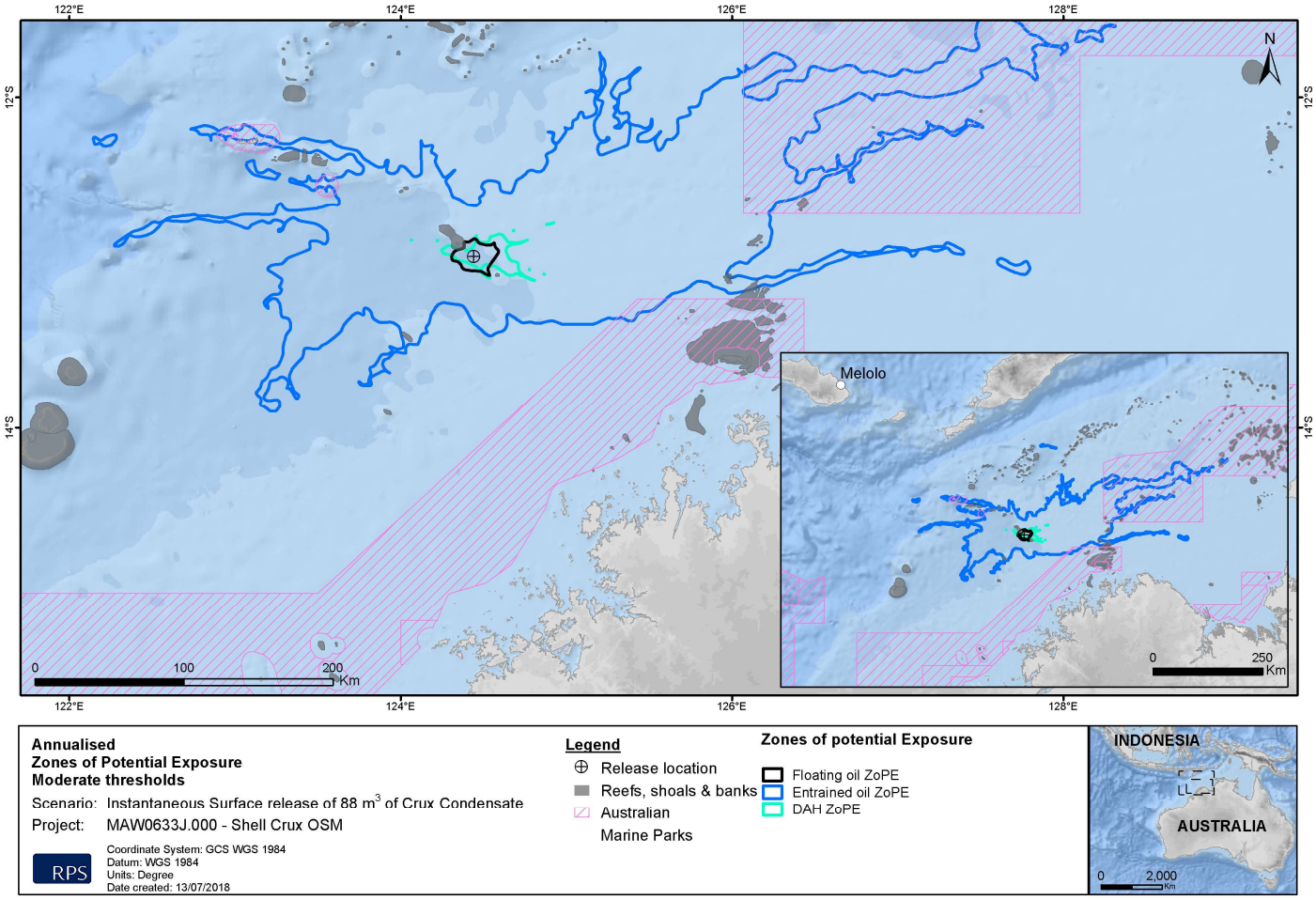


Figure 3.13 Surface and Subsurface Hydrocarbons | Inventory Scenario | Stochastic Outcomes. Areal extent of potential exposure at the moderate thresholds resulting from an instantaneous surface release of Crux condensate at the Crux platform.

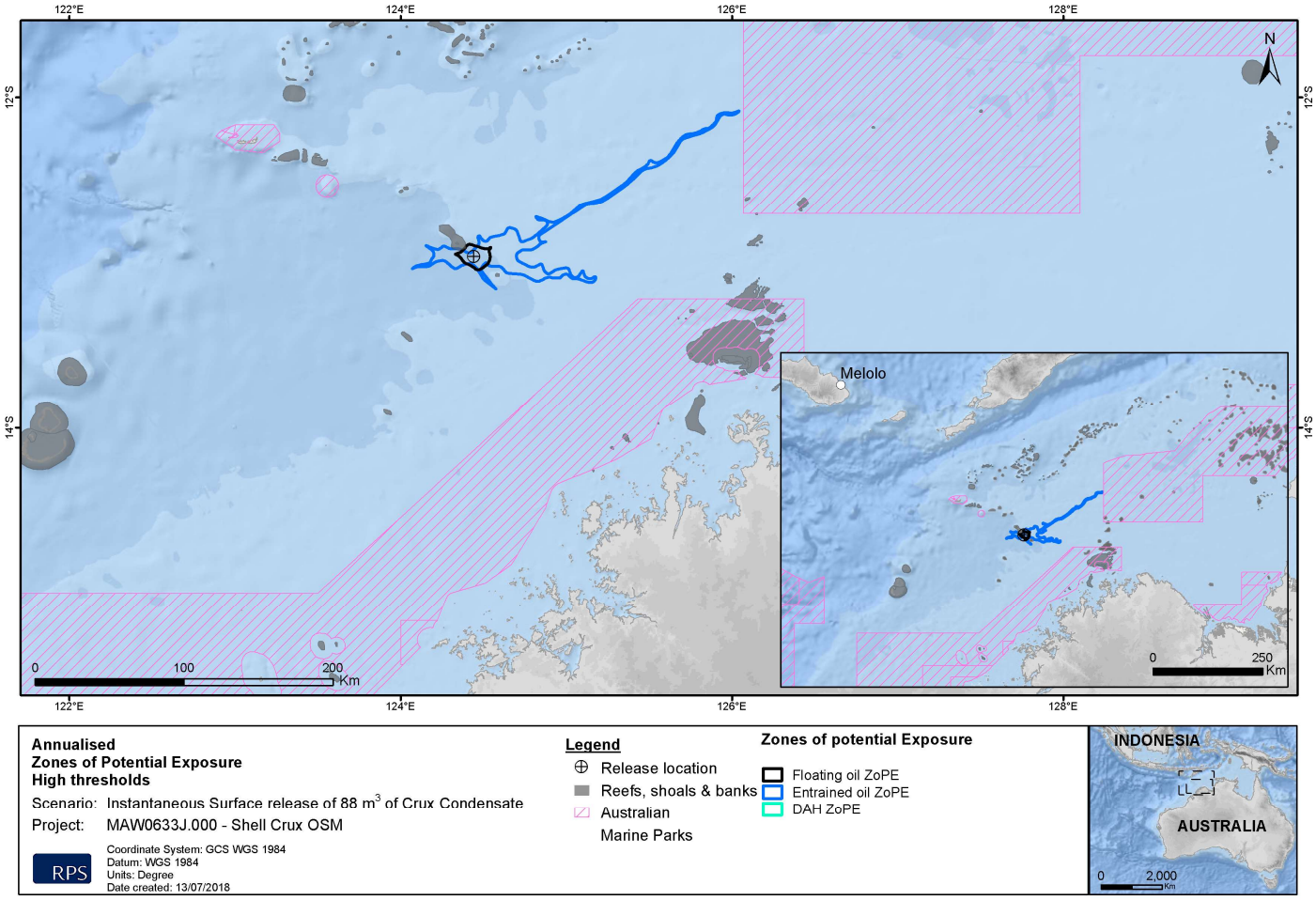


Figure 3.14 Surface and Subsurface Hydrocarbons | Inventory Scenario | Stochastic Outcomes. Areal extent of potential exposure at the high thresholds resulting from an instantaneous surface release of Crux condensate at the Crux platform.

RPS

3.3.1.2 Floating and Shoreline Hydrocarbons

The annualised probability contour figures (Figure 3.16, Figure 3.17 and Appendix B) indicate that hydrocarbons on the sea surface at or greater than the threshold concentrations remain in relatively close proximity to the release location, with limited potential for interaction with the nearest shoreline receptors. The maximum distance to the outer extent of the low floating oil threshold (1 g/m^2) is predicted to be 116 km (Table 3.8). The ZoPE at the moderate and high floating oil threshold is further reduced, with floating oil not predicted to exceed the moderate (10 g/m^2) and high (25 g/m^2) thresholds beyond distances of 17 km and 14 km, respectively.

The Southern Bluefin Tuna Fishery, Western Skipjack Fishery and Western Tuna and Billfish Fishery receptors have the highest predicted probability of contact, being 100% for all thresholds (Table 3.9). Only a small number of other receptors are predicted to receive floating oil at the low threshold concentration, with the highest probability of contact with the waters above Vulcan Shoals being 7.2%.

The minimum time to contact with any receptor by floating oil at the low threshold is forecast at approximately 1 hour at the Southern Bluefin Tuna Fishery, Western Skipjack Fishery and Western Tuna and Billfish Fishery receptors.

Potential for accumulation of hydrocarbons on shorelines is predicted to be low (<1% probability at the moderate threshold of 100 g/m^2), with a maximum accumulated volume of 2 m^3 forecast at Ashmore Reef and Cartier Island and Surrounding Commonwealth Waters, and also Green Turtle BIA, and maximum local accumulated concentration on shorelines of 127 g/m^2 forecast at Ashmore Reef and Cartier Island, Green Turtle BIA and Hawksbill Turtle BIA (Table 3.9).

Table 3.8 Maximum distances from the release location to zones of floating oil exposure for Scenario 2 (88 m^3 Crux condensate).

	Floating Oil Exposure Threshold		
	Low (1-10 g/m^2)	**Moderate (10-25 g/m^2)**	**High (>25 g/m^2)**
Maximum distance travelled (km) by a spill trajectory	116	17	14

3.3.1.3 Subsurface – Entrained Hydrocarbons

The annualised probability contour figures (Figure 3.19 and Appendix B) indicate that entrained oil concentrations at or greater than the threshold concentrations travel up to 566 km (10 ppb) from the release location. The maximum extent is forecast to be reduced for the moderate (100 ppb; 494 km) and high (500 ppb; 195 km) thresholds.

A small number of receptors are predicted to receive entrained oil at high threshold concentrations. Southern Bluefin Tuna Fishery, Western Skipjack Fishery and Western Tuna and Billfish Fishery receptors are predicted to be contacted at the high threshold with probabilities less than 4% (Table 3.10). Higher probabilities of contact at a greater number of receptors are predicted at the low and moderate thresholds.

Receptors with the highest probability of receiving entrained oil concentrations at the low threshold are Southern Bluefin Tuna Fishery (14%), Western Skipjack Fishery (14%), Western Tuna and Billfish Fishery (14%) and North-West Slope Trawl Fishery (13%). Entrained oil concentrations at the low threshold are also forecast at Vulcan Shoals (11%), Continental Slope Demersal Fish Communities KEF (7%), Carbonate Bank

and Terrace System of Sahul Shelf KEF (7%), Green Turtle BIA (5%), Goeree Shoal (6%), Ancient Coastline at 125 m Depth Contour KEF (5%), Flatback Turtle BIA (5%), Loggerhead Turtle BIA (5%), Olive Ridley Turtle BIA (5%), Oceanic Shoals AMP (5%), Ashmore Reef AMP (3%) and Cartier Island AMP (4%). The listed sensitive receptors are also contacted at the moderate threshold with lower probabilities.

The minimum time to contact with any receptor by entrained oil at the low and moderate thresholds is forecast at Southern Bluefin Tuna Fishery, Western Skipjack Fishery and Western Tuna and Billfish Fishery, at approximately 1 hour.

3.3.1.4 Subsurface – Dissolved Aromatic Hydrocarbons

The annualised probability contour figures (Figure 3.21 and Figure 3.22) indicate that dissolved aromatic hydrocarbons at or greater than the threshold concentrations travel up to 465 km (6 ppb) from the release location. The maximum extent is forecast to be reduced for the moderate threshold (50 ppb; 47 km), and the high (400 ppb) threshold is not exceeded for this scenario.

No receptors are predicted to receive dissolved aromatic hydrocarbons at high threshold concentrations. Southern Bluefin Tuna Fishery, Western Skipjack Fishery, Western Tuna and Billfish Fishery receptors are predicted to have the highest probability of contact at the low and moderate thresholds with probabilities of 8% and 1%, respectively (Table 3.11). Lower probabilities of contact are predicted at several receptors at the low threshold, with the highest at Vulcan Shoals (4%).

3.3.1.5 Deterministic Cases

A replicate simulation during the winter season (spill starting at 14:00 12th April 2013) has been identified as the worst-case replicate according to the maximum oil volume accumulated across all shoreline receptors, minimum time to commencement of oil accumulation at any shoreline receptor and maximum length of oiled shoreline criteria for Scenario 2 (2 m^3, 11.9 days and 2 km, respectively, at Ashmore Reef and Cartier Island and Surrounding Commonwealth Waters KEF). Figures showing the evolution of this spill simulation are contained in Appendix E. Hydrocarbons on the sea surface mainly drifted north-west of the release location. The potential floating oil exposure zones were shown up to 57 km, 8 km and 1 km of the release location at the low, moderate and high thresholds, respectively. The entrained oil and dissolved aromatic hydrocarbons were shown to move west of the release location. Low entrained hydrocarbons were recorded up to 304 km from the release location. Low dissolved aromatic hydrocarbons were observed up to 1 km from the release location.

RPS

3.3.2 Floating and Shoreline Hydrocarbons

Table 3.9 Expected annualised floating and shoreline oil outcomes at sensitive receptors resulting from an instantaneous surface release of Crux condensate at the Crux platform.

	Receptor	Probability (%) of films arriving at receptors at			Minimum time to receptor (hours) for films at			Probability (%) of shoreline oil on receptors at			Minimum time to receptor (hours) for shoreline oil at			Maximum local accumulated concentration (g/m²)		Maximum accumulated volume (m³) along this shoreline		Maximum length of shoreline (km) with concentrations ≥10.0 g/m²	
		≥1 g/m²	≥10 g/m²	≥25 g/m²	≥1 g/m²	≥10 g/m²	≥25 g/m²	≥10 g/m²	≥100 g/m²	≥1,000 g/m²	≥10 g/m²	≥100 g/m²	≥1,000 g/m²	averaged over all replicate simulations	worst replicate simulation	averaged over all replicate simulations	worst replicate simulation	averaged over all replicate simulations	worst replicate simulation
Islands	Browse Island	<0.3	<0.3	<0.3	NC	NC	NC	0.6	<0.3	<0.3	218	NC	NC	<0.1	16	<1	<1	<1	<1
Reefs	East Holothuria Reef*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Hibernia Reef*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Sandy Islet	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	<0.1	<1	<1	NC	NC
	Scott Reef North*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Scott Reef South	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	<0.1	<1	<1	NC	NC
	Seringapatam Reef*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	The Boxers*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	The Boxers Area*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	West Holothuria Reef*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Shoals	Barracouta Shoals*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Barton Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Deep Shoal 1*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Deep Shoal 2*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Dillon Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Echuca Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Eugene McDermott Shoal*	1.5	<0.3	<0.3	20	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Fantome Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Goeree Shoal*	2.1	<0.3	<0.3	15	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Heywood Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Jabiru Shoals*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Karmt Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Mangola Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Penguin Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Penguin Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Van Cloon Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

RPS

	Receptor	Probability (%) of films arriving at receptors at			Minimum time to receptor (hours) for films at			Probability (%) of shoreline oil on receptors at			Minimum time to receptor (hours) for shoreline oil at			Maximum local accumulated concentration (g/m²)		Maximum accumulated volume (m³) along this shoreline		Maximum length of shoreline (km) with concentrations ≥10.0 g/m²	
		≥1 g/m²	≥10 g/m²	≥25 g/m²	≥1 g/m²	≥10 g/m²	≥25 g/m²	≥10 g/m²	≥100 g/m²	≥1,000 g/m²	≥10 g/m²	≥100 g/m²	≥1,000 g/m²	averaged over all replicate simulations	worst replicate simulation	averaged over all replicate simulations	worst replicate simulation	averaged over all replicate simulations	worst replicate simulation
	Vee Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Vulcan Shoals*	7.2	0.9	0.6	5	5	5	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Banks	Baldwin Bank*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Banks	Favell Bank*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Banks	Flat Top Bank*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Banks	Gale Bank*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Banks	Holothuria Banks*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Banks	Johnson Bank*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Banks	Otway Bank*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Banks	Sahul Bank*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Banks	Woodbine Bank*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Marine Parks	Ashmore Reef AMP	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	1.5	<1	<1	NC	NC
Marine Parks	Cartier Island AMP	<0.3	<0.3	<0.3	NC	NC	NC	0.6	0.6	<0.3	285	294	NC	0.4	127	<1	2	<1	2
Marine Parks	Kimberley AMP	0.9	<0.3	<0.3	109	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	NC	NC	NC	NC	NC	NC
Marine Parks	North Lalang-garram MP & North Kimberley MP	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	0.3	<1	<1	NC	NC
Marine Parks	Oceanic Shoals AMP*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Key Ecological Features	Ancient Coastline at 125 m depth contour*	0.9	<0.3	<0.3	40	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Key Ecological Features	Ashmore Reef and Cartier Island and surrounding Commonwealth Waters	<0.3	<0.3	<0.3	NC	NC	NC	0.6	0.6	<0.3	285	294	NC	0.4	127	<1	2	<1	2
Key Ecological Features	Carbonate bank & terrace system of Van Diemen Rise*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Key Ecological Features	Carbonate bank and terrace system of Sahul Shelf	0.6	<0.3	<0.3	174	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	NC	NC	NC	NC	NC	NC
Key Ecological Features	Continental Slope Demersal Fish Communities*	0.6	<0.3	<0.3	114	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Key Ecological Features	Pinnacles of the Bonaparte Basin*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Key Ecological Features	Seringapatam Reef and Commonwealth Waters in the Scott Reef Complex	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	<0.1	<1	<1	NC	NC

RPS

	Receptor	Probability (%) of films arriving at receptors at			Minimum time to receptor (hours) for films at			Probability (%) of shoreline oil on receptors at			Minimum time to receptor (hours) for shoreline oil at			Maximum local accumulated concentration (g/m²)		Maximum accumulated volume (m³) along this shoreline		Maximum length of shoreline (km) with concentrations ≥10.0 g/m²	
		≥1 g/m²	≥10 g/m²	≥25 g/m²	≥1 g/m²	≥10 g/m²	≥25 g/m²	≥10 g/m²	≥100 g/m²	≥1,000 g/m²	≥10 g/m²	≥100 g/m²	≥1,000 g/m²	averaged over all replicate simulations	worst replicate simulation	averaged over all replicate simulations	worst replicate simulation	averaged over all replicate simulations	worst replicate simulation
Fisheries	Northern Prawn Fishery	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	NC	NC	NC	NC	NC	NC
	North-West Slope Trawl Fishery*	3.6	<0.3	<0.3	15	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Southern Bluefin Tuna Fishery	100	100	100	1	1	1	0.6	0.6	<0.3	285	294	NC	0.4	127	NC	NC	NC	NC
	Western Skipjack Fishery	100	100	100	1	1	1	0.6	0.6	<0.3	285	294	NC	0.4	127	NC	NC	NC	NC
	Western Tuna and Billfish Fishery	100	100	100	1	1	1	0.6	0.6	<0.3	285	294	NC	0.4	127	NC	NC	NC	NC
Biologically Important Areas	Flatback Turtle BIA	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	NC	NC	NC	NC	NC	NC
	Green Turtle BIA	<0.3	<0.3	<0.3	NC	NC	NC	0.6	0.6	<0.3	285	294	NC	0.4	127	<1	2	<1	2
	Hawksbill Turtle BIA	<0.3	<0.3	<0.3	NC	NC	NC	0.6	0.6	<0.3	285	294	NC	0.4	127	<1	<1	<1	2
	Loggerhead Turtle BIA*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Olive Ridley Turtle BIA*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

NC: No contact to receptor predicted for specified threshold. NA: Not applicable.

** Floating oil will not accumulate on submerged features and at open ocean locations.*

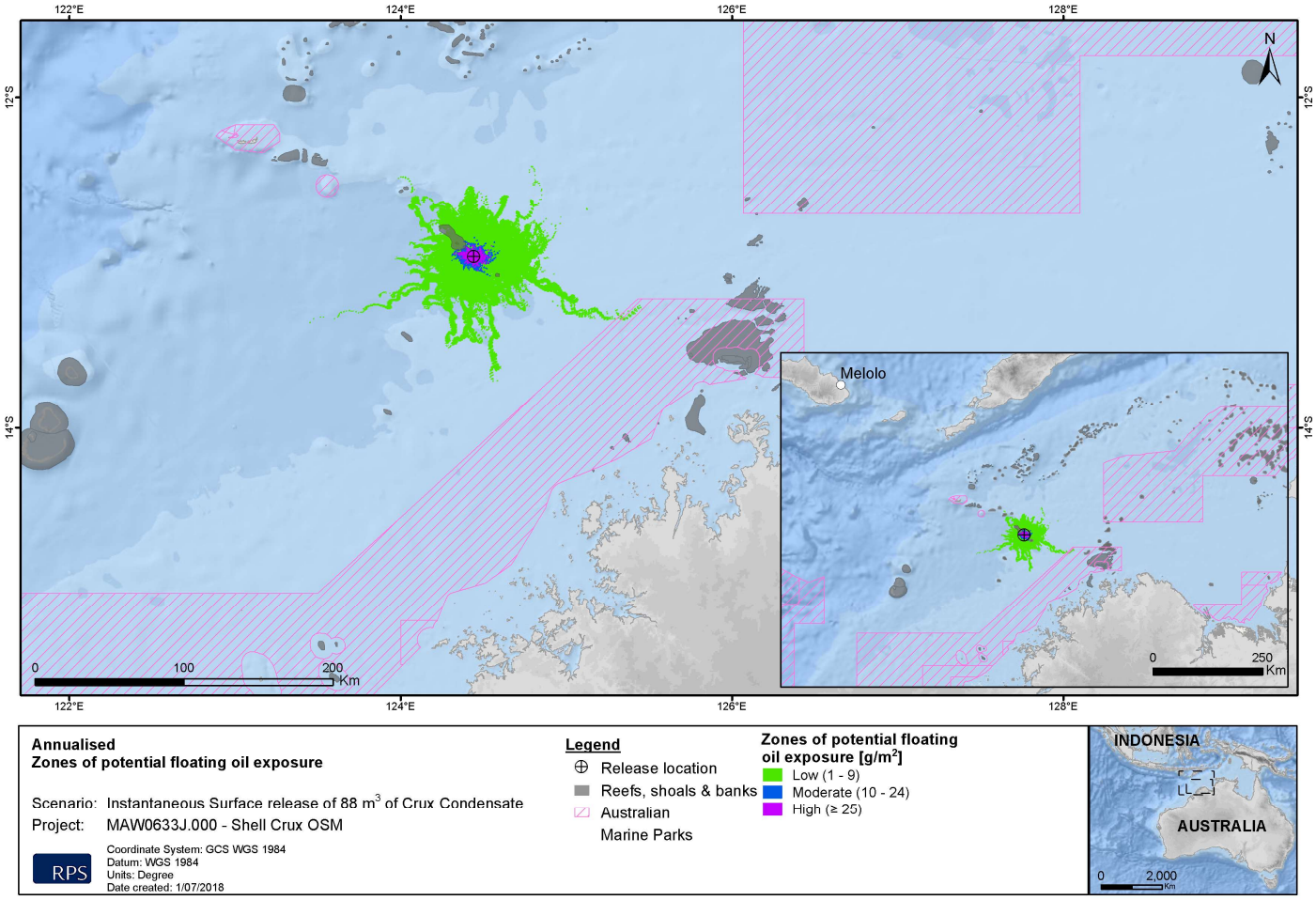


Figure 3.15 Surface Hydrocarbons | Inventory Scenario | Stochastic Outcomes. Areal extent of potential exposure at defined floating oil threshold concentrations resulting from an instantaneous surface release of Crux condensate at the Crux platform.

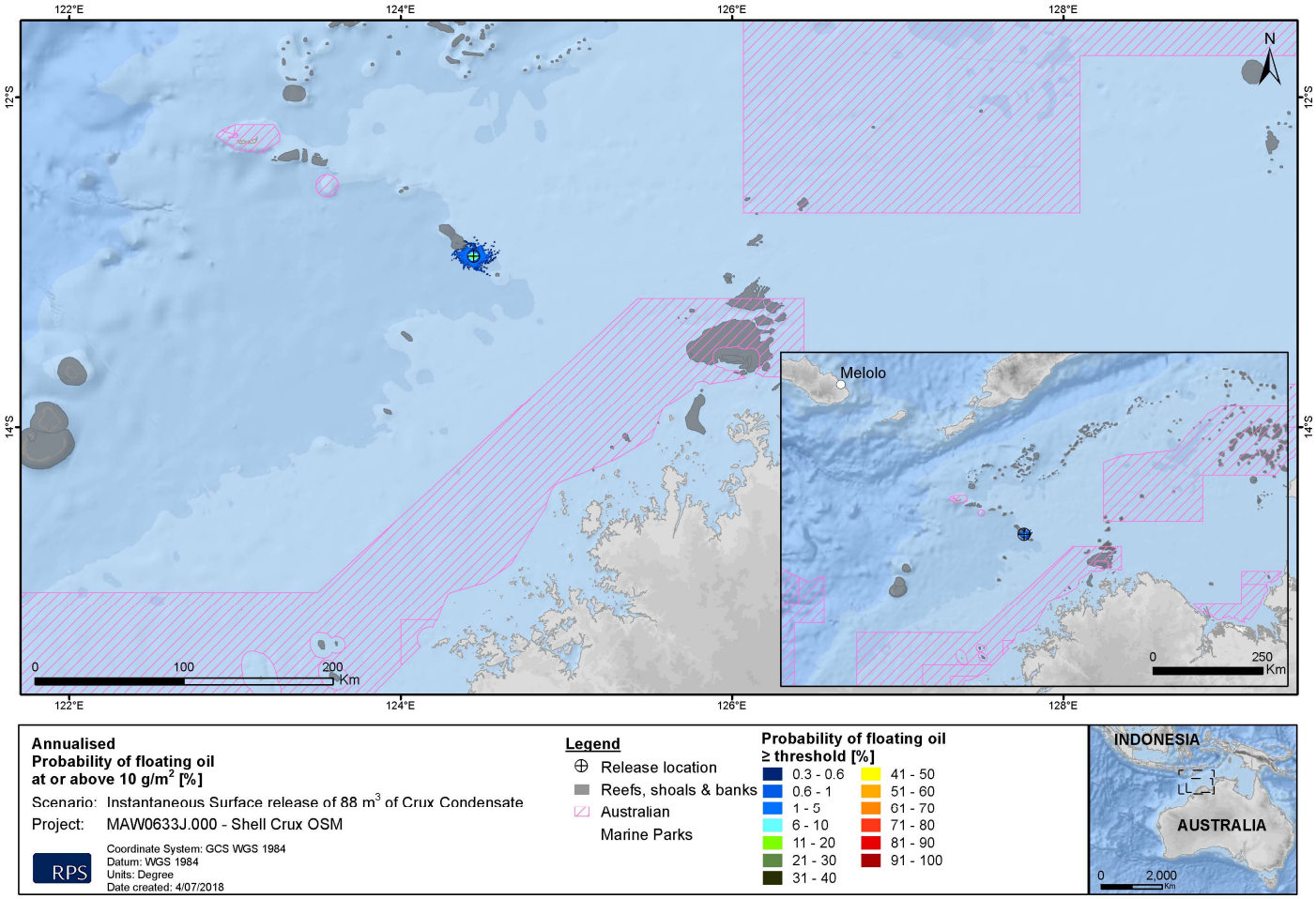


Figure 3.16 Surface Hydrocarbons | Inventory Scenario | Stochastic Outcomes. Predicted annualised probability of floating oil concentrations at or above 10 g/m^2 resulting from an instantaneous surface release of Crux condensate at the Crux platform.

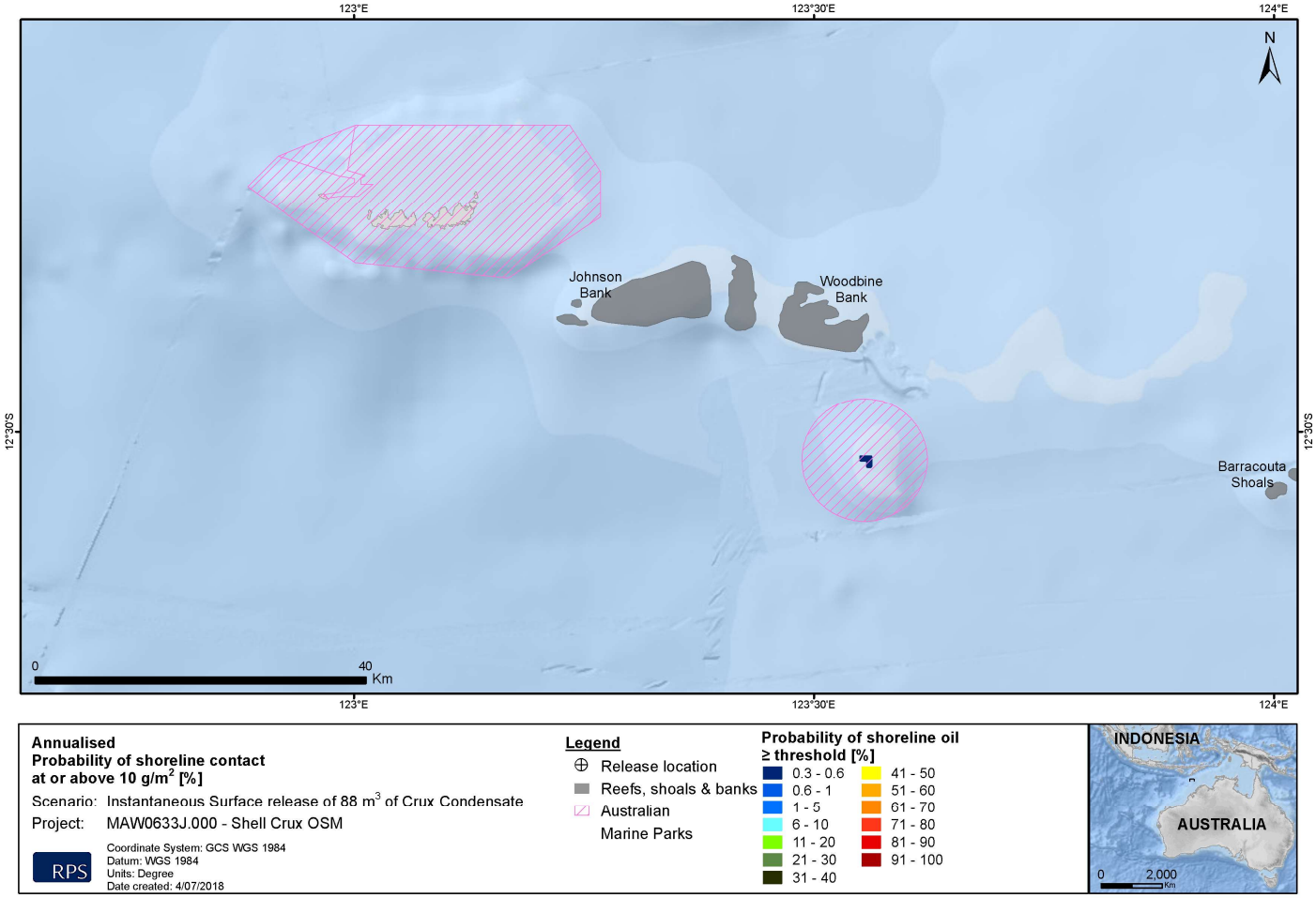


Figure 3.17 Shoreline Hydrocarbons | Inventory Scenario | Stochastic Outcomes. Predicted annualised probability of shoreline oil concentrations at or above 10 g/m^2 resulting from an instantaneous surface release of Crux condensate at the Crux platform.

RPS

3.3.3 Entrained Hydrocarbons

Table 3.10 Expected annualised entrained oil outcomes at sensitive receptors resulting from an instantaneous surface release of Crux condensate at the Crux platform.

	Receptor	Probability (%) of entrained hydrocarbon concentration contact at specific receptor depth			Minimum time to receptor waters (hours) at		
		≥10 ppb	≥100 ppb	≥500 ppb	≥10 ppb	≥100 ppb	≥500 ppb
Islands	Browse Island	1.2	<0.3	<0.3	244	NC	NC
Reefs	East Holothuria Reef	0.6	<0.3	<0.3	232	NC	NC
	Hibernia Reef	1.5	<0.3	<0.3	165	NC	NC
	Sandy Islet	0.6	<0.3	<0.3	444	NC	NC
	Scott Reef North	0.9	<0.3	<0.3	439	NC	NC
	Scott Reef South	0.9	<0.3	<0.3	438	NC	NC
	Seringapatam Reef	0.9	<0.3	<0.3	398	NC	NC
	The Boxers	1.2	<0.3	<0.3	424	NC	NC
	The Boxers Area	1.2	0.6	<0.3	416	425	NC
	West Holothuria Reef	0.6	<0.3	<0.3	213	NC	NC
Shoals	Barracouta Shoals	3.6	0.9	<0.3	68	170	NC
	Barton Shoal	0.6	<0.3	<0.3	399	NC	NC
	Deep Shoal 1	2.1	<0.3	<0.3	169	NC	NC
	Deep Shoal 2	1.2	<0.3	<0.3	374	NC	NC
	Dillon Shoal	<0.3	<0.3	<0.3	NC	NC	NC
	Echuca Shoal	2.4	<0.3	<0.3	263	NC	NC
	Eugene McDermott Shoal	3	0.6	<0.3	25	49	NC
	Fantome Shoal	<0.3	<0.3	<0.3	NC	NC	NC
	Goeree Shoal	5.7	0.6	<0.3	10	17	NC
	Heywood Shoal	2.4	0.6	<0.3	80	80	NC
	Jabiru Shoals	0.9	<0.3	<0.3	180	NC	NC
	Karmt Shoal	<0.3	<0.3	<0.3	NC	NC	NC
	Mangola Shoal	0.6	<0.3	<0.3	371	NC	NC
	Penguin Shoal	1.2	0.6	<0.3	152	154	NC
	Penguin Shoal	1.2	0.6	<0.3	152	154	NC
	Van Cloon Shoal	1.5	<0.3	<0.3	166	NC	NC
	Vee Shoal	0.6	<0.3	<0.3	231	NC	NC

RPS

	Receptor	Probability (%) of entrained hydrocarbon concentration contact at specific receptor depth			Minimum time to receptor waters (hours) at		
		≥10 ppb	≥100 ppb	≥500 ppb	≥10 ppb	≥100 ppb	≥500 ppb
	Vulcan Shoals	11.1	3	0.6	6	7	7
Banks	Baldwin Bank	1.8	0.6	<0.3	274	278	NC
	Favell Bank	1.5	0.6	<0.3	87	370	NC
	Flat Top Bank	0.6	<0.3	<0.3	439	NC	NC
	Gale Bank	1.5	<0.3	<0.3	149	NC	NC
	Holothuria Banks	0.9	0.6	<0.3	188	190	NC
	Johnson Bank	2.7	0.6	<0.3	152	162	NC
	Otway Bank	<0.3	<0.3	<0.3	NC	NC	NC
	Sahul Bank	1.2	<0.3	<0.3	130	NC	NC
	Woodbine Bank	1.8	<0.3	<0.3	161	NC	NC
Marine Parks	Ashmore Reef AMP	3	0.9	<0.3	167	176	NC
	Cartier Island AMP	3.6	0.6	<0.3	117	135	NC
	Kimberley AMP	3	0.9	<0.3	76	120	NC
	North Lalang-garram MP & North Kimberley MP	0.6	<0.3	<0.3	225	NC	NC
	Oceanic Shoals AMP	4.5	0.9	0.6	85	86	132
Key Ecological Features	Ancient Coastline at 125 m depth contour	4.8	0.9	<0.3	28	29	NC
	Ashmore Reef and Cartier Island and surrounding Commonwealth Waters	3.6	0.9	<0.3	112	130	NC
	Carbonate bank & terrace system of Van Diemen Rise	1.5	0.6	<0.3	390	393	NC
	Carbonate bank and terrace system of Sahul Shelf	6.6	1.5	0.6	29	29	30
	Continental Slope Demersal Fish Communities	6.9	0.9	<0.3	48	49	NC
	Pinnacles of the Bonaparte Basin	2.4	0.9	<0.3	237	240	NC
	Seringapatam Reef and Commonwealth Waters in the Scott Reef Complex	1.2	<0.3	<0.3	398	NC	NC
Fisheries	Northern Prawn Fishery	2.7	0.9	0.6	174	176	268
	North-West Slope Trawl Fishery	13.2	5.1	0.6	7	8	9
	Southern Bluefin Tuna Fishery	14.4	7.2	1.5	1	1	1
	Western Skipjack Fishery	14.4	7.2	1.5	1	1	1
	Western Tuna and Billfish Fishery	14.4	7.2	1.5	1	1	1

	Receptor	Probability (%) of entrained hydrocarbon concentration contact at specific receptor depth			Minimum time to receptor waters (hours) at		
		≥10 ppb	≥100 ppb	≥500 ppb	≥10 ppb	≥100 ppb	≥500 ppb
Biologically Important Areas	Flatback Turtle BIA	4.5	0.9	0.6	99	101	142
	Green Turtle BIA	5.4	0.9	<0.3	64	66	NC
	Hawksbill Turtle BIA	3.6	0.9	<0.3	142	175	NC
	Loggerhead Turtle BIA	4.5	0.9	0.6	99	101	142
	Olive Ridley Turtle BIA	4.5	0.9	0.6	99	101	142

NC: No contact to receptor predicted for specified threshold.

** Probabilities and maximum concentrations calculated at depth of submerged feature.*

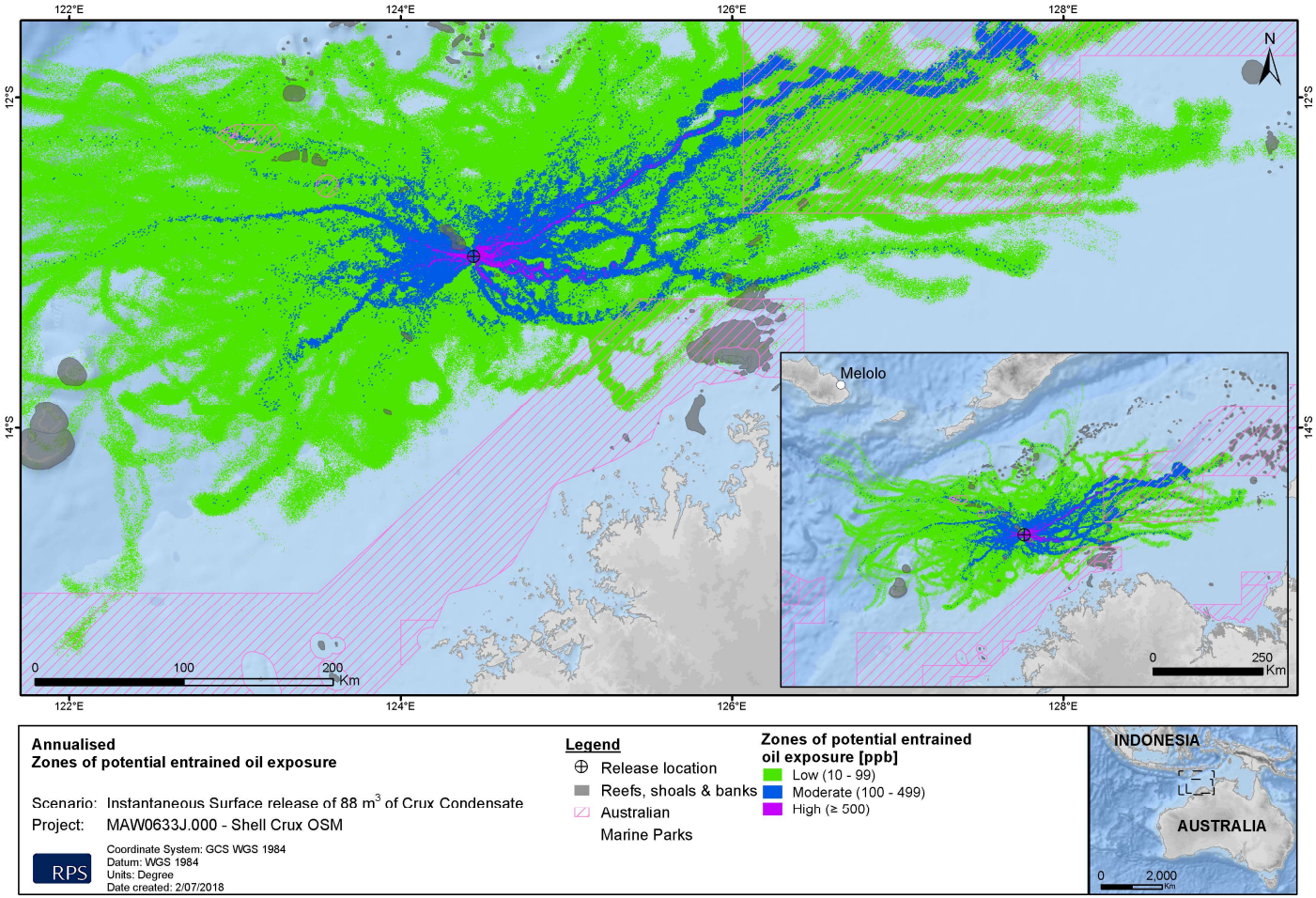


Figure 3.18 Subsurface Hydrocarbons | Entrained | Inventory Scenario | Stochastic Outcomes. Areal extent of potential exposure at defined entrained oil threshold concentrations resulting from an instantaneous surface release of Crux condensate at the Crux platform.

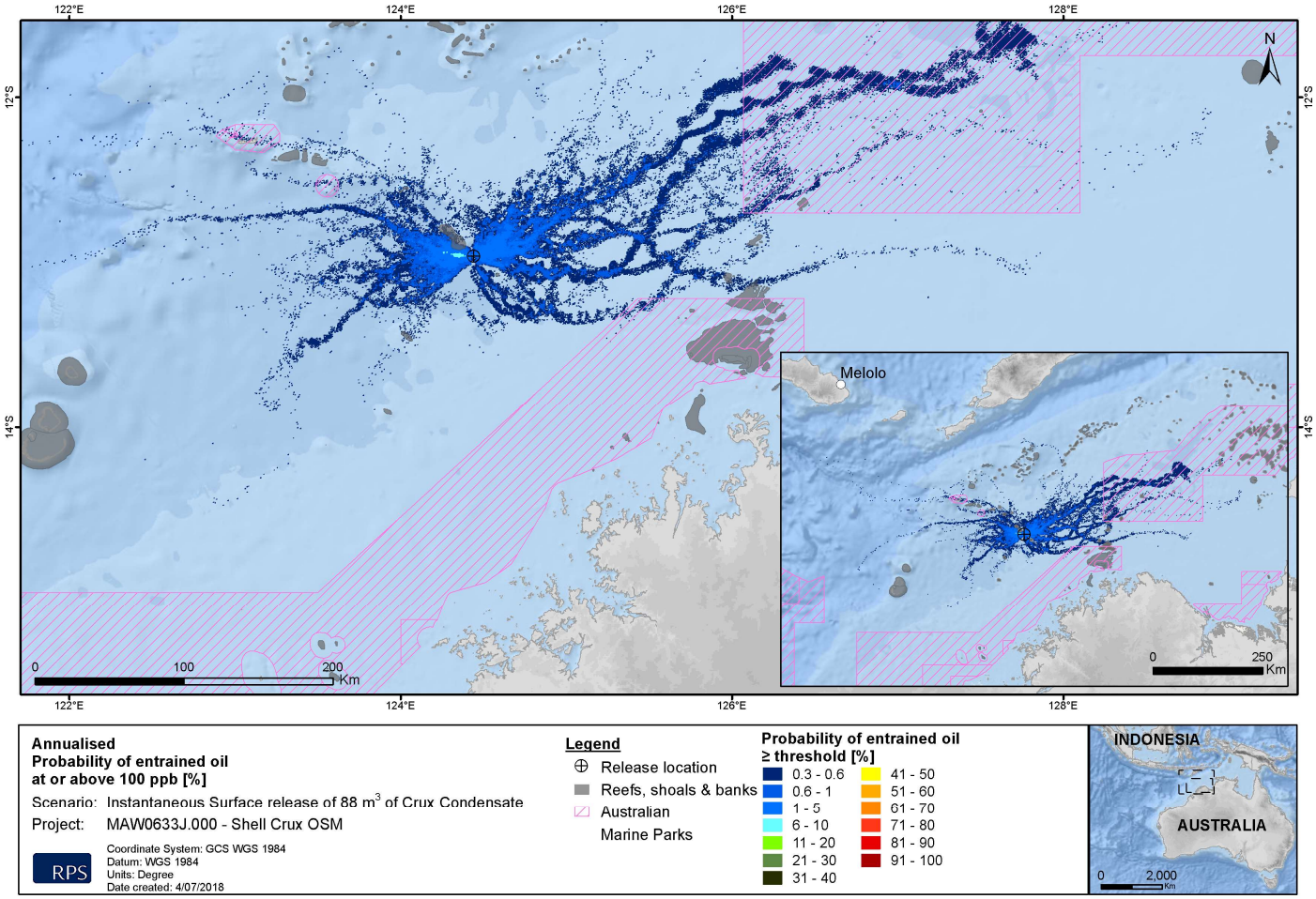


Figure 3.19 Subsurface Hydrocarbons | Entrained | Inventory Scenario | Stochastic Outcomes. Predicted annualised probability of entrained oil concentrations at or above 100 ppb resulting from an instantaneous surface release of Crux condensate at the Crux platform.

RPS

3.3.4 Dissolved Aromatic Hydrocarbons

Table 3.11 Expected annualised dissolved aromatic hydrocarbon outcomes at sensitive receptors resulting from an instantaneous surface release of Crux condensate at the Crux platform.

	Receptor	Probability (%) of dissolved aromatic concentration at specific receptor depth		
		≥6 ppb	≥50 ppb	≥400 ppb
Islands	Browse Island	<0.3	<0.3	<0.3
Reefs	East Holothuria Reef	<0.3	<0.3	<0.3
	Hibernia Reef	<0.3	<0.3	<0.3
	Sandy Islet	<0.3	<0.3	<0.3
	Scott Reef North	<0.3	<0.3	<0.3
	Scott Reef South	<0.3	<0.3	<0.3
	Seringapatam Reef	<0.3	<0.3	<0.3
	The Boxers	<0.3	<0.3	<0.3
	The Boxers Area	<0.3	<0.3	<0.3
	West Holothuria Reef	<0.3	<0.3	<0.3
Shoals	Barracouta Shoals	0.6	<0.3	<0.3
	Barton Shoal	<0.3	<0.3	<0.3
	Deep Shoal 1	<0.3	<0.3	<0.3
	Deep Shoal 2	<0.3	<0.3	<0.3
	Dillon Shoal	<0.3	<0.3	<0.3
	Echuca Shoal	0.6	<0.3	<0.3
	Eugene McDermott Shoal	0.6	<0.3	<0.3
	Fantome Shoal	<0.3	<0.3	<0.3
	Goeree Shoal	0.9	<0.3	<0.3
	Heywood Shoal	<0.3	<0.3	<0.3
	Jabiru Shoals	<0.3	<0.3	<0.3
	Karmt Shoal	<0.3	<0.3	<0.3
	Mangola Shoal	<0.3	<0.3	<0.3
	Penguin Shoal	0.6	<0.3	<0.3
	Penguin Shoal	0.6	<0.3	<0.3
	Van Cloon Shoal	0.6	<0.3	<0.3
	Vee Shoal	<0.3	<0.3	<0.3

	Receptor	Probability (%) of dissolved aromatic concentration at specific receptor depth		
		≥6 ppb	≥50 ppb	≥400 ppb
	Vulcan Shoals	3.9	0.6	<0.3
Banks	Baldwin Bank	<0.3	<0.3	<0.3
	Favell Bank	<0.3	<0.3	<0.3
	Flat Top Bank	<0.3	<0.3	<0.3
	Gale Bank	0.6	<0.3	<0.3
	Holothuria Banks	0.6	<0.3	<0.3
	Johnson Bank	0.6	<0.3	<0.3
	Otway Bank	<0.3	<0.3	<0.3
	Sahul Bank	<0.3	<0.3	<0.3
	Woodbine Bank	0.6	<0.3	<0.3
Marine Parks	Ashmore Reef AMP	<0.3	<0.3	<0.3
	Cartier Island AMP	0.6	<0.3	<0.3
	Kimberley AMP	0.6	<0.3	<0.3
	North Lalang-garram MP & North Kimberley MP	<0.3	<0.3	<0.3
	Oceanic Shoals AMP	0.9	<0.3	<0.3
Key Ecological Features	Ancient Coastline at 125 m depth contour	0.9	<0.3	<0.3
	Ashmore Reef and Cartier Island and surrounding Commonwealth Waters	0.6	<0.3	<0.3
	Carbonate bank & terrace system of Van Diemen Rise	<0.3	<0.3	<0.3
	Carbonate bank and terrace system of Sahul Shelf	1.2	<0.3	<0.3
	Continental Slope Demersal Fish Communities	0.9	<0.3	<0.3
	Pinnacles of the Bonaparte Basin	0.6	<0.3	<0.3
	Seringapatam Reef and Commonwealth Waters in the Scott Reef Complex	<0.3	<0.3	<0.3

	Receptor	Probability (%) of dissolved aromatic concentration at specific receptor depth		
		≥6 ppb	≥50 ppb	≥400 ppb
Fisheries	Northern Prawn Fishery	0.9	<0.3	<0.3
	North-West Slope Trawl Fishery	2.7	0.6	<0.3
	Southern Bluefin Tuna Fishery	7.8	1.2	<0.3
	Western Skipjack Fishery	7.8	1.2	<0.3
	Western Tuna and Billfish Fishery	7.8	1.2	<0.3
Biologically Important Areas	Flatback Turtle BIA	0.9	<0.3	<0.3
	Green Turtle BIA	0.9	<0.3	<0.3
	Hawksbill Turtle BIA	0.6	<0.3	<0.3
	Loggerhead Turtle BIA	0.9	<0.3	<0.3
	Olive Ridley Turtle BIA	0.9	<0.3	<0.3

NC: No contact to receptor predicted for specified threshold.

** Probabilities and maximum concentrations calculated at depth of submerged feature.*

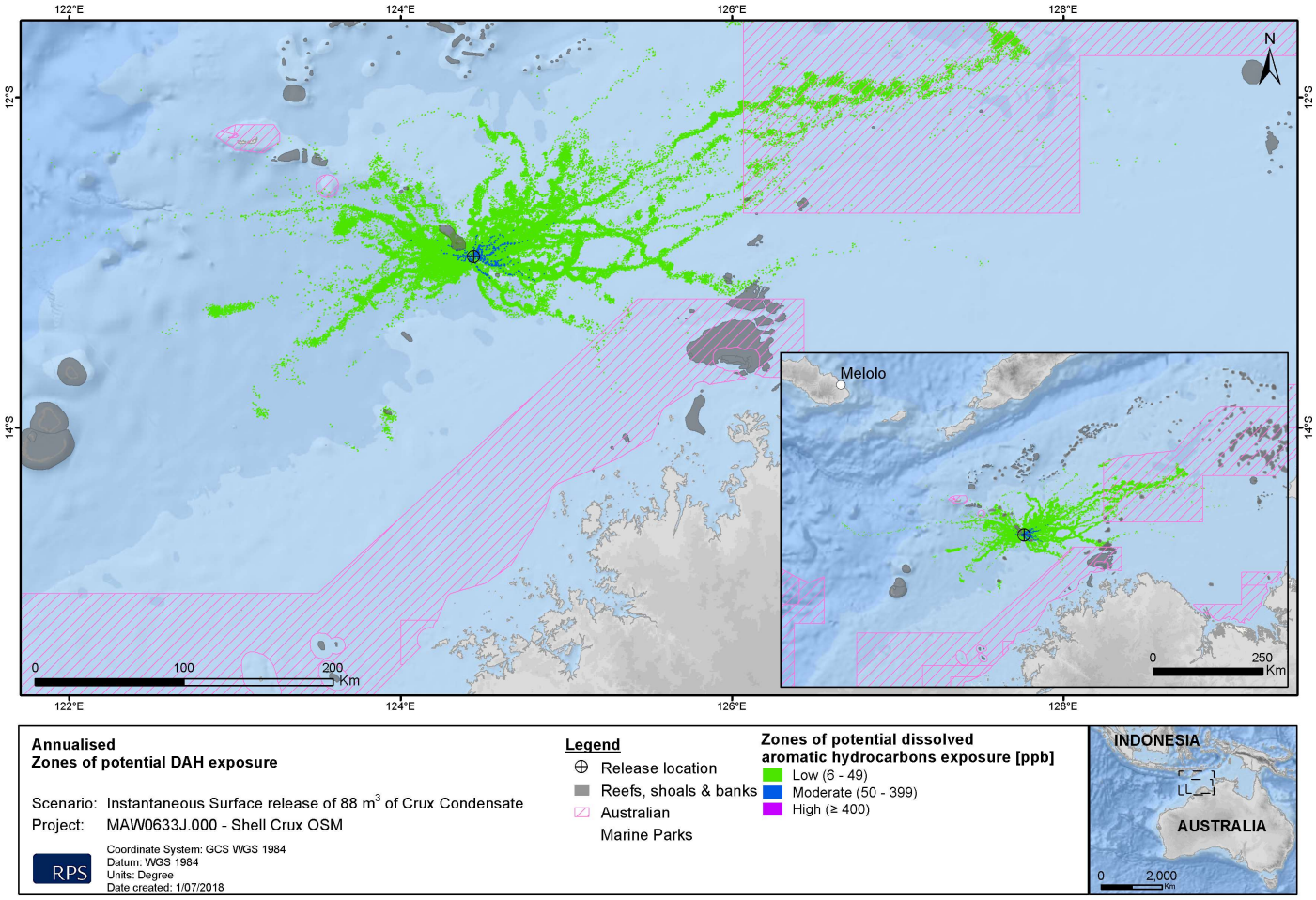


Figure 3.20 Subsurface Hydrocarbons | Dissolved | Inventory Scenario | Stochastic Outcomes. Areal extent of potential exposure at defined dissolved aromatic hydrocarbon threshold concentrations resulting from an instantaneous surface release of Crux condensate at the Crux platform.

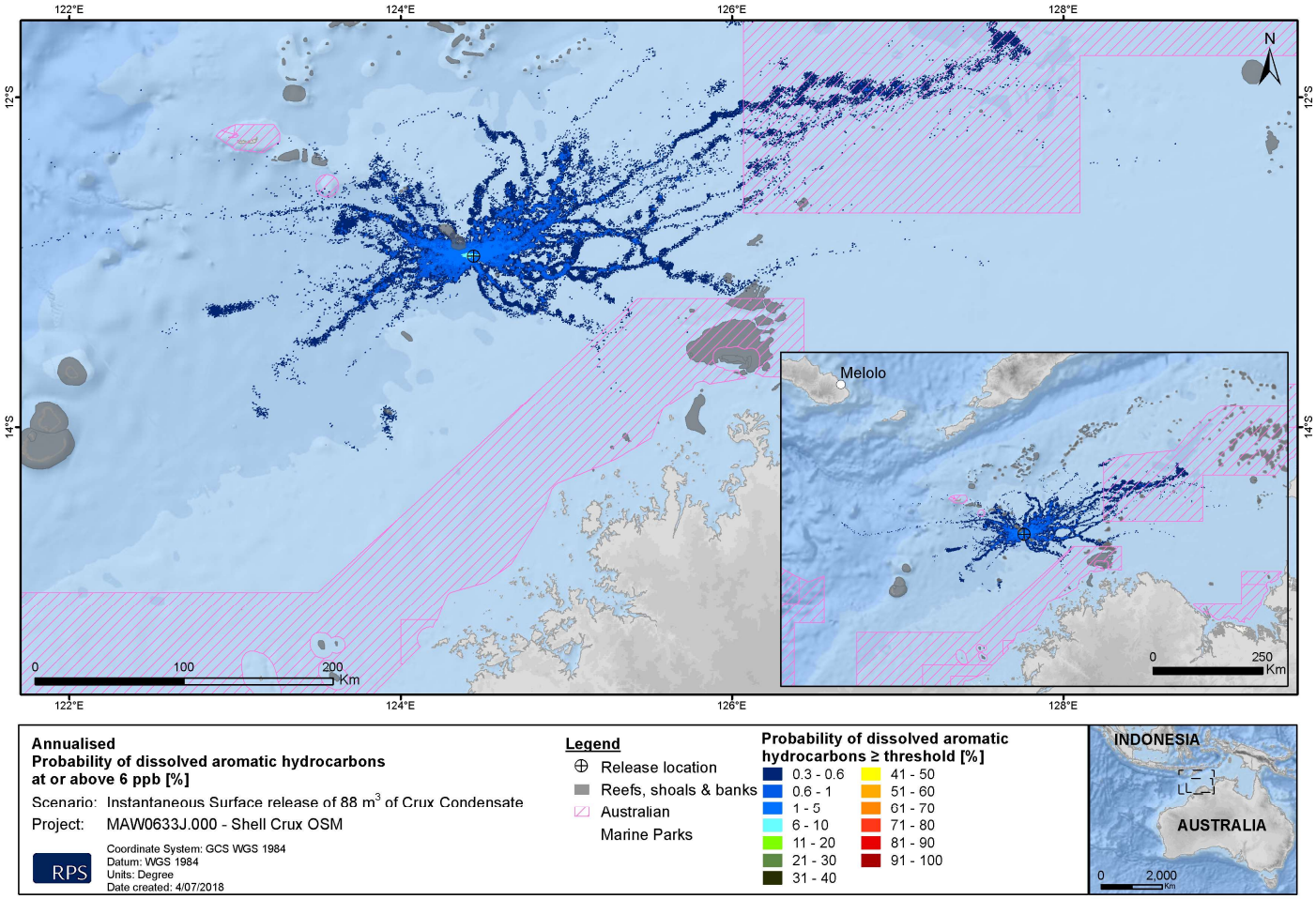


Figure 3.21 Subsurface Hydrocarbons | Dissolved | Inventory Scenario | Stochastic Outcomes. Predicted annualised probability of dissolved aromatic hydrocarbon concentrations at or above 6 ppb resulting from an instantaneous surface release of Crux condensate at the Crux platform.

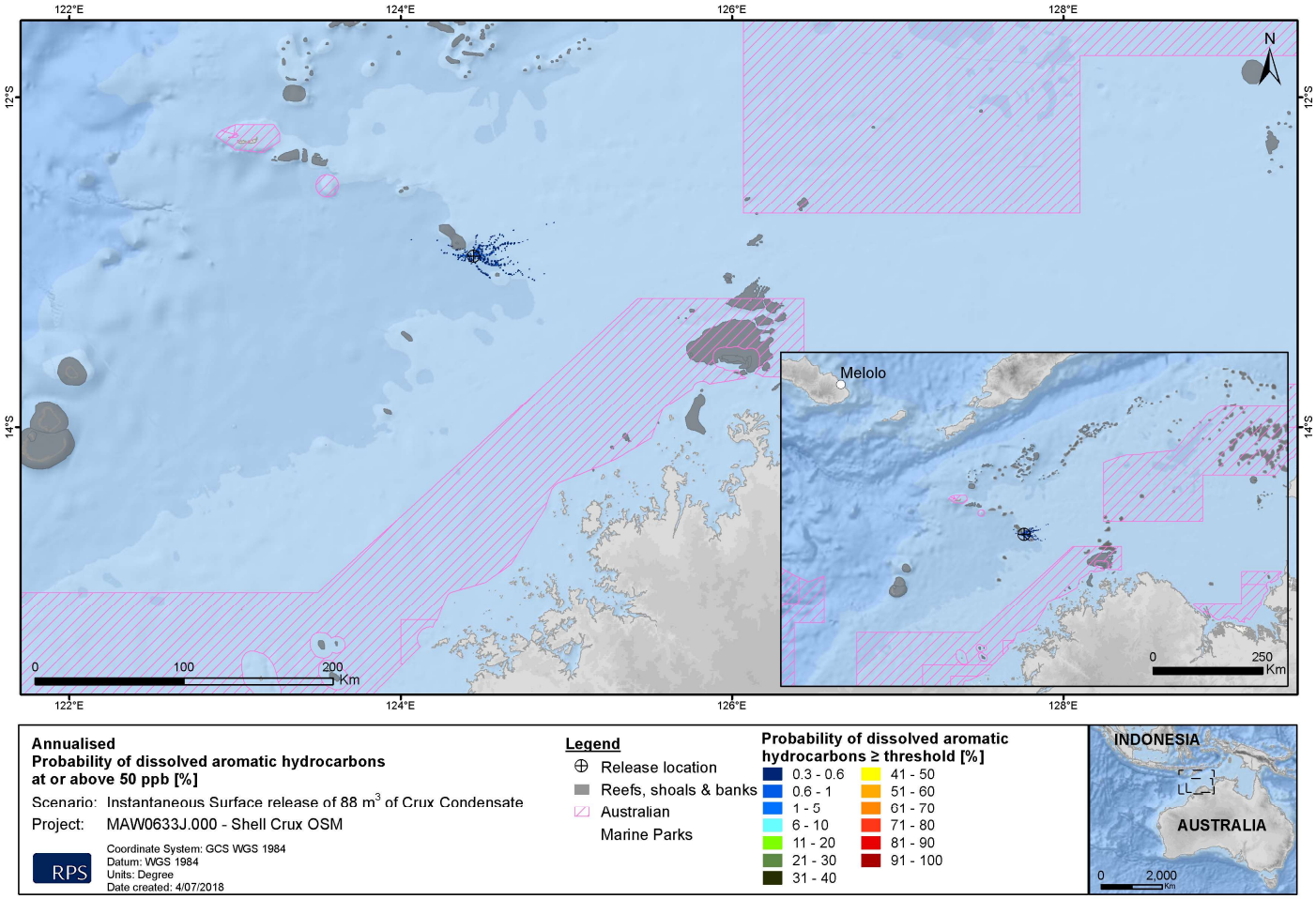


Figure 3.22 Subsurface Hydrocarbons | Dissolved | Inventory Scenario | Stochastic Outcomes. Predicted annualised probability of dissolved aromatic hydrocarbon concentrations at or above 50 ppb resulting from an instantaneous surface release of Crux condensate at the Crux platform.

3.4 Scenario 3 – Short-Term Subsurface Release of Crux Condensate from a Pipeline Rupture Near Heywood Shoal

3.4.1 Discussion of Results

3.4.1.1 Overview

This scenario investigated the probability of exposure to key sensitive receptors by hydrocarbons resulting from a short-term (5.6 hour) subsurface release following from a rupture of the export pipeline, discharging 2,037 m^3 of Crux condensate at the closest point to Heywood Shoal at any time of year, with no spill response mitigation measures applied.

Considering the discharge characteristics, the properties of the hydrocarbon and its expected weathering behaviour, the relatively large hydrocarbon droplets initially entrained in the water column will rise to the surface within a few hours after release. Floating films are likely to be formed under typical wind conditions, and condensate that is re-entrained into the wave-mixed layer under stronger wind conditions will have the potential to rise back to the surface once calmer conditions prevail. It is likely that the bulk of the hydrocarbon mass will initially be found on the water surface or in the wave-mixed layer. Once at the surface evaporation rates will be high, given the large proportion of volatile (55%) and semi-volatile (23%) compounds within the oil, with the residual fraction (8%) persisting in the environment until degradation processes occur (over periods of weeks to months). Considering the spill volume and the relatively high likelihood of entrainment occurring, there is a high potential for dissolution of soluble aromatic compounds.

Figure 3.23 to Figure 3.25 show a summary of the areal extent for all hydrocarbon phases at the low, moderate and high thresholds, respectively.

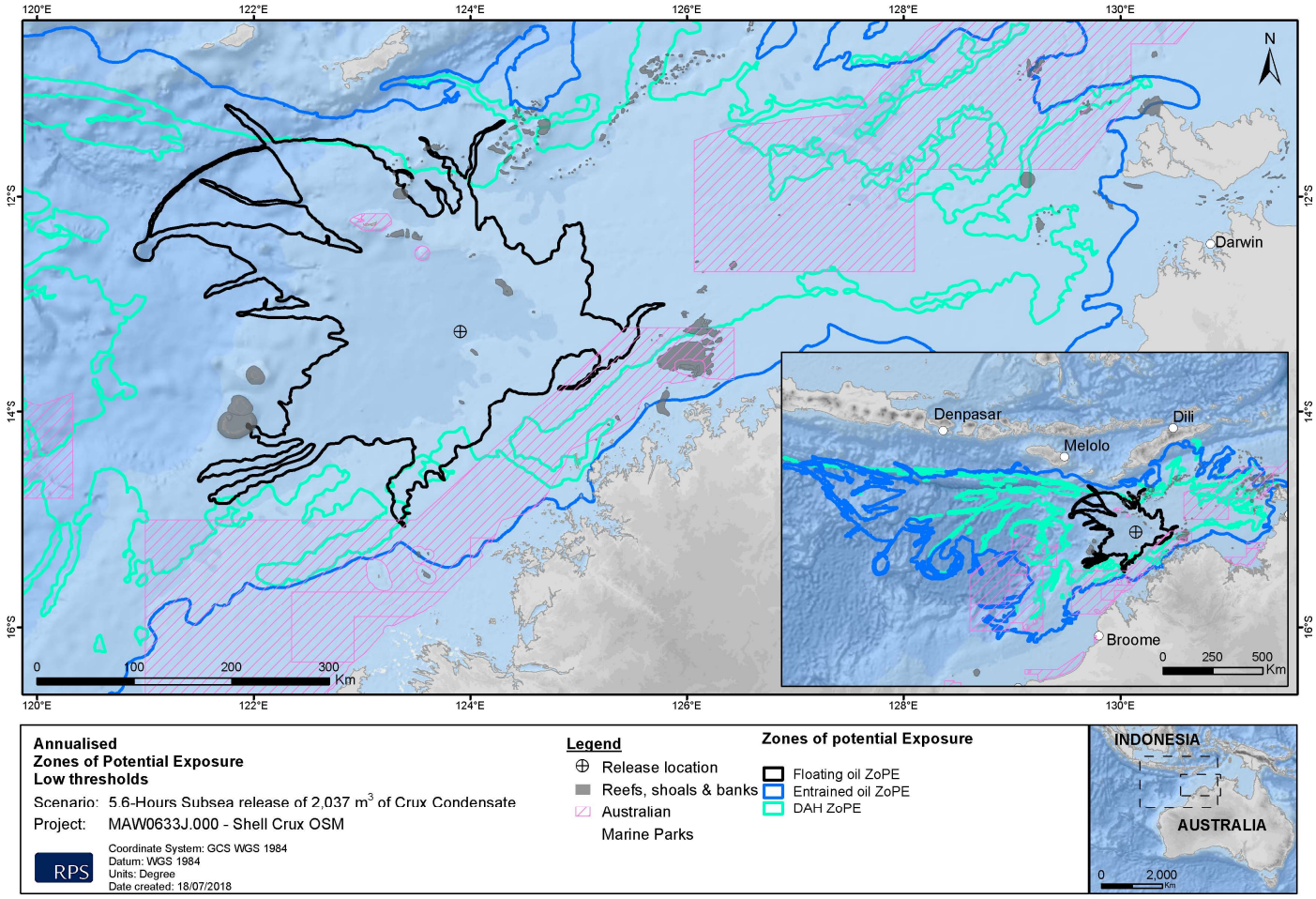


Figure 3.23 Surface and Subsurface Hydrocarbons | Pipeline Scenario | Stochastic Outcomes. Areal extent of potential exposure at the low thresholds resulting from a 5.6-hour subsurface release of Crux condensate from the export pipeline.

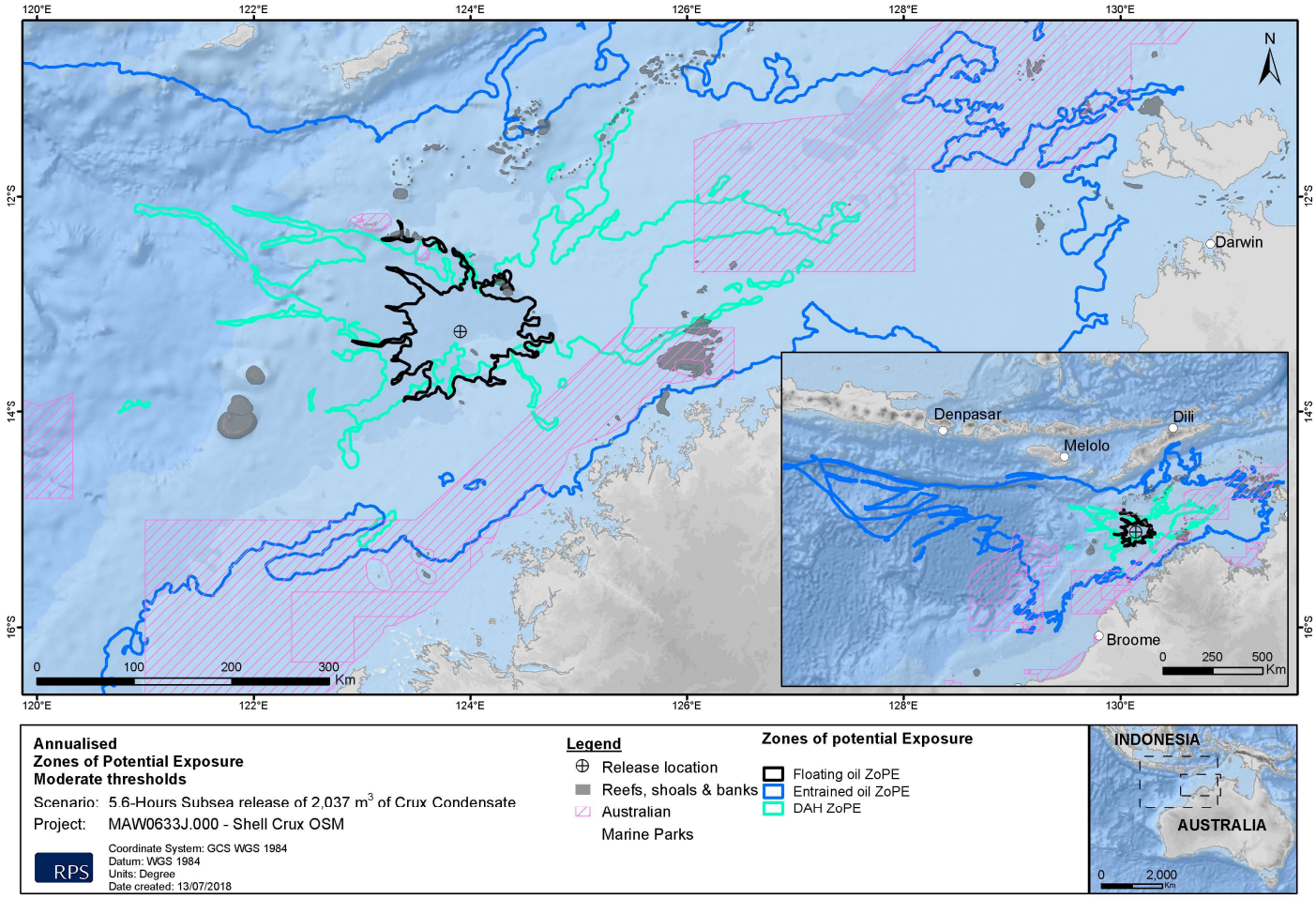


Figure 3.24 Surface and Subsurface Hydrocarbons | Pipeline Scenario | Stochastic Outcomes. Areal extent of potential exposure at the moderate thresholds resulting from a 5.6-hour subsurface release of Crux condensate from the export pipeline.

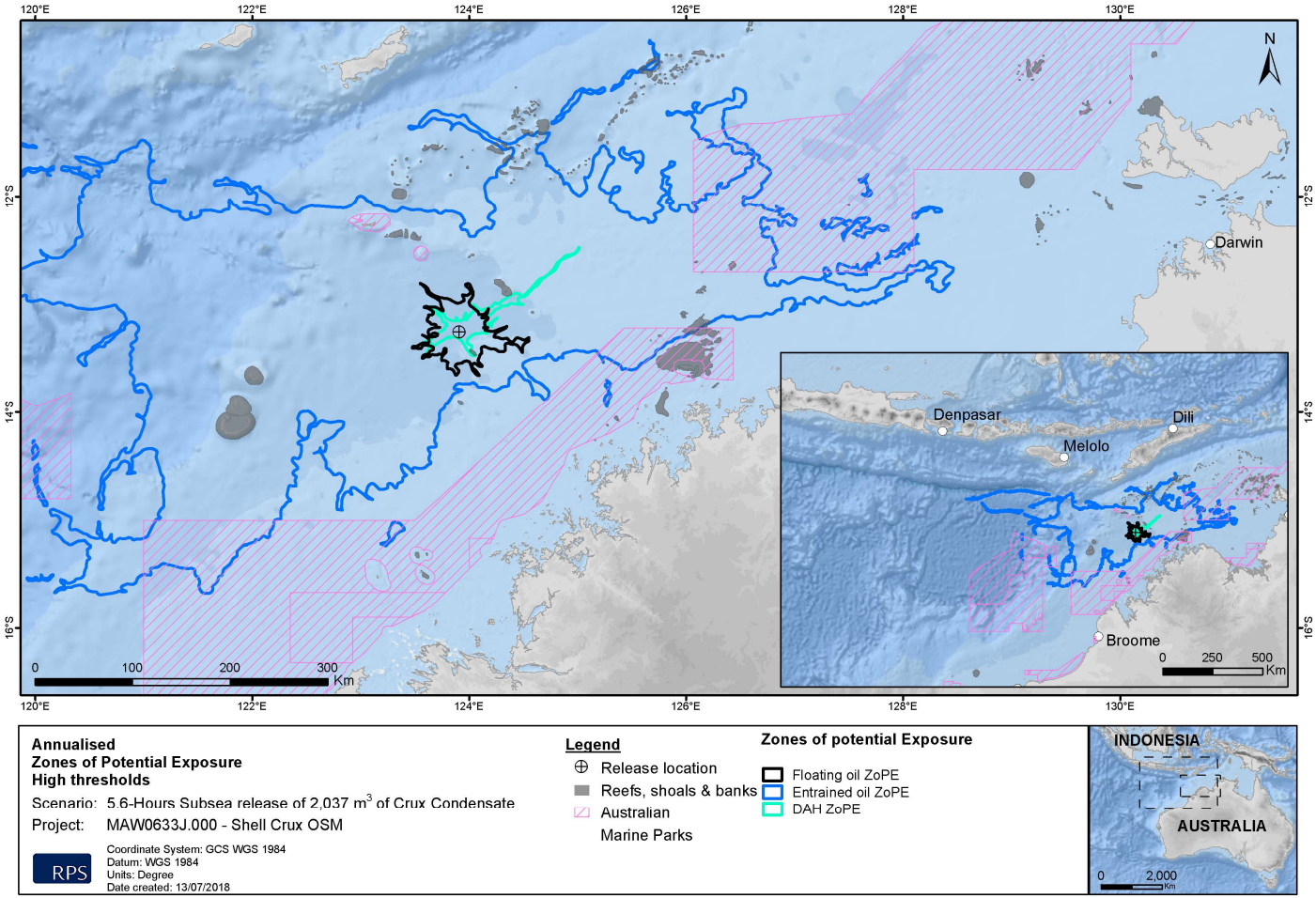


Figure 3.25 Surface and Subsurface Hydrocarbons | Pipeline Scenario | Stochastic Outcomes. Areal extent of potential exposure at the high thresholds resulting from a 5.6-hour subsurface release of Crux condensate from the export pipeline.

RPS

3.4.1.2 Floating and Shoreline Hydrocarbons

The annualised probability contour figures (Figure 3.27 and Appendix C) indicate that hydrocarbons on the sea surface at or greater than the threshold concentrations may travel up to 581 km (1 g/m^2) from the release location, with low probability of contact to the nearest shoreline receptors. The ZoPE at the moderate and high floating oil threshold is further reduced, with floating oil not predicted to exceed the moderate (10 g/m^2) and high (25 g/m^2) thresholds beyond distances of 130 km and 118 km, respectively.

Only a small number of receptors are predicted to receive floating oil at high threshold concentrations. The Southern Bluefin Tuna Fishery, Western Skipjack Fishery and Western Tuna and Billfish Fishery receptors have the highest predicted probability of contact at the high threshold, being 71% (Table 3.13). Probabilities of 75% are predicted at the moderate threshold for these receptors.

The minimum time to contact with any receptor by floating oil at the low and moderate thresholds is forecast at approximately 2 hours at the Southern Bluefin Tuna Fishery, Western Skipjack Fishery, Western Tuna and Billfish Fishery, and North-West Slope Trawl Fishery receptors.

Potential for accumulation of hydrocarbons on shorelines is predicted to be low (<3% probability at the moderate threshold of 100 g/m^2), with a maximum accumulated volume of 116 m^3 forecast at Hawksbill Turtle BIA, Green Turtle BIA and Ashmore Reef AMP. Maximum local accumulated concentration on shorelines of 3,131 g/m^2 is forecast at Hawksbill Turtle BIA, Green Turtle BIA and Ashmore Reef AMP (Table 3.13).

Table 3.12 Maximum distances from the release location to zones of floating oil exposure for Scenario 3 (2,037 m^3 Crux condensate).

	Floating Oil Exposure Threshold		
	Low (1-10 g/m^2)	**Moderate (10-25 g/m^2)**	**High (>25 g/m^2)**
Maximum distance travelled (km) by a spill trajectory	581	130	118

3.4.1.3 Subsurface – Entrained Hydrocarbons

The annualised probability contour figures (Figure 3.29 and Appendix C) indicate that entrained oil concentrations at or greater than the threshold concentrations travel up to 1,770 km (10 ppb) from the release location. The maximum extent is forecast to be reduced for the moderate (100 ppb; 1,762 km) and high (500 ppb; 1,478 km) thresholds.

A small number of receptors are predicted to receive entrained oil at high threshold concentrations. Southern Bluefin Tuna Fishery, Western Skipjack Fishery, Western Tuna and Billfish Fishery, and North-West Slope Trawl Fishery receptors are predicted to be contacted at the high threshold with probabilities greater than 45% (Table 3.14). Higher probabilities of contact at a greater number of receptors are predicted at the low and moderate thresholds.

Receptors with the highest probability of receiving entrained oil concentrations at the low threshold are Continental Slope Demersal Fish Communities KEF (23%), Ancient Coastline at 125 m Depth Contour KEF (22%), Carbonate Bank and Terrace System of Sahul Shelf KEF (17%), Eugene McDermott Shoal (23%) and Vulcan Shoals (16%). The listed sensitive receptors are also contacted at the moderate threshold with lower probabilities.

The minimum time to contact with any receptor by entrained oil at the low threshold is forecast at Southern Bluefin Tuna Fishery, Western Skipjack Fishery, Western Tuna and Billfish Fishery, and North-West Slope Trawl Fishery, at approximately 1 hour.

3.4.1.4 Subsurface – Dissolved Aromatic Hydrocarbons

The annualised probability contour figures (Figure 3.32 to Figure 3.34) indicate that dissolved aromatic hydrocarbons at or greater than the threshold concentrations travel up to 1,770 km (6 ppb) from the release location. The maximum extent is forecast to be reduced for the moderate (50 ppb; 715 km) and high (400 ppb; 251 km) thresholds.

A small number of receptors are predicted to receive dissolved aromatic hydrocarbons at high threshold concentrations. Southern Bluefin Tuna Fishery, Western Skipjack Fishery, Western Tuna and Billfish Fishery, and North-West Slope Trawl Fishery receptors are predicted to be contacted at the high threshold with probabilities of 5 % (Table 3.15). These receptors are predicted to be contacted at the moderate threshold with probabilities of 16%.

Receptors with the highest probability of receiving dissolved aromatic hydrocarbons at low threshold concentrations are Continental Slope Demersal Fish Communities KEF (9%), Ancient Coastline at 125 m Depth Contour KEF (8%), and Eugene McDermott Shoal (7%). These receptors are also contacted at the moderate threshold with lower probabilities.

3.4.1.5 Deterministic Cases

A replicate simulation during the transitional season (spill starting at 21:00 14th September 2011) has been identified as the worst-case replicate according to the maximum oil volume accumulated across all shoreline receptors and minimum time to commencement of oil accumulation at any shoreline receptor criteria for Scenario 3 (116 m^3 and 6 days, respectively, at Ashmore Reef and Cartier Island and Surrounding Commonwealth Waters KEF). Figures showing the evolution of this spill simulation are contained in Appendix E. Hydrocarbons on the sea surface mainly drifted north-west of the release location. The potential floating oil exposure zones were shown up to 312 km, 34 km and 14 km of the release location at the low, moderate and high thresholds, respectively. The entrained oil and dissolved aromatic hydrocarbons were shown to move west and south-west of the release location. Low, moderate and high entrained hydrocarbons were recorded up to 1,419 km, 1,323 km and 12 km, respectively, from the release location. Low and moderate dissolved aromatic hydrocarbons were observed up to 428 km, 276 km, respectively, from the release location.

A replicate simulation during the transitional season (spill starting at 10:00 19th September 2014) has been identified as the worst-case replicate according to the maximum length of oiled shoreline criteria for Scenario 3 (10 km at Ashmore Reef and Cartier Island and Surrounding Commonwealth Waters KEF). Hydrocarbons on the sea surface mainly drifted north-west of the release location. The potential floating oil exposure zones were shown up to 115 km, 12 km and 10 km of the release location at the low, moderate and high thresholds, respectively. The entrained oil and dissolved aromatic hydrocarbons were shown to move west and northwest of the release location. Low, moderate and high entrained hydrocarbons were recorded up to 1,017km, 2 km and 2 km, respectively, from the release location. Low and moderate dissolved aromatic hydrocarbons were observed up to 20 km and 2 km, respectively, from the release location.

RPS

3.4.2 Floating and Shoreline Hydrocarbons

Table 3.13 Expected annualised floating and shoreline oil outcomes at sensitive receptors resulting from a 5.6-hour subsurface release of Crux condensate from the export pipeline.

	Receptor	Probability (%) of films arriving at receptors at			Minimum time to receptor (hours) for films at			Probability (%) of shoreline oil on receptors at			Minimum time to receptor (hours) for shoreline oil at			Maximum local accumulated concentration (g/m²)		Maximum accumulated volume (m³) along this shoreline		Maximum length of shoreline (km) with concentrations ≥10.0 g/m²	
		≥1 g/m²	≥10 g/m²	≥25 g/m²	≥1 g/m²	≥10 g/m²	≥25 g/m²	≥10 g/m²	≥100 g/m²	≥1,000 g/m²	≥10 g/m²	≥100 g/m²	≥1,000 g/m²	averaged over all replicate simulations	worst replicate simulation	averaged over all replicate simulations	worst replicate simulation	averaged over all replicate simulations	worst replicate simulation
Coastlines	Cobourg Peninsula	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	4.2	<1	<1	NC	NC
	Indonesia	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	2.1	<1	<1	NC	NC
	Joseph Bonaparte Gulf Northern Territory	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	1.3	<1	<1	NC	NC
	Kimberley Coast	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	5.4	<1	<1	NC	NC
	Timor Leste	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	NC	NC	NC	NC	NC	NC
Islands	Admiralty Gulf Islands	<0.3	<0.3	<0.3	NC	NC	NC	0.6	<0.3	<0.3	959	NC	NC	<0.1	24	<1	<1	<1	<1
	Bathurst Island	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	0.2	<1	<1	NC	NC
	Bigge Island	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	2	<1	<1	NC	NC
	Bonaparte Archipelago	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	6.7	<1	<1	NC	NC
	Browse Island	1.5	<0.3	<0.3	142	NC	NC	4.2	2.7	0.9	148	149	151	23	2,009	2	48	<1	3
	Cassini Island	<0.3	<0.3	<0.3	NC	NC	NC	0.6	<0.3	<0.3	874	NC	NC	0.1	32	<1	<1	<1	4
	Coronation Island Group	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	0.3	<1	<1	NC	NC
	Croker Island	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	0.7	<1	<1	NC	NC
	Greenhill Island	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	0.9	<1	<1	NC	NC
	Jones Island	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	0.8	<1	<1	NC	NC
	Long Island Kimberley	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	6.7	<1	<1	NC	NC
	Melville Island	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	4.6	<1	<1	NC	NC
	Montalivet Island	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	0.2	<1	<1	NC	NC
	Montgomery Islands	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	1.4	<1	<1	NC	NC
	Montgomery Islands and Reef	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	1.4	<1	<1	NC	NC
	Peron Islands	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	<0.1	<1	<1	NC	NC
	Troughton Island	<0.3	<0.3	<0.3	NC	NC	NC	0.9	<0.3	<0.3	819	NC	NC	0.3	75	<1	<1	<1	<1
	White Island*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Reefs	Beagle and Dingo Reefs*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	East Holothuria Reef*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Heritage Reef*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Hibernia Reef*	0.6	<0.3	<0.3	281	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Ingram Reef*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

RPS

	Receptor	Probability (%) of films arriving at receptors at			Minimum time to receptor (hours) for films at			Probability (%) of shoreline oil on receptors at			Minimum time to receptor (hours) for shoreline oil at			Maximum local accumulated concentration (g/m²)		Maximum accumulated volume (m³) along this shoreline		Maximum length of shoreline (km) with concentrations ≥10.0 g/m²	
		≥1 g/m²	≥10 g/m²	≥25 g/m²	≥1 g/m²	≥10 g/m²	≥25 g/m²	≥10 g/m²	≥100 g/m²	≥1,000 g/m²	≥10 g/m²	≥100 g/m²	≥1,000 g/m²	averaged over all replicate simulations	worst replicate simulation	averaged over all replicate simulations	worst replicate simulation	averaged over all replicate simulations	worst replicate simulation
Shoals	Jamieson Reef*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Long Reef	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	8.9	<1	<1	NC	NC
	Oliver Rock*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Rothery Reef*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Sandy Islet	<0.3	<0.3	<0.3	NC	NC	NC	2.1	<0.3	<0.3	244	NC	NC	0.7	54	<1	<1	<1	<1
	Scott Reef North*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Scott Reef South	0.6	<0.3	<0.3	199	NC	NC	2.1	<0.3	<0.3	244	NC	NC	0.7	54	<1	<1	<1	<1
	Seringapatam Reef*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	The Boxers*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	The Boxers Area*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	West Holothuria Reef*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Barracouta Shoals*	1.2	<0.3	<0.3	156	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Barton Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Bassett-Smith Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Big Bank Shoals*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Calder Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Cootamundra Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Deep Shoal 1*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Deep Shoal 2*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Dillon Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Echo Shoals*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Echuca Shoal*	1.8	<0.3	<0.3	142	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Eugene McDermott Shoal*	3.6	<0.3	<0.3	77	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Fantome Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Goeree Shoal*	1.8	<0.3	<0.3	65	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Heywood Shoal*	6	2.7	1.2	13	13	14	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Jabiru Shoals*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Karmt Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Mangola Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Marie Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Mermaid Shoal	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	<0.1	<1	<1	NC	NC

RPS

	Receptor	Probability (%) of films arriving at receptors at			Minimum time to receptor (hours) for films at			Probability (%) of shoreline oil on receptors at			Minimum time to receptor (hours) for shoreline oil at			Maximum local accumulated concentration (g/m²)		Maximum accumulated volume (m³) along this shoreline		Maximum length of shoreline (km) with concentrations ≥10.0 g/m²	
		≥1 g/m²	≥10 g/m²	≥25 g/m²	≥1 g/m²	≥10 g/m²	≥25 g/m²	≥10 g/m²	≥100 g/m²	≥1,000 g/m²	≥10 g/m²	≥100 g/m²	≥1,000 g/m²	averaged over all replicate simulations	worst replicate simulation	averaged over all replicate simulations	worst replicate simulation	averaged over all replicate simulations	worst replicate simulation
	Moss Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Newby Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Parry Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Pee Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Penguin Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Penguin Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Shepparton Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Van Cloon Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Vee Shoal*	0.6	<0.3	<0.3	260	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Vulcan Shoals*	2.7	0.6	<0.3	61	107	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Banks	Baldwin Bank*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Banks	Bellona Bank*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Banks	Branch Banks*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Banks	Favell Bank*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Banks	Flat Top Bank*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Banks	Gale Bank*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Banks	Holothuria Banks*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Banks	Johnson Bank*	1.8	0.9	<0.3	122	132	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Banks	Margaret Harries Bank*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Banks	Otway Bank*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Banks	Sahul Bank*	0.6	<0.3	<0.3	299	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Banks	Sunrise Bank*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Banks	Tait Bank*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Banks	Woodbine Bank*	2.1	0.9	<0.3	115	121	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Marine Parks	Ashmore Reef AMP	1.2	<0.3	<0.3	145	NC	NC	2.7	1.2	0.9	145	150	155	15	3,131	2	116	<1	7
Marine Parks	Lalang-garram/Camden Sound MP	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	1.4	<1	<1	NC	NC
Marine Parks	Cartier Island AMP	1.5	<0.3	<0.3	104	NC	NC	4.2	2.7	0.6	197	215	338	17	3,131	2	62	<1	4
Marine Parks	Garig Gunak Barlu NP	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	0.9	<1	<1	NC	NC
Marine Parks	Kimberley AMP	0.9	<0.3	<0.3	239	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	0.4	<1	<1	NC	NC
Marine Parks	North Lalang-garram MP & North Kimberley MP	<0.3	<0.3	<0.3	NC	NC	NC	0.9	<0.3	<0.3	819	NC	NC	0.3	75	<1	3	<1	7
Marine Parks	Mermaid Reef AMP	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	0.5	<1	<1	NC	NC

RPS

	Receptor	Probability (%) of films arriving at receptors at			Minimum time to receptor (hours) for films at			Probability (%) of shoreline oil on receptors at			Minimum time to receptor (hours) for shoreline oil at			Maximum local accumulated concentration (g/m²)		Maximum accumulated volume (m³) along this shoreline		Maximum length of shoreline (km) with concentrations ≥10.0 g/m²	
		≥1 g/m²	≥10 g/m²	≥25 g/m²	≥1 g/m²	≥10 g/m²	≥25 g/m²	≥10 g/m²	≥100 g/m²	≥1,000 g/m²	≥10 g/m²	≥100 g/m²	≥1,000 g/m²	averaged over all replicate simulations	worst replicate simulation	averaged over all replicate simulations	worst replicate simulation	averaged over all replicate simulations	worst replicate simulation
	Oceanic Shoals AMP*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Prince Regent NP Coast	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	0.9	<1	<1	NC	NC
Ecological Features	Ancient Coastline at 125 m depth contour*	10.2	5.7	3.9	7	8	8	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Ashmore Reef and Cartier Island and surrounding Commonwealth Waters	2.1	0.9	0.9	103	111	122	4.2	2.7	0.9	145	150	155	17	3,131	3	116	<1	10
	Canyons linking the Argo Abyssal Plain with the Scott Plateau*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Carbonate bank & terrace system of Van Diemen Rise*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Carbonate bank and terrace system of Sahul Shelf	0.9	<0.3	<0.3	127	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	0.2	<1	<1	NC	NC
	Continental Slope Demersal Fish Communities*	7.2	2.4	0.9	23	30	30	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Mermaid Reef and Commonwealth Waters surrounding Rowley Shoals	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	0.5	<1	<1	NC	NC
	Pinnacles of the Bonaparte Basin*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Seringapatam Reef and Commonwealth Waters in the Scott Reef Complex	0.6	<0.3	<0.3	198	NC	NC	2.1	<0.3	<0.3	244	NC	NC	0.7	54	<1	<1	<1	<1
	Shelf break and slope of the Arafura Shelf*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Fisheries	Northern Prawn Fishery	0.6	<0.3	<0.3	933	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	4.6	NC	NC	NC	NC
	North-West Slope Trawl Fishery	78.9	74.7	71.4	2	2	2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Southern Bluefin Tuna Fishery	78.9	74.7	71.4	2	2	2	4.2	2.7	0.9	145	150	155	17	3,131	NC	NC	NC	NC
	Timor Reef Fishery (NT Managed)*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Western Skipjack Fishery	78.9	74.7	71.4	2	2	2	4.2	2.7	0.9	145	150	155	17	3,131	NC	NC	NC	NC
	Western Tuna and Billfish Fishery	78.9	74.7	71.4	2	2	2	4.2	2.7	0.9	145	150	155	17	3,131	NC	NC	NC	NC
Biologically Important Areas	Flatback Turtle BIA	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	4.6	<1	<1	NC	NC
	Green Turtle BIA	3	0.9	0.9	91	98	122	4.2	2.7	0.9	145	150	155	17	3,131	3	116	<1	10
	Hawksbill Turtle BIA	1.2	0.9	<0.3	136	139	NC	2.7	1.2	0.9	145	150	155	15	3,131	2	116	<1	7
	Leatherback Turtle BIA	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	0.9	<1	<1	NC	NC
	Loggerhead Turtle BIA	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	NC	NC	NC	NC	NC	NC
	Olive Ridley Turtle BIA	0.6	<0.3	<0.3	933	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	1	<1	<1	NC	NC

NC: No contact to receptor predicted for specified threshold. NA: Not applicable.

** Floating oil will not accumulate on submerged features and at open ocean locations.*

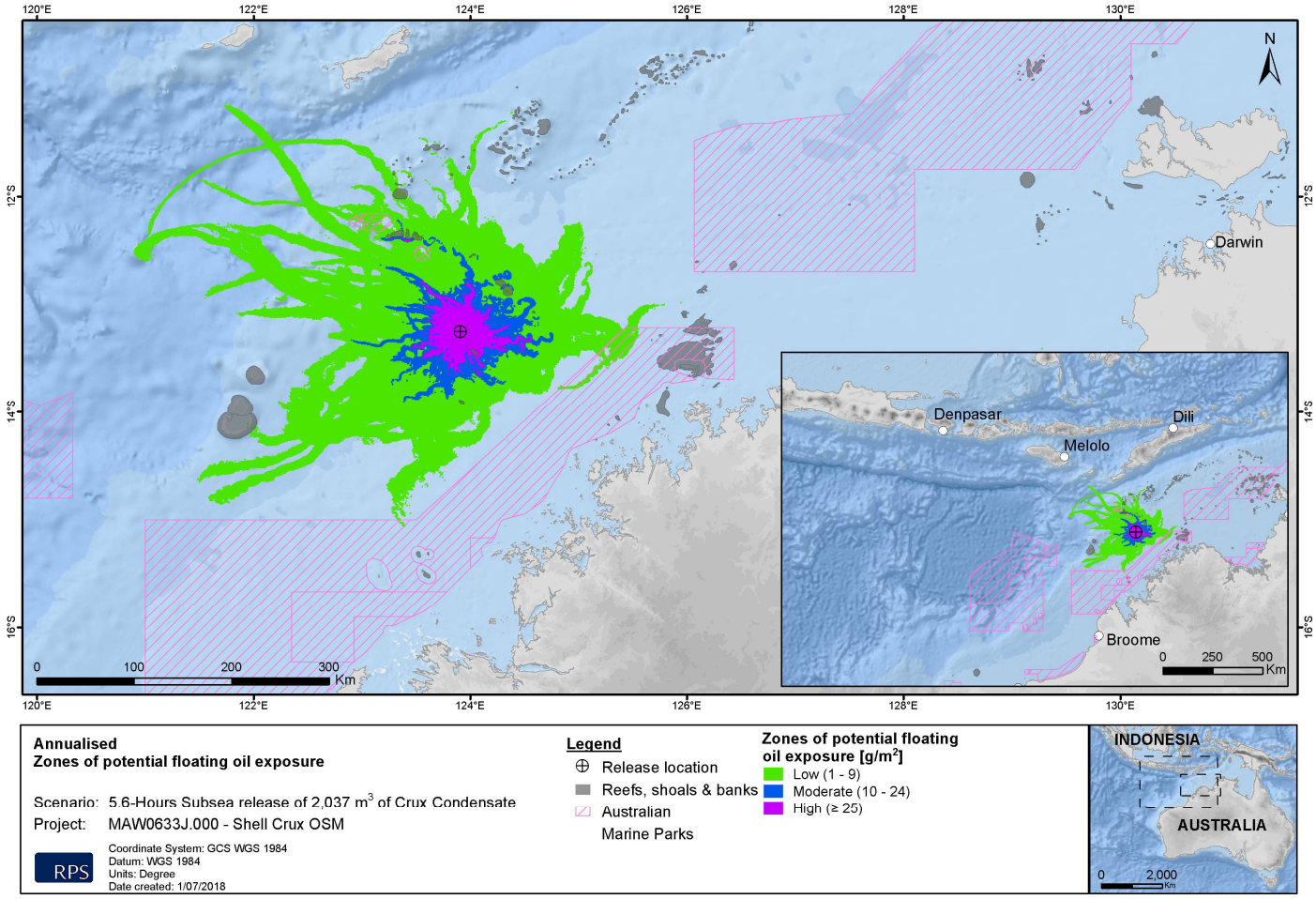


Figure 3.26 Surface Hydrocarbons | Pipeline Scenario | Stochastic Outcomes. Areal extent of potential exposure at defined floating oil threshold concentrations resulting from a 5.6-hour subsurface release of Crux condensate from the export pipeline.

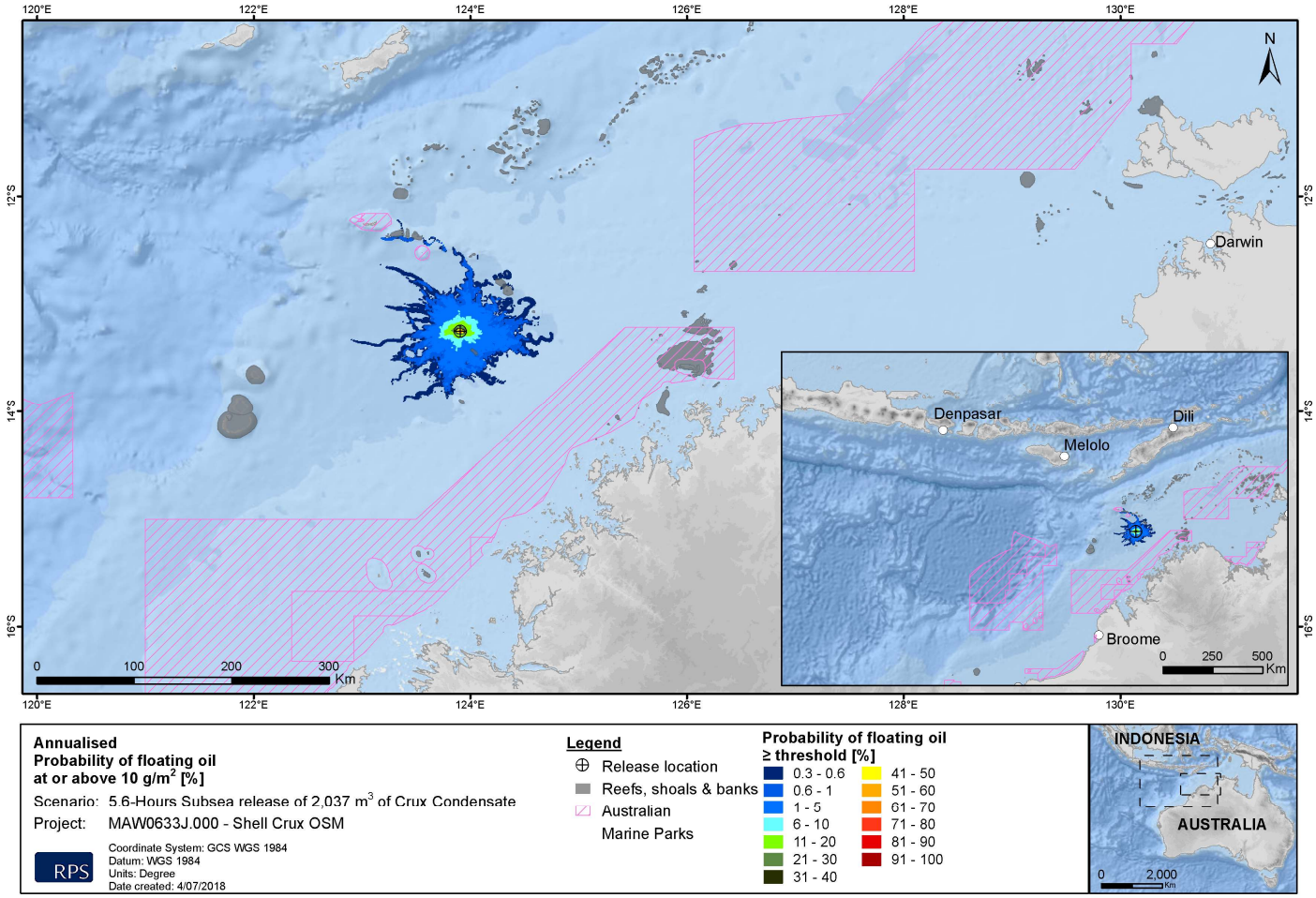


Figure 3.27 Surface Hydrocarbons | Pipeline Scenario | Stochastic Outcomes. Predicted annualised probability of floating oil concentrations at or above 10 g/m^2 resulting from a 5.6-hour subsurface release of Crux condensate from the export pipeline.

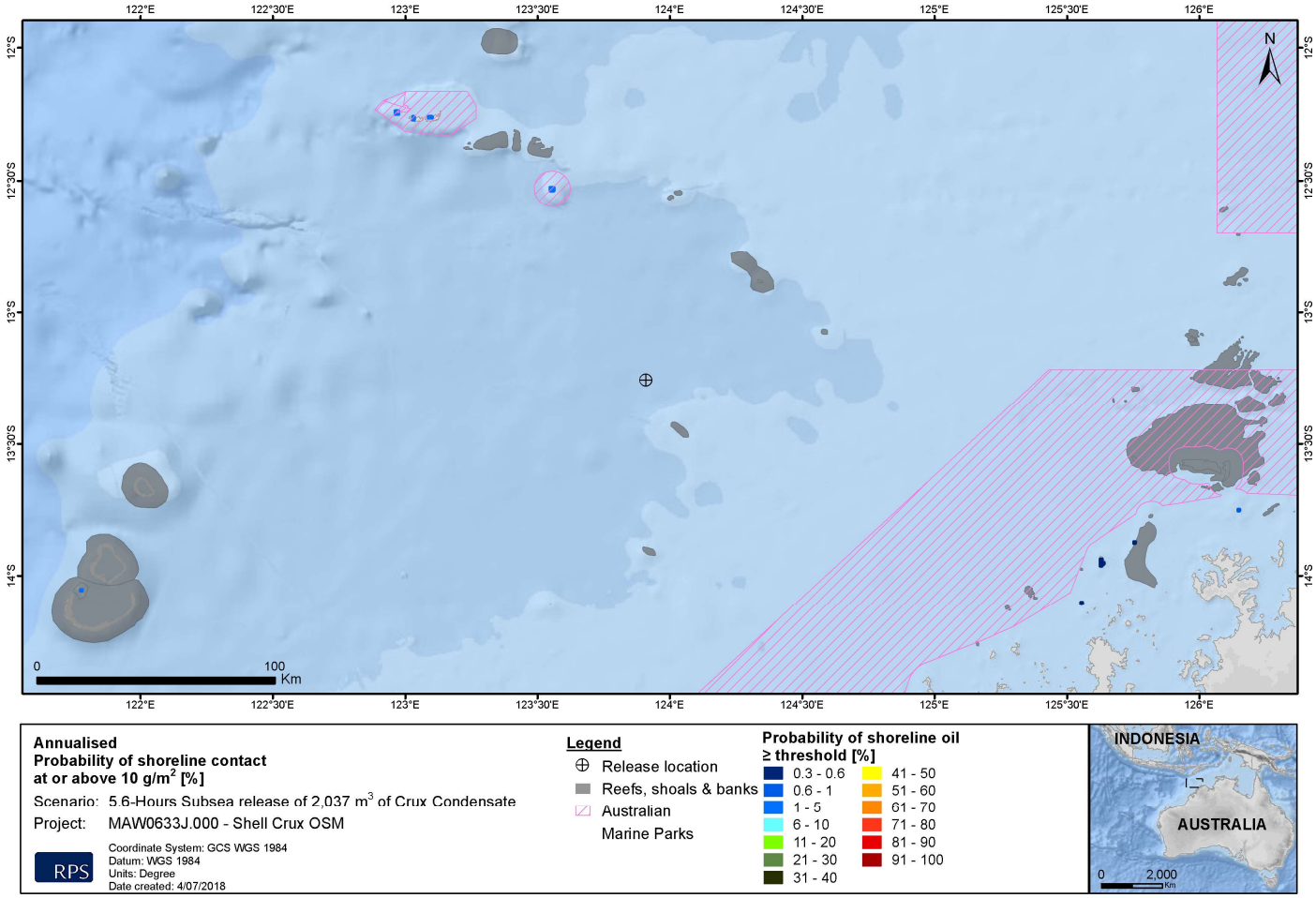


Figure 3.28 Shoreline Hydrocarbons | Pipeline Scenario | Stochastic Outcomes. Predicted annualised probability of shoreline oil concentrations at or above 10 g/m^2 resulting from a 5.6-hour subsurface release of Crux condensate from the export pipeline.

RPS

3.4.3 Entrained Hydrocarbons

Table 3.14 Expected annualised entrained oil outcomes at sensitive receptors resulting from a 5.6-hour subsurface release of Crux condensate from the export pipeline.

	Receptor	Probability (%) of entrained hydrocarbon concentration contact at specific receptor depth			Minimum time to receptor waters (hours)		
		≥10 ppb	≥100 ppb	≥500 ppb	≥10 ppb	≥100 ppb	≥500 ppb
Coastlines	Cobourg Peninsula	<0.3	<0.3	<0.3	NC	NC	NC
	Indonesia	0.6	<0.3	<0.3	520	NC	NC
	Joseph Bonaparte Gulf Northern Territory	<0.3	<0.3	<0.3	NC	NC	NC
	Kimberley Coast	0.6	<0.3	<0.3	950	NC	NC
	Timor Leste	0.9	0.6	<0.3	926	987	NC
Islands	Admiralty Gulf Islands	0.6	<0.3	<0.3	444	NC	NC
	Bathurst Island	0.6	<0.3	<0.3	996	NC	NC
	Bigge Island	0.9	0.6	<0.3	347	413	NC
	Bonaparte Archipelago	1.2	0.9	<0.3	283	302	NC
	Browse Island	7.5	1.8	<0.3	97	99	NC
	Cassini Island	0.6	0.6	<0.3	434	439	NC
	Coronation Island Group	0.9	<0.3	<0.3	260	NC	NC
	Croker Island	<0.3	<0.3	<0.3	NC	NC	NC
	Greenhill Island	<0.3	<0.3	<0.3	NC	NC	NC
	Jones Island	<0.3	<0.3	<0.3	NC	NC	NC
	Long Island Kimberley	1.2	0.9	<0.3	261	290	NC
	Melville Island	<0.3	<0.3	<0.3	NC	NC	NC
	Montalivet Island	1.2	0.6	<0.3	362	373	NC
	Montgomery Islands	<0.3	<0.3	<0.3	NC	NC	NC
	Montgomery Islands and Reef	<0.3	<0.3	<0.3	NC	NC	NC
	Peron Islands	0.6	<0.3	<0.3	1,006	NC	NC
	Troughton Island	0.9	0.6	<0.3	544	544	NC
	White Island	0.6	<0.3	<0.3	689	NC	NC
Reefs	Beagle and Dingo Reefs	0.6	0.6	<0.3	390	413	NC
	East Holothuria Reef	1.5	0.6	<0.3	447	470	NC
	Heritage Reef	1.2	0.6	<0.3	360	384	NC
	Hibernia Reef	2.4	0.6	<0.3	291	306	NC
	Ingram Reef	1.2	0.6	<0.3	339	342	NC

RPS

	Receptor	Probability (%) of entrained hydrocarbon concentration contact at specific receptor depth			Minimum time to receptor waters (hours)		
		≥10 ppb	≥100 ppb	≥500 ppb	≥10 ppb	≥100 ppb	≥500 ppb
	Jamieson Reef	1.8	0.6	<0.3	344	368	NC
	Long Reef	1.2	<0.3	<0.3	445	NC	NC
	Oliver Rock	0.6	0.6	<0.3	418	437	NC
	Rothery Reef	0.9	0.9	<0.3	445	457	NC
	Sandy Islet	7.8	0.9	<0.3	321	522	NC
	Scott Reef North	11.1	3.6	0.9	248	289	343
	Scott Reef South	8.4	1.5	0.6	193	207	556
	Seringapatam Reef	10.5	2.4	0.9	127	135	136
	The Boxers	1.8	0.6	<0.3	698	712	NC
	The Boxers Area	2.4	1.2	<0.3	697	712	NC
	West Holothuria Reef	1.2	<0.3	<0.3	435	NC	NC
Shoals	Barracouta Shoals	6	2.1	0.9	104	122	131
	Barton Shoal	3.9	1.2	<0.3	448	459	NC
	Bassett-Smith Shoal	3.6	0.6	<0.3	278	662	NC
	Big Bank Shoals	1.8	0.6	<0.3	477	596	NC
	Calder Shoal	1.2	<0.3	<0.3	890	NC	NC
	Cootamundra Shoal	0.9	<0.3	<0.3	904	NC	NC
	Deep Shoal 1	5.4	2.7	<0.3	225	225	NC
	Deep Shoal 2	5.1	0.6	<0.3	443	664	NC
	Dillon Shoal	3.9	0.9	<0.3	414	730	NC
	Echo Shoals	1.2	0.6	<0.3	712	723	NC
	Echuca Shoal	7.2	0.9	<0.3	82	84	NC
	Eugene McDermott Shoal	22.5	9.3	2.7	49	51	63
	Fantome Shoal	1.5	<0.3	<0.3	454	NC	NC
	Goeree Shoal	14.1	5.7	2.1	38	38	38
	Heywood Shoal	16.2	5.4	1.5	13	14	15
	Jabiru Shoals	6.6	2.1	0.6	263	265	341
	Karmt Shoal	4.2	1.2	0.6	432	541	618
	Mangola Shoal	5.7	1.2	<0.3	299	372	NC
	Marie Shoal	0.6	<0.3	<0.3	987	NC	NC
	Mermaid Shoal	0.6	<0.3	<0.3	969	NC	NC
	Moss Shoal	0.6	<0.3	<0.3	955	NC	NC

RPS

	Receptor	Probability (%) of entrained hydrocarbon concentration contact at specific receptor depth			Minimum time to receptor waters (hours)		
		≥10 ppb	≥100 ppb	≥500 ppb	≥10 ppb	≥100 ppb	≥500 ppb
	Newby Shoal	2.1	1.2	<0.3	830	893	NC
	Parry Shoal	0.6	0.6	<0.3	938	944	NC
	Pee Shoal	3.6	0.9	<0.3	333	344	NC
	Penguin Shoal	3	0.6	<0.3	204	217	NC
	Penguin Shoal	3	0.6	<0.3	204	217	NC
	Shepparton Shoal	0.9	0.6	<0.3	955	1,006	NC
	Van Cloon Shoal	3.9	1.2	<0.3	402	418	NC
	Vee Shoal	2.1	0.6	<0.3	264	766	NC
	Vulcan Shoals	16.2	7.2	2.7	36	36	36
Banks	Baldwin Bank	4.5	1.8	0.9	186	211	212
Banks	Bellona Bank	1.2	<0.3	<0.3	829	NC	NC
Banks	Branch Banks	0.9	0.6	<0.3	556	557	NC
Banks	Favell Bank	2.7	0.6	<0.3	392	502	NC
Banks	Flat Top Bank	1.2	0.9	<0.3	628	631	NC
Banks	Gale Bank	4.8	1.5	0.9	124	125	127
Banks	Holothuria Banks	3	1.2	0.6	219	226	325
Banks	Johnson Bank	6.9	2.4	0.6	125	140	143
Banks	Margaret Harries Bank	1.8	0.9	0.6	683	709	822
Banks	Otway Bank	1.5	0.9	<0.3	462	462	NC
Banks	Sahul Bank	6	1.8	0.6	273	276	315
Banks	Sunrise Bank	1.2	<0.3	<0.3	976	NC	NC
Banks	Tait Bank	0.9	<0.3	<0.3	567	NC	NC
Banks	Woodbine Bank	8.4	1.8	0.9	117	119	245
Marine Parks	Ashmore Reef AMP	7.5	2.4	0.9	154	157	283
Marine Parks	Lalang-garram/Camden Sound MP	0.6	<0.3	<0.3	475	NC	NC
Marine Parks	Cartier Island AMP	12	3.6	0.6	98	100	111
Marine Parks	Garig Gunak Barlu NP	<0.3	<0.3	<0.3	NC	NC	NC
Marine Parks	Kimberley AMP	8.4	3	1.2	82	95	140
Marine Parks	North Lalang-garram MP & North Kimberley MP	1.5	0.9	0.6	234	246	384
Marine Parks	Mermaid Reef AMP	1.8	0.9	<0.3	796	809	NC
Marine Parks	Oceanic Shoals AMP	11.1	4.2	1.2	123	124	124

RPS

	Receptor	Probability (%) of entrained hydrocarbon concentration contact at specific receptor depth			Minimum time to receptor waters (hours)		
		≥10 ppb	≥100 ppb	≥500 ppb	≥10 ppb	≥100 ppb	≥500 ppb
	Prince Regent NP Coast	<0.3	<0.3	<0.3	NC	NC	NC
Key Ecological Features	Ancient Coastline at 125 m depth contour	22.2	11.4	5.1	6	7	8
	Ashmore Reef and Cartier Island and surrounding Commonwealth Waters	12	3.6	0.9	98	100	111
	Canyons linking the Argo Abyssal Plain with the Scott Plateau	2.7	0.9	<0.3	523	592	NC
	Carbonate bank & terrace system of Van Diemen Rise	3	1.2	0.6	659	662	889
	Carbonate bank and terrace system of Sahul Shelf	17.1	8.1	2.1	74	74	75
	Continental Slope Demersal Fish Communities	23.7	11.7	5.1	24	26	26
	Mermaid Reef and Commonwealth Waters surrounding Rowley Shoals	1.8	0.9	<0.3	729	809	NC
	Pinnacles of the Bonaparte Basin	6.3	2.1	0.6	287	298	531
	Seringapatam Reef and Commonwealth Waters in the Scott Reef Complex	11.1	3.6	0.9	126	134	136
	Shelf break and slope of the Arafura Shelf	0.6	<0.3	<0.3	996	NC	NC
Fisheries	Northern Prawn Fishery	6.3	2.4	0.9	231	235	239
	North-West Slope Trawl Fishery	79.5	59.7	52.2	1	1	1
	Southern Bluefin Tuna Fishery	79.5	59.7	52.2	1	1	1
	Timor Reef Fishery (NT Managed)	1.8	0.9	0.6	758	780	822
	Western Skipjack Fishery	79.5	59.7	52.2	1	1	1
	Western Tuna and Billfish Fishery	79.5	59.7	52.2	1	1	1
Biologically Important Areas	Flatback Turtle BIA	9.6	3.9	1.2	136	137	140
	Green Turtle BIA	16.8	6	1.5	65	65	66
	Hawksbill Turtle BIA	11.1	4.5	1.2	109	142	143
	Leatherback Turtle BIA	<0.3	<0.3	<0.3	NC	NC	NC
	Loggerhead Turtle BIA	9.6	3.9	1.2	136	137	140
	Olive Ridley Turtle BIA	9.6	3.9	1.2	136	137	140

NC: No contact to receptor predicted for specified threshold.

** Probabilities and maximum concentrations calculated at depth of submerged feature.*

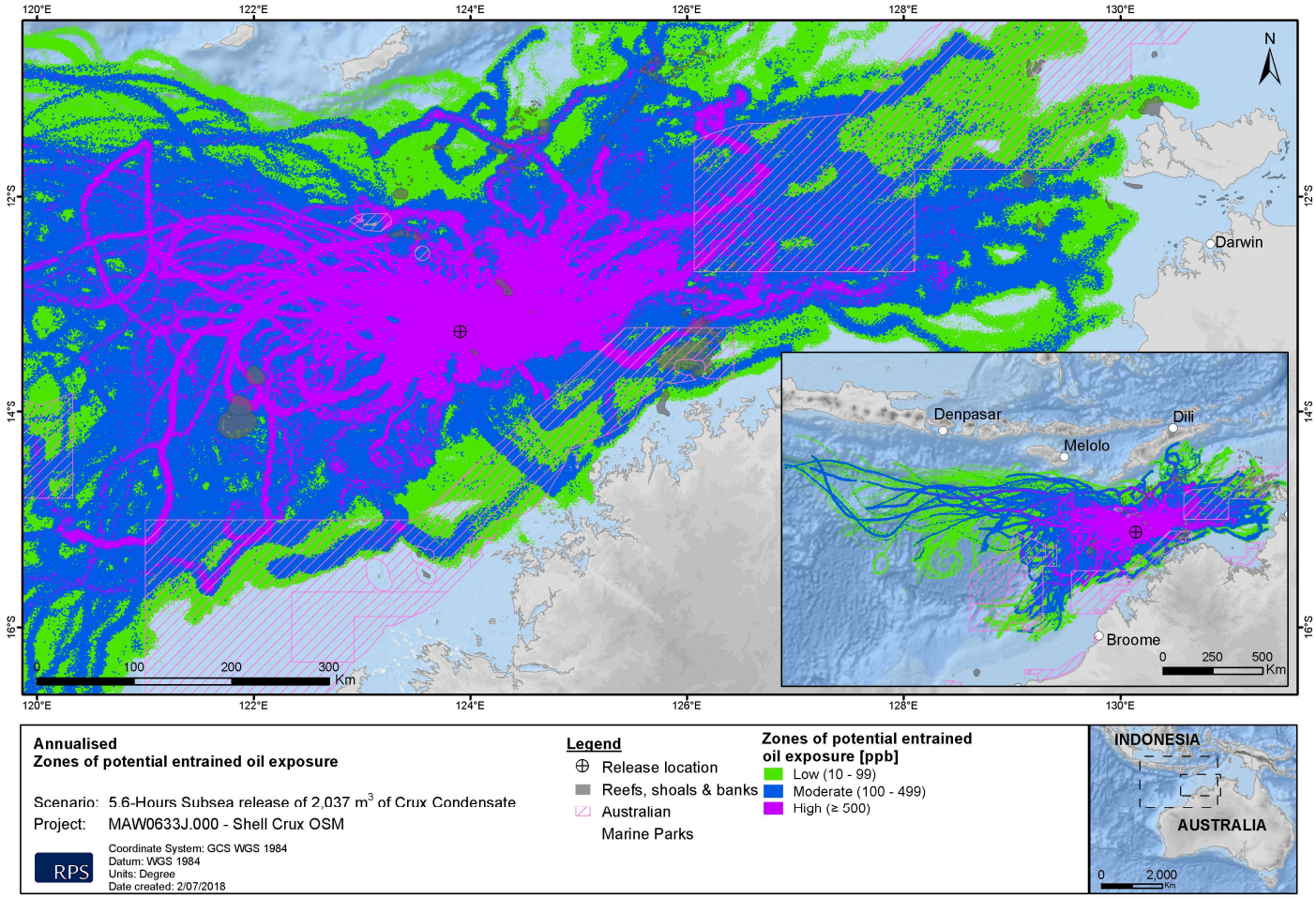


Figure 3.29 Subsurface Hydrocarbons | Entrained | Pipeline Scenario | Stochastic Outcomes. Areal extent of potential exposure at defined entrained oil threshold concentrations resulting from a 5.6-hour subsurface release of Crux condensate from the export pipeline.

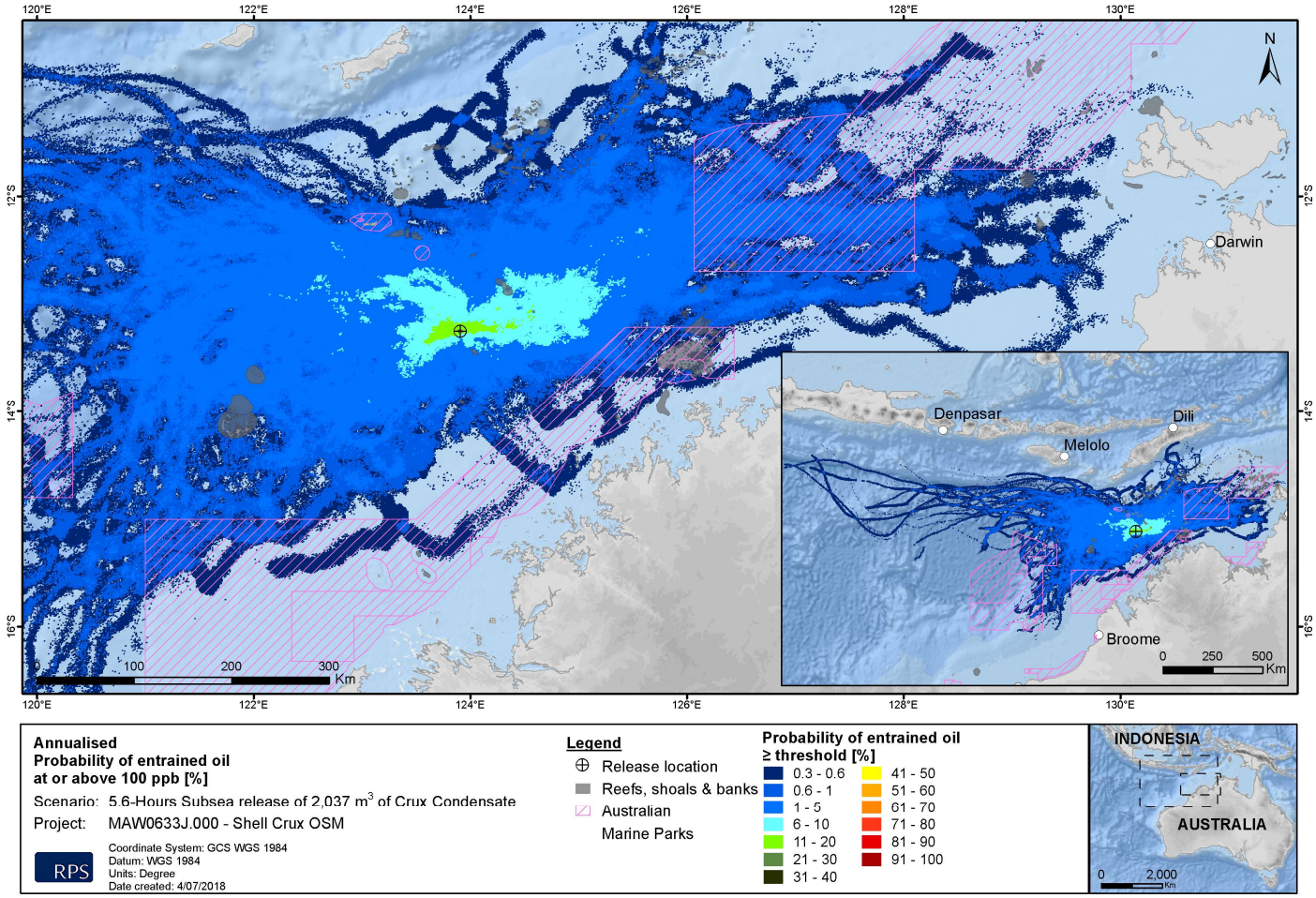


Figure 3.30 Subsurface Hydrocarbons | Entrained | Pipeline Scenario | Stochastic Outcomes. Predicted annualised probability of entrained oil concentrations at or above 100 ppb resulting from a 5.6-hour subsurface release of Crux condensate from the export pipeline.

RPS

3.4.4 Dissolved Aromatic Hydrocarbons

Table 3.15 Expected annualised dissolved aromatic hydrocarbon outcomes at sensitive receptors resulting from a 5.6-hour subsurface release of Crux condensate from the export pipeline.

	Receptor	Probability (%) of dissolved aromatic concentration at specific receptor depth		
		≥6 ppb	≥50 ppb	≥400 ppb
Coastlines	Cobourg Peninsula	<0.3	<0.3	<0.3
	Indonesia	0.6	<0.3	<0.3
	Joseph Bonaparte Gulf Northern Territory	<0.3	<0.3	<0.3
	Kimberley Coast	<0.3	<0.3	<0.3
	Timor Leste	<0.3	<0.3	<0.3
Islands	Admiralty Gulf Islands	<0.3	<0.3	<0.3
	Bathurst Island	<0.3	<0.3	<0.3
	Bigge Island	0.6	<0.3	<0.3
	Bonaparte Archipelago	0.6	<0.3	<0.3
	Browse Island	2.1	<0.3	<0.3
	Cassini Island	<0.3	<0.3	<0.3
	Coronation Island Group	<0.3	<0.3	<0.3
	Croker Island	<0.3	<0.3	<0.3
	Greenhill Island	<0.3	<0.3	<0.3
	Jones Island	<0.3	<0.3	<0.3
	Long Island Kimberley	0.6	<0.3	<0.3
	Melville Island	<0.3	<0.3	<0.3
	Montalivet Island	<0.3	<0.3	<0.3
	Montgomery Islands	<0.3	<0.3	<0.3
	Montgomery Islands and Reef	<0.3	<0.3	<0.3
	Peron Islands	<0.3	<0.3	<0.3
	Troughton Island	<0.3	<0.3	<0.3
	White Island	<0.3	<0.3	<0.3
Reefs	Beagle and Dingo Reefs	<0.3	<0.3	<0.3
	East Holothuria Reef	<0.3	<0.3	<0.3
	Heritage Reef	0.6	<0.3	<0.3
	Hibernia Reef	0.6	<0.3	<0.3
	Ingram Reef	0.6	<0.3	<0.3
	Jamieson Reef	<0.3	<0.3	<0.3

	Receptor	Probability (%) of dissolved aromatic concentration at specific receptor depth		
		≥6 ppb	≥50 ppb	≥400 ppb
	Long Reef	<0.3	<0.3	<0.3
	Oliver Rock	<0.3	<0.3	<0.3
	Rothery Reef	<0.3	<0.3	<0.3
	Sandy Islet	0.9	<0.3	<0.3
	Scott Reef North	1.2	0.6	<0.3
	Scott Reef South	0.9	<0.3	<0.3
	Seringapatam Reef	1.5	<0.3	<0.3
	The Boxers	<0.3	<0.3	<0.3
	The Boxers Area	0.6	<0.3	<0.3
	West Holothuria Reef	<0.3	<0.3	<0.3
Shoals	Barracouta Shoals	1.5	<0.3	<0.3
	Barton Shoal	0.6	0.6	<0.3
	Bassett-Smith Shoal	0.9	0.6	<0.3
	Big Bank Shoals	<0.3	<0.3	<0.3
	Calder Shoal	<0.3	<0.3	<0.3
	Cootamundra Shoal	<0.3	<0.3	<0.3
	Deep Shoal 1	1.5	0.6	<0.3
	Deep Shoal 2	0.6	<0.3	<0.3
	Dillon Shoal	0.9	<0.3	<0.3
	Echo Shoals	<0.3	<0.3	<0.3
	Echuca Shoal	0.9	0.6	<0.3
	Eugene McDermott Shoal	7.2	1.2	<0.3
	Fantome Shoal	<0.3	<0.3	<0.3
	Goeree Shoal	3.9	0.6	<0.3
	Heywood Shoal	3.9	1.5	0.6
	Jabiru Shoals	1.8	0.6	<0.3
	Karmt Shoal	0.6	<0.3	<0.3
	Mangola Shoal	<0.3	<0.3	<0.3
	Marie Shoal	<0.3	<0.3	<0.3
	Mermaid Shoal	<0.3	<0.3	<0.3
	Moss Shoal	0.6	<0.3	<0.3
	Newby Shoal	0.6	<0.3	<0.3

RPS

	Receptor	Probability (%) of dissolved aromatic concentration at specific receptor depth		
		≥6 ppb	≥50 ppb	≥400 ppb
	Parry Shoal	0.6	<0.3	<0.3
	Pee Shoal	0.9	<0.3	<0.3
	Penguin Shoal	0.6	<0.3	<0.3
	Penguin Shoal	0.6	<0.3	<0.3
	Shepparton Shoal	<0.3	<0.3	<0.3
	Van Cloon Shoal	0.6	<0.3	<0.3
	Vee Shoal	0.6	<0.3	<0.3
	Vulcan Shoals	4.8	1.8	<0.3
Banks	Baldwin Bank	0.6	<0.3	<0.3
Banks	Bellona Bank	<0.3	<0.3	<0.3
Banks	Branch Banks	<0.3	<0.3	<0.3
Banks	Favell Bank	0.6	<0.3	<0.3
Banks	Flat Top Bank	0.6	<0.3	<0.3
Banks	Gale Bank	1.5	0.6	<0.3
Banks	Holothuria Banks	1.2	0.6	<0.3
Banks	Johnson Bank	1.5	<0.3	<0.3
Banks	Margaret Harries Bank	0.6	<0.3	<0.3
Banks	Otway Bank	<0.3	<0.3	<0.3
Banks	Sahul Bank	2.1	0.6	<0.3
Banks	Sunrise Bank	<0.3	<0.3	<0.3
Banks	Tait Bank	<0.3	<0.3	<0.3
Banks	Woodbine Bank	1.5	<0.3	<0.3
Marine Parks	Ashmore Reef AMP	1.5	<0.3	<0.3
Marine Parks	Lalang-garram/Camden Sound MP	<0.3	<0.3	<0.3
Marine Parks	Cartier Island AMP	2.4	0.6	<0.3
Marine Parks	Garig Gunak Barlu NP	<0.3	<0.3	<0.3
Marine Parks	Kimberley AMP	1.8	0.9	0.6
Marine Parks	North Lalang-garram MP & North Kimberley MP	0.6	<0.3	<0.3
Marine Parks	Mermaid Reef AMP	0.6	<0.3	<0.3
Marine Parks	Oceanic Shoals AMP	2.7	0.9	<0.3
Marine Parks	Prince Regent NP Coast	<0.3	<0.3	<0.3

	Receptor	Probability (%) of dissolved aromatic concentration at specific receptor depth		
		≥6 ppb	≥50 ppb	≥400 ppb
Key Ecological Features	Ancient Coastline at 125 m depth contour	8.4	3.6	0.6
	Ashmore Reef and Cartier Island and surrounding Commonwealth Waters	2.4	0.6	<0.3
	Canyons linking the Argo Abyssal Plain with the Scott Plateau	0.6	<0.3	<0.3
	Carbonate bank & terrace system of Van Diemen Rise	0.9	<0.3	<0.3
	Carbonate bank and terrace system of Sahul Shelf	4.2	1.2	0.6
	Continental Slope Demersal Fish Communities	8.7	3.6	0.6
	Mermaid Reef and Commonwealth Waters surrounding Rowley Shoals	0.6	<0.3	<0.3
	Pinnacles of the Bonaparte Basin	1.2	<0.3	<0.3
	Seringapatam Reef and Commonwealth Waters in the Scott Reef Complex	1.8	0.6	<0.3
	Shelf break and slope of the Arafura Shelf	<0.3	<0.3	<0.3
Fisheries	Northern Prawn Fishery	1.8	0.9	<0.3
	North-West Slope Trawl Fishery	66.3	15.9	5.4
	Southern Bluefin Tuna Fishery	66.3	15.9	5.4
	Timor Reef Fishery (NT Managed)	0.6	<0.3	<0.3
	Western Skipjack Fishery	66.3	15.9	5.4
	Western Tuna and Billfish Fishery	66.3	15.9	5.4
Ecologically Important Areas	Flatback Turtle BIA	2.7	0.9	<0.3
	Green Turtle BIA	4.8	1.2	<0.3
	Hawksbill Turtle BIA	2.4	0.6	<0.3
	Leatherback Turtle BIA	<0.3	<0.3	<0.3
	Loggerhead Turtle BIA	2.7	0.9	<0.3
	Olive Ridley Turtle BIA	2.7	0.9	<0.3

NC: No contact to receptor predicted for specified threshold.

** Probabilities and maximum concentrations calculated at depth of submerged feature.*

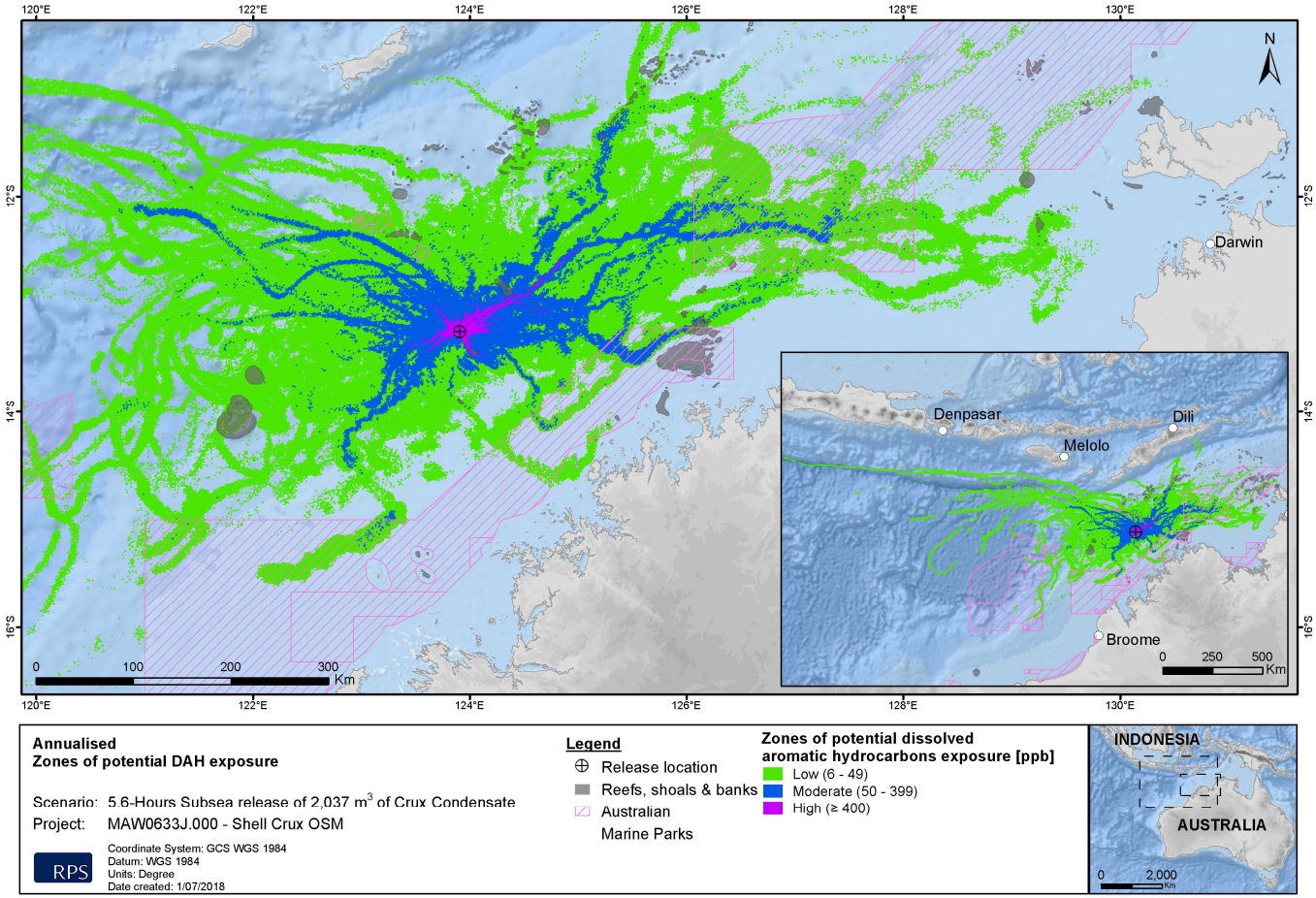


Figure 3.31 Subsurface Hydrocarbons | Dissolved | Pipeline Scenario | Stochastic Outcomes. Areal extent of potential exposure at defined dissolved aromatic hydrocarbon threshold concentrations resulting from a 5.6-hour subsurface release of Crux condensate from the export pipeline.

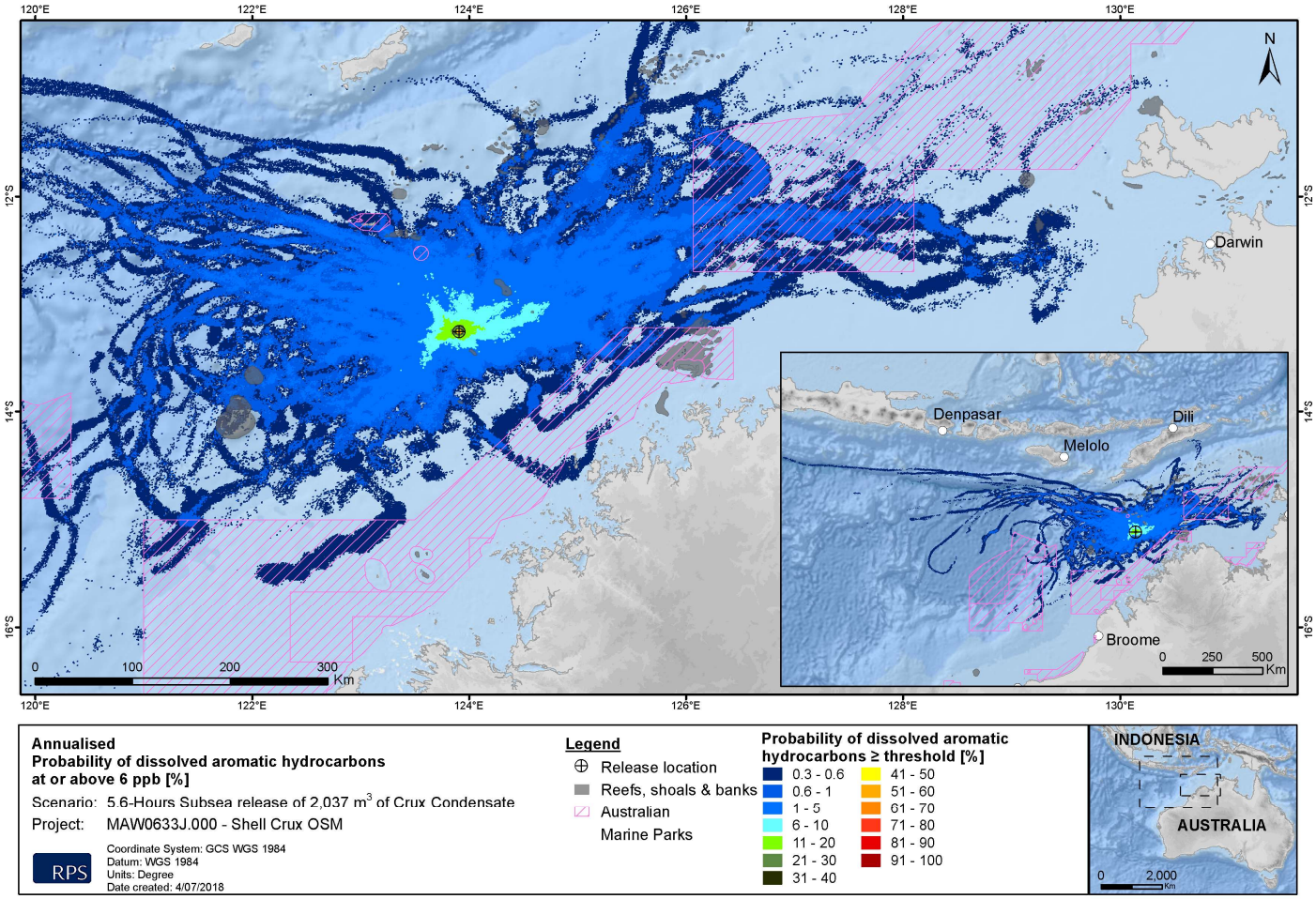


Figure 3.32 Subsurface Hydrocarbons | Dissolved | Pipeline Scenario | Stochastic Outcomes. Predicted annualised probability of dissolved aromatic hydrocarbon concentrations at or above 6 ppb resulting from a 5.6-hour subsurface release of Crux condensate from the export pipeline.

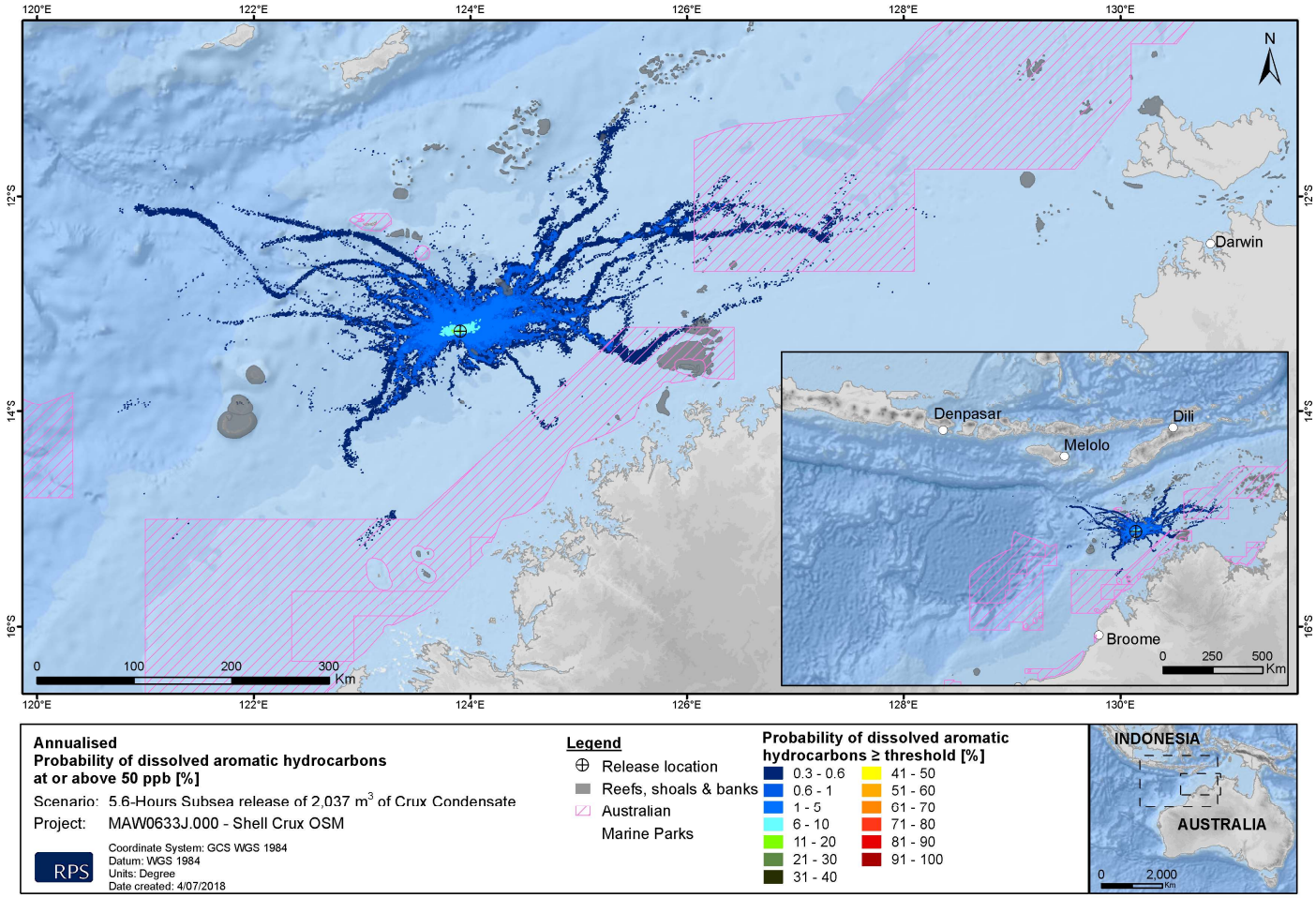


Figure 3.33 Subsurface Hydrocarbons | Dissolved | Pipeline Scenario | Stochastic Outcomes. Predicted annualised probability of dissolved aromatic hydrocarbon concentrations at or above 50 ppb resulting from a 5.6-hour subsurface release of Crux condensate from the export pipeline.

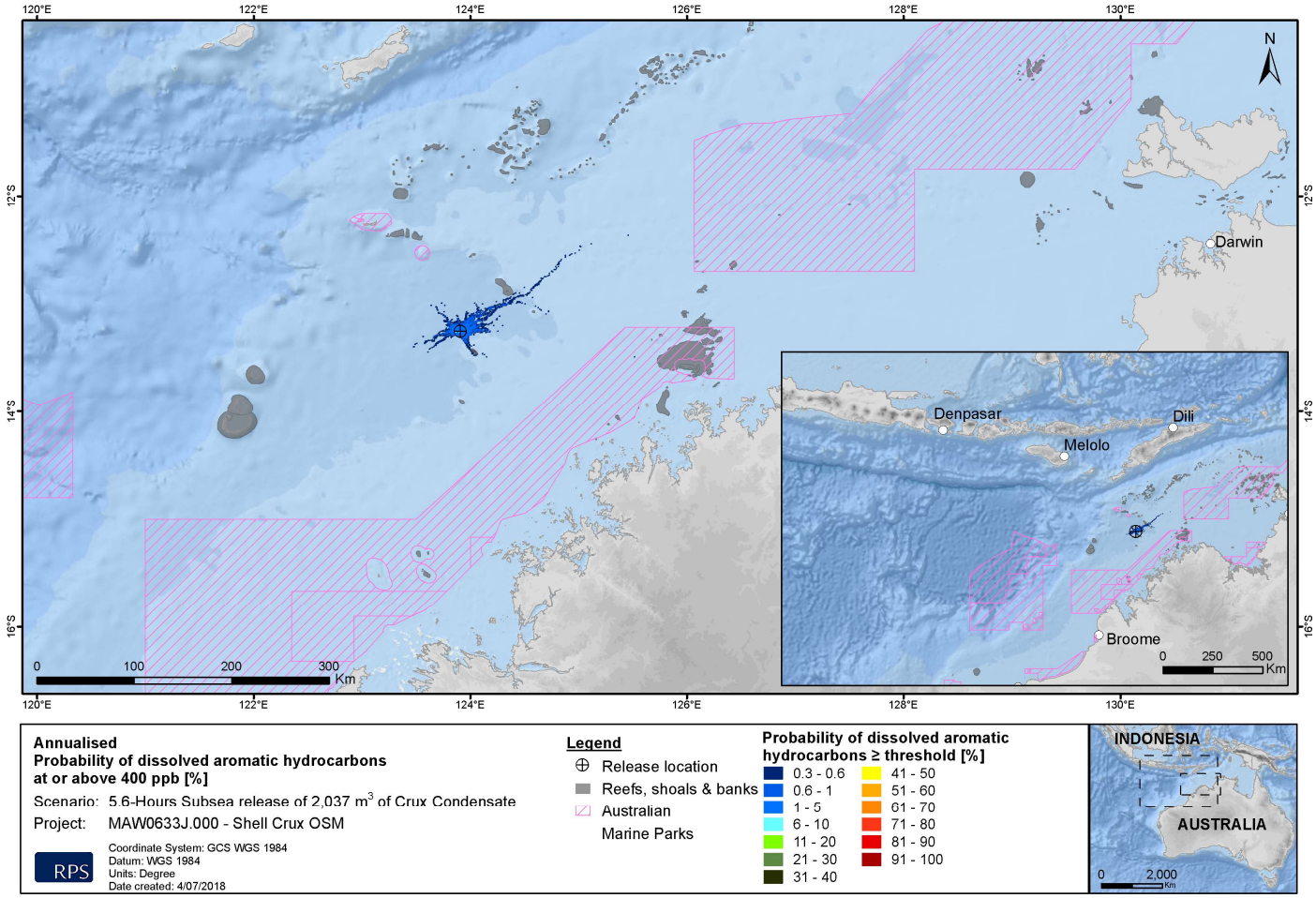


Figure 3.34 Subsurface Hydrocarbons | Dissolved | Pipeline Scenario | Stochastic Outcomes. Predicted annualised probability of dissolved aromatic hydrocarbon concentrations at or above 400 ppb resulting from a 5.6-hour subsurface release of Crux condensate from the export pipeline.

RPS

3.5 Scenario 4 – Short-Term Surface Release of IFO-180 from a Pipelay Vessel Collision at the Crux End of the Export Pipeline

3.5.1 Discussion of Results

3.5.1.1 Overview

This scenario investigated the probability of exposure to key sensitive receptors by hydrocarbons resulting from a short-term (1-hour) surface release following a pipelay vessel collision, discharging 1,000 m^3 of IFO-180 at the Crux end of the export pipeline at any time of year, with no spill response mitigation measures applied.

Considering the discharge characteristics, the properties of the hydrocarbon and its expected weathering behaviour, floating films are likely to be formed under typical wind conditions. Given the high viscosity of the hydrocarbon, entrainment into the water column is only likely to occur under relatively windy conditions. It is likely that the bulk of the hydrocarbon mass at any time will be found on the water surface. Evaporation rates will be relatively low, given the large proportion (21%) of low-volatility compounds within the hydrocarbon, and the residual fraction (64%) will persist in the environment until degradation processes occur (over periods of weeks to months). Considering the relatively low likelihood of entrainment occurring, the potential for dissolution of soluble aromatic compounds is low.

Figure 3.35 to Figure 3.37 show a summary of the areal extent for all hydrocarbon phases at the low, moderate and high thresholds, respectively.

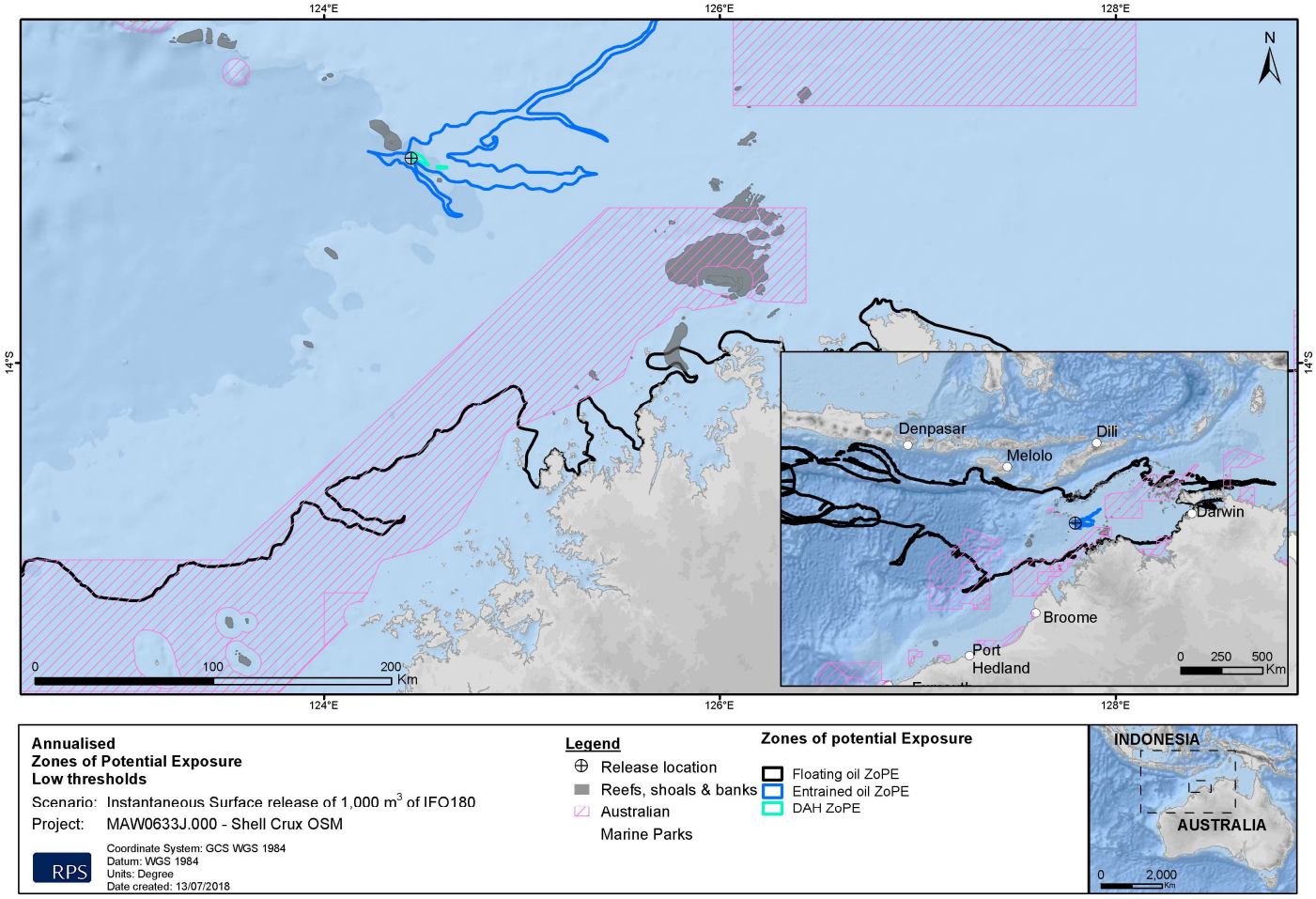


Figure 3.35 Surface and Subsurface Hydrocarbons | Pipeline Scenario | Stochastic Outcomes. Areal extent of potential exposure at the low thresholds resulting from a 1-hour surface release of IFO-180 at the Crux end of the export pipeline.

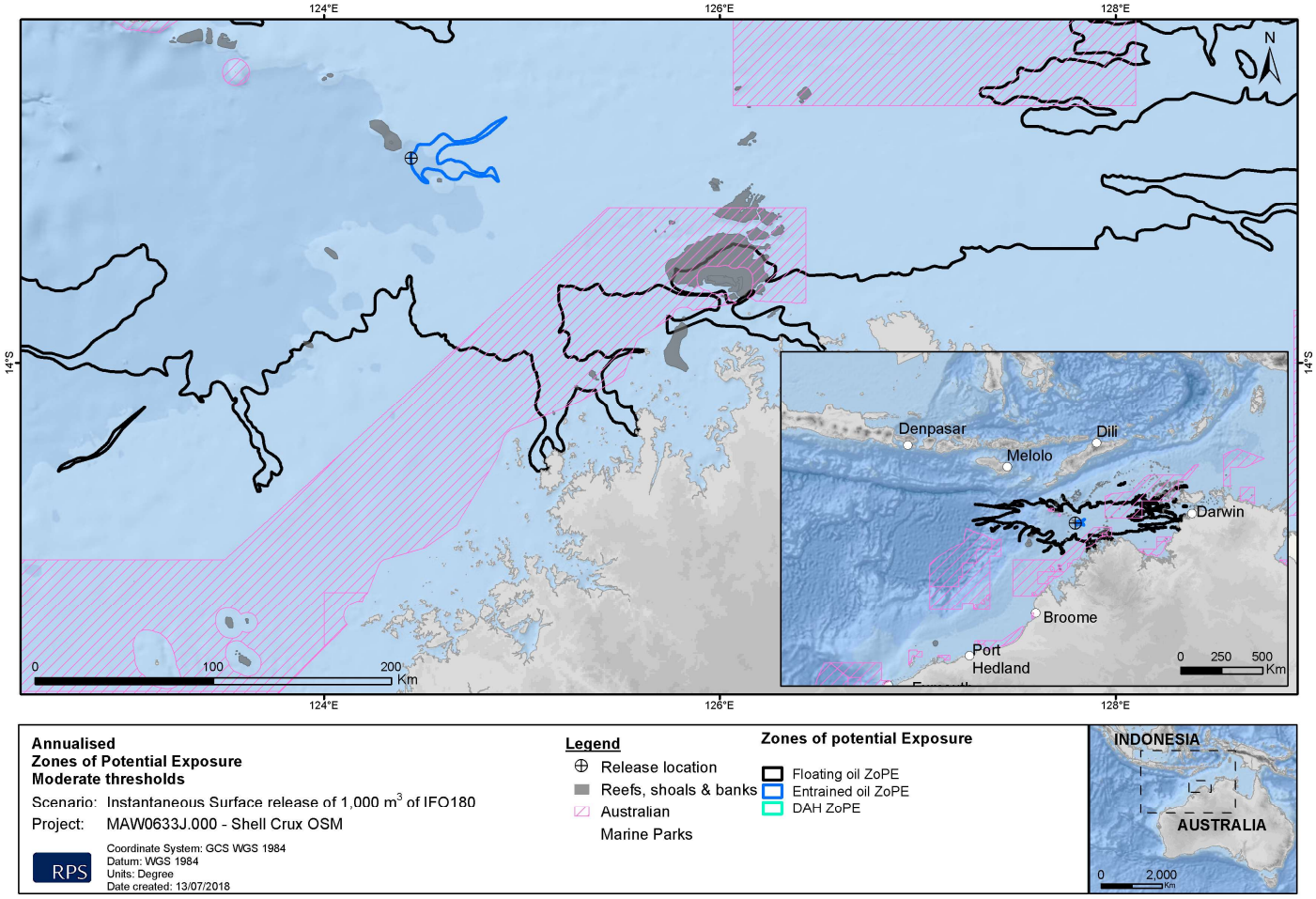


Figure 3.36 Surface and Subsurface Hydrocarbons | Pipeline Scenario | Stochastic Outcomes. Areal extent of potential exposure at the moderate thresholds resulting from a 1-hour surface release of IFO-180 at the Crux end of the export pipeline.

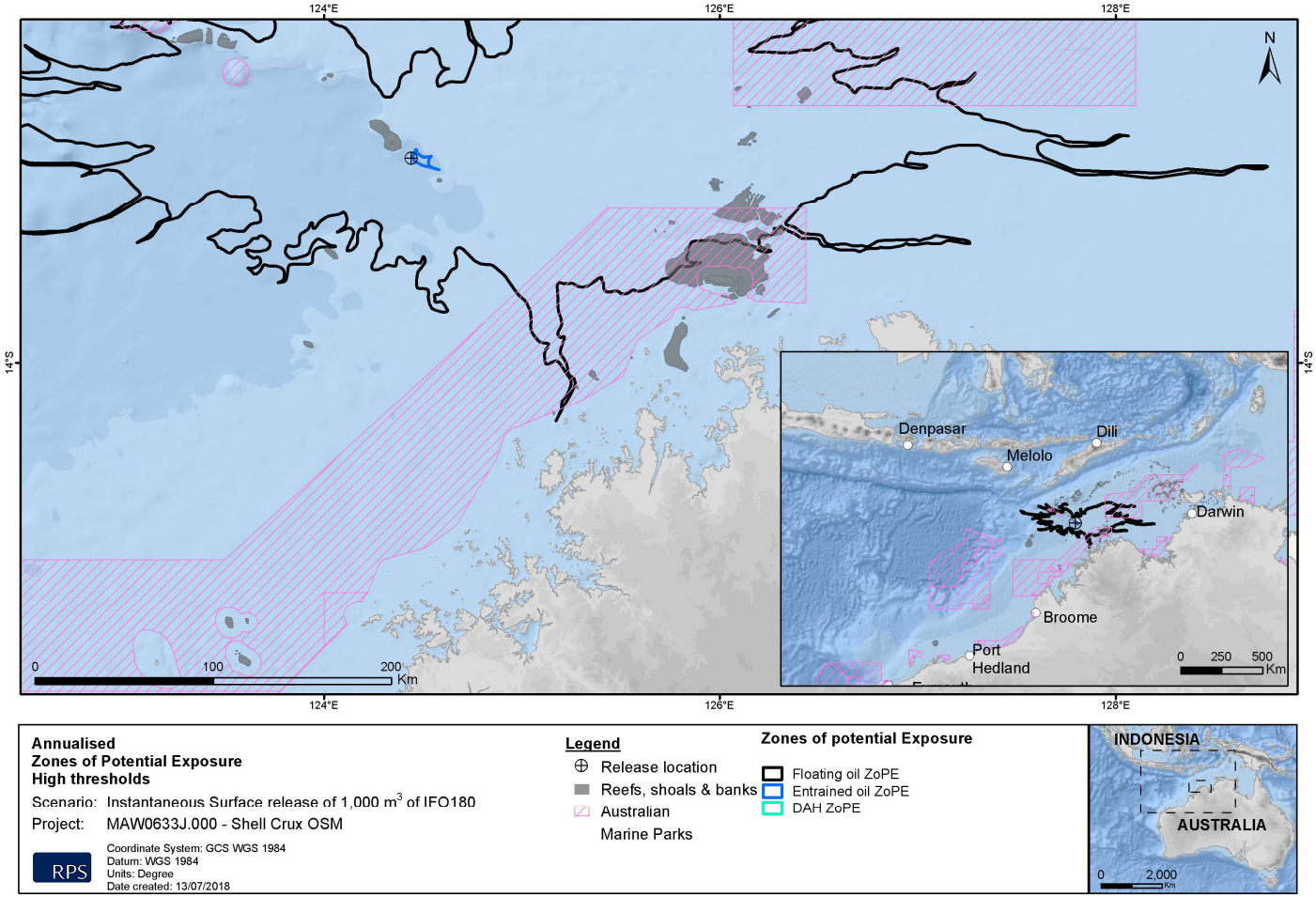


Figure 3.37 Surface and Subsurface Hydrocarbons | Pipeline Scenario | Stochastic Outcomes. Areal extent of potential exposure at the low thresholds resulting from a 1-hour surface release of IFO-180 at the Crux end of the export pipeline.

RPS

3.5.1.2 Floating and Shoreline Hydrocarbons

The annualised probability contour figures (Figure 3.39 and Appendix D) indicate that hydrocarbons on the sea surface at or greater than the threshold concentrations travel up to 1,853 km (1 g/m^2) from the release location. The ZoPE at the moderate and high floating oil threshold is further reduced, with floating oil not predicted to exceed the moderate (10 g/m^2) and high (25 g/m^2) thresholds beyond distances of 1,061 km and 484 km, respectively.

The Southern Bluefin Tuna Fishery, Western Skipjack Fishery and Western Tuna and Billfish Fishery receptors have the highest predicted probability of contact, being 100% at all thresholds (Table 3.17). Several other receptors are predicted to receive floating oil at low threshold concentrations, with the highest probabilities of contact occurring at North-West Slope Trawl Fishery (24%), Vulcan Shoals (23%), Ancient Coastline at 125 m Depth Contour KEF (16%), Continental Slope Demersal Fish Communities KEF (27%), Carbonate Bank and Terrace System of Sahul Shelf KEF (24%), Green Turtle BIA (10%), Loggerhead Turtle BIA (8%), Flatback Turtle BIA (8%), Northern Prawn Fishery (8%), Olive Ridley Turtle BIA (8%), Oceanic Shoals AMP (8%), Eugene McDermott Shoal (17%) and Pinnacles of the Bonaparte Basin KEF (7%).

The minimum time to contact with any receptor by floating oil at the low threshold is forecast at approximately 1 hour at the Southern Bluefin Tuna Fishery, Western Skipjack Fishery, and Western Tuna and Billfish Fishery receptors.

Potential for accumulation of oil on shorelines is predicted to be low (≤6% probability at the moderate threshold of 100 g/m^2), with a maximum accumulated volume of 771 m^3 forecast at Bonaparte Archipelago and North Lalang-garram MP & North Kimberley MP, and maximum local accumulated concentration on shorelines of 7,777 g/m^2 forecast at Bonaparte Archipelago, Kimberley Coast and North Lalang-garram MP & North Kimberley MP (Table 3.17).

Table 3.16 Maximum distances from the release location to zones of floating oil exposure for Scenario 4 (1,000 m^3 IFO-180).

	Floating Oil Exposure Threshold		
	Low (1-10 g/m^2)	**Moderate (10-25 g/m^2)**	**High (>25 g/m^2)**
Maximum distance travelled (km) by a spill trajectory	1,853	1,061	484

3.5.1.3 Subsurface – Entrained Hydrocarbons

The annualised probability contour figures (Figure 3.43 and Appendix D) indicate that entrained oil concentrations at or greater than the threshold concentrations do not travel a significant distance from the release location. The maximum distance to the outer extent of the low entrained oil threshold (10 ppb) is predicted to extend up to 170 km. The maximum extent is forecast to be reduced for the moderate (100 ppb; 57 km) and high (500 ppb; 17 km) thresholds for all the seasons.

A small number of receptors are predicted to be contacted by entrained oil at high threshold concentrations. Southern Bluefin Tuna Fishery, Western Skipjack Fishery, and Western Tuna and Billfish Fishery receptors are predicted to be contacted at the high threshold with probabilities of 1% (Entrained Hydrocarbons

Table 3.18). Higher probabilities of contact at a greater number of receptors are predicted at the low and moderate thresholds.

Receptors with the highest probability of receiving entrained oil at low threshold concentrations were Southern Bluefin Tuna Fishery (5%), Western Skipjack Fishery (5%), Western Tuna and Billfish Fishery (5%), and Carbonate Bank and Terrace System of Sahul Shelf KEF (1%).

The minimum time to contact with any receptor by entrained oil at the low threshold is forecast at Southern Bluefin Tuna Fishery, Western Skipjack Fishery. and Western Tuna and Billfish Fishery, at approximately 1 hour.

3.5.1.4 Subsurface – Dissolved Aromatic Hydrocarbons

The annualised probability contour figures (Figure 3.45) indicate that dissolved aromatic hydrocarbons at or greater than the threshold concentrations travel a small distance from the release location. The maximum distance to the outer extent of the low dissolved aromatic hydrocarbon threshold (6 ppb) is predicted to extend up to 20 km. The moderate (50 ppb) and high (400 ppb) thresholds are not exceeded for this scenario.

No receptors are predicted to receive dissolved aromatic hydrocarbons at moderate or high threshold concentrations. Southern Bluefin Tuna Fishery, Western Skipjack Fishery, and Western Tuna and Billfish Fishery receptors are predicted to have the highest probability of contact at the low threshold with probabilities of 2% (Table 3.19). Low probability of contact (<1%) is predicted at all other receptors at the low threshold.

3.5.1.5 Deterministic Cases

A replicate simulation during the summer season (spill starting at 07:00 6th February 2011) has been identified as the worst-case replicate according to the maximum oil volume accumulated across all shoreline receptors criteria for Scenario 4 (624 m^3 at Bonaparte Archipelago/Bigge Island). Figures showing the evolution of this spill simulation are contained in Appendix E. Hydrocarbons on the sea surface mainly drifted south of the release location. The potential floating oil exposure zones were shown up to 198 km, 190 km and 159 km of the release location at the low, moderate and high thresholds, respectively. There was no entrained oil or dissolved aromatic hydrocarbon exposure predicted at any threshold; consequently, no subsea images are presented for this scenario.

A replicate simulation during the winter season (spill starting at 07:00 20th July 2008) has been identified as the worst-case replicate according to the minimum time to commencement of oil accumulation at any shoreline receptor criteria for Scenario 4 (5.1 days at Ashmore Reef and Cartier Island and Surrounding Commonwealth Waters KEF). Hydrocarbons on the sea surface mainly drifted west and northwest of the release location. The potential floating oil exposure zones were shown up to 1,819 km, 380 km and 251 km of the release location at the low, moderate and high thresholds, respectively. There was no entrained oil or dissolved aromatic hydrocarbon exposure predicted at any threshold; consequently, no subsea images are presented for this scenario.

A replicate simulation during the transitional season (spill starting at 12:00 19th November 2016) has been identified as the worst-case replicate according to the maximum length of oiled shoreline criteria for Scenario 4 (117 km at North Lalang-garram MP & North Kimberley MP). Hydrocarbons on the sea surface mainly drifted southwest of the release location. The potential floating oil exposure zones were shown up to 206 km, 73 km and 66 km of the release location at the low, moderate and high thresholds, respectively. There was no entrained oil or dissolved aromatic hydrocarbon exposure predicted at any threshold; consequently, no subsea images are presented for this scenario.

RPS

3.5.2 Floating and Shoreline Hydrocarbons

Table 3.17 Expected annualised floating and shoreline oil outcomes at sensitive receptors resulting from a 1-hour surface release of IFO-180 at the Crux end of the export pipeline.

	Receptor	Probability (%) of films arriving at receptors at			Minimum time to receptor (hours) for films at			Probability (%) of shoreline oil on receptors at			Minimum time to receptor (hours) for shoreline oil at			Maximum local accumulated concentration (g/m²)		Maximum accumulated volume (m³) along this shoreline		Maximum length of shoreline (km) with concentrations ≥10.0 g/m²	
		≥1 g/m²	≥10 g/m²	≥25 g/m²	≥1 g/m²	≥10 g/m²	≥25 g/m²	≥10 g/m²	≥100 g/m²	≥1,000 g/m²	≥10 g/m²	≥100 g/m²	≥1,000 g/m²	averaged over all replicate simulations	worst replicate simulation	averaged over all replicate simulations	worst replicate simulation	averaged over all replicate simulations	worst replicate simulation
Coastlines	Cobourg Peninsula	<0.3	<0.3	<0.3	NC	NC	NC	1.5	0.6	<0.3	495	588	NC	0.9	231	<1	9	<1	12
	Darwin Coast	1.2	<0.3	<0.3	525	NC	NC	2.7	2.4	1.5	489	525	532	36	4,601	10	307	3	68
	Indonesia	<0.3	<0.3	<0.3	NC	NC	NC	0.6	0.6	<0.3	527	641	NC	0.8	245	<1	47	<1	84
	Joseph Bonaparte Gulf Northern Territory	2.4	1.2	<0.3	300	313	NC	4.2	3	1.5	300	301	314	55	7,777	60	523	12	99
	Kakadu Coast	0.6	<0.3	<0.3	735	NC	NC	0.6	0.6	0.6	732	739	763	3.9	1,165	2	107	<1	35
	Kakadu National Park	0.6	<0.3	<0.3	735	NC	NC	0.9	0.6	0.6	732	739	763	3.9	1,165	2	84	<1	40
	Kimberley Coast	1.8	0.6	<0.3	190	195	NC	2.4	1.8	1.5	189	190	196	44	7,777	12	491	4	69
	West Arnhem Land	0.6	<0.3	<0.3	872	NC	NC	1.2	1.2	0.6	864	870	1,002	3.9	1,164	2	68	2	34
Islands	Admiralty Gulf Islands	0.6	<0.3	<0.3	890	NC	NC	1.5	1.5	<0.3	490	772	NC	5.3	894	2	73	<1	32
	Bathurst Island	3.6	0.9	<0.3	409	413	NC	6	4.5	2.4	409	410	412	77	7,773	37	417	11	92
	Bigge Island	0.9	0.6	<0.3	181	188	NC	1.5	0.9	0.6	194	197	200	23	6,657	10	624	<1	48
	Bonaparte Archipelago	0.9	0.6	0.6	163	198	207	1.5	0.9	0.6	189	197	199	27	7,777	12	625	2	82
	Browse Island	2.7	0.6	0.6	164	165	166	9.6	5.7	2.1	166	167	168	72	7,197	4	124	<1	3
	Cape Londonderry Islands	0.6	<0.3	<0.3	353	NC	NC	2.4	1.2	<0.3	354	354	NC	4.6	916	<1	50	<1	15
	Cassini Island	0.9	0.6	<0.3	190	193	NC	2.1	1.5	0.6	189	191	193	22	4,850	2	139	<1	4
	Coronation Island Group	<0.3	<0.3	<0.3	NC	NC	NC	0.6	<0.3	<0.3	900	NC	NC	0.1	42	<1	<1	<1	4
	Croker Island	1.5	<0.3	<0.3	511	NC	NC	1.5	1.5	1.5	506	510	519	52	4,991	12	347	2	30
	East Vernon Island	0.9	<0.3	<0.3	626	NC	NC	1.8	1.2	0.6	624	626	629	12	2,462	<1	39	<1	6
	Eclipse Archipelago	1.8	0.6	<0.3	382	395	NC	2.4	1.8	1.8	382	384	394	61	6,680	4	128	<1	14
	Field Island	<0.3	<0.3	<0.3	NC	NC	NC	0.9	0.6	<0.3	841	850	NC	0.7	210	<1	11	NC	NC
	Greenhill Island	<0.3	<0.3	<0.3	NC	NC	NC	0.6	<0.3	<0.3	967	NC	NC	<0.1	12	<1	<1	NC	NC
	Jones Island	1.2	<0.3	<0.3	501	NC	NC	2.7	2.1	<0.3	382	501	NC	8.4	833	<1	7	<1	<1
	Lawson Island	0.9	<0.3	<0.3	551	NC	NC	1.5	1.2	<0.3	545	549	NC	7.2	774	<1	11	<1	4
	Lesueur Island	0.6	<0.3	<0.3	371	NC	NC	1.5	0.6	<0.3	370	373	NC	2.8	704	<1	12	<1	4
	Long Island Kimberley	0.9	0.6	<0.3	180	183	NC	1.5	0.6	<0.3	189	936	NC	3	883	<1	78	<1	26
	McCluer Island	1.2	<0.3	<0.3	558	NC	NC	1.5	1.2	0.6	555	560	571	9.4	1,087	<1	25	<1	6
	Melville Island	1.2	<0.3	<0.3	631	NC	NC	2.4	1.5	0.9	474	490	652	15	2,200	11	287	4	69
	Mogogout Island	<0.3	<0.3	<0.3	NC	NC	NC	<0.3	<0.3	<0.3	NC	NC	NC	<0.1	5.3	<1	<1	NC	NC

RPS

	Receptor	Probability (%) of films arriving at receptors at			Minimum time to receptor (hours) for films at			Probability (%) of shoreline oil on receptors at			Minimum time to receptor (hours) for shoreline oil at			Maximum local accumulated concentration (g/m²)		Maximum accumulated volume (m³) along this shoreline		Maximum length of shoreline (km) with concentrations ≥10.0 g/m²	
		≥1 g/m²	≥10 g/m²	≥25 g/m²	≥1 g/m²	≥10 g/m²	≥25 g/m²	≥10 g/m²	≥100 g/m²	≥1,000 g/m²	≥10 g/m²	≥100 g/m²	≥1,000 g/m²	averaged over all replicate simulations	worst replicate simulation	averaged over all replicate simulations	worst replicate simulation	averaged over all replicate simulations	worst replicate simulation
	Montalivet Island	0.9	0.6	<0.3	160	164	NC	2.1	0.9	0.6	164	165	173	5.4	1,320	<1	18	<1	8
	Morse Island	<0.3	<0.3	<0.3	NC	NC	NC	0.6	<0.3	<0.3	985	NC	NC	<0.1	22	<1	<1	<1	<1
	Napier Broome Bay Islands	1.8	0.9	<0.3	393	410	NC	2.1	1.8	1.8	394	394	407	64	6,236	9	188	2	31
	New Year Island	<0.3	<0.3	<0.3	NC	NC	NC	0.6	<0.3	<0.3	702	NC	NC	<0.1	16	<1	<1	<1	<1
	North Goulburn Island	<0.3	<0.3	<0.3	NC	NC	NC	1.2	<0.3	<0.3	756	NC	NC	0.4	51	<1	2	<1	7
	North West Vernon Island	0.9	0.6	<0.3	626	629	NC	2.4	1.2	0.6	623	625	627	22	5,318	2	155	<1	8
	Oxley Island	1.2	<0.3	<0.3	536	NC	NC	1.5	1.5	1.2	535	541	550	18	1,961	2	48	<1	5
	Peron Islands	1.8	0.6	<0.3	380	427	NC	2.4	1.5	0.9	380	381	428	21	3,061	4	166	<1	17
	Roche Islands and Reefs	2.1	0.9	<0.3	444	444	NC	4.5	2.7	2.1	403	446	447	51	4,560	12	298	2	22
	South Goulburn Island	<0.3	<0.3	<0.3	NC	NC	NC	0.6	<0.3	<0.3	861	NC	NC	0.1	19	<1	<1	<1	2
	South West Vernon Island	0.9	<0.3	<0.3	621	NC	NC	1.8	0.9	<0.3	621	622	NC	3.2	710	<1	20	<1	5
	Stewarts Islands	0.6	<0.3	<0.3	354	NC	NC	2.4	1.2	<0.3	354	354	NC	4.6	916	<1	27	<1	5
	Troughton Island	2.4	0.6	<0.3	219	489	NC	3.9	2.7	1.8	286	373	489	35	2,782	<1	23	<1	<1
Reefs	Beatrice Reef*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Christine Reef*	0.6	<0.3	<0.3	915	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Draytons Reef*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	East Holothuria Reef*	1.5	<0.3	<0.3	226	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Elphinstone Reef*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Fish Reef*	1.5	<0.3	<0.3	530	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Harris Reef*	0.6	<0.3	<0.3	822	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Heritage Reef*	0.6	<0.3	<0.3	454	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Hibernia Reef*	1.5	0.6	0.6	148	156	158	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Hunt Patch*	0.6	<0.3	<0.3	845	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Ingram Reef*	0.9	0.6	<0.3	146	149	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Jamieson Reef*	0.9	<0.3	<0.3	162	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Knight Reef*	0.6	<0.3	<0.3	631	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Long Reef	1.2	0.6	<0.3	194	204	NC	3	2.1	<0.3	195	203	NC	8	655	<1	9	<1	3
	Lyne Reef*	0.6	<0.3	<0.3	620	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Middle Reef*	1.8	<0.3	<0.3	473	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Oliver Reef*	0.9	<0.3	<0.3	629	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Oliver Rock*	0.6	<0.3	<0.3	188	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

RPS

	Receptor	Probability (%) of films arriving at receptors at			Minimum time to receptor (hours) for films at			Probability (%) of shoreline oil on receptors at			Minimum time to receptor (hours) for shoreline oil at			Maximum local accumulated concentration (g/m²)		Maximum accumulated volume (m³) along this shoreline		Maximum length of shoreline (km) with concentrations ≥10.0 g/m²	
		≥1 g/m²	≥10 g/m²	≥25 g/m²	≥1 g/m²	≥10 g/m²	≥25 g/m²	≥10 g/m²	≥100 g/m²	≥1,000 g/m²	≥10 g/m²	≥100 g/m²	≥1,000 g/m²	averaged over all replicate simulations	worst replicate simulation	averaged over all replicate simulations	worst replicate simulation	averaged over all replicate simulations	worst replicate simulation
	Orontes Reef*	0.9	<0.3	<0.3	492	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Rothery Reef*	1.5	<0.3	<0.3	197	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Sandy Islet	1.2	<0.3	<0.3	414	NC	NC	7.2	3	0.9	308	415	667	20	1,279	<1	11	<1	<1
	Scott Reef North*	1.5	<0.3	<0.3	285	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Scott Reef South	1.2	<0.3	<0.3	363	NC	NC	7.2	3	0.9	308	415	667	20	1,279	<1	11	<1	<1
	Seringapatam Reef*	2.4	0.6	<0.3	229	235	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Taylor Patches*	0.6	<0.3	<0.3	644	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	The Boxers*	1.8	<0.3	<0.3	411	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	The Boxers Area*	4.5	1.2	<0.3	322	329	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Tregenna Reef*	0.9	<0.3	<0.3	748	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	West Holothuria Reef*	1.2	0.6	<0.3	134	144	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Shoals	Abbott Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Afghan Shoal*	1.5	<0.3	<0.3	527	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Ann Shoals*	0.6	<0.3	<0.3	963	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Barbara Shoal*	0.6	<0.3	<0.3	900	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Barracouta Shoals*	6.9	0.9	<0.3	61	74	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Barton Shoal*	0.6	<0.3	<0.3	717	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Bassett-Smith Shoal*	2.4	0.6	<0.3	273	324	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Beagle Shoals*	0.6	<0.3	<0.3	855	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Big Bank Shoals*	0.6	<0.3	<0.3	468	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Bill Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Britomart Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Calder Shoal*	0.6	<0.3	<0.3	642	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Cootamundra Shoal*	0.6	<0.3	<0.3	645	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Deep Shoal 1*	5.4	0.6	<0.3	195	241	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Deep Shoal 2*	1.8	<0.3	<0.3	296	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Dillon Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Echo Shoals*	0.9	<0.3	<0.3	506	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Echuca Shoal*	2.4	0.6	<0.3	173	220	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Eugene McDermott Shoal*	17.1	5.7	3	10	11	11	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Fantome Shoal*	0.6	<0.3	<0.3	900	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

RPS

	Receptor	Probability (%) of films arriving at receptors at			Minimum time to receptor (hours) for films at			Probability (%) of shoreline oil on receptors at			Minimum time to receptor (hours) for shoreline oil at			Maximum local accumulated concentration (g/m²)		Maximum accumulated volume (m³) along this shoreline		Maximum length of shoreline (km) with concentrations ≥10.0 g/m²	
		≥1 g/m²	≥10 g/m²	≥25 g/m²	≥1 g/m²	≥10 g/m²	≥25 g/m²	≥10 g/m²	≥100 g/m²	≥1,000 g/m²	≥10 g/m²	≥100 g/m²	≥1,000 g/m²	averaged over all replicate simulations	worst replicate simulation	averaged over all replicate simulations	worst replicate simulation	averaged over all replicate simulations	worst replicate simulation
	Fitzpatrick Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Giles Shoal*	0.6	<0.3	<0.3	885	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Goeree Shoal*	16.2	7.8	4.5	9	9	9	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Hancox Shoal*	1.2	<0.3	<0.3	635	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Heywood Shoal*	6	1.5	<0.3	109	112	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Jabiru Shoals*	2.4	<0.3	<0.3	362	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Jones Shoal*	1.2	<0.3	<0.3	498	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Karmt Shoal*	0.9	<0.3	<0.3	295	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Lowry Shoal*	0.9	<0.3	<0.3	482	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Mangola Shoal*	1.8	<0.3	<0.3	423	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Marie Shoal*	1.5	<0.3	<0.3	382	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Marsh Shoal*	0.9	<0.3	<0.3	621	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Mermaid Shoal	1.5	<0.3	<0.3	590	NC	NC	2.4	1.5	0.9	588	598	653	13	2,012	<1	21	<1	2
	Moresby Shoals*	1.8	<0.3	<0.3	473	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Moss Shoal*	2.1	<0.3	<0.3	374	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Newby Shoal*	4.2	<0.3	<0.3	362	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Parry Shoal*	2.4	0.6	<0.3	354	370	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Pee Shoal*	1.8	<0.3	<0.3	396	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Penguin Shoal*	3.9	1.5	0.9	68	68	68	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Penguin Shoal*	3.9	1.5	0.9	68	68	68	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Shepparton Shoal*	1.2	<0.3	<0.3	420	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Skottowe Shoal*	1.2	<0.3	<0.3	478	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Taiyun Shoal*	0.6	<0.3	<0.3	844	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Van Cloon Shoal*	3.6	1.2	0.6	123	125	130	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Vee Shoal*	0.9	<0.3	<0.3	680	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Victoria Shoal*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Vulcan Shoals*	23.1	13.5	10.8	4	4	4	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Wells Shoal*	0.6	<0.3	<0.3	867	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Banks	Baldwin Bank*	2.4	0.9	0.6	101	102	103	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Banks	Bellona Bank*	0.6	<0.3	<0.3	673	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Banks	Branch Banks*	1.8	<0.3	<0.3	221	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

RPS

	Receptor	Probability (%) of films arriving at receptors at			Minimum time to receptor (hours) for films at			Probability (%) of shoreline oil on receptors at			Minimum time to receptor (hours) for shoreline oil at			Maximum local accumulated concentration (g/m²)		Maximum accumulated volume (m³) along this shoreline		Maximum length of shoreline (km) with concentrations ≥10.0 g/m²	
		≥1 g/m²	≥10 g/m²	≥25 g/m²	≥1 g/m²	≥10 g/m²	≥25 g/m²	≥10 g/m²	≥100 g/m²	≥1,000 g/m²	≥10 g/m²	≥100 g/m²	≥1,000 g/m²	averaged over all replicate simulations	worst replicate simulation	averaged over all replicate simulations	worst replicate simulation	averaged over all replicate simulations	worst replicate simulation
	Favell Bank*	4.2	1.2	0.6	116	124	124	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Flat Top Bank*	2.1	0.6	<0.3	267	268	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Foelsche Bank*	<0.3	<0.3	<0.3	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Gale Bank*	4.8	1.8	0.6	109	109	134	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Goodrich Bank*	0.6	<0.3	<0.3	965	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Holothuria Banks*	3.6	1.5	0.9	69	71	71	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Johnson Bank*	4.2	1.8	0.9	97	98	98	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Jones Bank*	1.5	<0.3	<0.3	475	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Margaret Harries Bank*	1.8	<0.3	<0.3	504	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Otway Bank*	1.8	0.9	<0.3	215	472	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Parsons Bank*	0.9	<0.3	<0.3	729	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Sahul Bank*	1.2	0.6	<0.3	166	167	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Sunrise Bank*	0.6	<0.3	<0.3	666	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Tait Bank*	1.8	<0.3	<0.3	372	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Woodbine Bank*	4.5	1.2	0.9	90	91	91	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Marine Parks	Arafura AMP*	0.6	<0.3	<0.3	666	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Marine Parks	Arnhem AMP*	0.6	<0.3	<0.3	623	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Marine Parks	Ashmore Reef AMP	4.5	2.4	1.5	110	113	114	8.7	5.7	3	122	123	124	130	7,781	12	302	<1	7
Marine Parks	Cartier Island AMP	6.6	1.5	0.9	74	76	77	9.6	6	3	134	139	144	136	7,781	6	149	<1	4
Marine Parks	Charles Darwin NP	1.2	<0.3	<0.3	544	NC	NC	1.8	1.2	0.6	504	553	626	7.5	1,903	2	77	<1	13
Marine Parks	Djukbinj NP	0.6	<0.3	<0.3	635	NC	NC	0.6	<0.3	<0.3	980	NC	NC	<0.1	27	<1	<1	<1	4
Marine Parks	Garig Gunak Barlu NP	1.5	<0.3	<0.3	494	NC	NC	1.5	0.9	<0.3	500	501	NC	2	306	<1	4	<1	2
Marine Parks	Kakadu NP	0.6	<0.3	<0.3	707	NC	NC	0.9	0.6	0.6	732	739	763	3.9	1,165	2	84	<1	55
Marine Parks	Kimberley AMP	6.9	2.1	1.5	42	43	43	<0.3	<0.3	<0.3	NC	NC	NC	NC	NC	NC	NC	NC	NC
Marine Parks	North Lalang-garram MP & North Kimberley MP	2.4	0.9	0.6	155	159	164	3.9	2.7	1.8	189	190	193	64	7,777	38	625	8	122
Marine Parks	Mary River NP	0.6	<0.3	<0.3	653	NC	NC	0.6	0.6	<0.3	763	781	NC	0.7	224	<1	8	<1	8
Marine Parks	Oceanic Shoals AMP*	7.5	2.4	1.8	60	60	61	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Marine Parks	Prince Regent NP Coast	<0.3	<0.3	<0.3	NC	NC	NC	0.6	<0.3	<0.3	496	NC	NC	<0.1	11	<1	<1	NC	NC
Key Eco	Ancient Coastline at 125 m depth contour*	15.9	3.9	1.8	19	19	20	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

RPS

	Receptor	Probability (%) of films arriving at receptors at			Minimum time to receptor (hours) for films at			Probability (%) of shoreline oil on receptors at			Minimum time to receptor (hours) for shoreline oil at			Maximum local accumulated concentration (g/m²)		Maximum accumulated volume (m³) along this shoreline		Maximum length of shoreline (km) with concentrations ≥10.0 g/m²	
		≥1 g/m²	≥10 g/m²	≥25 g/m²	≥1 g/m²	≥10 g/m²	≥25 g/m²	≥10 g/m²	≥100 g/m²	≥1,000 g/m²	≥10 g/m²	≥100 g/m²	≥1,000 g/m²	averaged over all replicate simulations	worst replicate simulation	averaged over all replicate simulations	worst replicate simulation	averaged over all replicate simulations	worst replicate simulation
	Ashmore Reef and Cartier Island and surrounding Commonwealth Waters	6.6	2.4	1.5	74	76	77	9.6	6	3	122	123	124	136	7,781	18	302	2	10
	Canyons linking the Argo Abyssal Plain with the Scott Plateau*	0.9	<0.3	<0.3	417	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Carbonate bank & terrace system of Van Diemen Rise*	4.5	1.2	<0.3	286	294	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Carbonate bank and terrace system of Sahul Shelf	14.4	6	2.7	18	18	18	0.9	0.6	<0.3	373	375	NC	1.7	478	<1	5	<1	2
	Continental Slope Demersal Fish Communities*	11.4	4.8	2.4	29	30	30	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Pinnacles of the Bonaparte Basin*	6.9	1.2	0.6	135	148	154	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Seringapatam Reef and Commonwealth Waters in the Scott Reef Complex	2.4	<0.3	<0.3	232	NC	NC	7.2	3	0.9	308	415	667	20	1,279	<1	11	<1	<1
	Shelf break and slope of the Arafura Shelf*	0.9	<0.3	<0.3	949	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Fisheries	Northern Prawn Fishery	7.2	2.1	0.9	86	86	87	6	4.5	2.4	345	347	412	77	7,773	NC	NC	NC	NC
Fisheries	North-West Slope Trawl Fishery*	24.3	13.8	9.9	7	7	7	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Fisheries	Southern Bluefin Tuna Fishery	100	100	100	1	1	1	9.6	6	3	122	123	124	136	7,781	NC	NC	NC	NC
Fisheries	Timor Reef Fishery (NT Managed)*	1.5	<0.3	<0.3	528	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Fisheries	Western Skipjack Fishery	100	100	100	1	1	1	9.6	6	3	122	123	124	136	7,781	NC	NC	NC	NC
Fisheries	Western Tuna and Billfish Fishery	100	100	100	1	1	1	9.6	6	3	122	123	124	136	7,781	NC	NC	NC	NC
Biologically Important Areas	Flatback Turtle BIA	7.5	2.4	1.2	65	65	65	6	4.5	2.4	345	347	412	77	7,773	85	417	3	12
Biologically Important Areas	Green Turtle BIA	9.9	4.5	1.5	63	64	65	9.6	6	3	122	123	124	136	7,781	18	302	2	10
Biologically Important Areas	Hawksbill Turtle BIA	4.5	2.4	1.5	106	107	108	8.7	5.7	3	122	123	124	130	7,781	12	302	<1	7
Biologically Important Areas	Leatherback Turtle BIA	1.5	<0.3	<0.3	494	NC	NC	1.5	1.5	0.9	496	501	519	28	4,796	2	71	<1	5
Biologically Important Areas	Loggerhead Turtle BIA	7.5	2.4	1.2	65	65	65	<0.3	<0.3	<0.3	NC	NC	NC	NC	NC	NC	NC	NC	NC
Biologically Important Areas	Olive Ridley Turtle BIA	7.5	2.4	1.2	65	65	65	4.5	2.7	2.1	345	347	425	51	4,560	16	315	<1	9

NC: No contact to receptor predicted for specified threshold. NA: Not applicable.

** Floating oil will not accumulate on submerged features and at open ocean locations.*

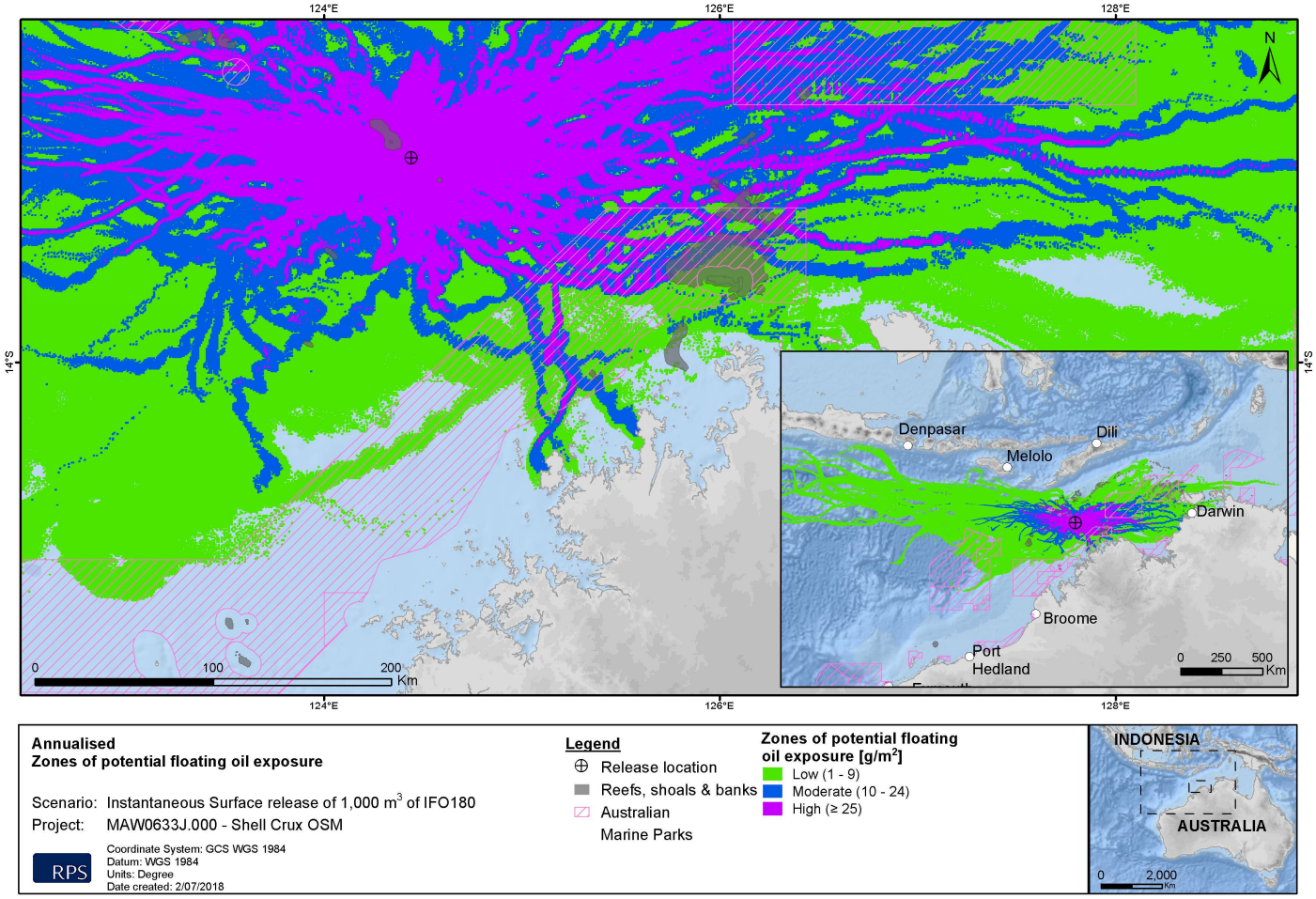


Figure 3.38 Surface Hydrocarbons | Collision Scenario | Stochastic Outcomes. Areal extent of potential exposure at defined floating oil threshold concentrations resulting from a 1-hour surface release of IFO-180 at the Crux end of the export pipeline.

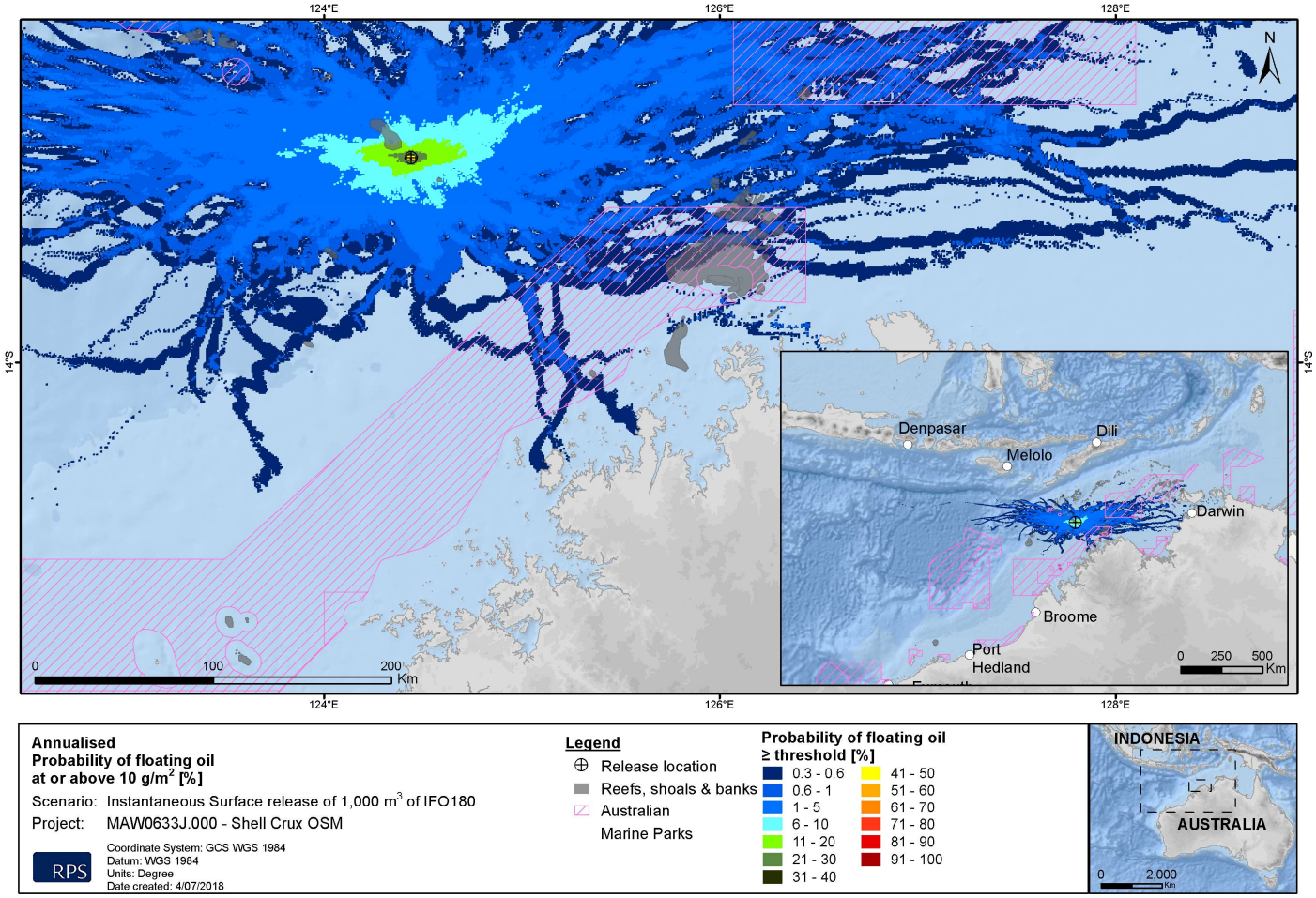


Figure 3.39 Surface Hydrocarbons | Collision Scenario | Stochastic Outcomes. Predicted annualised probability of floating oil concentrations at or above 10 g/m^2 resulting from a 1-hour surface release of IFO-180 at the Crux end of the export pipeline.

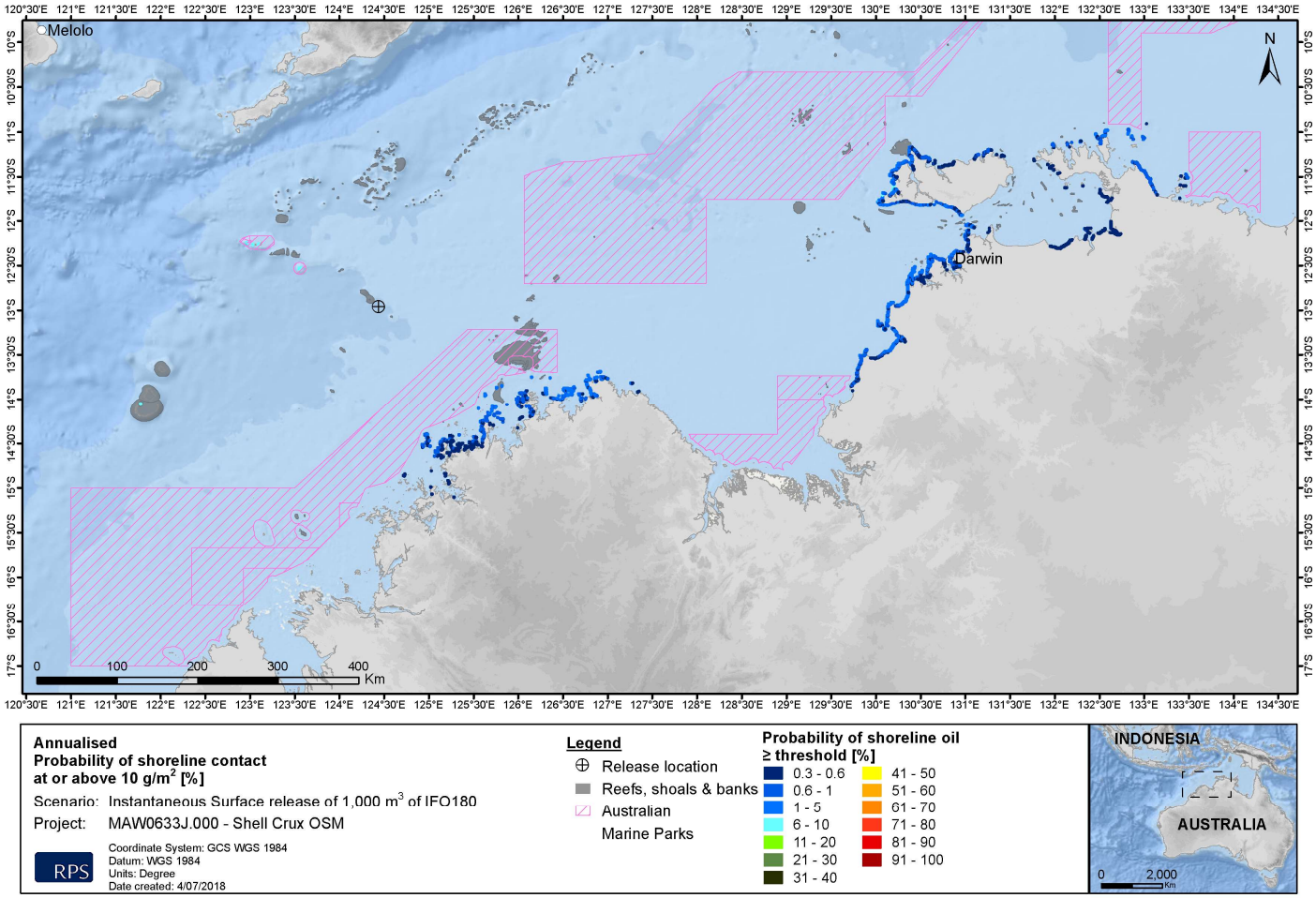


Figure 3.40 Shoreline Hydrocarbons | Collision Scenario | Stochastic Outcomes. Predicted annualised probability of shoreline oil concentrations at or above 10 g/m^2 resulting from a 1-hour surface release of IFO-180 at the Crux end of the export pipeline.

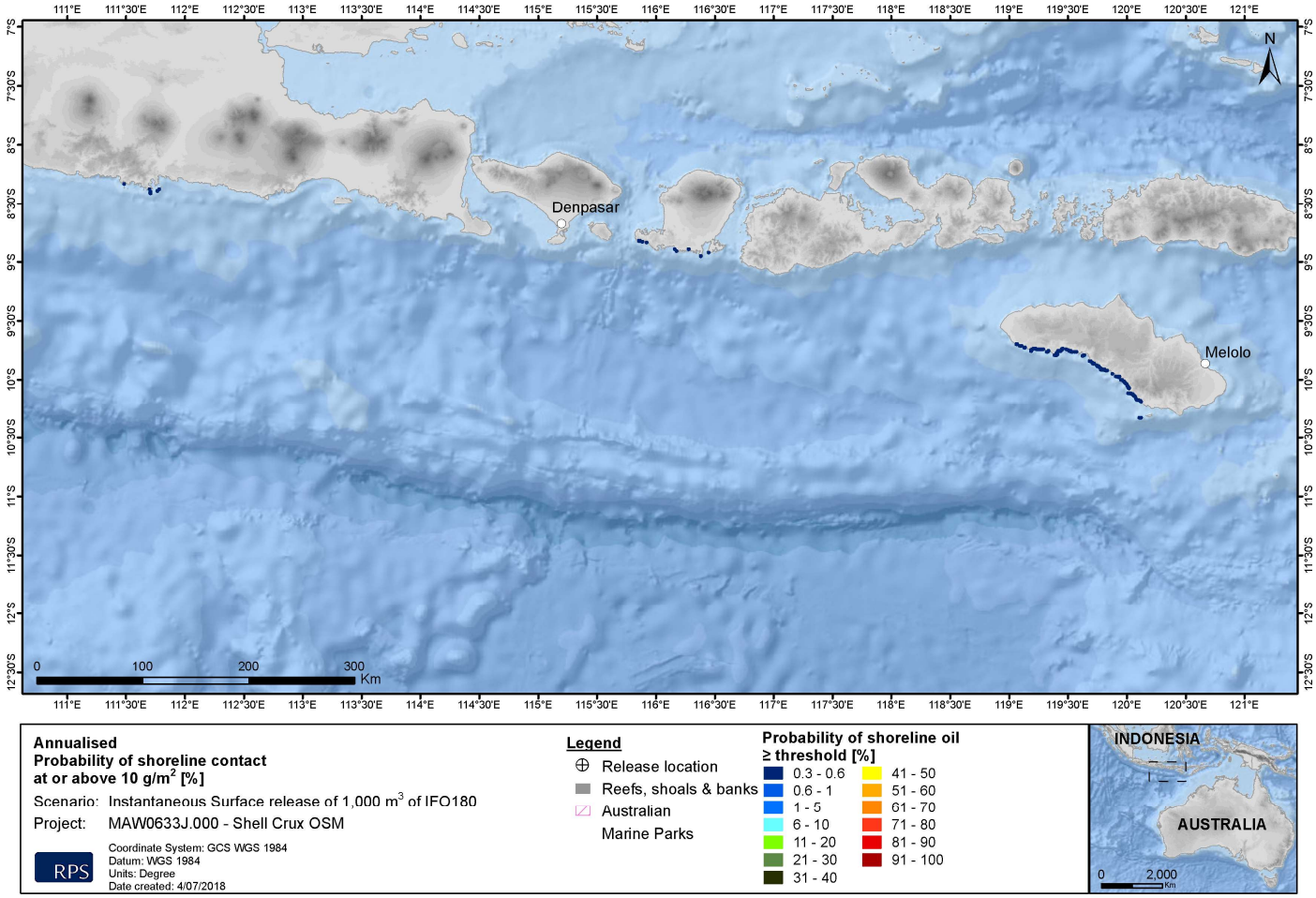


Figure 3.41 Shoreline Hydrocarbons | Collision Scenario | Stochastic Outcomes. Predicted annualised probability of shoreline oil concentrations at or above 10 g/m^2 resulting from a 1-hour surface release of IFO-180 at the Crux end of the export pipeline.

RPS

3.5.3 Entrained Hydrocarbons

Table 3.18 Expected annualised entrained oil outcomes at sensitive receptors resulting from a 1-hour surface release of IFO-180 at the Crux end of the export pipeline.

	Receptor	Probability (%) of entrained hydrocarbon concentration contact at specific receptor depth			Minimum time to receptor waters (hours) at		
		≥10 ppb	≥100 ppb	≥500 ppb	≥10 ppb	≥100 ppb	≥500 ppb
Coastlines	Cobourg Peninsula	<0.3	<0.3	<0.3	NC	NC	NC
	Darwin Coast	<0.3	<0.3	<0.3	NC	NC	NC
	Indonesia	<0.3	<0.3	<0.3	NC	NC	NC
	Joseph Bonaparte Gulf Northern Territory	<0.3	<0.3	<0.3	NC	NC	NC
	Kakadu Coast	<0.3	<0.3	<0.3	NC	NC	NC
	Kakadu National Park	<0.3	<0.3	<0.3	NC	NC	NC
	Kimberley Coast	<0.3	<0.3	<0.3	NC	NC	NC
	West Arnhem Land	<0.3	<0.3	<0.3	NC	NC	NC
Islands	Admiralty Gulf Islands	<0.3	<0.3	<0.3	NC	NC	NC
	Bathurst Island	<0.3	<0.3	<0.3	NC	NC	NC
	Bigge Island	<0.3	<0.3	<0.3	NC	NC	NC
	Bonaparte Archipelago	<0.3	<0.3	<0.3	NC	NC	NC
	Browse Island	<0.3	<0.3	<0.3	NC	NC	NC
	Cape Londonderry Islands	<0.3	<0.3	<0.3	NC	NC	NC
	Cassini Island	<0.3	<0.3	<0.3	NC	NC	NC
	Coronation Island Group	<0.3	<0.3	<0.3	NC	NC	NC
	Croker Island	<0.3	<0.3	<0.3	NC	NC	NC
	East Vernon Island	<0.3	<0.3	<0.3	NC	NC	NC
	Eclipse Archipelago	<0.3	<0.3	<0.3	NC	NC	NC
	Field Island	<0.3	<0.3	<0.3	NC	NC	NC
	Greenhill Island	<0.3	<0.3	<0.3	NC	NC	NC
	Jones Island	<0.3	<0.3	<0.3	NC	NC	NC
	Lawson Island	<0.3	<0.3	<0.3	NC	NC	NC
	Lesueur Island	<0.3	<0.3	<0.3	NC	NC	NC
	Long Island Kimberley	<0.3	<0.3	<0.3	NC	NC	NC
	McCluer Island	<0.3	<0.3	<0.3	NC	NC	NC
	Melville Island	<0.3	<0.3	<0.3	NC	NC	NC
	Mogogout Island	<0.3	<0.3	<0.3	NC	NC	NC

RPS

	Receptor	Probability (%) of entrained hydrocarbon concentration contact at specific receptor depth			Minimum time to receptor waters (hours) at		
		≥10 ppb	≥100 ppb	≥500 ppb	≥10 ppb	≥100 ppb	≥500 ppb
	Montalivet Island	<0.3	<0.3	<0.3	NC	NC	NC
	Morse Island	<0.3	<0.3	<0.3	NC	NC	NC
	Napier Broome Bay Islands	<0.3	<0.3	<0.3	NC	NC	NC
	New Year Island	<0.3	<0.3	<0.3	NC	NC	NC
	North Goulburn Island	<0.3	<0.3	<0.3	NC	NC	NC
	North West Vernon Island	<0.3	<0.3	<0.3	NC	NC	NC
	Oxley Island	<0.3	<0.3	<0.3	NC	NC	NC
	Peron Islands	<0.3	<0.3	<0.3	NC	NC	NC
	Roche Islands and Reefs	<0.3	<0.3	<0.3	NC	NC	NC
	South Goulburn Island	<0.3	<0.3	<0.3	NC	NC	NC
	South West Vernon Island	<0.3	<0.3	<0.3	NC	NC	NC
	Stewarts Islands	<0.3	<0.3	<0.3	NC	NC	NC
	Troughton Island	<0.3	<0.3	<0.3	NC	NC	NC
Reefs	Beatrice Reef	<0.3	<0.3	<0.3	NC	NC	NC
	Christine Reef	<0.3	<0.3	<0.3	NC	NC	NC
	Draytons Reef	<0.3	<0.3	<0.3	NC	NC	NC
	East Holothuria Reef	<0.3	<0.3	<0.3	NC	NC	NC
	Elphinstone Reef	<0.3	<0.3	<0.3	NC	NC	NC
	Fish Reef	<0.3	<0.3	<0.3	NC	NC	NC
	Harris Reef	<0.3	<0.3	<0.3	NC	NC	NC
	Heritage Reef	<0.3	<0.3	<0.3	NC	NC	NC
	Hibernia Reef	<0.3	<0.3	<0.3	NC	NC	NC
	Hunt Patch	<0.3	<0.3	<0.3	NC	NC	NC
	Ingram Reef	<0.3	<0.3	<0.3	NC	NC	NC
	Jamieson Reef	<0.3	<0.3	<0.3	NC	NC	NC
	Knight Reef	<0.3	<0.3	<0.3	NC	NC	NC
	Long Reef	<0.3	<0.3	<0.3	NC	NC	NC
	Lyne Reef	<0.3	<0.3	<0.3	NC	NC	NC
	Middle Reef	<0.3	<0.3	<0.3	NC	NC	NC
	Oliver Reef	<0.3	<0.3	<0.3	NC	NC	NC
	Oliver Rock	<0.3	<0.3	<0.3	NC	NC	NC
	Orontes Reef	<0.3	<0.3	<0.3	NC	NC	NC

RPS

	Receptor	Probability (%) of entrained hydrocarbon concentration contact at specific receptor depth			Minimum time to receptor waters (hours) at		
		≥10 ppb	≥100 ppb	≥500 ppb	≥10 ppb	≥100 ppb	≥500 ppb
	Rothery Reef	<0.3	<0.3	<0.3	NC	NC	NC
	Sandy Islet	<0.3	<0.3	<0.3	NC	NC	NC
	Scott Reef North	<0.3	<0.3	<0.3	NC	NC	NC
	Scott Reef South	<0.3	<0.3	<0.3	NC	NC	NC
	Seringapatam Reef	<0.3	<0.3	<0.3	NC	NC	NC
	Taylor Patches	<0.3	<0.3	<0.3	NC	NC	NC
	The Boxers	<0.3	<0.3	<0.3	NC	NC	NC
	The Boxers Area	<0.3	<0.3	<0.3	NC	NC	NC
	Tregenna Reef	<0.3	<0.3	<0.3	NC	NC	NC
	West Holothuria Reef	<0.3	<0.3	<0.3	NC	NC	NC
Shoals	Abbott Shoal	<0.3	<0.3	<0.3	NC	NC	NC
	Afghan Shoal	<0.3	<0.3	<0.3	NC	NC	NC
	Ann Shoals	<0.3	<0.3	<0.3	NC	NC	NC
	Barbara Shoal	<0.3	<0.3	<0.3	NC	NC	NC
	Barracouta Shoals	<0.3	<0.3	<0.3	NC	NC	NC
	Barton Shoal	<0.3	<0.3	<0.3	NC	NC	NC
	Bassett-Smith Shoal	<0.3	<0.3	<0.3	NC	NC	NC
	Beagle Shoals	<0.3	<0.3	<0.3	NC	NC	NC
	Big Bank Shoals	<0.3	<0.3	<0.3	NC	NC	NC
	Bill Shoal	<0.3	<0.3	<0.3	NC	NC	NC
	Britomart Shoal	<0.3	<0.3	<0.3	NC	NC	NC
	Calder Shoal	<0.3	<0.3	<0.3	NC	NC	NC
	Cootamundra Shoal	<0.3	<0.3	<0.3	NC	NC	NC
	Deep Shoal 1	<0.3	<0.3	<0.3	NC	NC	NC
	Deep Shoal 2	<0.3	<0.3	<0.3	NC	NC	NC
	Dillon Shoal	<0.3	<0.3	<0.3	NC	NC	NC
	Echo Shoals	<0.3	<0.3	<0.3	NC	NC	NC
	Echuca Shoal	<0.3	<0.3	<0.3	NC	NC	NC
	Eugene McDermott Shoal	<0.3	<0.3	<0.3	NC	NC	NC
	Fantome Shoal	<0.3	<0.3	<0.3	NC	NC	NC
	Fitzpatrick Shoal	<0.3	<0.3	<0.3	NC	NC	NC
	Giles Shoal	<0.3	<0.3	<0.3	NC	NC	NC

RPS

	Receptor	Probability (%) of entrained hydrocarbon concentration contact at specific receptor depth			Minimum time to receptor waters (hours) at		
		≥10 ppb	≥100 ppb	≥500 ppb	≥10 ppb	≥100 ppb	≥500 ppb
	Goeree Shoal	<0.3	<0.3	<0.3	NC	NC	NC
	Hancox Shoal	<0.3	<0.3	<0.3	NC	NC	NC
	Heywood Shoal	<0.3	<0.3	<0.3	NC	NC	NC
	Jabiru Shoals	<0.3	<0.3	<0.3	NC	NC	NC
	Jones Shoal	<0.3	<0.3	<0.3	NC	NC	NC
	Karmt Shoal	<0.3	<0.3	<0.3	NC	NC	NC
	Lowry Shoal	<0.3	<0.3	<0.3	NC	NC	NC
	Mangola Shoal	<0.3	<0.3	<0.3	NC	NC	NC
	Marie Shoal	<0.3	<0.3	<0.3	NC	NC	NC
	Marsh Shoal	<0.3	<0.3	<0.3	NC	NC	NC
	Mermaid Shoal	<0.3	<0.3	<0.3	NC	NC	NC
	Moresby Shoals	<0.3	<0.3	<0.3	NC	NC	NC
	Moss Shoal	<0.3	<0.3	<0.3	NC	NC	NC
	Newby Shoal	<0.3	<0.3	<0.3	NC	NC	NC
	Parry Shoal	<0.3	<0.3	<0.3	NC	NC	NC
	Pee Shoal	<0.3	<0.3	<0.3	NC	NC	NC
	Penguin Shoal	<0.3	<0.3	<0.3	NC	NC	NC
	Penguin Shoal	<0.3	<0.3	<0.3	NC	NC	NC
	Shepparton Shoal	<0.3	<0.3	<0.3	NC	NC	NC
	Skottowe Shoal	<0.3	<0.3	<0.3	NC	NC	NC
	Taiyun Shoal	<0.3	<0.3	<0.3	NC	NC	NC
	Van Cloon Shoal	<0.3	<0.3	<0.3	NC	NC	NC
	Vee Shoal	<0.3	<0.3	<0.3	NC	NC	NC
	Victoria Shoal	<0.3	<0.3	<0.3	NC	NC	NC
	Vulcan Shoals	<0.3	<0.3	<0.3	NC	NC	NC
	Wells Shoal	<0.3	<0.3	<0.3	NC	NC	NC
Banks	Baldwin Bank	<0.3	<0.3	<0.3	NC	NC	NC
	Bellona Bank	<0.3	<0.3	<0.3	NC	NC	NC
	Branch Banks	<0.3	<0.3	<0.3	NC	NC	NC
	Favell Bank	<0.3	<0.3	<0.3	NC	NC	NC
	Flat Top Bank	<0.3	<0.3	<0.3	NC	NC	NC
	Foelsche Bank	<0.3	<0.3	<0.3	NC	NC	NC

RPS

	Receptor	Probability (%) of entrained hydrocarbon concentration contact at specific receptor depth			Minimum time to receptor waters (hours) at		
		≥10 ppb	≥100 ppb	≥500 ppb	≥10 ppb	≥100 ppb	≥500 ppb
	Gale Bank	<0.3	<0.3	<0.3	NC	NC	NC
	Goodrich Bank	<0.3	<0.3	<0.3	NC	NC	NC
	Holothuria Banks	<0.3	<0.3	<0.3	NC	NC	NC
	Johnson Bank	<0.3	<0.3	<0.3	NC	NC	NC
	Jones Bank	<0.3	<0.3	<0.3	NC	NC	NC
	Margaret Harries Bank	<0.3	<0.3	<0.3	NC	NC	NC
	Otway Bank	<0.3	<0.3	<0.3	NC	NC	NC
	Parsons Bank	<0.3	<0.3	<0.3	NC	NC	NC
	Sahul Bank	<0.3	<0.3	<0.3	NC	NC	NC
	Sunrise Bank	<0.3	<0.3	<0.3	NC	NC	NC
	Tait Bank	<0.3	<0.3	<0.3	NC	NC	NC
	Woodbine Bank	<0.3	<0.3	<0.3	NC	NC	NC
Marine Parks	Arafura AMP	<0.3	<0.3	<0.3	NC	NC	NC
	Arnhem AMP	<0.3	<0.3	<0.3	NC	NC	NC
	Ashmore Reef AMP	<0.3	<0.3	<0.3	NC	NC	NC
	Cartier Island AMP	<0.3	<0.3	<0.3	NC	NC	NC
	Charles Darwin NP	<0.3	<0.3	<0.3	NC	NC	NC
	Djukbinj NP	<0.3	<0.3	<0.3	NC	NC	NC
	Garig Gunak Barlu NP	<0.3	<0.3	<0.3	NC	NC	NC
	Kakadu NP	<0.3	<0.3	<0.3	NC	NC	NC
	Kimberley AMP	<0.3	<0.3	<0.3	NC	NC	NC
	North Lalang-garram MP & North Kimberley MP	<0.3	<0.3	<0.3	NC	NC	NC
	Mary River NP	<0.3	<0.3	<0.3	NC	NC	NC
	Oceanic Shoals AMP	<0.3	<0.3	<0.3	NC	NC	NC
	Prince Regent NP Coast	<0.3	<0.3	<0.3	NC	NC	NC
Key Ecological Features	Ancient Coastline at 125 m depth contour	<0.3	<0.3	<0.3	NC	NC	NC
	Ashmore Reef and Cartier Island and surrounding Commonwealth Waters	<0.3	<0.3	<0.3	NC	NC	NC
	Canyons linking the Argo Abyssal Plain with the Scott Plateau	<0.3	<0.3	<0.3	NC	NC	NC
	Carbonate bank & terrace system of Van Diemen Rise	<0.3	<0.3	<0.3	NC	NC	NC

RPS

	Receptor	Probability (%) of entrained hydrocarbon concentration contact at specific receptor depth			Minimum time to receptor waters (hours) at		
		≥10 ppb	≥100 ppb	≥500 ppb	≥10 ppb	≥100 ppb	≥500 ppb
	Carbonate bank and terrace system of Sahul Shelf	0.9	<0.3	<0.3	29	NC	NC
	Continental Slope Demersal Fish Communities	<0.3	<0.3	<0.3	NC	NC	NC
	Pinnacles of the Bonaparte Basin	<0.3	<0.3	<0.3	NC	NC	NC
	Seringapatam Reef and Commonwealth Waters in the Scott Reef Complex	<0.3	<0.3	<0.3	NC	NC	NC
	Shelf break and slope of the Arafura Shelf	<0.3	<0.3	<0.3	NC	NC	NC
Fisheries	Northern Prawn Fishery	<0.3	<0.3	<0.3	NC	NC	NC
	North-West Slope Trawl Fishery	0.6	<0.3	<0.3	11	NC	NC
	Southern Bluefin Tuna Fishery	5.4	1.8	1.2	1	1	1
	Timor Reef Fishery (NT Managed)	<0.3	<0.3	<0.3	NC	NC	NC
	Western Skipjack Fishery	5.4	1.8	1.2	1	1	1
	Western Tuna and Billfish Fishery	5.4	1.8	1.2	1	1	1
Biologically Important Areas	Flatback Turtle BIA	<0.3	<0.3	<0.3	NC	NC	NC
	Green Turtle BIA	<0.3	<0.3	<0.3	NC	NC	NC
	Hawksbill Turtle BIA	<0.3	<0.3	<0.3	NC	NC	NC
	Leatherback Turtle BIA	<0.3	<0.3	<0.3	NC	NC	NC
	Loggerhead Turtle BIA	<0.3	<0.3	<0.3	NC	NC	NC
	Olive Ridley Turtle BIA	<0.3	<0.3	<0.3	NC	NC	NC

NC: No contact to receptor predicted for specified threshold.

** Probabilities and maximum concentrations calculated at depth of submerged feature.*

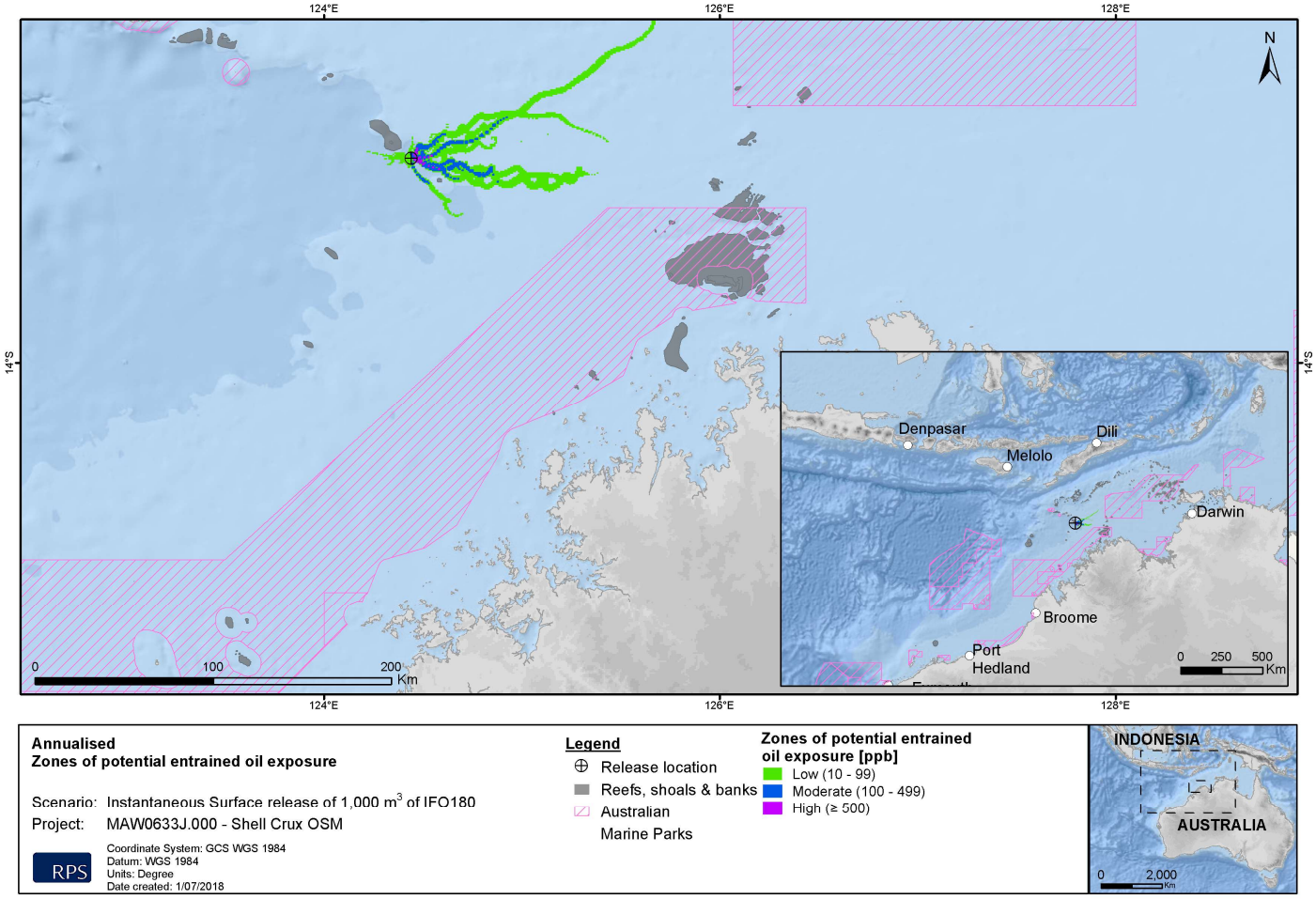


Figure 3.42 Subsurface Hydrocarbons | Entrained | Collision Scenario | Stochastic Outcomes. Areal extent of potential exposure at defined entrained oil threshold concentrations resulting from a 1-hour surface release of IFO-180 at the Crux end of the export pipeline.

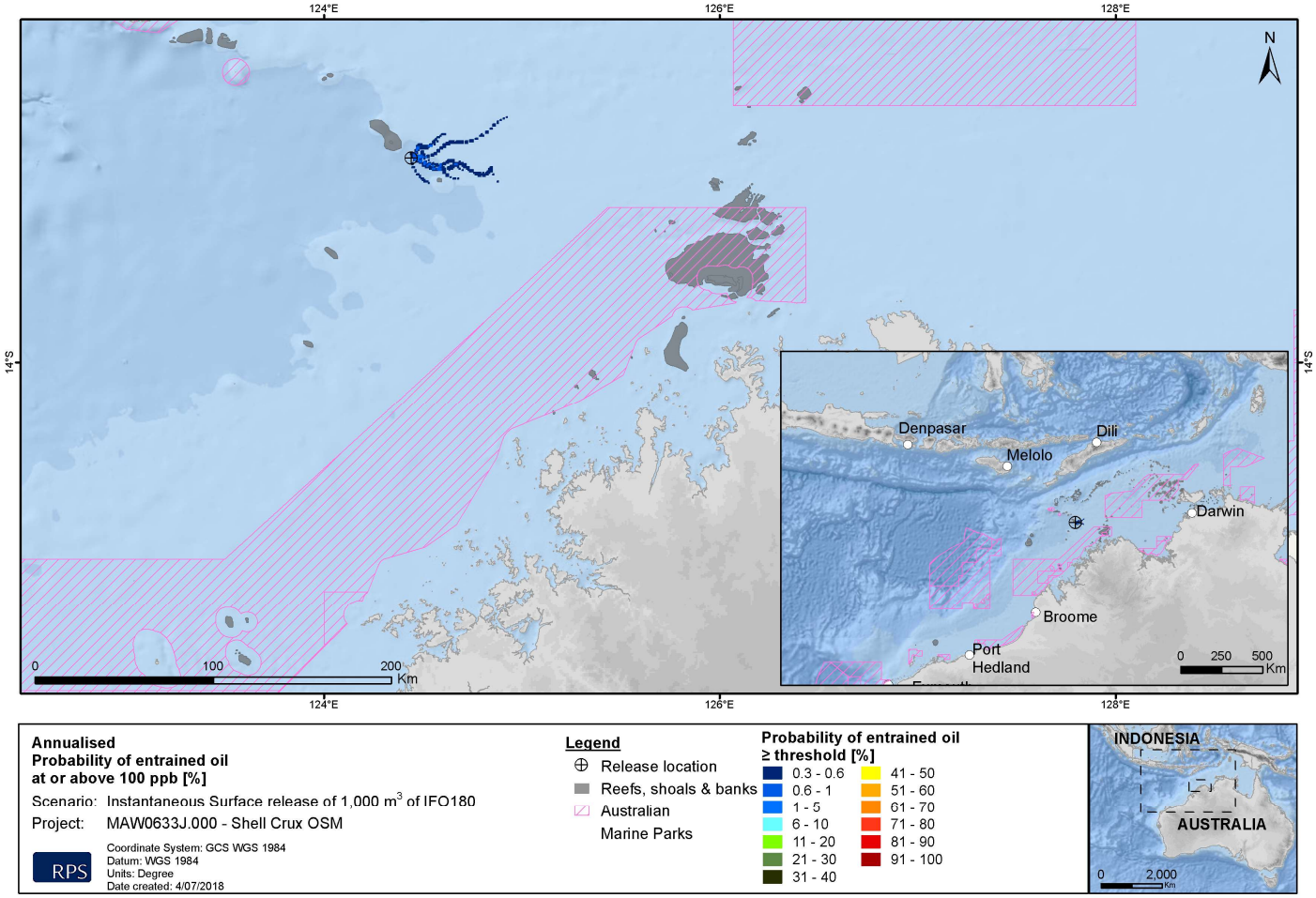


Figure 3.43 Subsurface Hydrocarbons | Entrained | Collision Scenario | Stochastic Outcomes. Predicted annualised probability of entrained oil concentrations at or above 100 ppb resulting from a 1-hour surface release of IFO-180 at the Crux end of the export pipeline.

RPS

3.5.4 Dissolved Aromatic Hydrocarbons

Table 3.19 Expected annualised dissolved aromatic hydrocarbon outcomes at sensitive receptors resulting from a 1-hour surface release of IFO-180 at the Crux end of the export pipeline.

	Receptor	Probability (%) of dissolved aromatic concentration at specific receptor depth		
		≥6 ppb	≥50 ppb	≥400 ppb
Coastlines	Cobourg Peninsula	<0.3	<0.3	<0.3
	Darwin Coast	<0.3	<0.3	<0.3
	Indonesia	<0.3	<0.3	<0.3
	Joseph Bonaparte Gulf Northern Territory	<0.3	<0.3	<0.3
	Kakadu Coast	<0.3	<0.3	<0.3
	Kakadu National Park	<0.3	<0.3	<0.3
	Kimberley Coast	<0.3	<0.3	<0.3
	West Arnhem Land	<0.3	<0.3	<0.3
Islands	Admiralty Gulf Islands	<0.3	<0.3	<0.3
	Bathurst Island	<0.3	<0.3	<0.3
	Bigge Island	<0.3	<0.3	<0.3
	Bonaparte Archipelago	<0.3	<0.3	<0.3
	Browse Island	<0.3	<0.3	<0.3
	Cape Londonderry Islands	<0.3	<0.3	<0.3
	Cassini Island	<0.3	<0.3	<0.3
	Coronation Island Group	<0.3	<0.3	<0.3
	Croker Island	<0.3	<0.3	<0.3
	East Vernon Island	<0.3	<0.3	<0.3
	Eclipse Archipelago	<0.3	<0.3	<0.3
	Field Island	<0.3	<0.3	<0.3
	Greenhill Island	<0.3	<0.3	<0.3
	Jones Island	<0.3	<0.3	<0.3
	Lawson Island	<0.3	<0.3	<0.3
	Lesueur Island	<0.3	<0.3	<0.3
	Long Island Kimberley	<0.3	<0.3	<0.3
	McCluer Island	<0.3	<0.3	<0.3
	Melville Island	<0.3	<0.3	<0.3
	Mogogout Island	<0.3	<0.3	<0.3
	Montalivet Island	<0.3	<0.3	<0.3

RPS

	Receptor	Probability (%) of dissolved aromatic concentration at specific receptor depth		
		≥6 ppb	≥50 ppb	≥400 ppb
	Morse Island	<0.3	<0.3	<0.3
	Napier Broome Bay Islands	<0.3	<0.3	<0.3
	New Year Island	<0.3	<0.3	<0.3
	North Goulburn Island	<0.3	<0.3	<0.3
	North West Vernon Island	<0.3	<0.3	<0.3
	Oxley Island	<0.3	<0.3	<0.3
	Peron Islands	<0.3	<0.3	<0.3
	Roche Islands and Reefs	<0.3	<0.3	<0.3
	South Goulburn Island	<0.3	<0.3	<0.3
	South West Vernon Island	<0.3	<0.3	<0.3
	Stewarts Islands	<0.3	<0.3	<0.3
	Troughton Island	<0.3	<0.3	<0.3
Reefs	Beatrice Reef	<0.3	<0.3	<0.3
	Christine Reef	<0.3	<0.3	<0.3
	Draytons Reef	<0.3	<0.3	<0.3
	East Holothuria Reef	<0.3	<0.3	<0.3
	Elphinstone Reef	<0.3	<0.3	<0.3
	Fish Reef	<0.3	<0.3	<0.3
	Harris Reef	<0.3	<0.3	<0.3
	Heritage Reef	<0.3	<0.3	<0.3
	Hibernia Reef	<0.3	<0.3	<0.3
	Hunt Patch	<0.3	<0.3	<0.3
	Ingram Reef	<0.3	<0.3	<0.3
	Jamieson Reef	<0.3	<0.3	<0.3
	Knight Reef	<0.3	<0.3	<0.3
	Long Reef	<0.3	<0.3	<0.3
	Lyne Reef	<0.3	<0.3	<0.3
	Middle Reef	<0.3	<0.3	<0.3
	Oliver Reef	<0.3	<0.3	<0.3
	Oliver Rock	<0.3	<0.3	<0.3
	Orontes Reef	<0.3	<0.3	<0.3
	Rothery Reef	<0.3	<0.3	<0.3

RPS

	Receptor	Probability (%) of dissolved aromatic concentration at specific receptor depth		
		≥6 ppb	≥50 ppb	≥400 ppb
	Sandy Islet	<0.3	<0.3	<0.3
	Scott Reef North	<0.3	<0.3	<0.3
	Scott Reef South	<0.3	<0.3	<0.3
	Seringapatam Reef	<0.3	<0.3	<0.3
	Taylor Patches	<0.3	<0.3	<0.3
	The Boxers	<0.3	<0.3	<0.3
	The Boxers Area	<0.3	<0.3	<0.3
	Tregenna Reef	<0.3	<0.3	<0.3
	West Holothuria Reef	<0.3	<0.3	<0.3
Shoals	Abbott Shoal	<0.3	<0.3	<0.3
	Afghan Shoal	<0.3	<0.3	<0.3
	Ann Shoals	<0.3	<0.3	<0.3
	Barbara Shoal	<0.3	<0.3	<0.3
	Barracouta Shoals	<0.3	<0.3	<0.3
	Barton Shoal	<0.3	<0.3	<0.3
	Bassett-Smith Shoal	<0.3	<0.3	<0.3
	Beagle Shoals	<0.3	<0.3	<0.3
	Big Bank Shoals	<0.3	<0.3	<0.3
	Bill Shoal	<0.3	<0.3	<0.3
	Britomart Shoal	<0.3	<0.3	<0.3
	Calder Shoal	<0.3	<0.3	<0.3
	Cootamundra Shoal	<0.3	<0.3	<0.3
	Deep Shoal 1	<0.3	<0.3	<0.3
	Deep Shoal 2	<0.3	<0.3	<0.3
	Dillon Shoal	<0.3	<0.3	<0.3
	Echo Shoals	<0.3	<0.3	<0.3
	Echuca Shoal	<0.3	<0.3	<0.3
	Eugene McDermott Shoal	<0.3	<0.3	<0.3
	Fantome Shoal	<0.3	<0.3	<0.3
	Fitzpatrick Shoal	<0.3	<0.3	<0.3
	Giles Shoal	<0.3	<0.3	<0.3
	Goeree Shoal	<0.3	<0.3	<0.3

	Receptor	Probability (%) of dissolved aromatic concentration at specific receptor depth		
		≥6 ppb	≥50 ppb	≥400 ppb
	Hancox Shoal	<0.3	<0.3	<0.3
	Heywood Shoal	<0.3	<0.3	<0.3
	Jabiru Shoals	<0.3	<0.3	<0.3
	Jones Shoal	<0.3	<0.3	<0.3
	Karmt Shoal	<0.3	<0.3	<0.3
	Lowry Shoal	<0.3	<0.3	<0.3
	Mangola Shoal	<0.3	<0.3	<0.3
	Marie Shoal	<0.3	<0.3	<0.3
	Marsh Shoal	<0.3	<0.3	<0.3
	Mermaid Shoal	<0.3	<0.3	<0.3
	Moresby Shoals	<0.3	<0.3	<0.3
	Moss Shoal	<0.3	<0.3	<0.3
	Newby Shoal	<0.3	<0.3	<0.3
	Parry Shoal	<0.3	<0.3	<0.3
	Pee Shoal	<0.3	<0.3	<0.3
	Penguin Shoal	<0.3	<0.3	<0.3
	Penguin Shoal	<0.3	<0.3	<0.3
	Shepparton Shoal	<0.3	<0.3	<0.3
	Skottowe Shoal	<0.3	<0.3	<0.3
	Taiyun Shoal	<0.3	<0.3	<0.3
	Van Cloon Shoal	<0.3	<0.3	<0.3
	Vee Shoal	<0.3	<0.3	<0.3
	Victoria Shoal	<0.3	<0.3	<0.3
	Vulcan Shoals	<0.3	<0.3	<0.3
	Wells Shoal	<0.3	<0.3	<0.3
Banks	Baldwin Bank	<0.3	<0.3	<0.3
	Bellona Bank	<0.3	<0.3	<0.3
	Branch Banks	<0.3	<0.3	<0.3
	Favell Bank	<0.3	<0.3	<0.3
	Flat Top Bank	<0.3	<0.3	<0.3
	Foelsche Bank	<0.3	<0.3	<0.3
	Gale Bank	<0.3	<0.3	<0.3

RPS

	Receptor	Probability (%) of dissolved aromatic concentration at specific receptor depth		
		≥6 ppb	≥50 ppb	≥400 ppb
	Goodrich Bank	<0.3	<0.3	<0.3
	Holothuria Banks	<0.3	<0.3	<0.3
	Johnson Bank	<0.3	<0.3	<0.3
	Jones Bank	<0.3	<0.3	<0.3
	Margaret Harries Bank	<0.3	<0.3	<0.3
	Otway Bank	<0.3	<0.3	<0.3
	Parsons Bank	<0.3	<0.3	<0.3
	Sahul Bank	<0.3	<0.3	<0.3
	Sunrise Bank	<0.3	<0.3	<0.3
	Tait Bank	<0.3	<0.3	<0.3
	Woodbine Bank	<0.3	<0.3	<0.3
Marine Parks	Arafura AMP	<0.3	<0.3	<0.3
	Arnhem AMP	<0.3	<0.3	<0.3
	Ashmore Reef AMP	<0.3	<0.3	<0.3
	Cartier Island AMP	<0.3	<0.3	<0.3
	Charles Darwin NP	<0.3	<0.3	<0.3
	Djukbinj NP	<0.3	<0.3	<0.3
	Garig Gunak Barlu NP	<0.3	<0.3	<0.3
	Kakadu NP	<0.3	<0.3	<0.3
	Kimberley AMP	<0.3	<0.3	<0.3
	North Lalang-garram MP & North Kimberley MP	<0.3	<0.3	<0.3
	Mary River NP	<0.3	<0.3	<0.3
	Oceanic Shoals AMP	<0.3	<0.3	<0.3
	Prince Regent NP Coast	<0.3	<0.3	<0.3
Key Ecological Features	Ancient Coastline at 125 m depth contour	<0.3	<0.3	<0.3
	Ashmore Reef and Cartier Island and surrounding Commonwealth Waters	<0.3	<0.3	<0.3
	Canyons linking the Argo Abyssal Plain with the Scott Plateau	<0.3	<0.3	<0.3
	Carbonate bank & terrace system of Van Diemen Rise	<0.3	<0.3	<0.3
	Carbonate bank and terrace system of Sahul Shelf	<0.3	<0.3	<0.3
	Continental Slope Demersal Fish Communities	<0.3	<0.3	<0.3

	Receptor	Probability (%) of dissolved aromatic concentration at specific receptor depth		
		≥6 ppb	≥50 ppb	≥400 ppb
	Pinnacles of the Bonaparte Basin	<0.3	<0.3	<0.3
	Seringapatam Reef and Commonwealth Waters in the Scott Reef Complex	<0.3	<0.3	<0.3
	Shelf break and slope of the Arafura Shelf	<0.3	<0.3	<0.3
Fisheries	Northern Prawn Fishery	<0.3	<0.3	<0.3
	North-West Slope Trawl Fishery	<0.3	<0.3	<0.3
	Southern Bluefin Tuna Fishery	0.9	<0.3	<0.3
	Timor Reef Fishery (NT Managed)	<0.3	<0.3	<0.3
	Western Skipjack Fishery	0.9	<0.3	<0.3
	Western Tuna and Billfish Fishery	0.9	<0.3	<0.3
Biologically Important Areas	Flatback Turtle BIA	<0.3	<0.3	<0.3
	Green Turtle BIA	<0.3	<0.3	<0.3
	Hawksbill Turtle BIA	<0.3	<0.3	<0.3
	Leatherback Turtle BIA	<0.3	<0.3	<0.3
	Loggerhead Turtle BIA	<0.3	<0.3	<0.3
	Olive Ridley Turtle BIA	<0.3	<0.3	<0.3

NC: No contact to receptor predicted for specified threshold.

** Probabilities and maximum concentrations calculated at depth of submerged feature.*

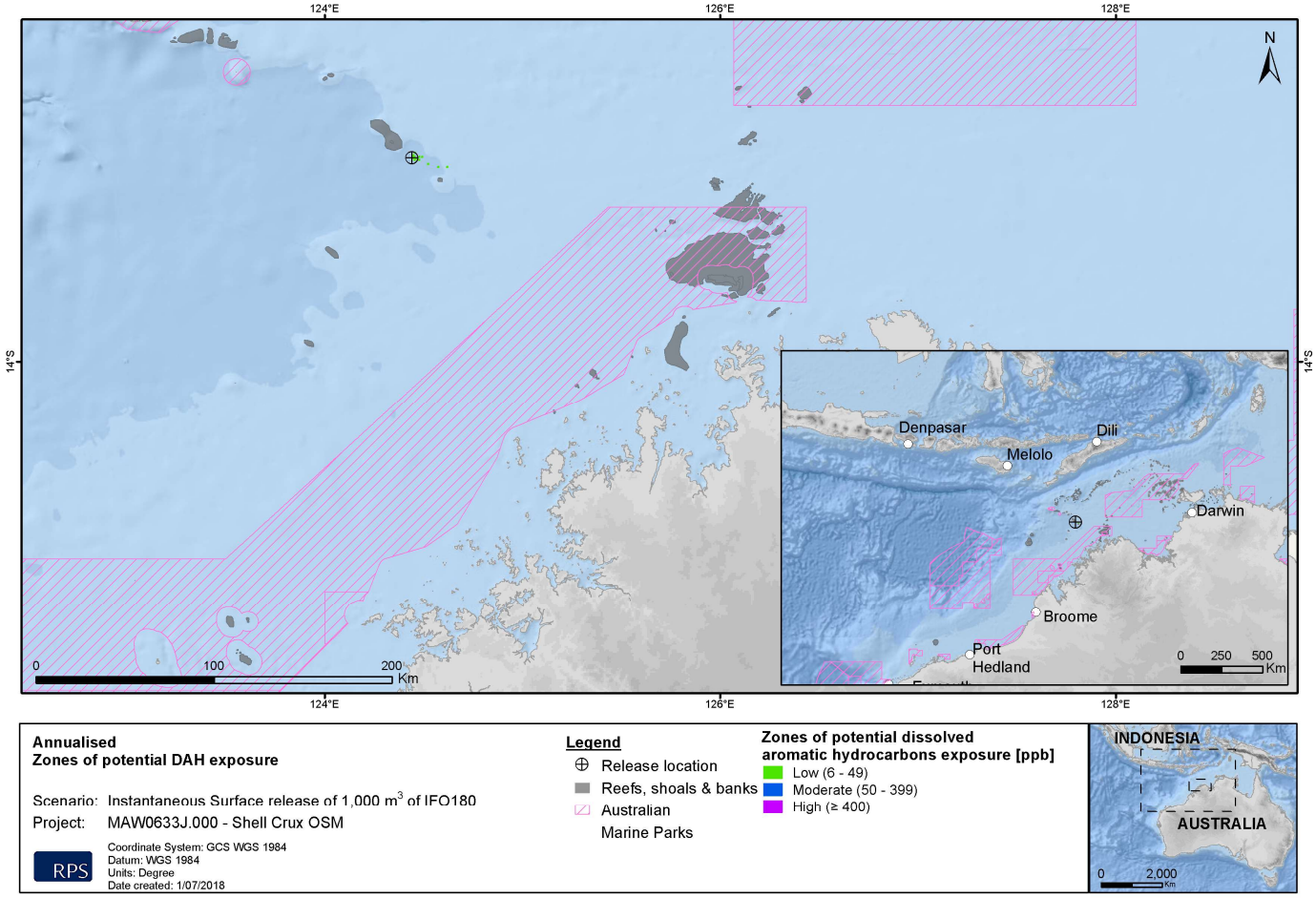


Figure 3.44 Subsurface Hydrocarbons | Dissolved | Collision Scenario | Stochastic Outcomes. Areal extent of potential exposure at defined dissolved aromatic hydrocarbon threshold concentrations resulting from a 1-hour surface release of IFO-180 at the Crux end of the export pipeline.

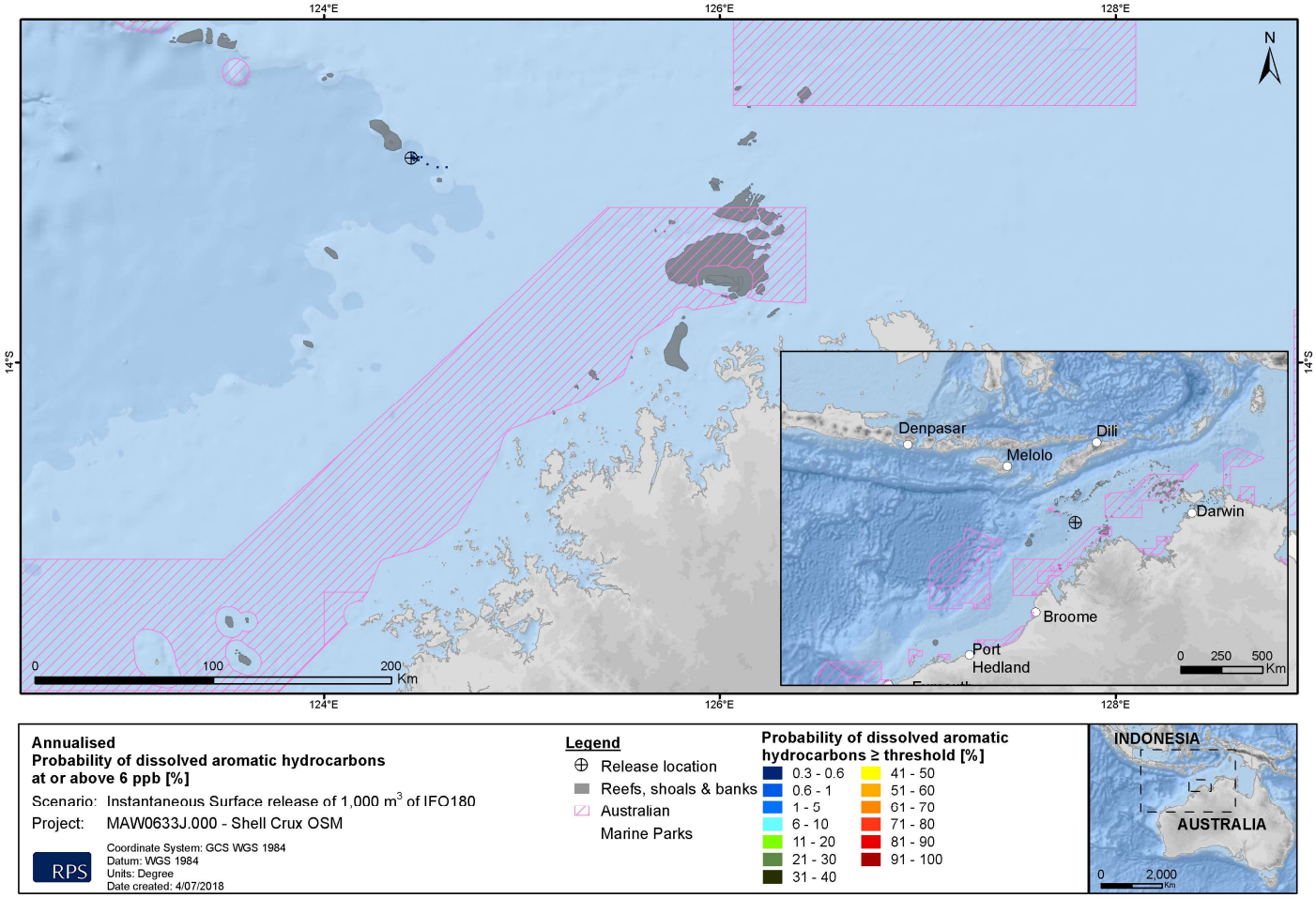


Figure 3.45 Subsurface Hydrocarbons | Dissolved | Collision Scenario | Stochastic Outcomes. Predicted annualised probability of dissolved aromatic hydrocarbon concentrations at or above 6 ppb resulting from a 1-hour surface release of IFO-180 at the Crux end of the export pipeline.

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Appendix A

Scenario 1 – Annualised Probability – Stochastic Modelling

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Figures – Appendix A

Figure A. 1 Surface Hydrocarbons | Blowout Scenario | Stochastic Outcomes. Predicted annualised probability of floating oil concentrations at or above 1 g/m^2 resulting from an 80-day subsurface release of Crux condensate at a development well.

Figure A. 2 Shoreline Hydrocarbons | Blowout Scenario | Stochastic Outcomes. Predicted annualised probability of shoreline oil concentrations at or above 100 g/m^2 resulting from an 80-day subsurface release of Crux condensate at a development well.

Figure A. 3 Subsurface Hydrocarbons | Entrained | Blowout Scenario | Stochastic Outcomes. Predicted annualised probability of entrained oil concentrations at or above 10 ppb resulting from an 80-day subsurface release of Crux condensate at a development well.

Figure A. 4 Subsurface Hydrocarbons | Entrained | Blowout Scenario | Stochastic Outcomes. Predicted annualised probability of entrained oil concentrations at or above 500 ppb resulting from an 80-day subsurface release of Crux condensate at a development well.

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Annualised Results

Floating and Shoreline Hydrocarbons

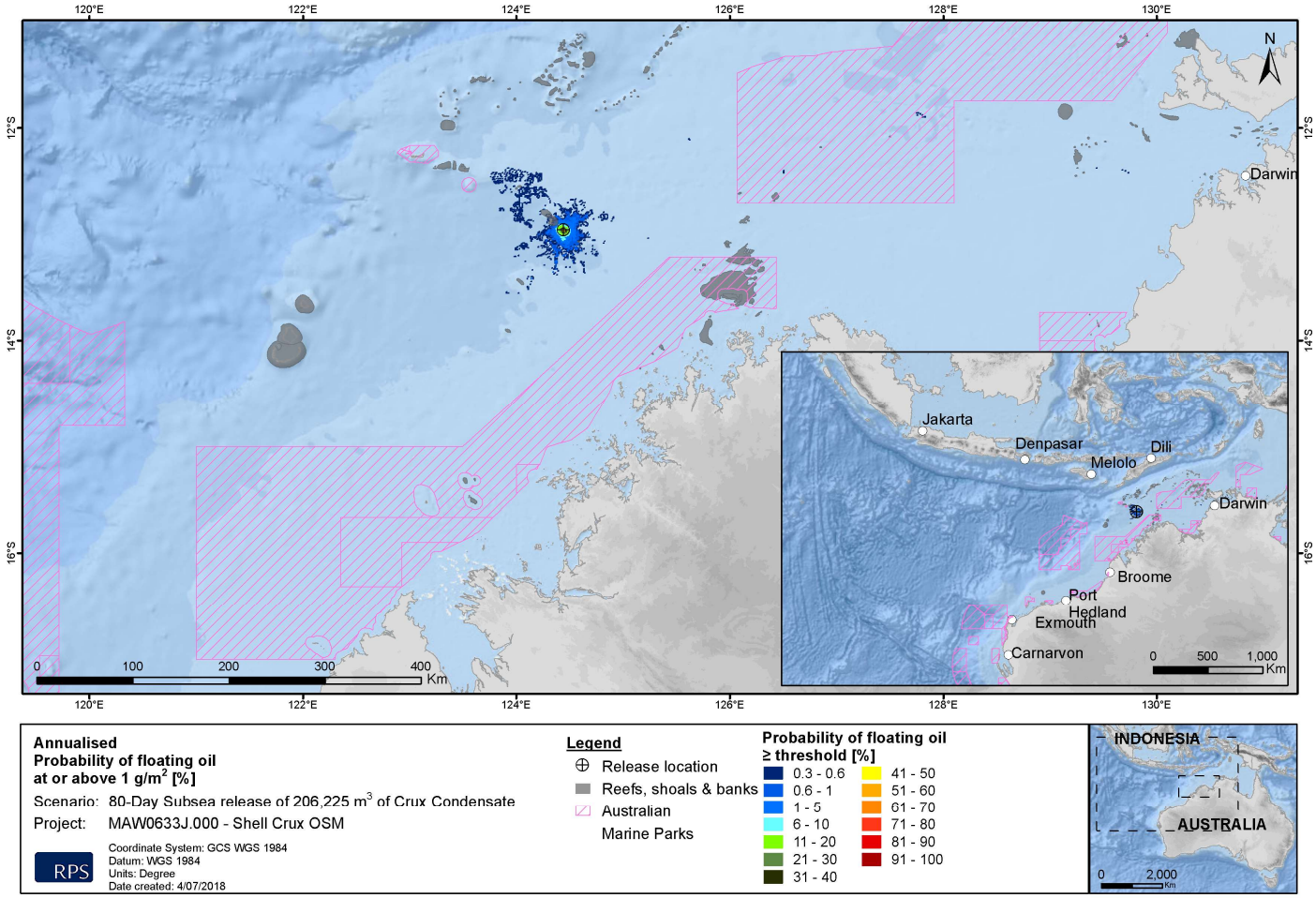


Figure A. 1 Surface Hydrocarbons | Blowout Scenario | Stochastic Outcomes. Predicted annualised probability of floating oil concentrations at or above 1 g/m^2 resulting from an 80-day subsurface release of Crux condensate at a development well.

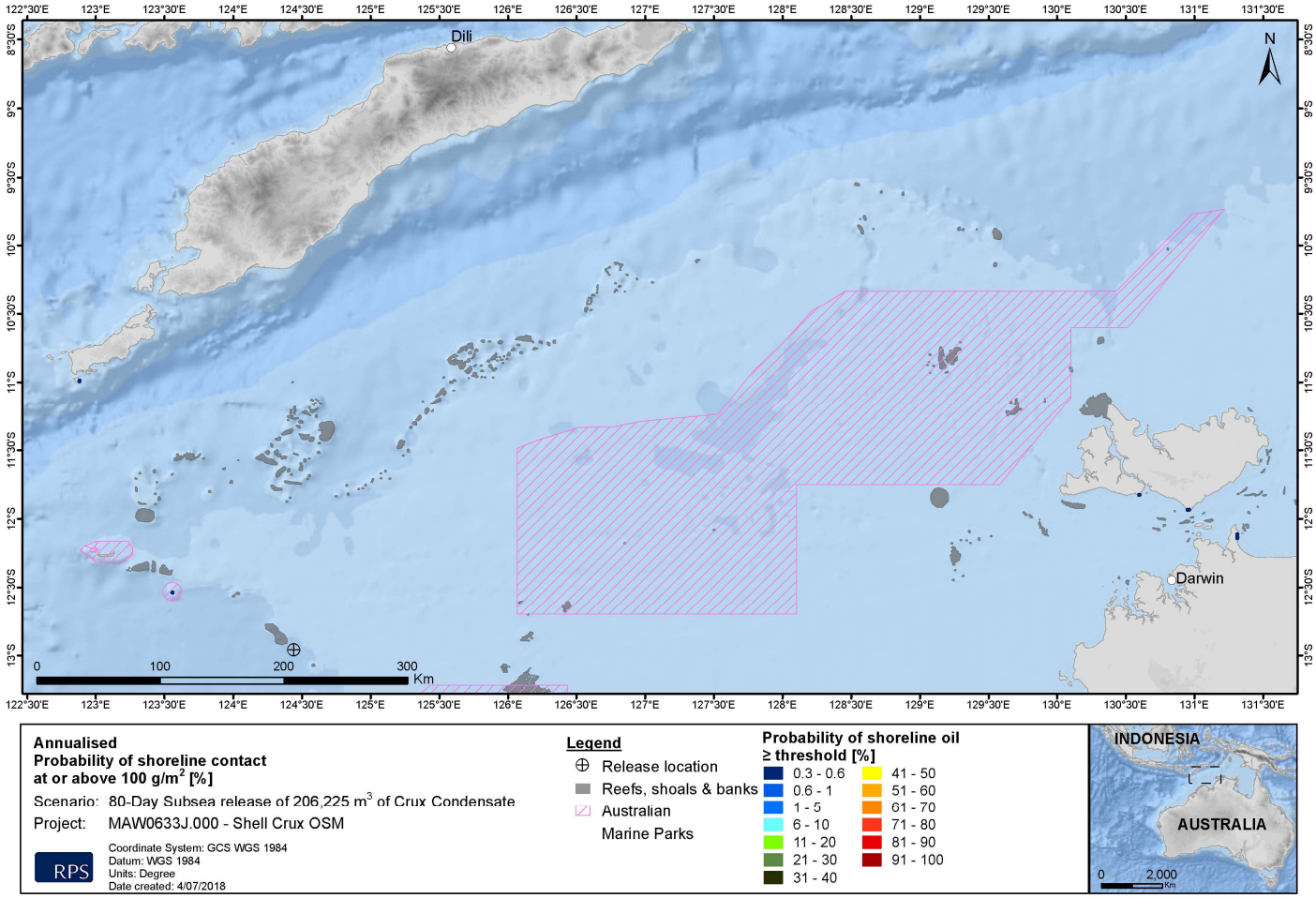


Figure A. 2 Shoreline Hydrocarbons | Blowout Scenario | Stochastic Outcomes. Predicted annualised probability of shoreline oil concentrations at or above 100 g/m^2 resulting from an 80-day subsurface release of Crux condensate at a development well.

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Entrained Hydrocarbons

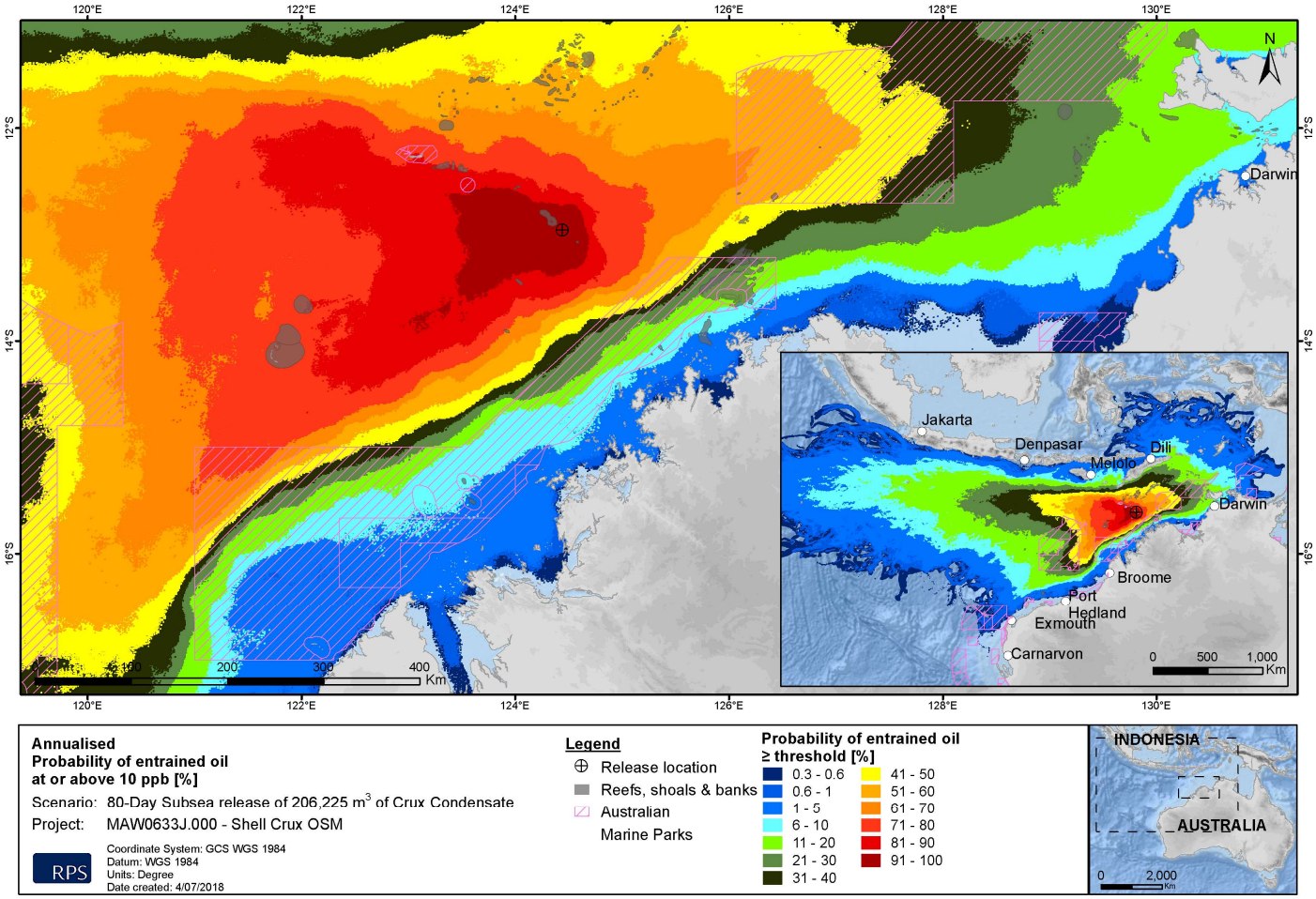


Figure A. 3 Subsurface Hydrocarbons | Entrained | Blowout Scenario | Stochastic Outcomes. Predicted annualised probability of entrained oil concentrations at or above 10 ppb resulting from an 80-day subsurface release of Crux condensate at a development well.

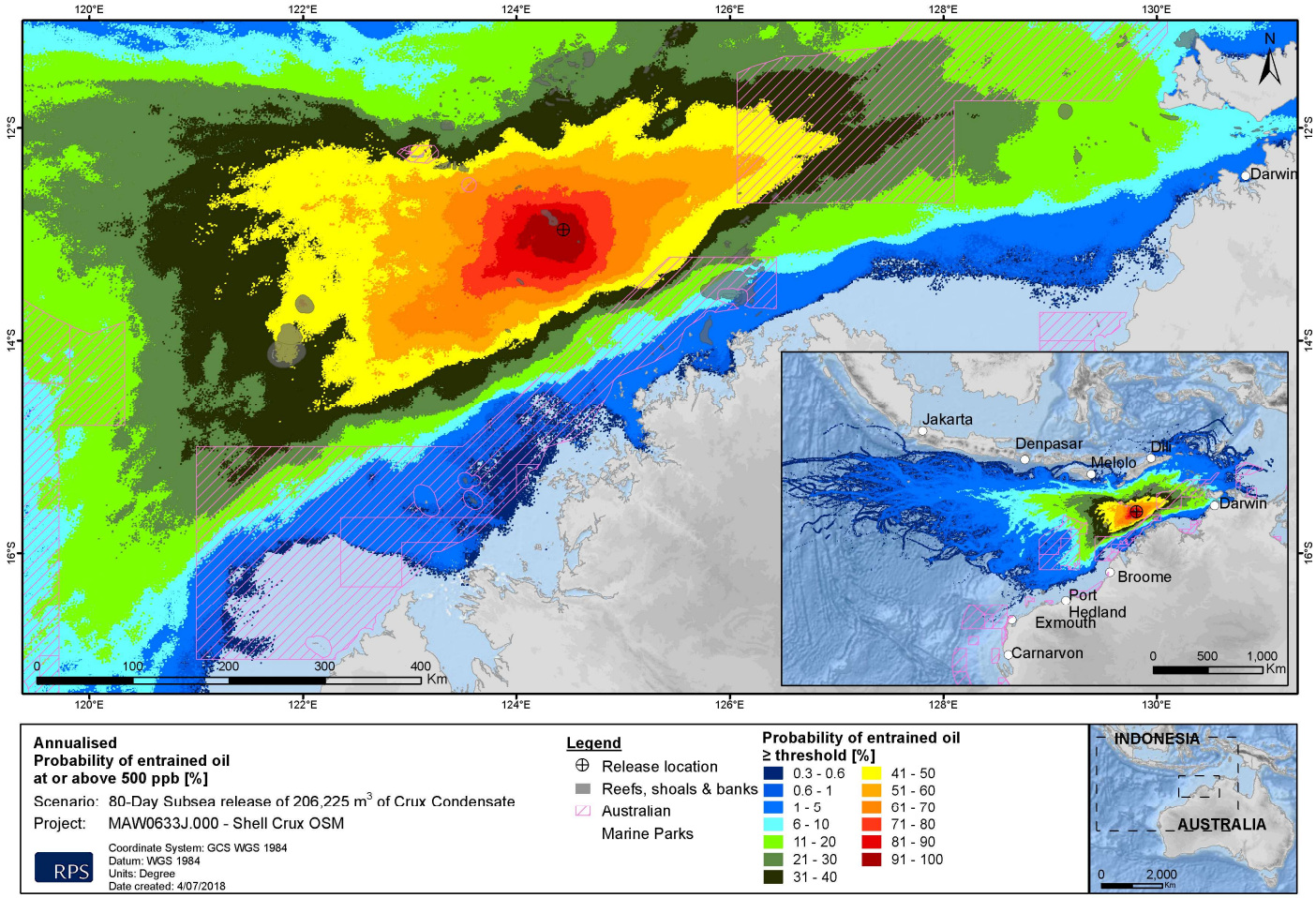


Figure A. 4 Subsurface Hydrocarbons | Entrained | Blowout Scenario | Stochastic Outcomes. Predicted annualised probability of entrained oil concentrations at or above 500 ppb resulting from an 80-day subsurface release of Crux condensate at a development well.

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Appendix B

Scenario 2 – Annualised Probability – Stochastic Modelling

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Figures – Appendix B

Figure B 1 Surface Hydrocarbons | Inventory Scenario | Stochastic Outcomes. Predicted annualised probability of floating oil concentrations at or above 1 g/m^2 resulting from an instantaneous surface release of Crux condensate at the Crux platform.

Figure B 2 Surface Hydrocarbons | Inventory Scenario | Stochastic Outcomes. Predicted annualised probability of floating oil concentrations at or above 25 g/m^2 resulting from an instantaneous surface release of Crux condensate at the Crux platform.

Figure B 3 Shoreline Hydrocarbons | Inventory Scenario | Stochastic Outcomes. Predicted annualised probability of shoreline oil concentrations at or above 100 g/m^2 resulting from an instantaneous surface release of Crux condensate at the Crux platform.

Figure B 4 Subsurface Hydrocarbons | Entrained | Inventory Scenario | Stochastic Outcomes. Predicted annualised probability of entrained oil concentrations at or above 10 ppb resulting from an instantaneous surface release of Crux condensate at the Crux platform.

Figure B 5 Subsurface Hydrocarbons | Entrained | Inventory Scenario | Stochastic Outcomes. Predicted annualised probability of entrained oil concentrations at or above 500 ppb resulting from an instantaneous surface release of Crux condensate at the Crux platform.

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Annualised Results

Floating and Shoreline Hydrocarbons

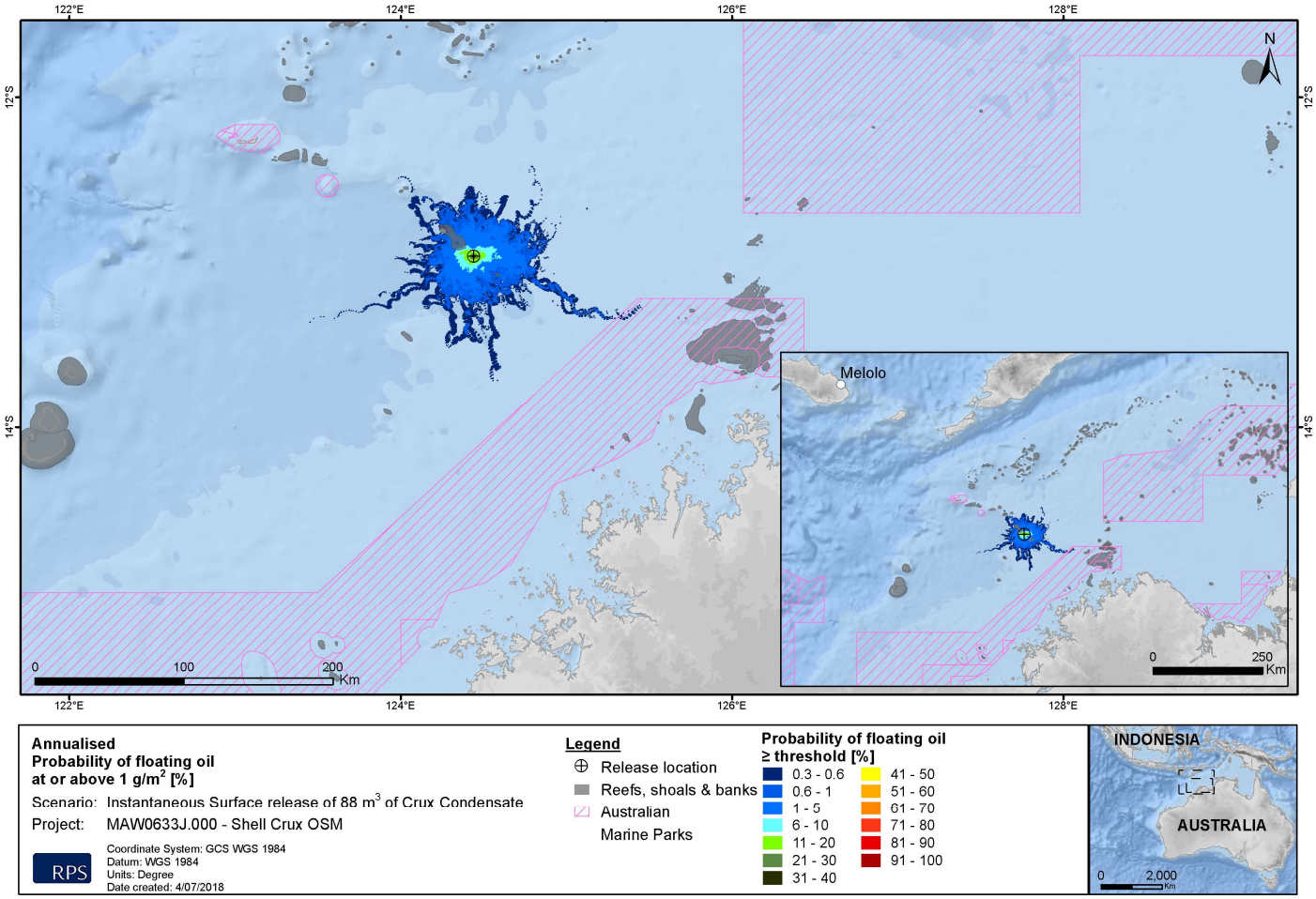


Figure B 1 Surface Hydrocarbons | Inventory Scenario | Stochastic Outcomes. Predicted annualised probability of floating oil concentrations at or above 1 g/m² resulting from an instantaneous surface release of Crux condensate at the Crux platform.

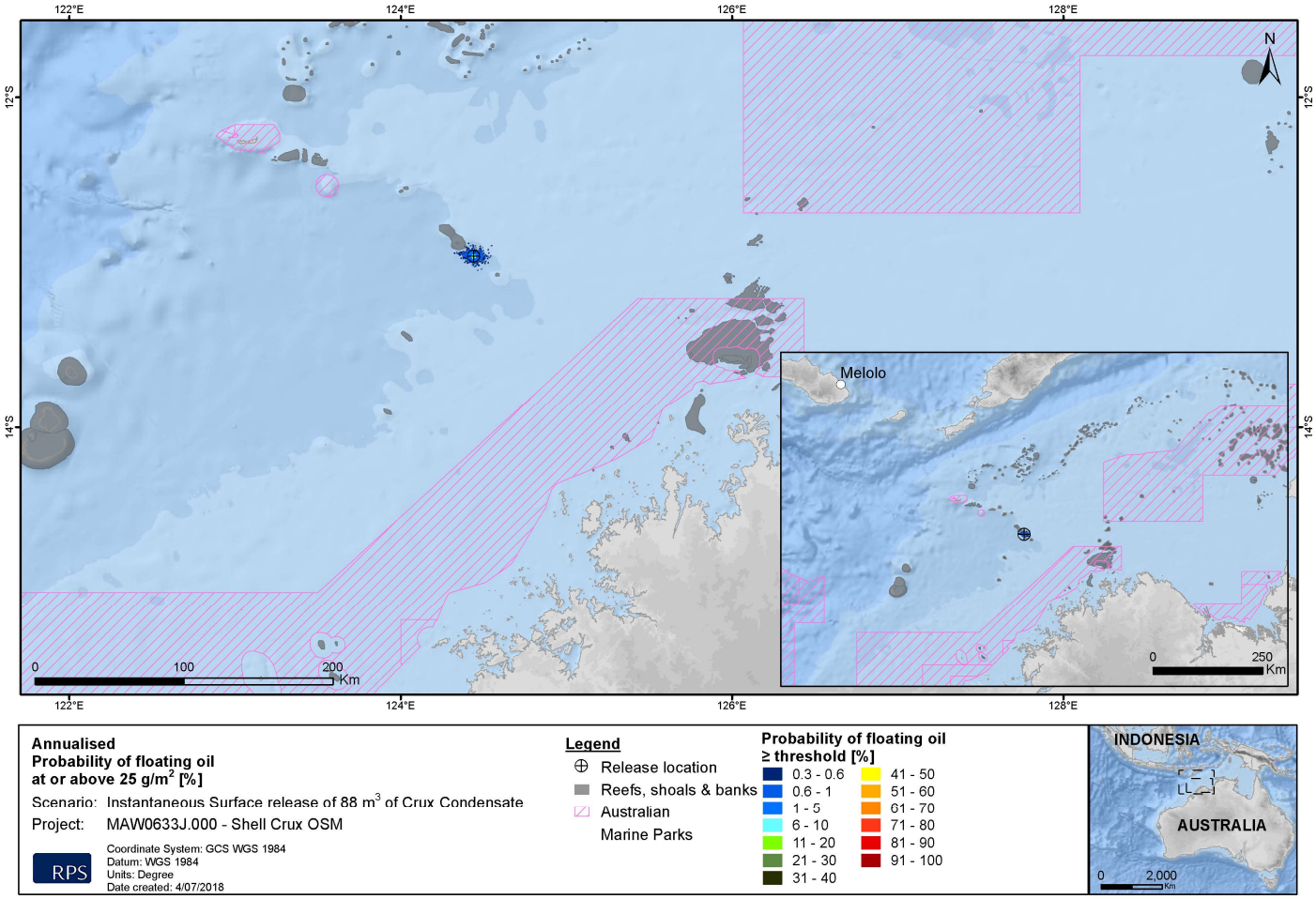


Figure B 2 Surface Hydrocarbons | Inventory Scenario | Stochastic Outcomes. Predicted annualised probability of floating oil concentrations at or above 25 g/m^2 resulting from an instantaneous surface release of Crux condensate at the Crux platform.

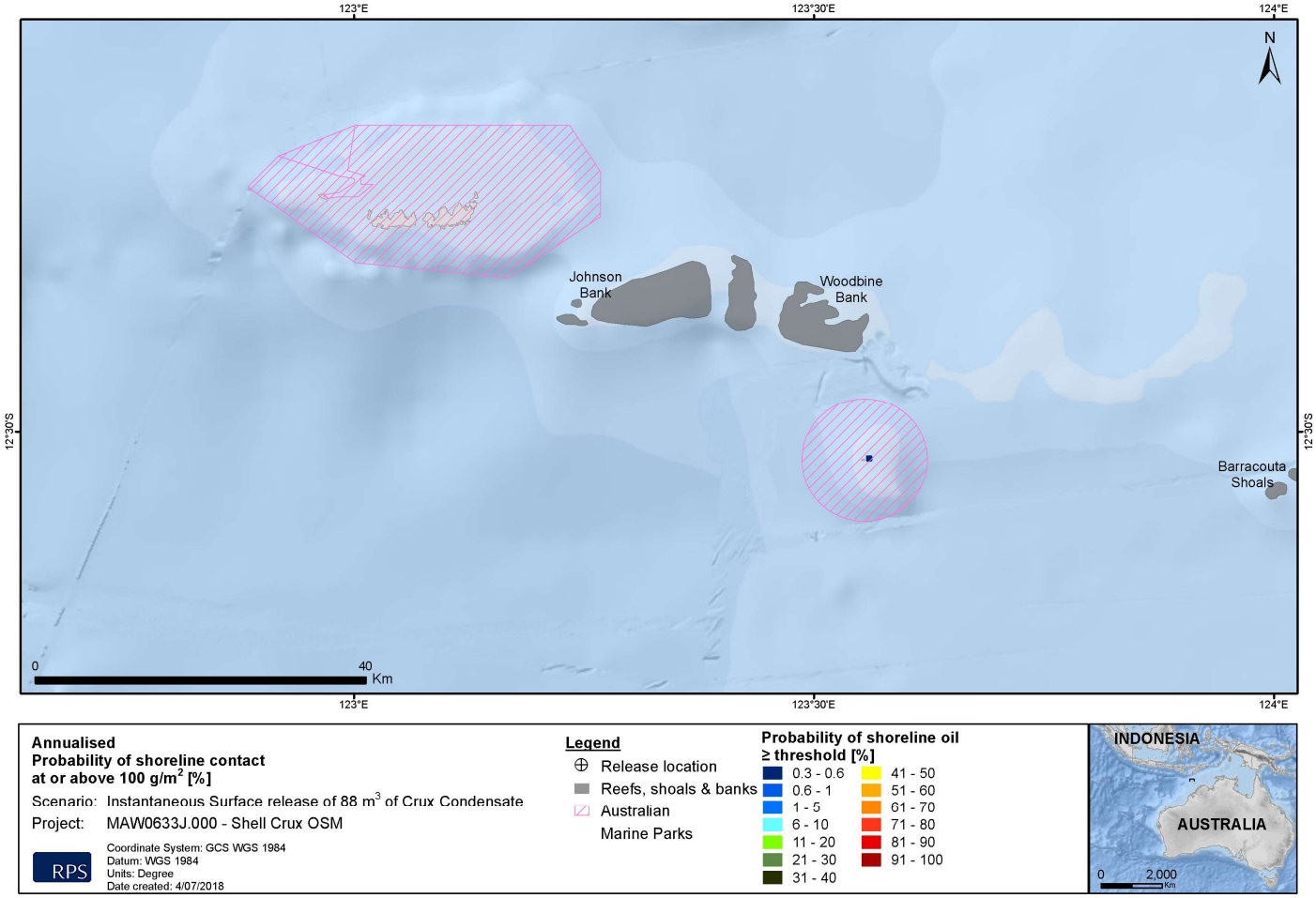


Figure B 3 Shoreline Hydrocarbons | Inventory Scenario | Stochastic Outcomes. Predicted annualised probability of shoreline oil concentrations at or above 100 g/m^2 resulting from an instantaneous surface release of Crux condensate at the Crux platform.

Entrained Hydrocarbons

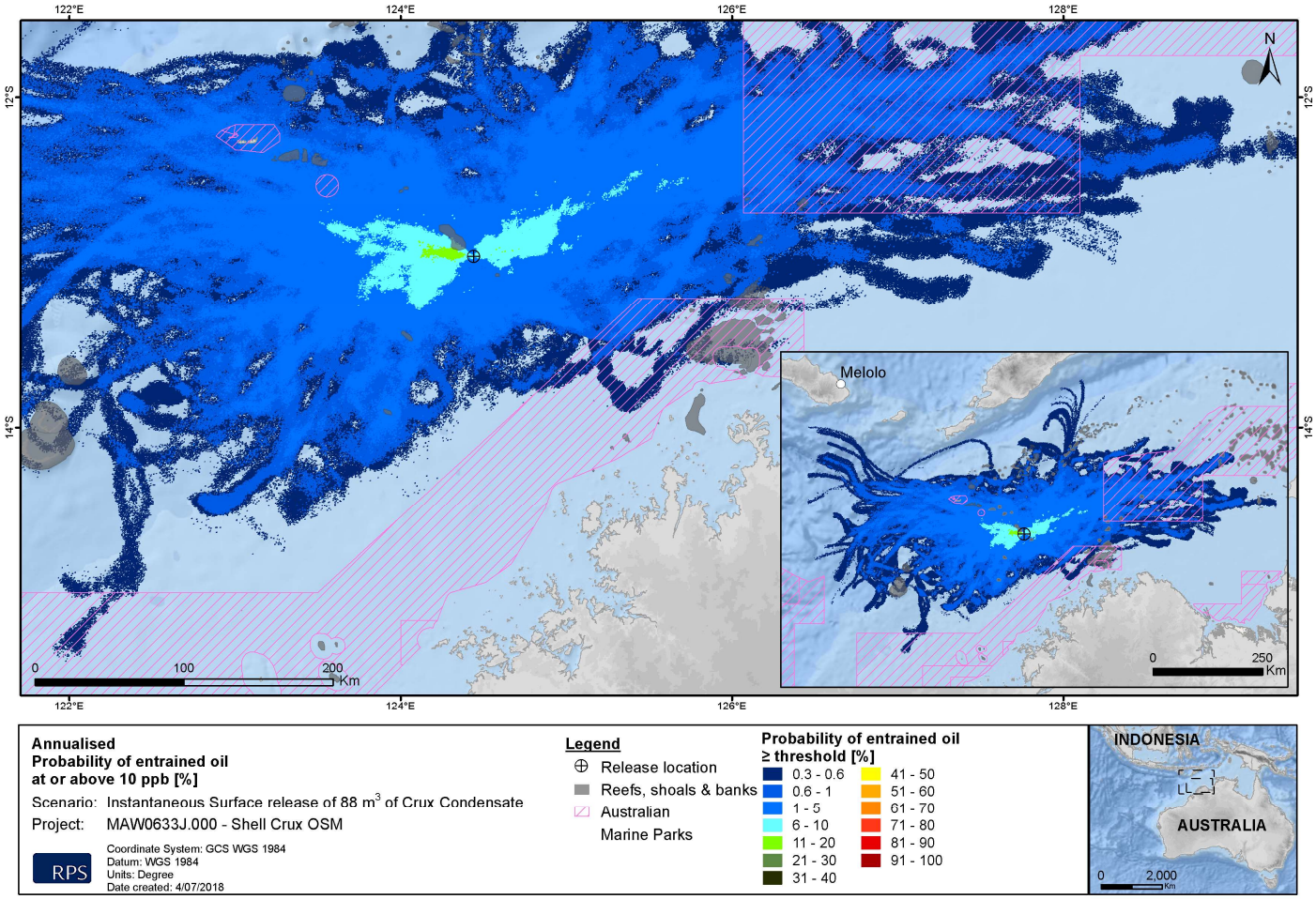


Figure B 4 Subsurface Hydrocarbons | Entrained | Inventory Scenario | Stochastic Outcomes. Predicted annualised probability of entrained oil concentrations at or above 10 ppb resulting from an instantaneous surface release of Crux condensate at the Crux platform.

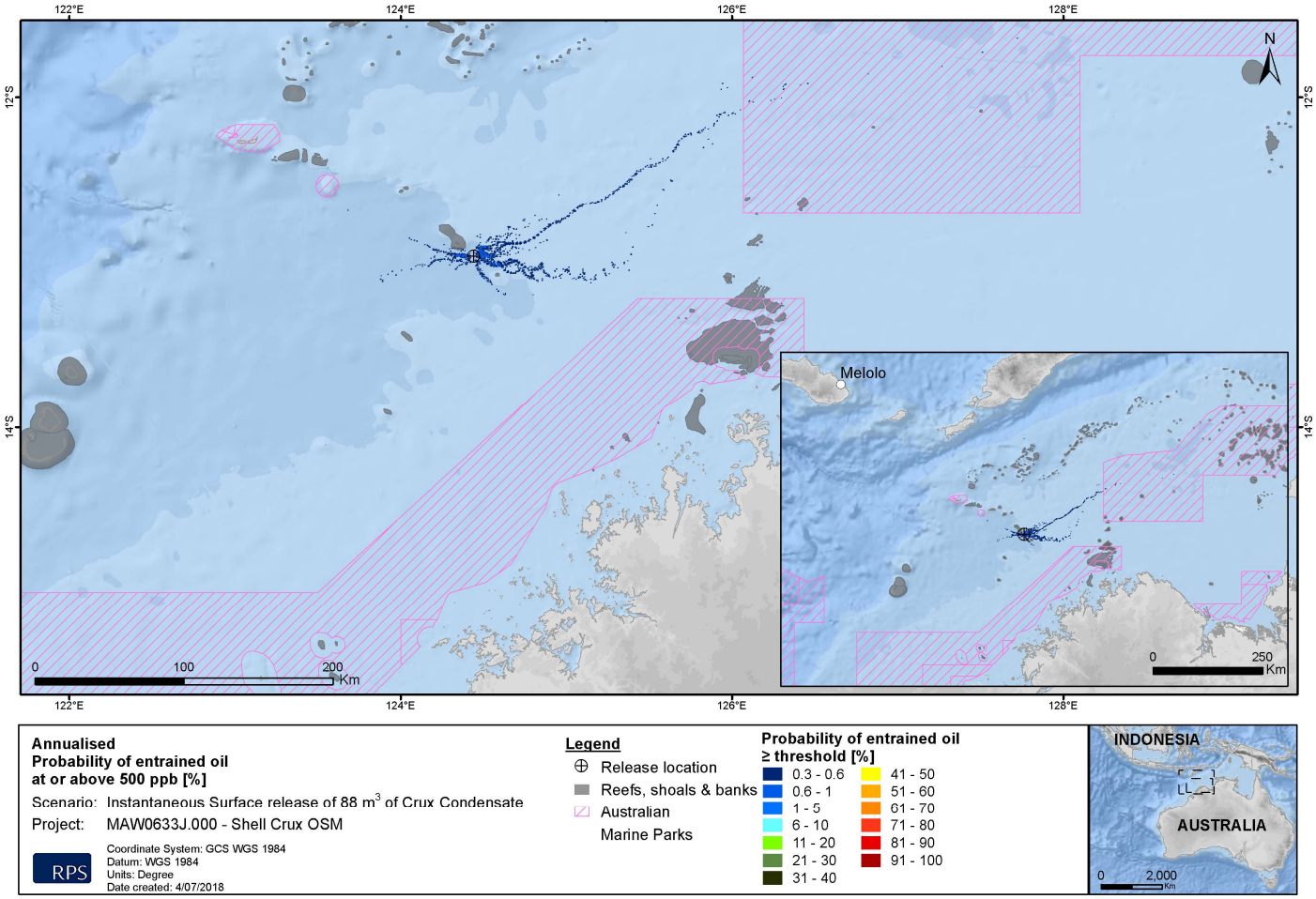


Figure B 5 Subsurface Hydrocarbons | Entrained | Inventory Scenario | Stochastic Outcomes. Predicted annualised probability of entrained oil concentrations at or above 500 ppb resulting from an instantaneous surface release of Crux condensate at the Crux platform.

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Appendix C

Scenario 3 – Annualised Probability – Stochastic Modelling

RPS

Figures – Appendix C

Figure C 1 Surface Hydrocarbons | Pipeline Scenario | Stochastic Outcomes. Predicted annualised probability of floating oil concentrations at or above 1 g/m^2 resulting from a 5.6-hour subsurface release of Crux condensate from the export pipeline. 202

Figure C 2 Surface Hydrocarbons | Pipeline Scenario | Stochastic Outcomes. Predicted annualised probability of floating oil concentrations at or above 25 g/m^2 resulting from a 5.6-hour subsurface release of Crux condensate from the export pipeline.....203

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Figure C 4 Shoreline Hydrocarbons | Pipeline Scenario | Stochastic Outcomes. Predicted annualised probability of shoreline oil concentrations at or above 1,000 g/m^2 resulting from a 5.6-hour subsurface release of Crux condensate from the export pipeline.....205

Figure C 5 Subsurface Hydrocarbons | Entrained | Pipeline Scenario | Stochastic Outcomes. Predicted annualised probability of entrained oil concentrations at or above 10 ppb resulting from a 5.6-hour subsurface release of Crux condensate from the export pipeline. 207

Figure C 6 Subsurface Hydrocarbons | Entrained | Pipeline Scenario | Stochastic Outcomes. Predicted annualised probability of entrained oil concentrations at or above 500 ppb resulting from a 5.6-hour subsurface release of Crux condensate from the export pipeline. 208

Annualised Results

Floating and Shoreline Hydrocarbons

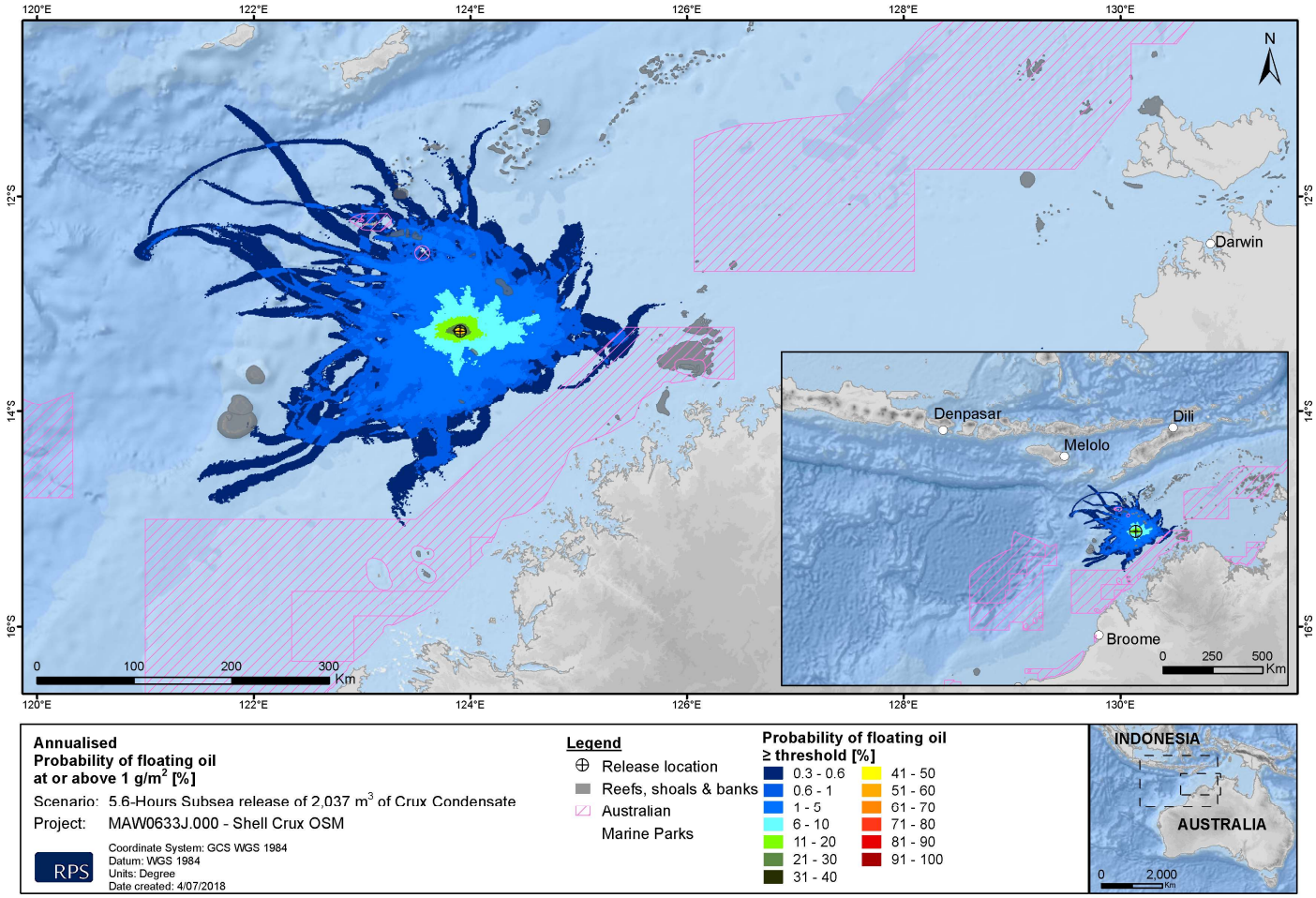


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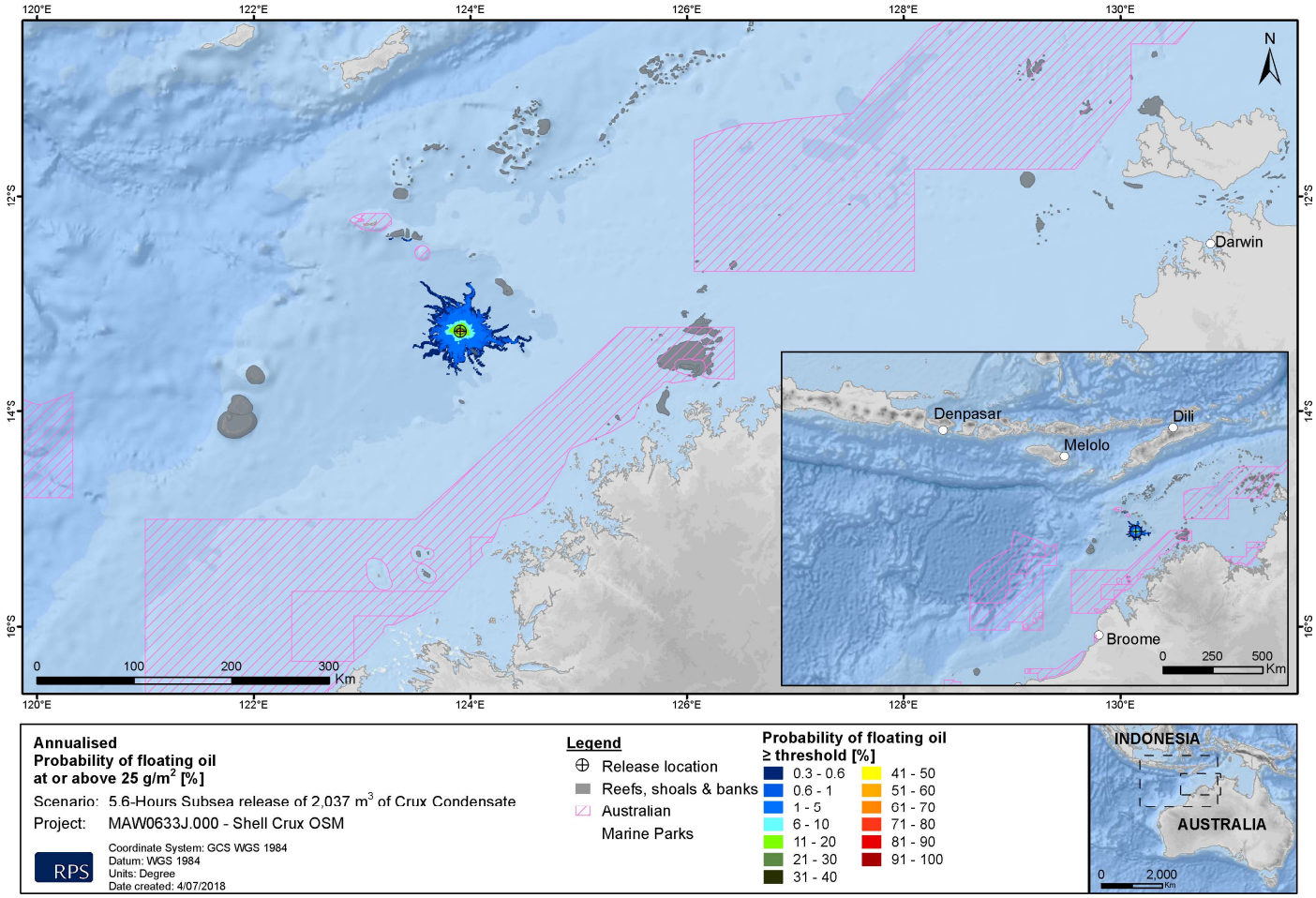


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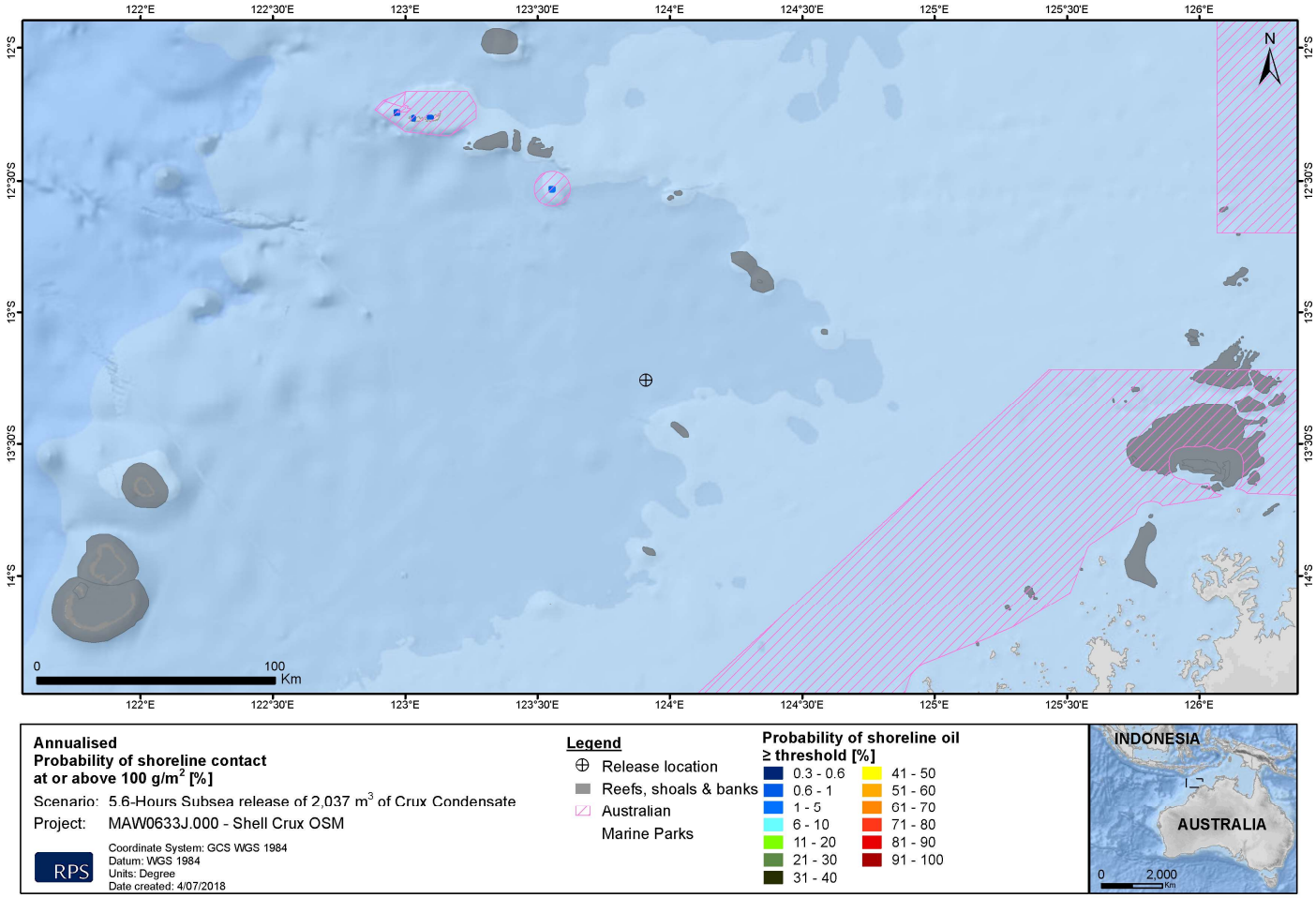


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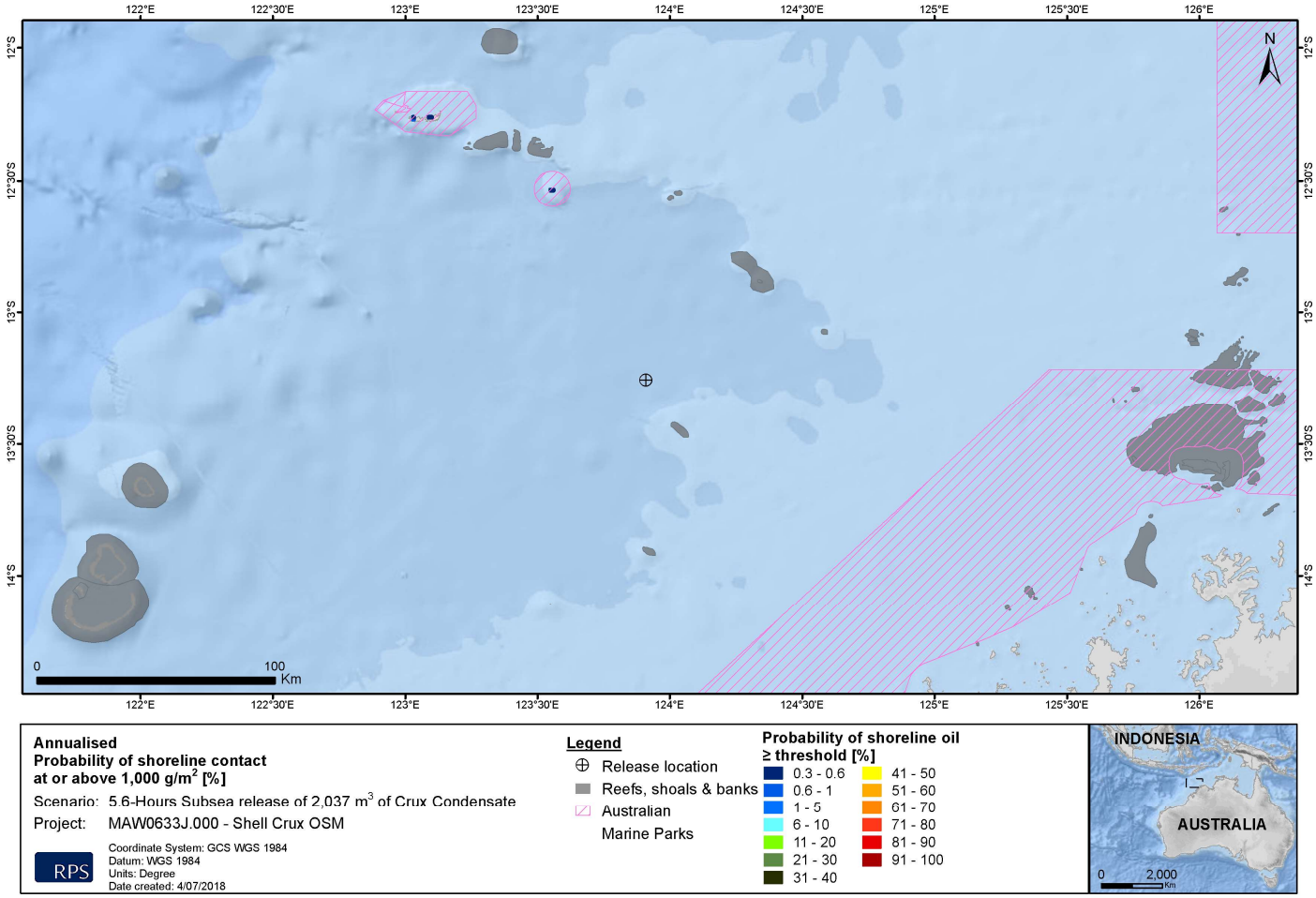


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Entrained Hydrocarbons

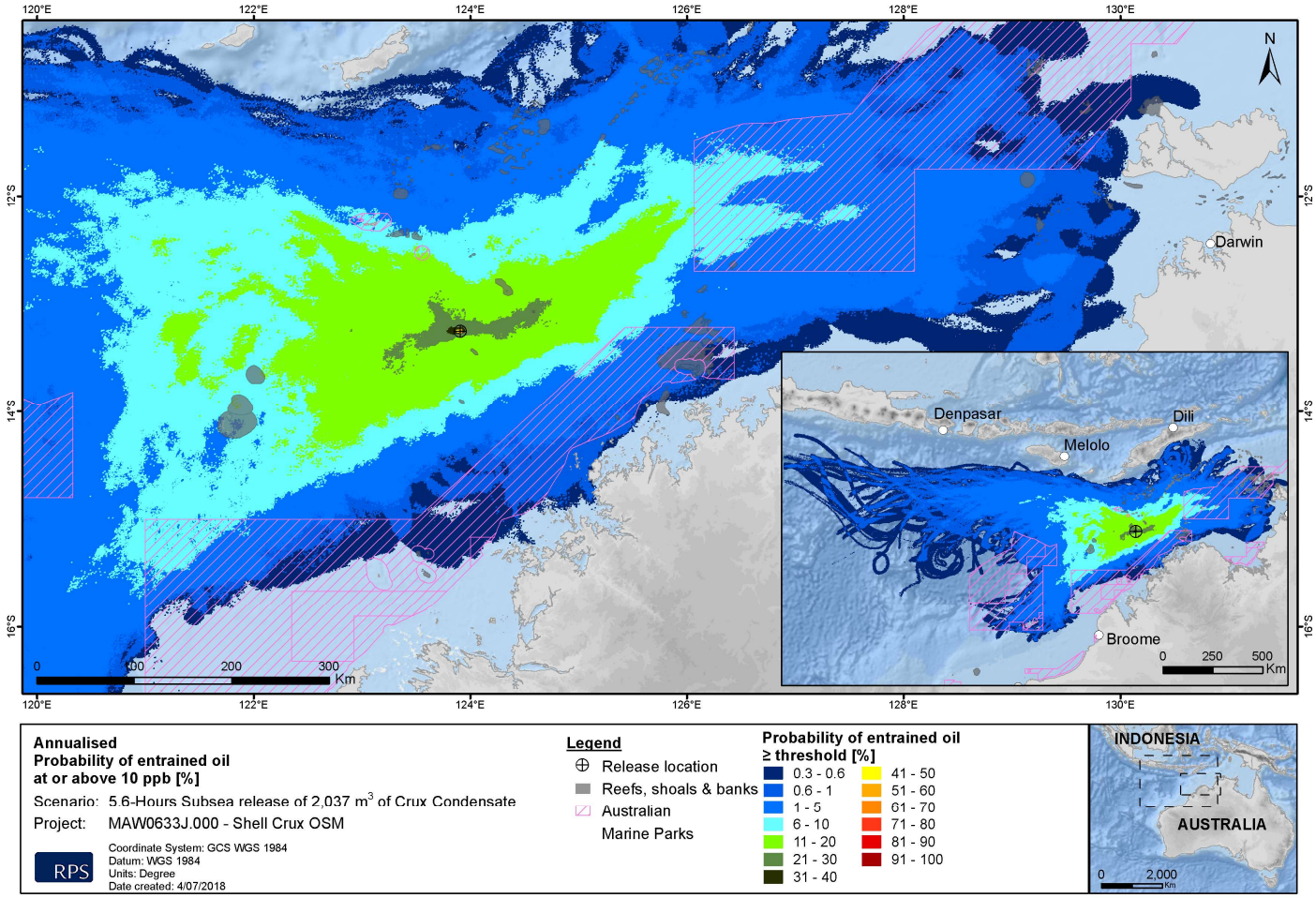


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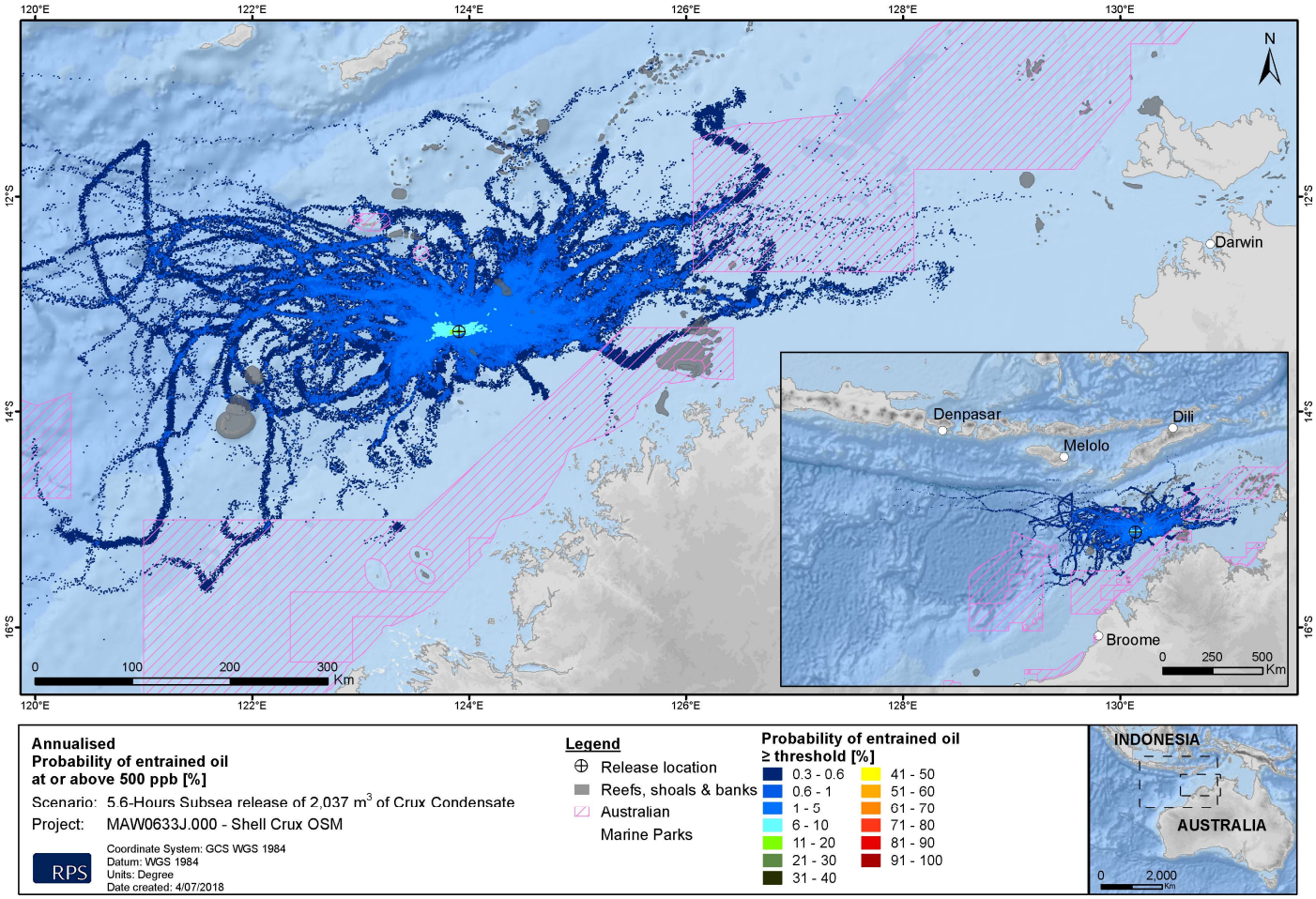


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Appendix D

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Annualised Results

Floating and Shoreline Hydrocarbons

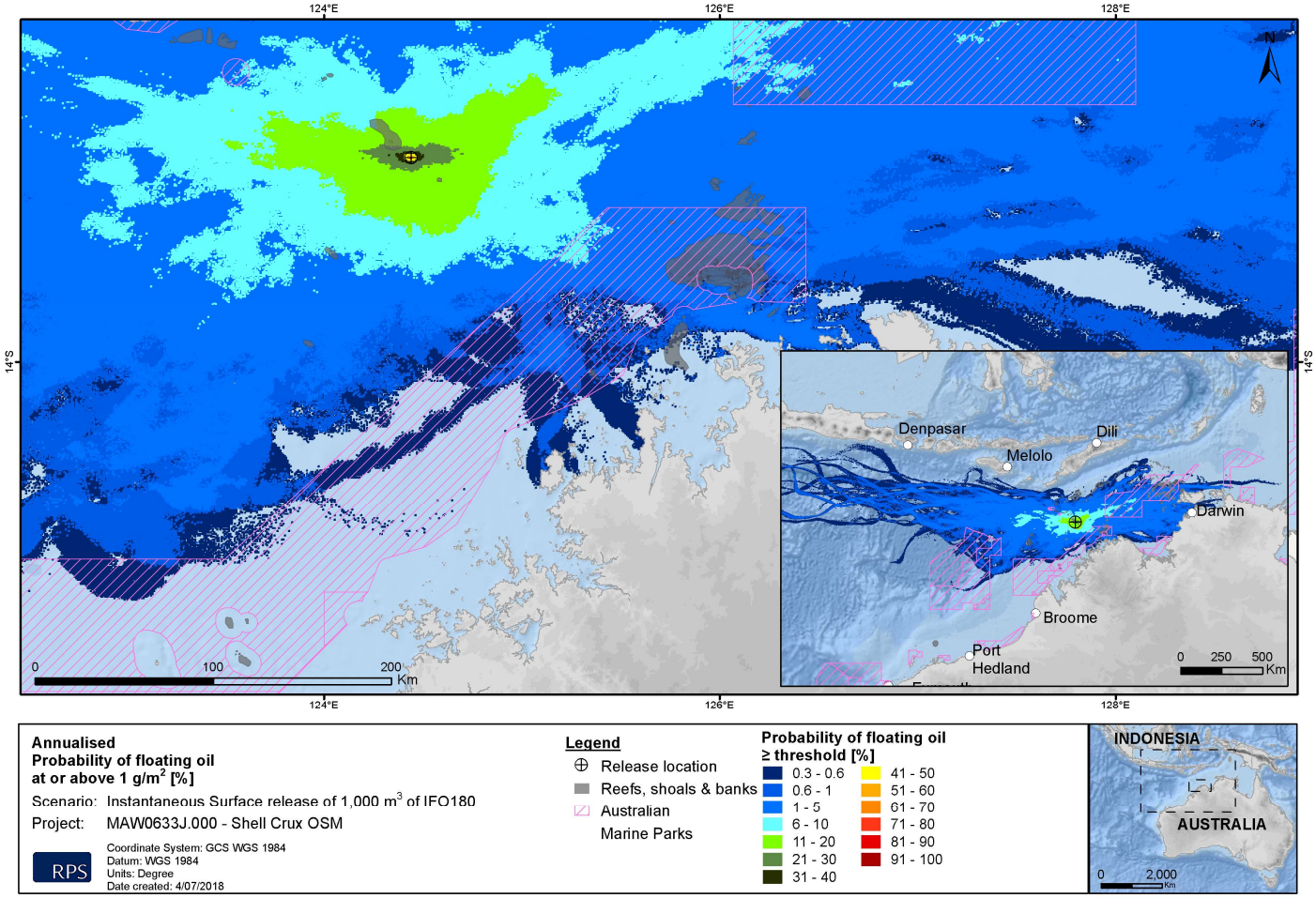


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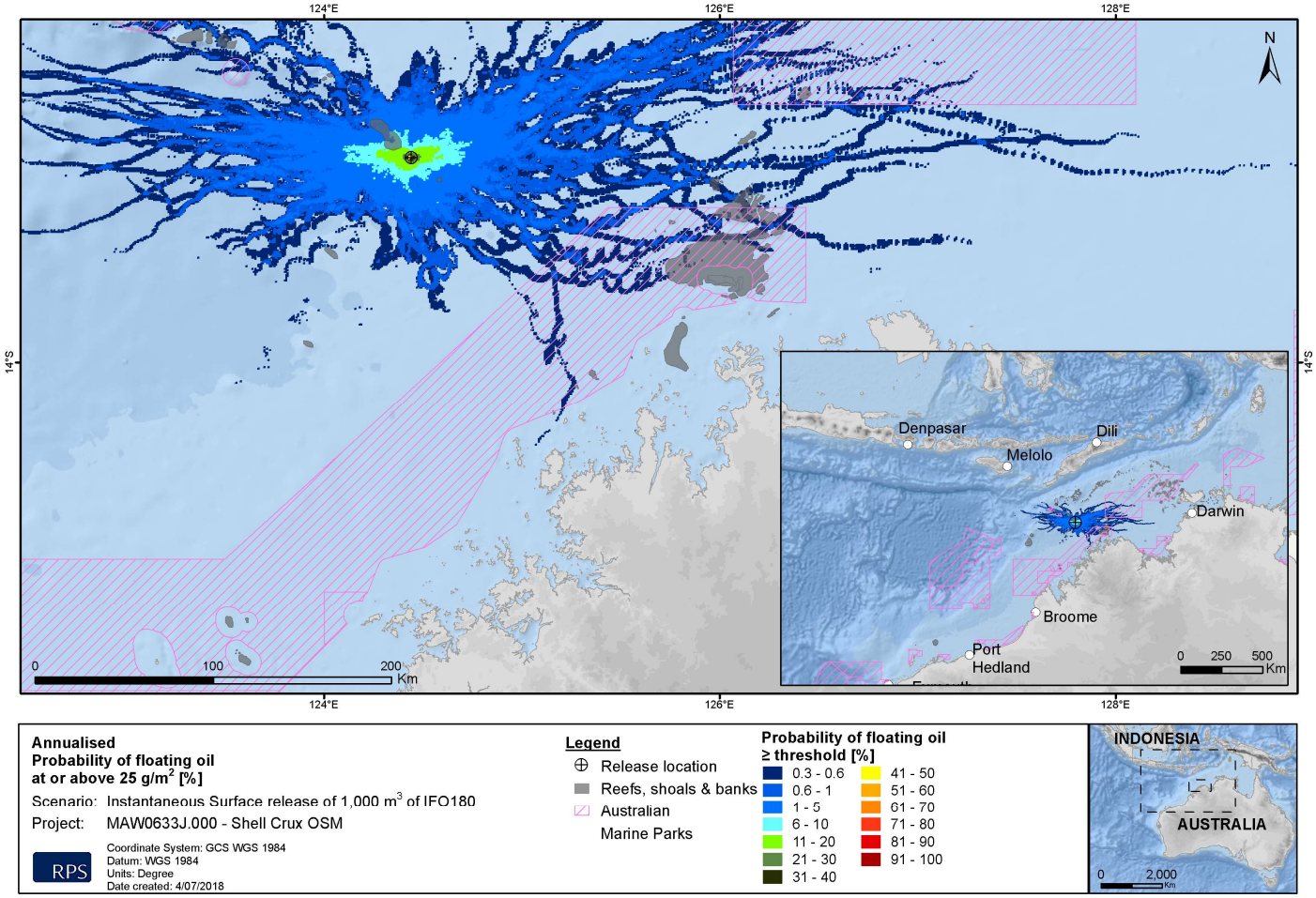


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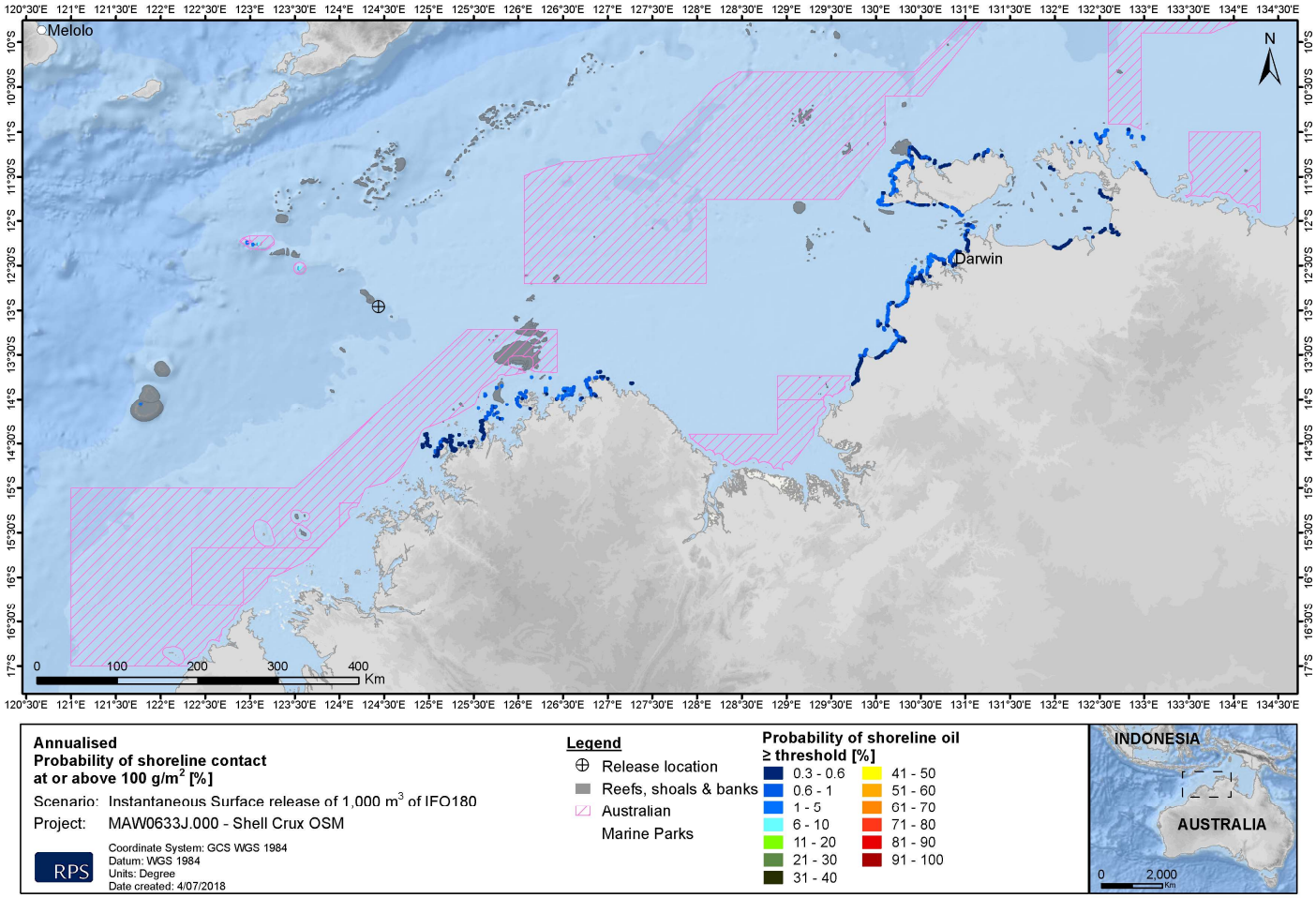


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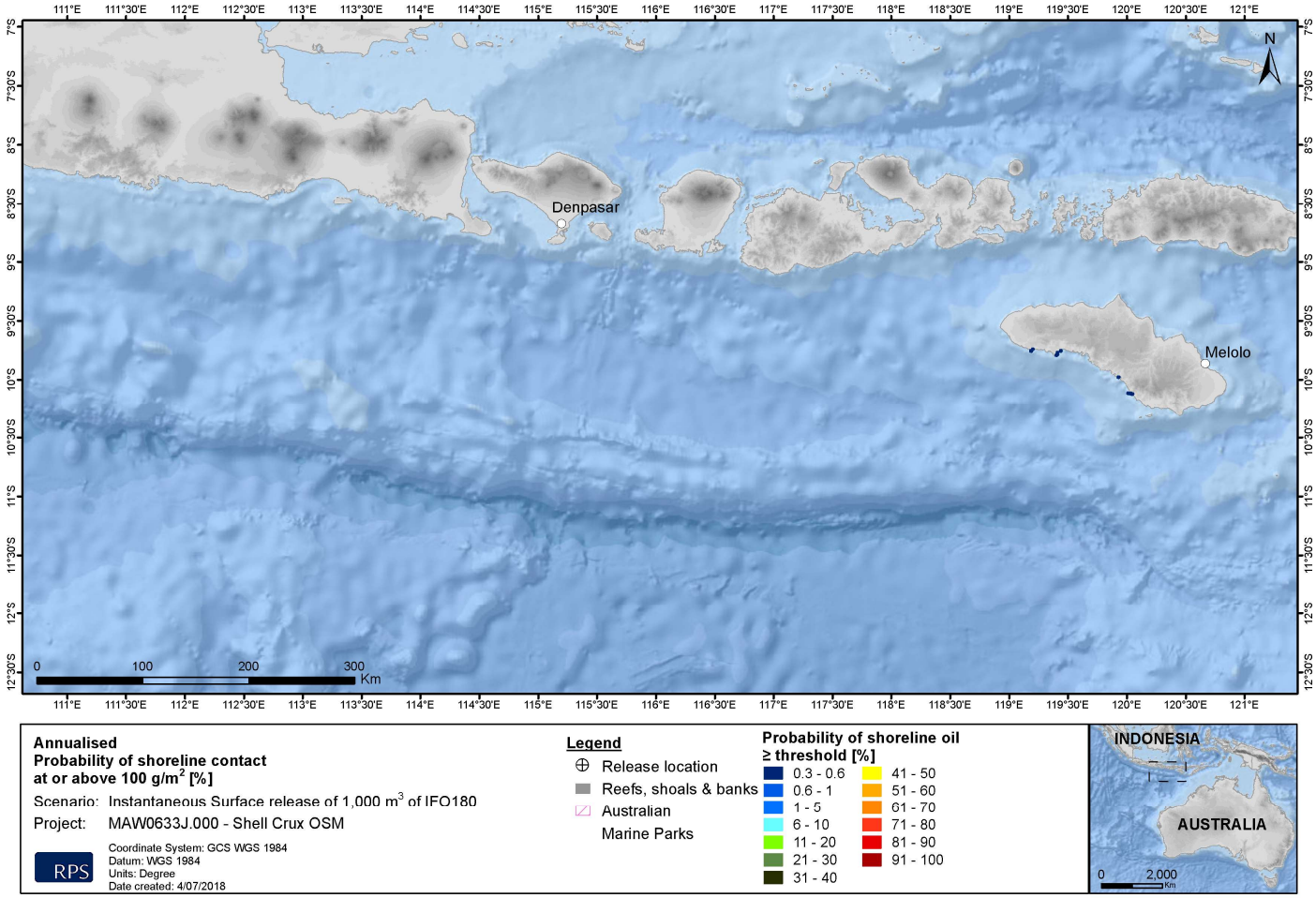


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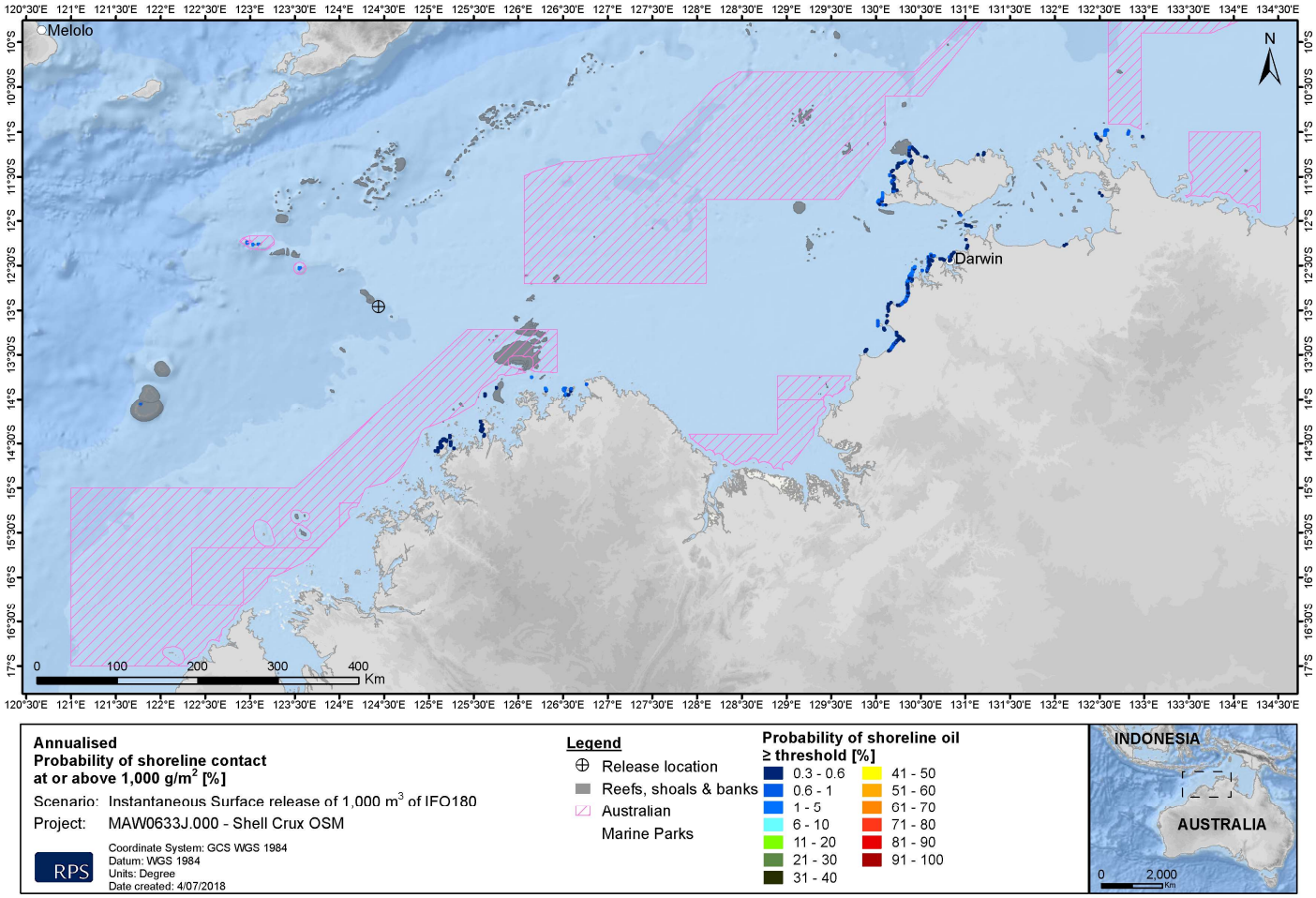


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Entrained Hydrocarbons

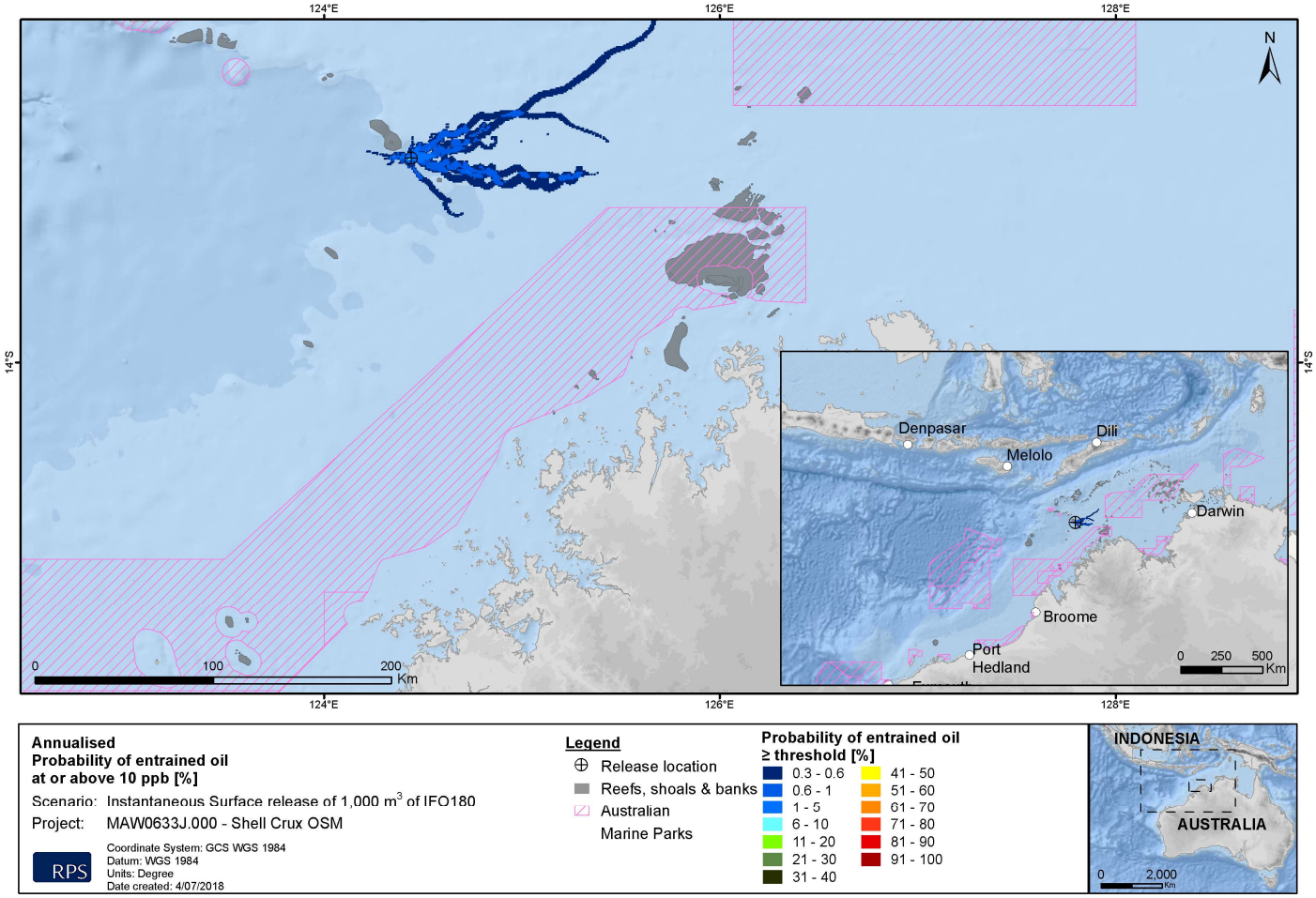


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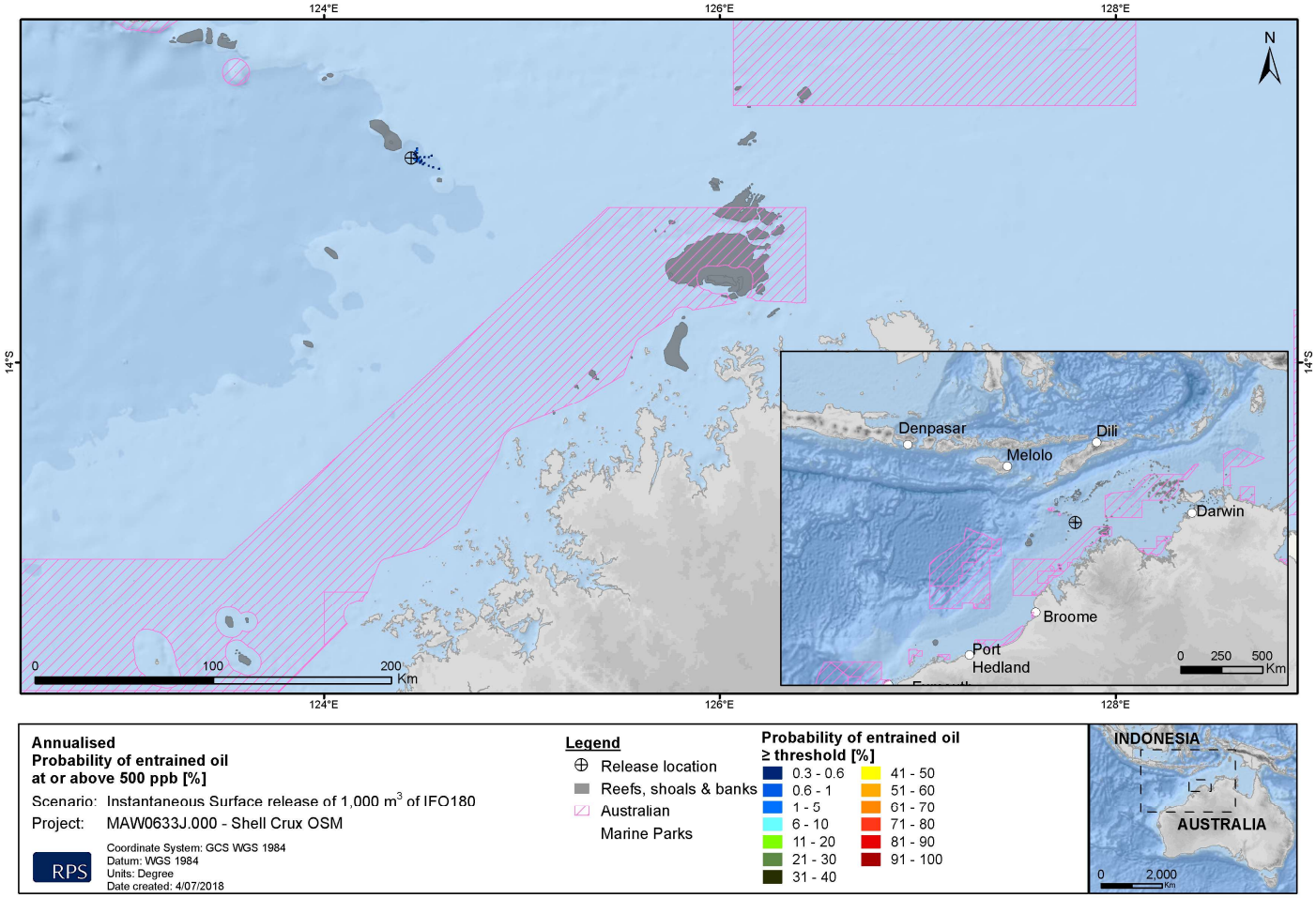


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Scenario 1 – 80-Day Subsurface Blowout of Crux Condensate at a Development Well

Maximum Volume Ashore

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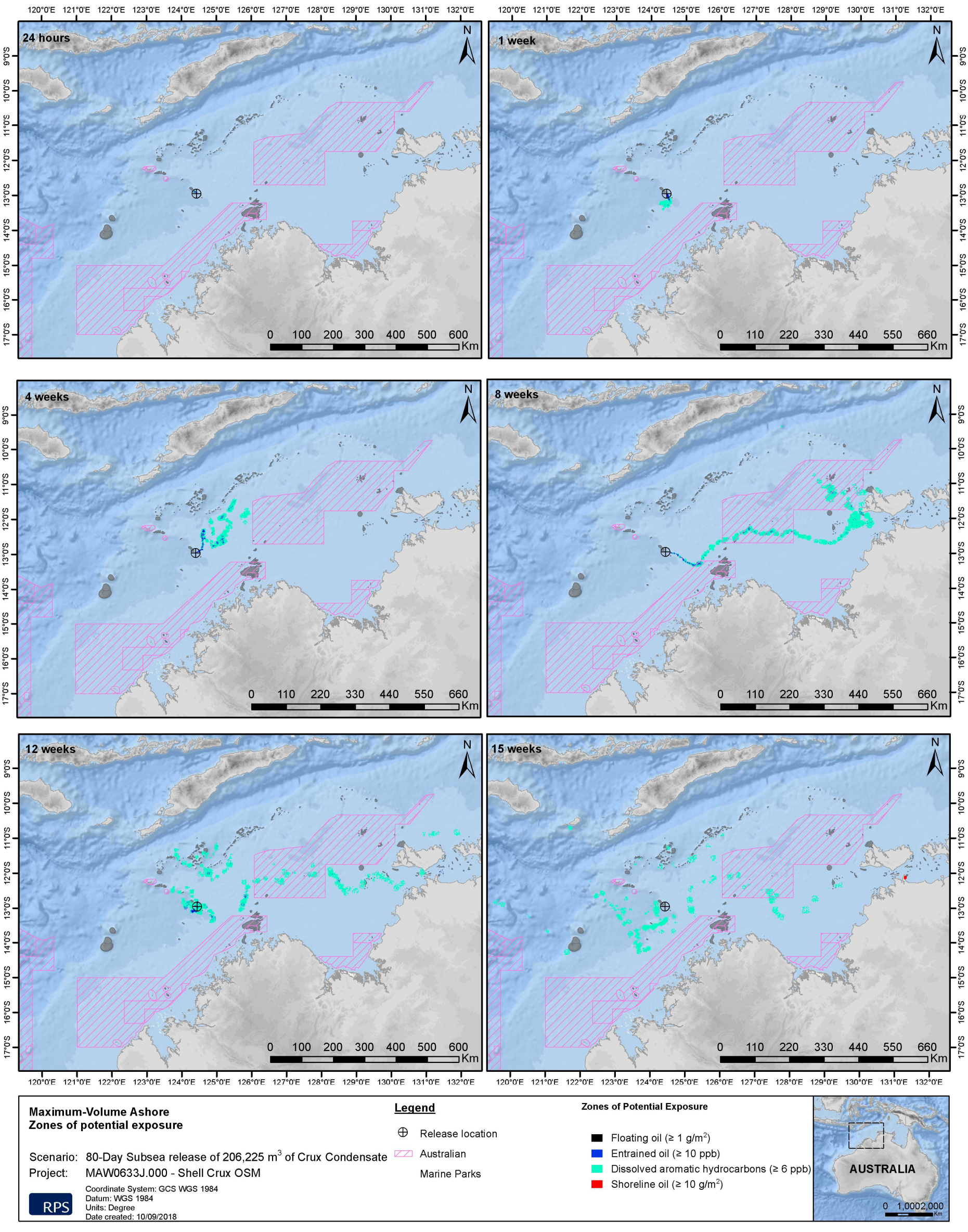


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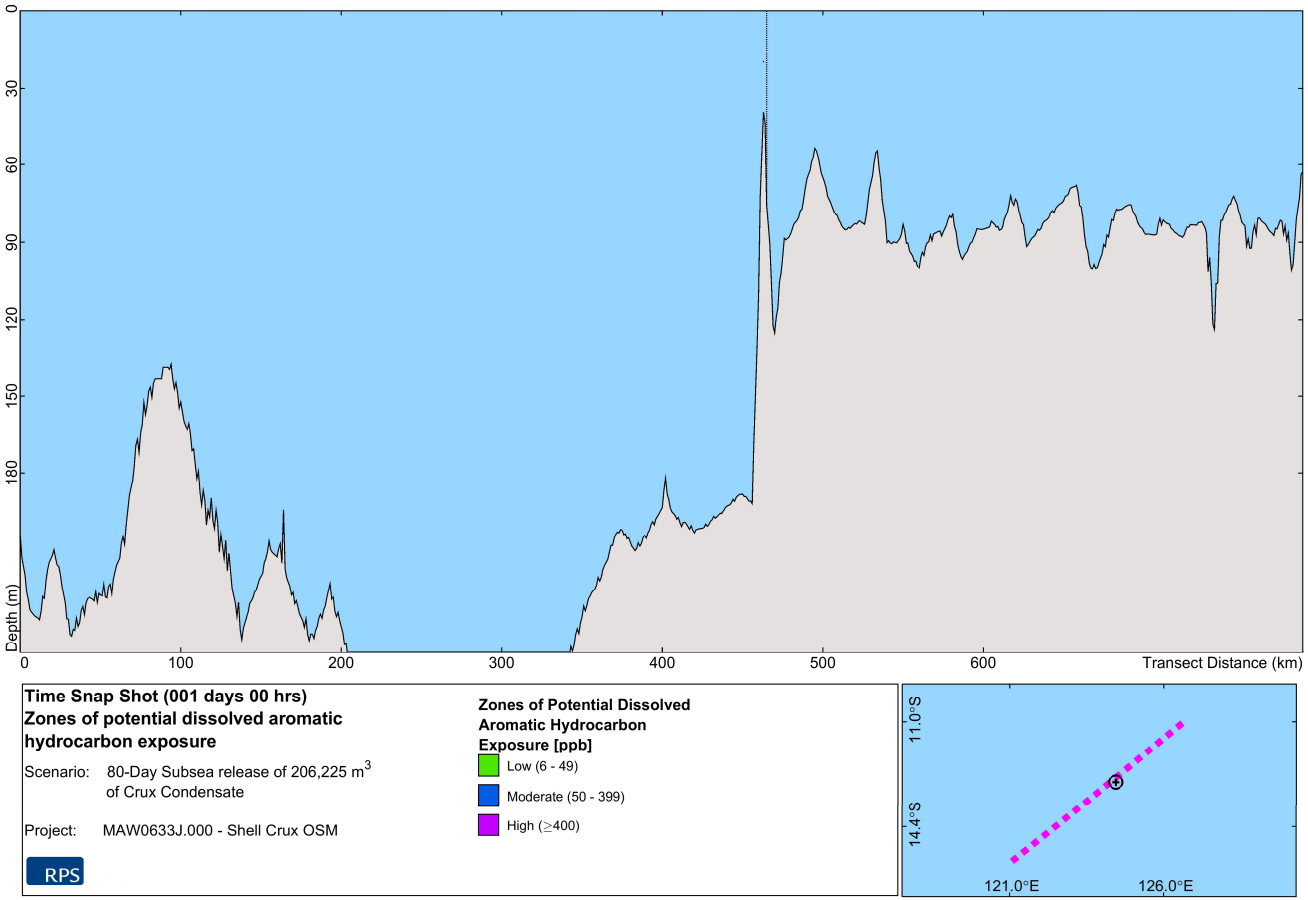


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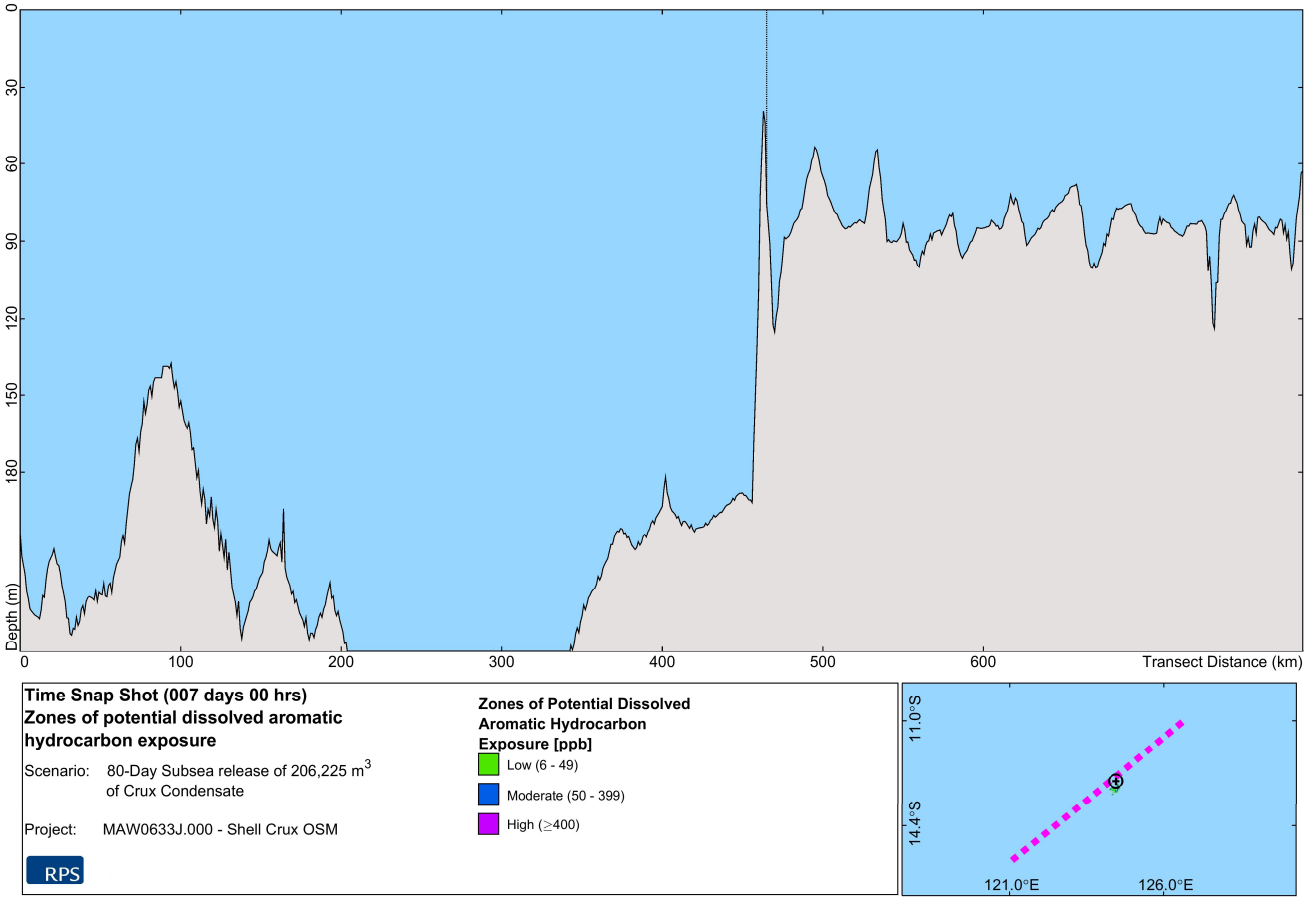


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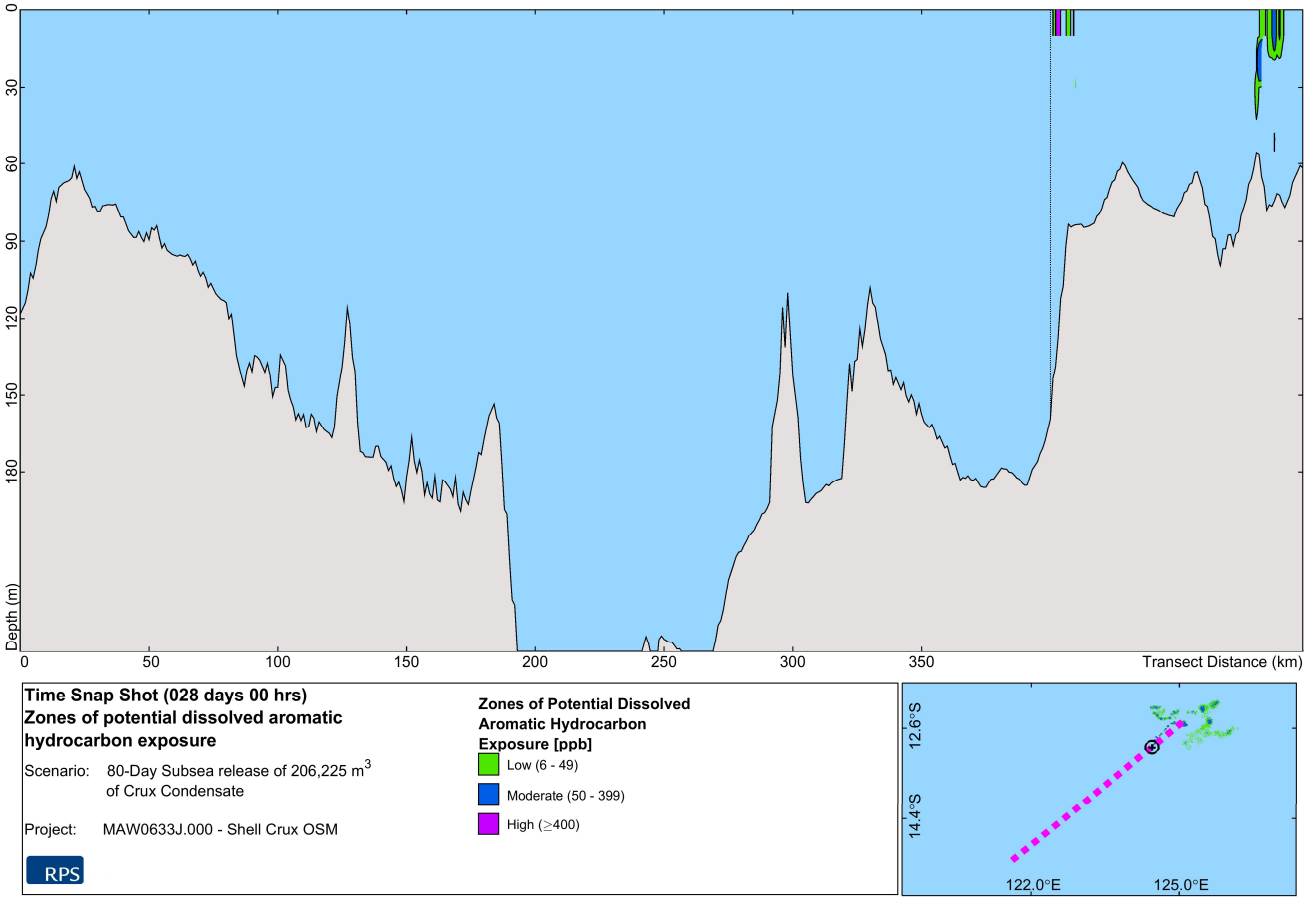


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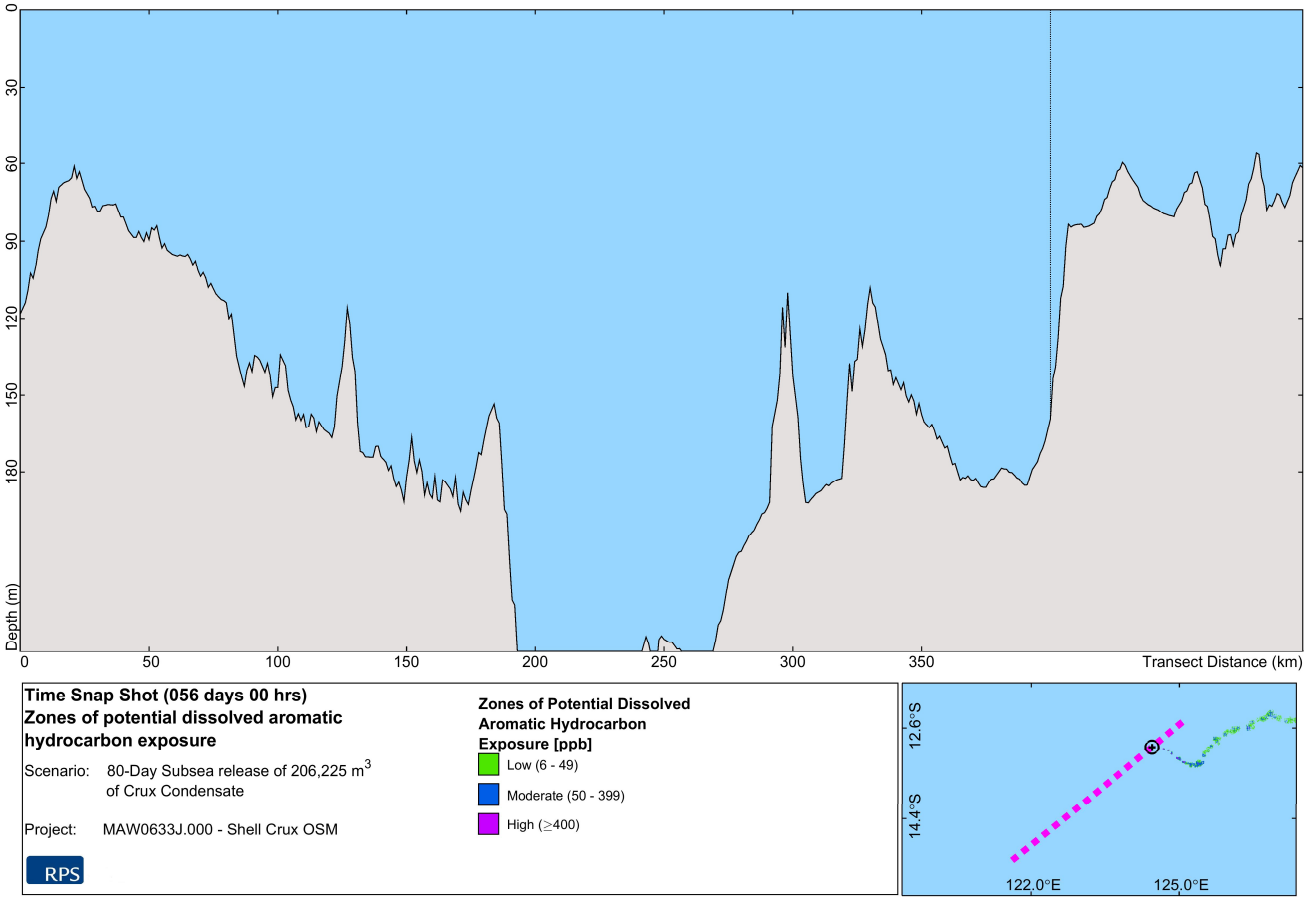


Figure E 5 Subsurface Hydrocarbons | Dissolved | Blowout Scenario | Deterministic Outcomes. Vertical distribution (after 8 weeks) of potential exposure at defined dissolved aromatic hydrocarbon threshold concentrations resulting from an 80-day subsurface release of Crux condensate at a development well. Replicate simulation with maximum volume ashore.

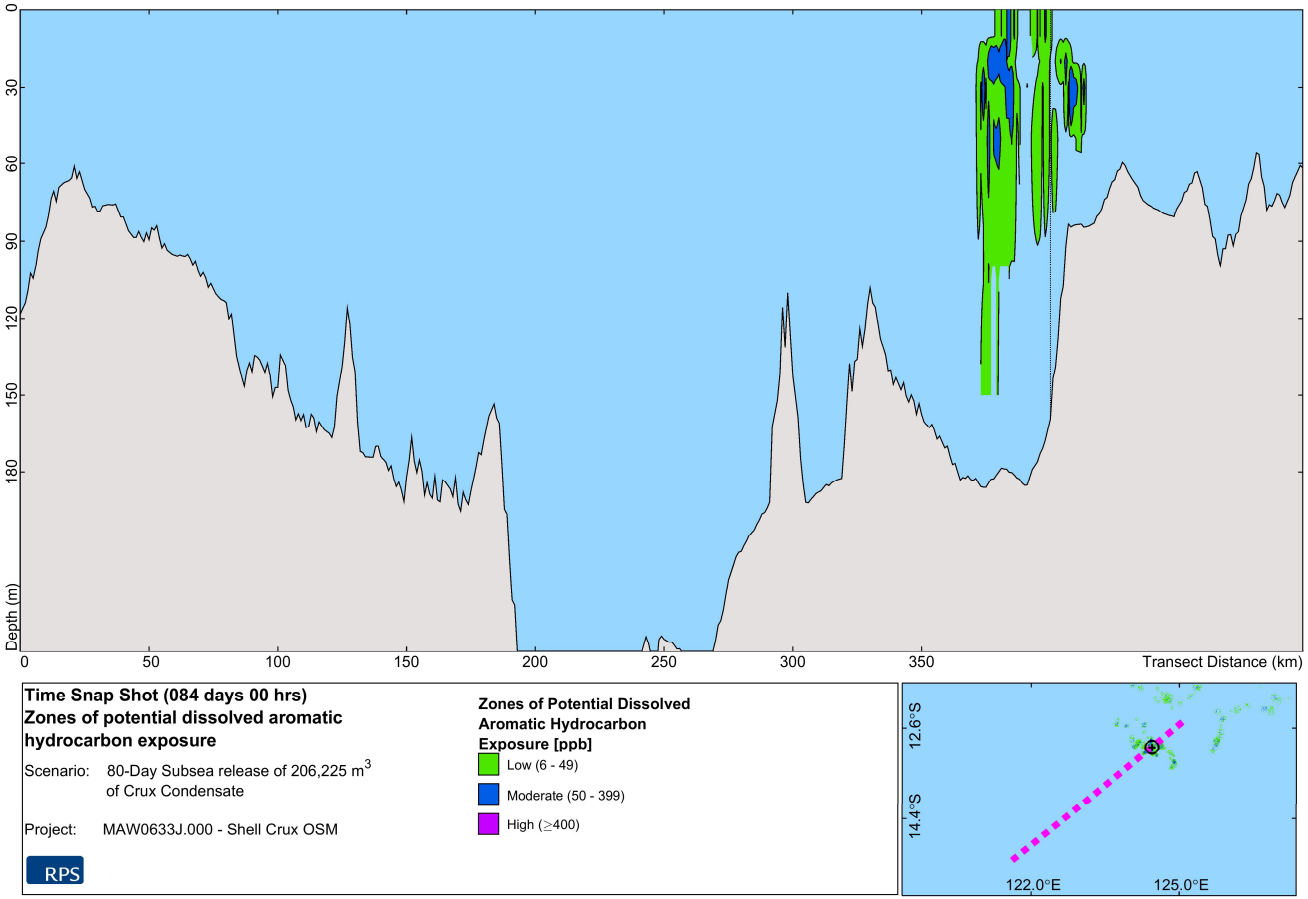


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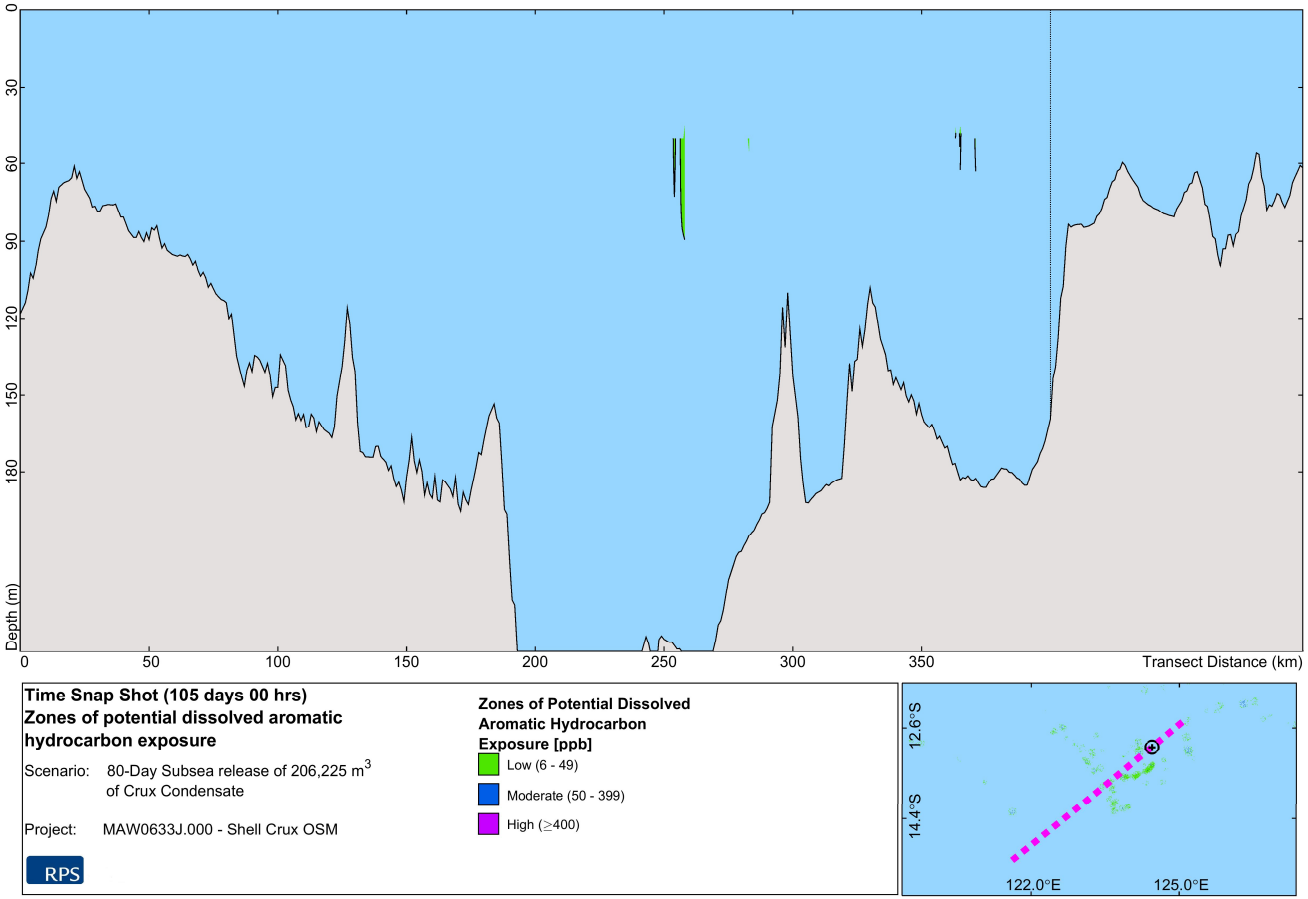


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Scenario 2 – Short-Term Surface Release of Crux Condensate at the Crux Platform

Maximum Volume Ashore

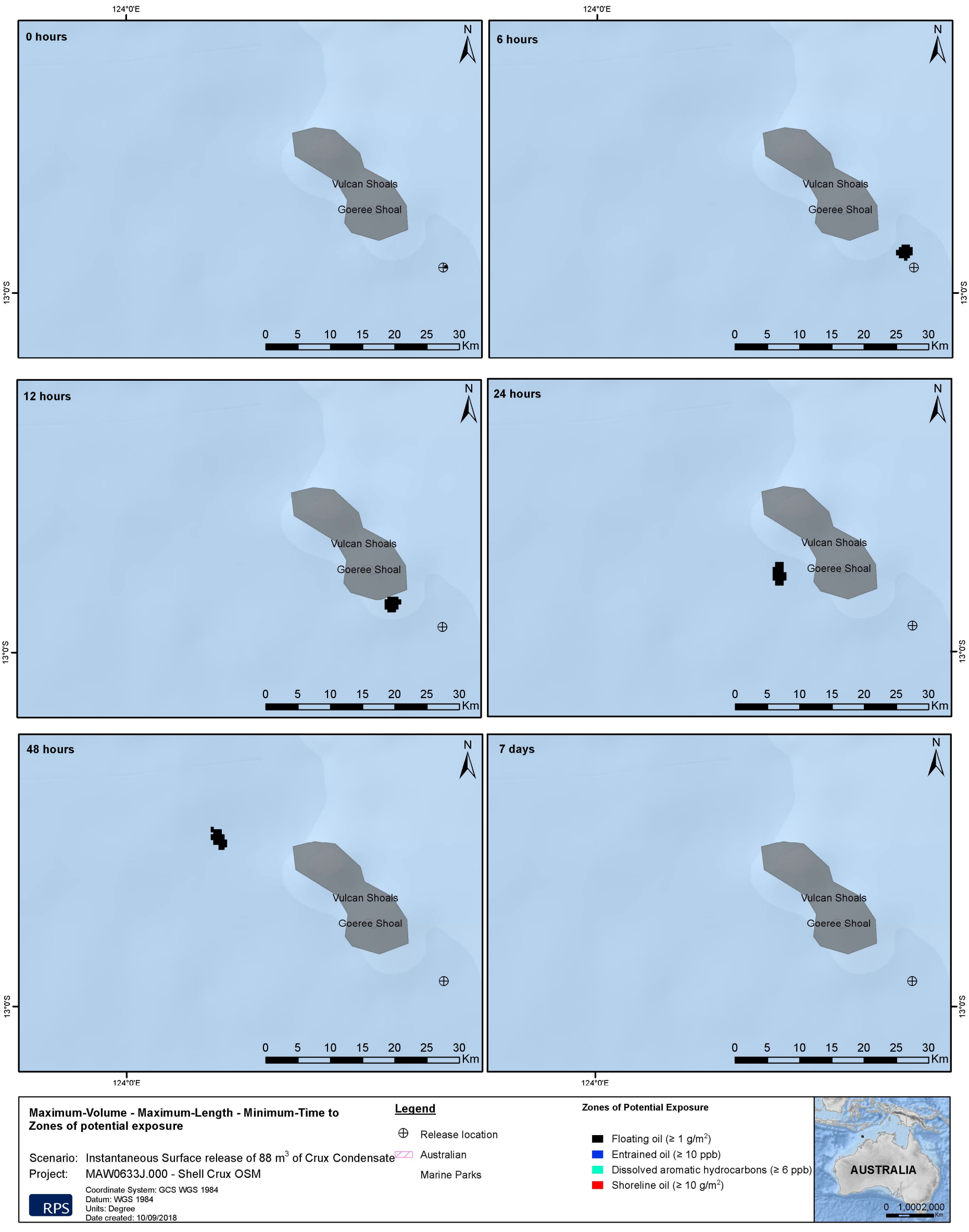


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Scenario 3 – Short-Term Subsurface Release of Crux Condensate from a Pipeline Rupture Near Heywood Shoal

Maximum Volume Ashore

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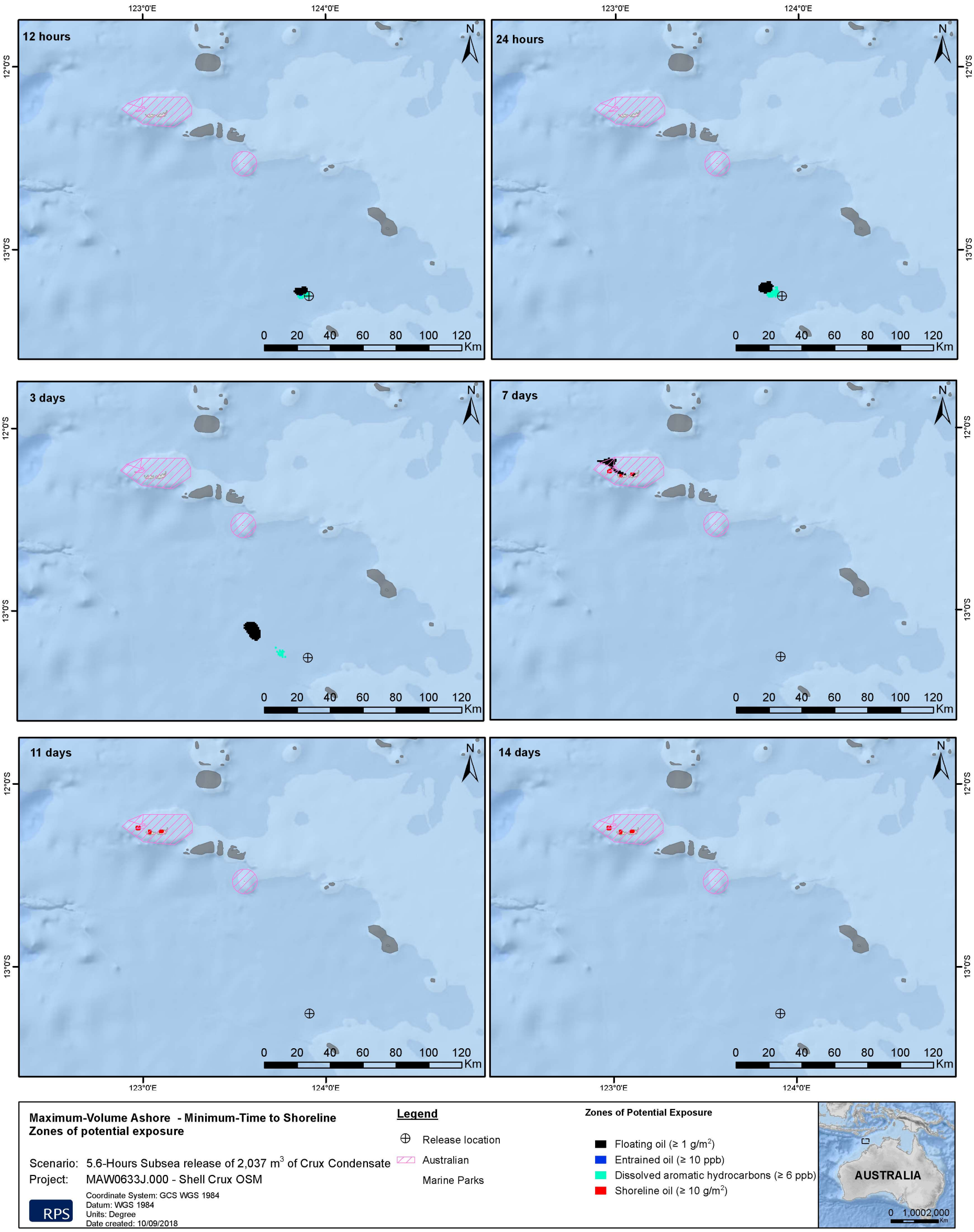


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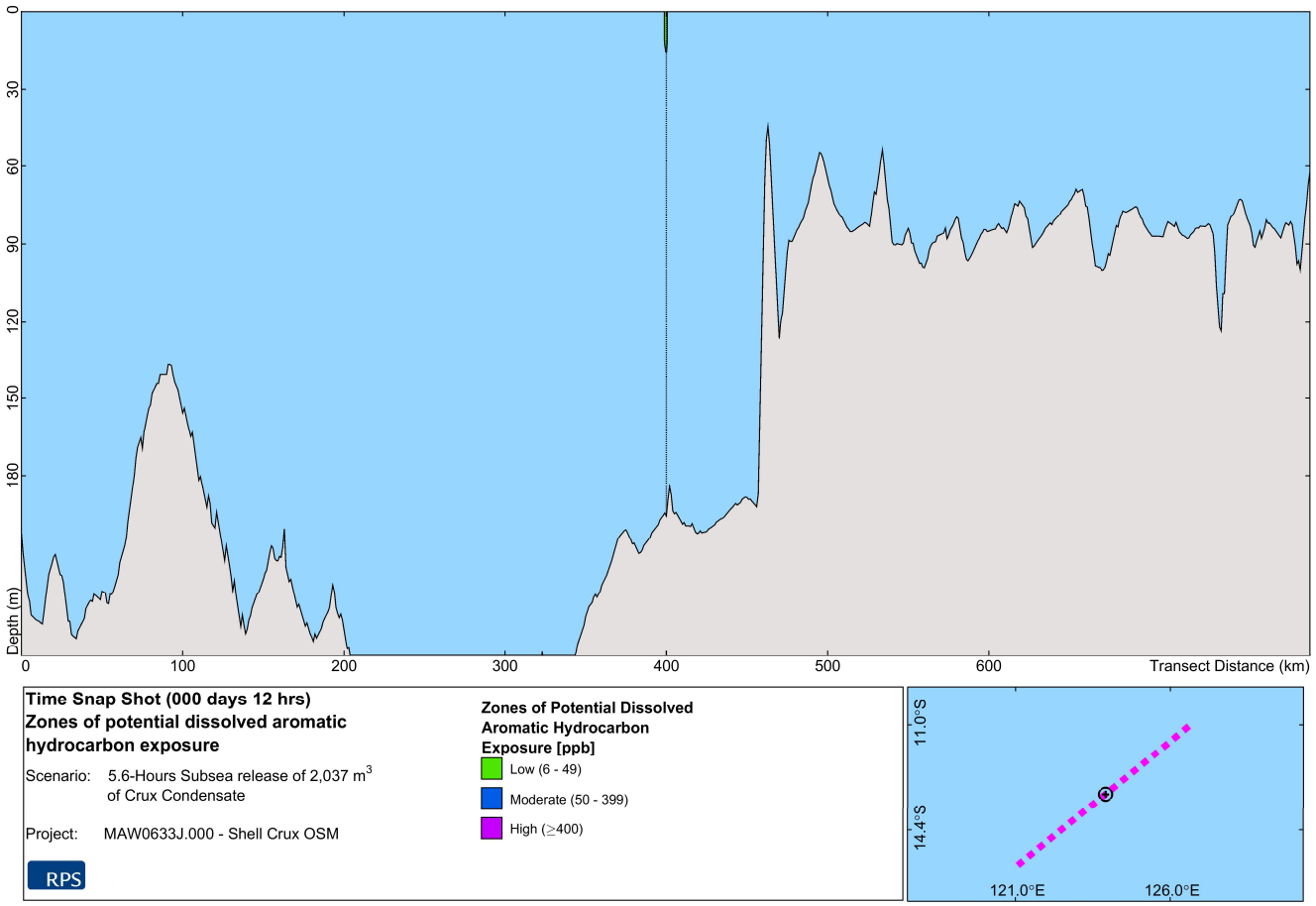


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Scenario 4 – Short-Term Surface Release of IFO-180 from a Pipelay Vessel Collision at the Crux End of the Export Pipeline

Maximum Volume Ashore

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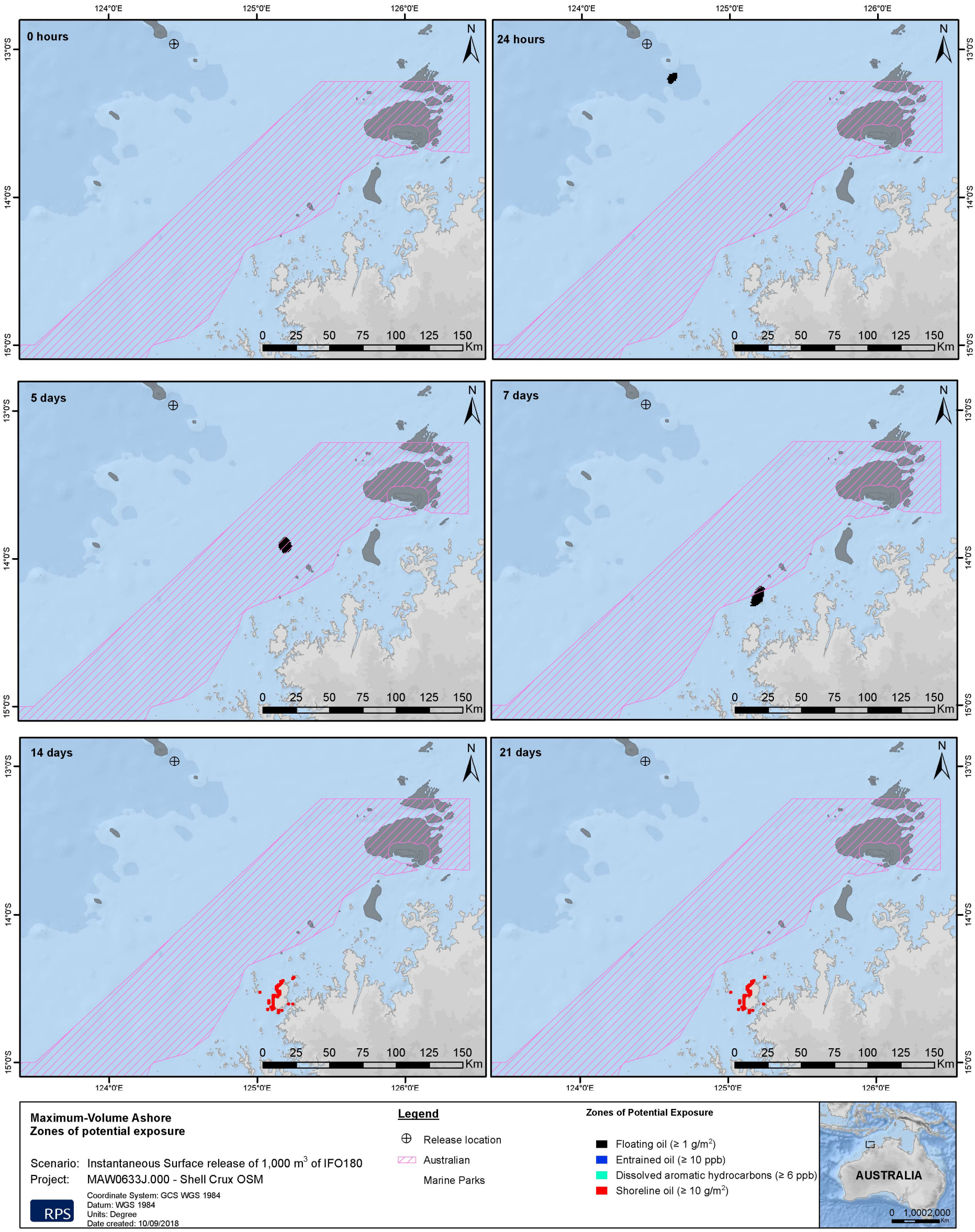


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Appendix H: Light Modelling Study (Imbricata 2018)

imbricata
Environmental



Crux Project

Light Modelling Study

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1.0 INTRODUCTION

Shell Australia Pty Ltd (Shell), in joint venture with SGH Energy and Osaka Gas, proposes to commercialise hydrocarbon resources from the Crux gas fields located in the northern Browse Basin, approximately 620 km north-north-east of Broome and 165 km north east of the Prelude FLNG facility (Figure 1). The offshore Crux Project will be tied back to the Prelude Floating LNG (FLNG) facility via an export pipeline. An initial five production wells are proposed to be drilled. The current concept for the Crux Project is a Not Normally Manned (NNM) platform containing minimal processing facilities, utility systems and accommodation. It will be operated remotely from the Prelude FLNG facility and only require periodic maintenance visits, significantly reducing light exposure to the surrounding marine environment. The notional drill rig will be located within the Crux development area, while the notional support vessel will be situated along the Crux export pipeline near the Crux development area (Figure 1).

CDM Smith, on behalf of Shell, contracted Imbricata Environmental (Imbricata) to undertake a light modelling study of the Crux Project including an NNM platform, drill rig and supply vessels to inform the preparation of an Offshore Project Proposal.

1.1 Purpose

The key purpose of the assessment was to characterise the sources of light emissions from the Crux Project and assess the predicted impact of light in the context of the nearest key habitats that support sensitive receptors.

1.2 Scope

Imbricata performed the following scope of work in undertaking this light modelling study:

- Provide context in relation to light theory (Section 2.1)
- Initial screening to identify potential sensitive receptors (Section 2.2)
- Define indicative lighting analogues and timing of the Crux Project light sources(e.g. Crux NNM platform (herein referred to as the Crux platform), drill rig and support vessel) to inform light modelling (Section 3.2)
- Undertake a Line of Sight (LOS) analysis to determine the extent of direct light from the Crux platform (including flaring), a drill rig and support vessel (Figure 1) (Section 4.1)
- Undertake light modelling to determine the extent and intensity of skyglow over the horizon from each light source (Section 4.2), and
- Identify the key habitats that the light will reach above ambient light conditions (i.e. moonless night with a clear sky) (Section 5).

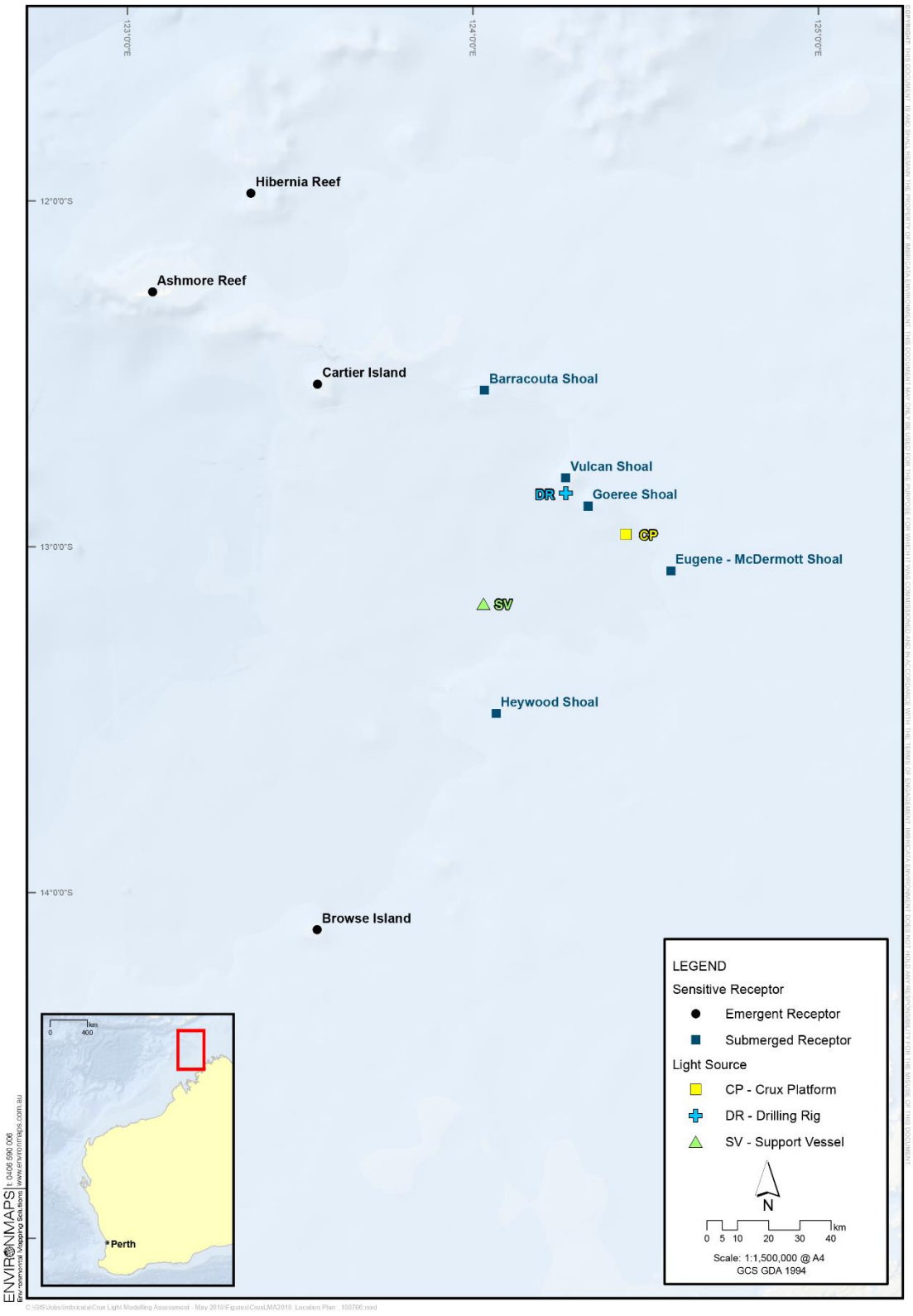


Figure 1 Location map of Crux Project with light sources and key receptors

2.0 BACKGROUND

2.1 Light Theory

2.1.1 Artificial Light Sources

Light propagating into the atmosphere directly from upward-directed, incompletely shielded sources, or after reflection from the ground, ocean or other surfaces, produce a diffuse glow that can be seen from large distances. Skyglow from artificial lights is most often noticed as a glowing dome of light over cities and towns.

Skyglow occurs when artificial light reflects off clouds and atmospheric particles such as dust and water vapour, causing a scattering effect. Sky glow is highly variable depending on localised weather conditions, quantity of dust and gas in the atmosphere, amount of light directed skyward, and the direction from which it is viewed. In cloudy weather conditions, more particles are present in the atmosphere to scatter the upward-bound light, so sky glow becomes a very visible effect of wasted light.

Air molecules are far smaller than the wavelength of light. They scatter light forwards and backwards equally, and scatter light sideways at half the forward intensity. They are very much more effective at scattering shorter (bluer) wavelengths. This is known as Rayleigh scattering (Strutt 1899), and is the reason why the sky appears blue. Aerosols are suspended water droplets and dust particles with sizes that are not always smaller than a wavelength of light. These scatter light sharply forwards, very little sideways, and only very slightly backwards, and are not affected by wavelength. This is known as Mie scattering (Cox 2002), and is why clouds appear white. Airborne particles, cloud density and height will all have an effect at which skyglow is perceived by an observer.

2.1.2 Skyglow and Distance

Sky glow brightness arising from artificial light sources decreases exponentially with distance from the light source, due to the geometric effects characterized by Rayleigh's inverse square law in combination with atmospheric absorption. Rayleigh's Law has been verified by observation to describe both the measurements of sky brightness at any given point or direction in the sky caused by a light source, as well as to integrated measures such as the brightness of the "light dome" over a city, or the integrated brightness of the entire night sky. At large distances (over about 50 km) the brightness of a light source falls more rapidly, largely due to extinction and geometric effects caused by the curvature of the Earth.

Different light sources produce differing amounts of visual sky glow. The dominant effect arises from the Purkinje shift, and not as commonly claimed from Rayleigh scattering of short wavelengths (Aubé et al. 2013; Luginbuhl et al. 2014). When observing the night sky, even from moderately light polluted areas, the eye becomes nearly or completely dark adapted or scotopic. The scotopic eye is much more sensitive to blue and green light, and much less sensitive to yellow and red light, than the photopic eye. Predominantly because of this effect, white light sources such as metal halide, fluorescent, or white LED can produce as much as three times the visual sky glow brightness of the most common high-pressure sodium lamp or a flame.

2.1.3 Influence of Clouds

The cloud-cover and cloud height influence the dispersal of skyglow by reflecting at the cloud-ceiling causing increased luminance at lower light intensities due to light scattering. Cloud cover refers to the fraction of the sky

(oktas 1-8) obscured by clouds when observed from a particular location, with cloud coverage of oktas 8 being overcast.

Cloud height is defined by the height of the cloud-ceiling from the ground. Clouds that enhance skyglow are often lower clouds between 1 – 2 km Australian Height Datum (AHD) (e.g. nimbostratus and stratocumulus) and mid-level clouds up to 4 km (e.g. altocumulus), as artificial upward light intensity decreases with altitude. A recent study by (Jechow et al. 2017) tracked the reach of skyglow from an urban into a remote area on a clear and on a partly cloudy night. They showed that zenith luminance reached near-natural levels at 5 km distance from a town on the clear night, but similar levels were reached at 27 km on the partly cloudy night.

Clouds behave like random disperse media with enhanced multiple-scattering efficiency and reflect light according to the water content, especially as a function of the size, spatial density and asymmetry parameter of the water droplets (Kokhanovsky and Rozanov 2012). The clouds amplify the flux density of downwelling radiation through the diffuse reflection of up-light, in which the direct emissions and forward scatter dominate. The spectral and angular behaviour of upwardly propagated radiation differs from that scattered in a cloudless atmosphere. Therefore, no simple approach to calculating the amplification factor exists, and, rather than being a simple function of input parameters, the amplification factor will have a complex dependence on the optical properties of clouds, the position of an observer with respect to the position of the dominant light source, and its size and spectral properties. Due to this complexity, the amplitude of reflectance from the cloud-ceiling will not be considered in the analysis.

2.2 Key Habitats and Sensitive Receptors

The presence of artificial lighting associated with activities during all phases of the Crux Project has the potential to impact marine fauna and birds, particularly those that use visual cues for orientation, navigation, or other purposes. The distance of key habitats and associated sensitive receptors from the Crux Project light sources are presented in Table 1. Impacts from artificial lighting associated with the Crux Project may include the following:

- disorientation, attraction or repulsion
- disruption to natural behavioural patterns and cycles, and
- secondary impacts such as increased predation and reduced fitness.

Table 1 Key habitats and sensitive receptors within 165 km of the Crux Project. Sensitive receptors: MT=marine turtles; SB=seabirds; MSB=migratory shorebirds; FI=fish; ZP=zooplankton; CR=coral reef

Key habitats	Sensitive receptor	Approx. distance to the Crux platform (km)	Approx. distance to the notional drilling rig within the Crux development area (km)	Approx. distance to the notional support vessel situated along the Crux export pipeline (km)
Goeree Shoal (GS)	FI, ZP	13	8	46
Eugene McDermott Shoals (EMS)	FI, ZP	18	42	60
Vulcan Shoal (VS)	FI, ZP	22	4	49
Barracouta Shoals (BS)	FI, ZP	63	39	64
Heywood Shoal (HS)	FI, ZP	70	70	29
Cartier Island (CI)	MT, SB, MSB, CR	105	78	85
Ashmore Reef (AR)	MT, SB, MSB, CR	155	127	134
Browse Island (BI)	MT, SB, MSB, CR	158	160	117
Hibernia Reef (HR)	FI, CR	160	135	149

For the purpose of the assessment, indicative locations of a drilling rig and support vessel were identified to provide an informed, conservative assessment of light in relative proximity to nearest receptors. In reality, these sources are mobile and may occur within the Crux Project area.

2.2.1 Marine Turtles

Six species of marine turtle occur in Australian waters and have potential to pass through the project area, including green turtles (*Chelonia mydas*), flatback turtles (*Natator depressus*), hawksbill turtles (*Eretmochelys imbricata*), olive-ridley turtle (*Lepidochelys olivacea*), leatherback turtle (*Dermochelys coriacea*) and loggerhead turtles (*Caretta caretta*) (Commonwealth of Australia 2017). Green and hawksbill turtles are known to nest at Ashmore, Cartier and Browse Islands, while loggerhead turtles have been recorded at Ashmore Island, but infrequently (Commonwealth of Australia 2017). All marine turtle species are protected under the *Environment Protection and Biodiversity Conservation Act* (EPBC Act).

Light pollution on nesting beaches can alter critical nocturnal behaviours in adult and hatchling turtles. Research suggests that artificial lighting can disrupt or affect the choice of nesting location by female turtles, particularly light visible on the landward side of nesting beaches (Salmon et al. 1992) the onshore and offshore orientation turtle hatchlings (Salmon et al. 1992). These studies demonstrated that hatchlings crawl away from tall, dark horizons (sand dunes and vegetation) towards lower and lighter horizons (the sea and stars), and that artificial lighting can alter this response.

As hatchlings swim offshore from their natal beach, they become less influenced by light cue and rely predominantly by wave motion, currents and the earth's magnetic field (Lohmann and Lohmann 1992). Studies also suggest that light generated by flares may not affect hatchlings as much as other light sources. Witherington and Bjorndal (1991) examined the roles of light wavelength and intensity in the sea-finding mechanisms of loggerhead and green turtle hatchlings and found the most disruptive wavelengths to be in the range of 300 to 500 nanometres (nm) (blue – green wavelengths). Spectral analysis of flares at Thevenard Island (Pendoley 2000) suggests that flare light does not contain a high proportion of light wavelengths within this range.

2.2.2 Sea Snakes

Sea snakes are found in tropical waters in a diverse range of habitats (Heatwole and Cogger 1993). Sea snakes are abundant throughout the shallow seas and inshore waters of tropical Australia, and twenty species are reported to occur in the North-west Marine Region (Wilson and Swan 2003). They occur widely from coral reefs to turbid inshore waters and estuaries, but there are few species known from the region that inhabit deep-water, oceanic environments. Tagging experiments on Ashmore Reef have revealed that some species of sea snake remain resident in localised areas for some years (Guinea and Whiting 2005). All sea snakes are listed marine species under the EPBC Act.

There is no literature available on the effects of light on sea snakes. However, anecdotal evidence based on absence of sea snakes in waters surrounding offshore vessels suggest that sea snakes are not attracted to artificial light sources.

2.2.3 Seabirds

Studies conducted between 1992 and 2002 in the North Sea confirmed that artificial light was the reason that birds were attracted to and accumulated around lit offshore infrastructure (Marquenie et al. 2008) and that lights can attract birds from large catchment areas (Wiese et al. 2001). Birds may either be attracted by the light source itself or indirectly as structures in deep water environments tend to attract marine life at all trophic levels, creating food

sources and shelter for seabirds (Surnam, 2002). The light from operating production facilities and flares may also provide further opportunities for seabirds to forage at night. Potential adverse impacts to seabirds attracted by artificial lighting are limited but includes collisions with infrastructure and flares and alteration of normal behaviours.

2.2.4 Migratory Shorebirds

There are recognised sites of importance for migratory shorebirds on the coast of northwest Western Australia (e.g. Roebuck Bay, 80 Mile Beach and the Lacepede Islands) and at Ashmore and Cartier Islands, which are 155 km and 105 km north-west of the Crux platform, respectively (Bamford et al. 2008) (Table 1). Migratory birds may pass in the vicinity of the Crux Project area 'en route' between these sites on mainland Australia and destinations on offshore islands or locations such as East Timor, Indonesia, Malaysia and Papua New Guinea (Commonwealth of Australia, 2002).

While little is known about how migratory shorebirds navigate, particularly over oceans and in the absence of terrestrial landmarks, many are thought to use the Earth's magnetic field, stars, the Sun and polarised light patterns to determine their migratory direction (Åkesson and Bäckman 1999). If migratory shorebirds are reliant on visual cues such as ambient light, moonlight and starlight to navigate, then artificial light could alter their natural migratory patterns, particularly over the ocean. Light from offshore platforms has been reported to attract migrating birds, particularly those that migrate during the night (Verheijen, 1985).

Studies have found that migratory shorebirds are particularly sensitive and attracted to the orange to red portion of the visible light spectrum (Van De Laar 2007). This equates to the wavelength range of roughly 590 – 750 nm within the electromagnetic spectrum. As most offshore infrastructure and vessels contain primarily white and orange (sodium vapour) coloured luminaries, a significant proportion of the total light emitted is within this range. Van De Laar (2007) reported that by replacing orange, red and white lights with primarily green and blue lights on an offshore platform, significantly reduced (up to ten times) the number of migratory shorebirds circling the platform. Whilst the literature suggests that migratory shorebirds are attracted to offshore light sources depending on their distance (< 5 km), there are no reports of migratory shorebirds landing on offshore platforms. It is likely that migratory shorebirds may be attracted to the light temporary during the night, but then continue their migration at daylight. The potential impacts on the migratory shorebirds population resulting from this temporary attraction to light sources is not well understood.

2.2.5 Cetaceans

There is no evidence to suggest that artificial light sources impact on the migratory, feeding or breeding behaviours of cetaceans. Cetaceans predominantly utilise acoustic senses to navigate their environment, rather than vision (Simmonds et al. 2004). However, anecdotal evidence from night observations on vessels suggest that dolphins prey on fish and other marine species that are attracted to artificial light sources. While this may present a minor change in behaviour of dolphins at a local scale, it is unlikely that the Crux Project will have a significant impact on cetacean species.

2.2.6 Zooplankton

The seas surrounding Australia contain a relatively low zooplankton biomass, particularly in the open ocean (Tranter 1962). Spatial and temporal patterns in the distribution and abundance of macrozooplankton on the North-west Shelf (which is representative of the Browse Basin area) are influenced by sporadic climatic and oceanographic events, with large inter-annual changes in assemblages (Wilson et al. 2003). Amphipods, euphausiids, copepods, mysids and cumaceans are among the most common components of the zooplankton in the region (Wilson et al. 2003).

Light has been reported as a fundamental factor controlling the daily vertical migration of zooplankton (Haney 1993). Light not only serves as the proximate cue triggering the ascent of zooplankton, but it also reduces the amplitude of migration if light levels are sufficiently high at night. Plankton migrate closer to the surface on dark nights than they do on clear, moonlit nights (Dietz 1962). Alterations of the ascent and descent cycles of marine plankton may indirectly affect the feeding of marine species. Some species of plankton have been reported foraging in darkness to avoid predation, only to be intensively predated when illuminated by a rising full moon (Gliwicz 1986).

2.2.7 Fish

Experiments using light traps have found that some fish species are attracted to light sources (Meekan et al. 2001), with traps drawing catches from up to 90 m (Milicich et al. 1992). The concentration of organisms attracted to light results in an increase in food source for predatory species and marine predators are known to aggregate at the edges of artificial light halos. A larval fish study around a platform in the Gulf of Mexico showed increased abundance of clupeids (herring and sardines) and engraulids (anchovies), which are both highly photopositive (Lindquist et al. 2005). Shaw et al. (2002), in a similar light trap study, noted that juvenile tunas (Scombridae) and jacks (Carangidae), which are highly predatory, may have been preying upon concentrations of zooplankton attracted to the light field of the platforms. This could potentially lead to increased predation rates compared to unlit areas.

2.2.8 Coral Reef

The Kimberley coast supports extensive reef systems, north of Cape Leveque. Coral reefs are also well developed around offshore islands including Ashmore, Cartier, Hibernia, Seringapatam and Scott Reefs, Browse Island and the Rowley Shoals. Coral distribution is likely driven by water depth and availability of hard substratum for anchorage.

The reef system at Cartier Island (105 km from the project area) represents the nearest major coral reef system in proximity to the Project area, with coral also observed to occur on the shoals and banks throughout the region.

3.0 METHODS

The light modelling assessment consisted of two methods for predicting the dispersal of light from a single light source, including:

- Line of sight (LOS) modelling - LOS modelling was undertaken to determine the extent of direct light to the horizon from the Crux Project light sources and identify which receptors fall within this area
- Light Intensity Modelling - Light intensity modelling was undertaken to calculate the intensity of luminance from the light sources to ambient light conditions.

It is important to note that, at the current stage of early engineering definition, the lighting design has not commenced and not likely to be definitively completed until significantly later in detailed design. Therefore, for this early stage assessment, the assumed inputs represent a current conservative project estimation of what could be reasonably expected in typical light scenarios from the Crux Project. Given the lighting philosophy has not been designed at the time of preparing this assessment, it may be subject to change / refinement over time.

3.1 Line of Sight Assessment

A LOS assessment was conducted to determine the visible extent of all of the direct light sources to the horizon. A total of nine points were chosen across the Crux Project to represent light source locations to be used in the assessment (Table 2). The points represent the key light sources that are likely to emit the greatest emissions from the highest points of the Crux Project (Figure 1).

The maximum height of the flares was calculated based on the estimated height of the flame plus the height of the flare stack. The flame height was estimated based on the rate of outputs and modelling undertaken for the Narrabri Gas Project (Imbricata 2018).

Lighting associated with deck locations on similar infrastructure typically consists of fluorescent 36 watt (W) fixtures, with HPS 500 W floodlights lights on the topside modules (Table 2). On the drill rig and support vessels, these lights will be used on a 24-hour basis in accordance with safety requirements during the operation. On the Crux platform, these lights will only be used during maintenance, which is expected to occur periodically only every 6-12 weeks throughout the year.

The frequency and timing of lights used was provided by Shell based on typical requirements for flaring during start-up, operations, maintenance and safety flaring events and during operations of the NNM Crux platform, drill rig and supply vessels (Table 2).

Imbricata used Viewshed in Global Map v15 (Blue Marble Geographics Hallowell, ME, USA.) to calculate the extent to which direct light reaches the distant horizon taking into account the curvature of the earth's surface. A Digital Evaluation Model was not required for this assessment given that there were no emergent features of high altitude within the study area.

3.2 Light Intensity Modelling

The extent of horizontal light intensity to ambient light conditions (i.e. moonless clear night, where exposure value (E_v) > 0.001 Lux) was modelled for three scenarios representing periodic flaring periods (start-up, safety flaring event and maintenance) and four scenarios representing continuous operations (pilot flaring, manned Crux platform, drill rig operations and supply vessel operations) (Table 3). A moonless clear night was considered the most frequent sky condition for the area and provides a conservative and realistic representation of ambient light conditions in the offshore northern Browse Basin.

The flaring analogues were extrapolated from in-situ luminance measurements taken from a light study for the Narrabri Gas Project (Imbricata 2018). The luminance from a single 4 m pilot flame was 5.7 Lux, while a 30 m flame during a safety flaring event was estimated to emit 1140 Lux from the same distance. The actual decay rates of light intensity validated the model outputs. These measurements were then used to estimate the maximum luminance of the proposed flaring scenarios at 100 m. These analogues were used to extrapolate the light intensity from the light sources until it reached ambient light conditions.

The operational lighting of the deck and topside modules of the Crux platform, drill rig and supply vessels were assumed to comprise different lighting outputs including florescent and HPS globes, which will emit light at lower wavelengths. Given that the specifications of these fixtures are currently unknown, Imbricata used the in-situ light measurements taken of the drill rig at the Torosa South-1 well (SKM and ERM 2008). The light intensity of the rig lighting was highest at 8.9 Lux, located 100 m from the rig and lowest at 0.03 Lux at the extremities of the survey grid approximately 1.4 km from the rig (SKM and ERM 2008). It was assumed that light emissions from the Torosa drill rig would be a realistic representation of the Crux platform, drill rig and supply vessels.

The dispersal of horizontal light emissions were estimated based on Rayleigh's inverse square law (intensity $\propto 1/r^2$), assuming consistent scattering at low altitude (Strutt 1899). The model outputs of the horizontal l propagation of light for each of the scenarios were presented in luminance/distance graphs and dispersal maps to show the exponential attenuation of light with distance. The intensity of light emitted from each scenario were divided into the following categories to compare against natural light conditions:

- >1 Lux (day light)
- 0.1 – 1 Lux (full moon to twilight)
- 0.01– 0.1 Lux (quarter moon to full moon), and
- 0.001 – 0.01 Lux (moonless clear night to quarter moon)

Table 2 Expected analogues and timing of light sources at the Crux Platform (CP), Drill Rig (DR) and Supply Vessel (SV).

Location of light source	Max. height above sea level (ASL) (m)	Type of light	Light shields/flame flow rate	Frequency	Max. time (hours)
Crux platform flaring					
CP flare – start-up	40	Flame	70 mmscf/d (+13m flame)	Start up	36
CP flare – operations (pilot)	90	Flame	3.5 mmscf/d (+ 5m flame)	Continuous	Continuous
CP flare - maintenance	91	Flame	4. 550 mmscf/d (+ 6m flame)	4 years	12
CP flare - safety event	115	Flame	550 mmscf/d (+ 30m flame)	1 year	0.4
Functional lighting					
CP deck (manned)	25	Fluorescent 36 W fixtures	Diffusing cover	Maintenance only	3 weeks
CP topside modules (manned)	75	HPS 500 W floodlights	Directional floodlights	Maintenance only	3 weeks
DR deck	25	Fluorescent 36 W fixtures	Diffusing cover	Continuous	Continuous
DR mast	75	HPS 500 W floodlights	Directional floodlights	Continuous	Continuous
SV stern	30	Fluorescent 36 W fixtures	Diffusing cover	Continuous	Continuous

Table 3 Lighting analogues and timing for light intensity modelling

Location of light source	Type of light	Modelling analogues (max. luminance at 100 m) (Lux)	Frequency	Max. time (hours)
Periodic flaring scenarios				
CP flare – start-up	13m flame	1.1	Start up only	36
CP flare - safety event	6m flame	103	approx. 4 years	12
CP flare - maintenance	30m flame	0.5	>1 year	0.4
Continuous operations				
CP flare – pilot (unmanned)	5m flame	0.5	Continuous	Continuous
CP deck & topside modules (manned)	Functional	8.9	Maintenance only	Continuous for ~3-week periods
DR deck & mast	Functional	8.9	Continuous	Continuous
SV stern	Functional	8.9	Continuous	Continuous

4.0 RESULTS

4.1 Line of Sight Assessment

The following section provides the results of the LOS assessment and are presented in Figure 2. The analysis shows that the theoretical limit of visibility from the Crux platform may extend up to 38.3 km during a safety flaring event, 34.1 km during maintenance, 33.7 km during operation and 22.6 km during start-up activities (Table 4). The direct light from all flaring scenarios has potential to be visible at Goeree Shoal, Eugene McDermott Shoals and Vulcan Shoal (Figure 2), however these represent submergent receptors with limited influence from atmospheric light.

Lights of the Crux platform and the drill rig and mast (assumed to be 25 m ASL) may be visible at distances of 30.9 km, encompassing Goeree Shoal, Eugene McDermott Shoals. The Crux platform and drill rig decks (assumed to be 25 m ASL) may be visible on the horizon at a distance of 17.9 km, which would be seen from Goeree Shoal. The lights of the supply vessel may be visible on the horizon at a distance of 19.6 km, which would not be visible from any of the key habitats (Table 4).

Table 4 Maximum distance that direct light will be visible at the horizon from each light source and key habitats within this distance

Location of light source	Max. height of light source ASL (m)	Direct LOS projection (km)	Key habitats reached *
CP flare - start-up	40	22.6	GS, EMS, VS
CP flare - operations (pilot)	90	33.9	GS, EMS, VS
CP flare - safety flaring event	115	38.3	GS, EMS, VS
CP flare - maintenance	91	34.1	GS, EMS, VS
CP deck (manned)	25	17.9	GS, EMS
CP topside modules (manned)	75	30.9	GS, VS
DR deck	25	17.9	GS, VS
DR mast	75	30.9	GS, VS
SV stern	30	19.6	none

* Note: Abbreviations of key habitats: Goeree Shoal (GS), Eugene McDermott Shoals (EMS) and Vulcan Shoal (VS).

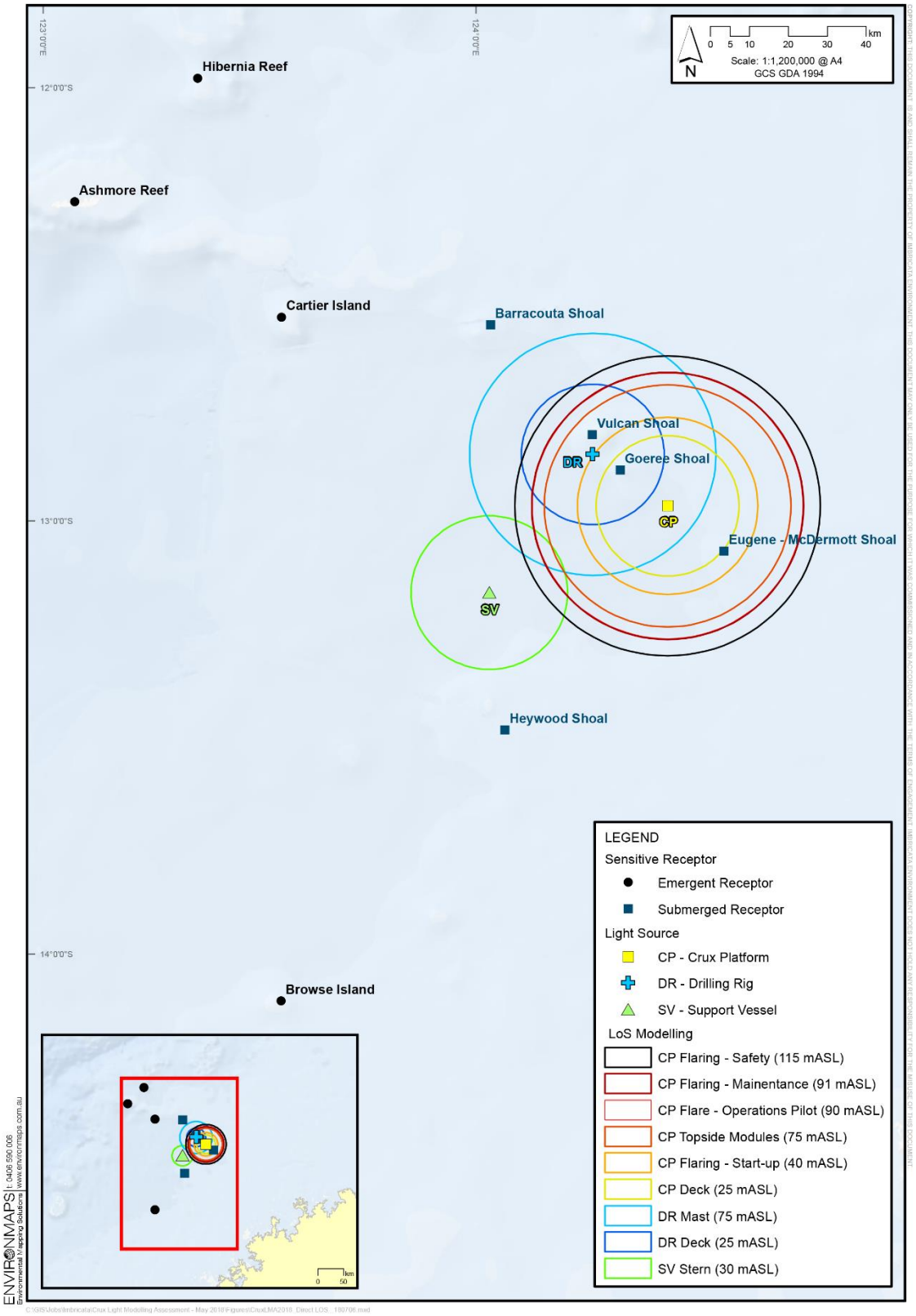


Figure 2 Theoretical limit of visibility from the Crux platform, drill rig and support vessel locations

4.2 Light Intensity Modelling

4.2.1.1 Periodic Flaring Scenarios

The following section provides the results of light intensity modelling outputs for the two flaring scenarios from the Crux platform: Safety flaring event (Figure 3), and start-up flaring (Figure 4). The extent of horizontal light propagation at ambient light conditions for each scenario are summarised in Table 5 and the spatial dispersal is presented in Figures 5 and 6. The modelling shows that the extent of horizontal light propagation at ambient conditions from a flaring event at the Crux platform was 32 km, which would reach Goeree Shoal (E_v= 0.0061 Lux), Eugene McDermott Shoals (E_v= 0.0031 Lux) and Vulcan Shoal (E_v= 0.0021 Lux) (Figure 5). The extent of horizontal light propagation at ambient conditions was significantly less for the start-up flaring scenario (3.2 km) and maintenance flaring (2.2 km) from the Crux platform (Table 5). Based on these estimates from these light sources, none of the sensitive receptors would be affected by light intensity greater than 0.001 Lux.

Table 5 Extent of horizontal and vertical light propagation at ambient light conditions (Luminance = 0.001 Lux) for various scenarios and key habitats within this range

Location of light source	Modelling analogues (max. luminance at 100 m) (Lux)	Horizontal light propagation (km)	Key habitats reached *
Periodic flaring scenarios			
CP flare - start up	1.1	3.2	none
CP flare - safety event	103	32	GS, EMS, VS
CP flare - maintenance	0.5	2.2	none
Continuous operations			
CP flare – pilot (unmanned)	0.5	2.2	none
CP deck & topside modules (manned)	8.9	9	none
DR deck & mast	8.9	9	GS, VS
SV stern	8.9	9	none

* Note: Abbreviations of key habitats: Goeree Shoal (GS), Eugene McDermott Shoals (EMS) and Vulcan Shoal (VS).

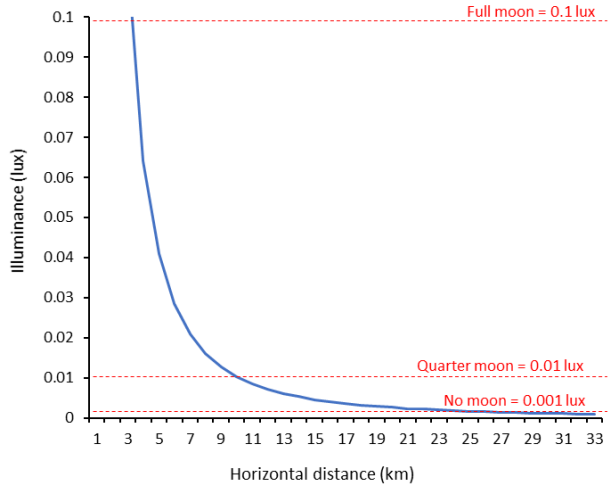


Figure 3 Modelling outputs for horizontal light propagation during a safety flaring event from the Crux platform

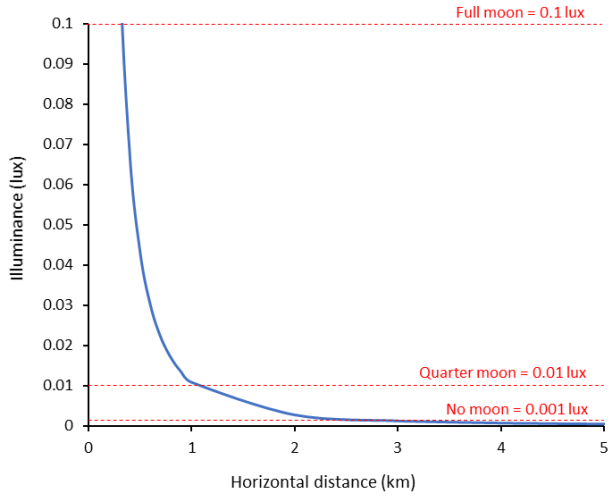


Figure 4 Modelling outputs for horizontal light propagation during a start-up flaring scenario from the Crux platform

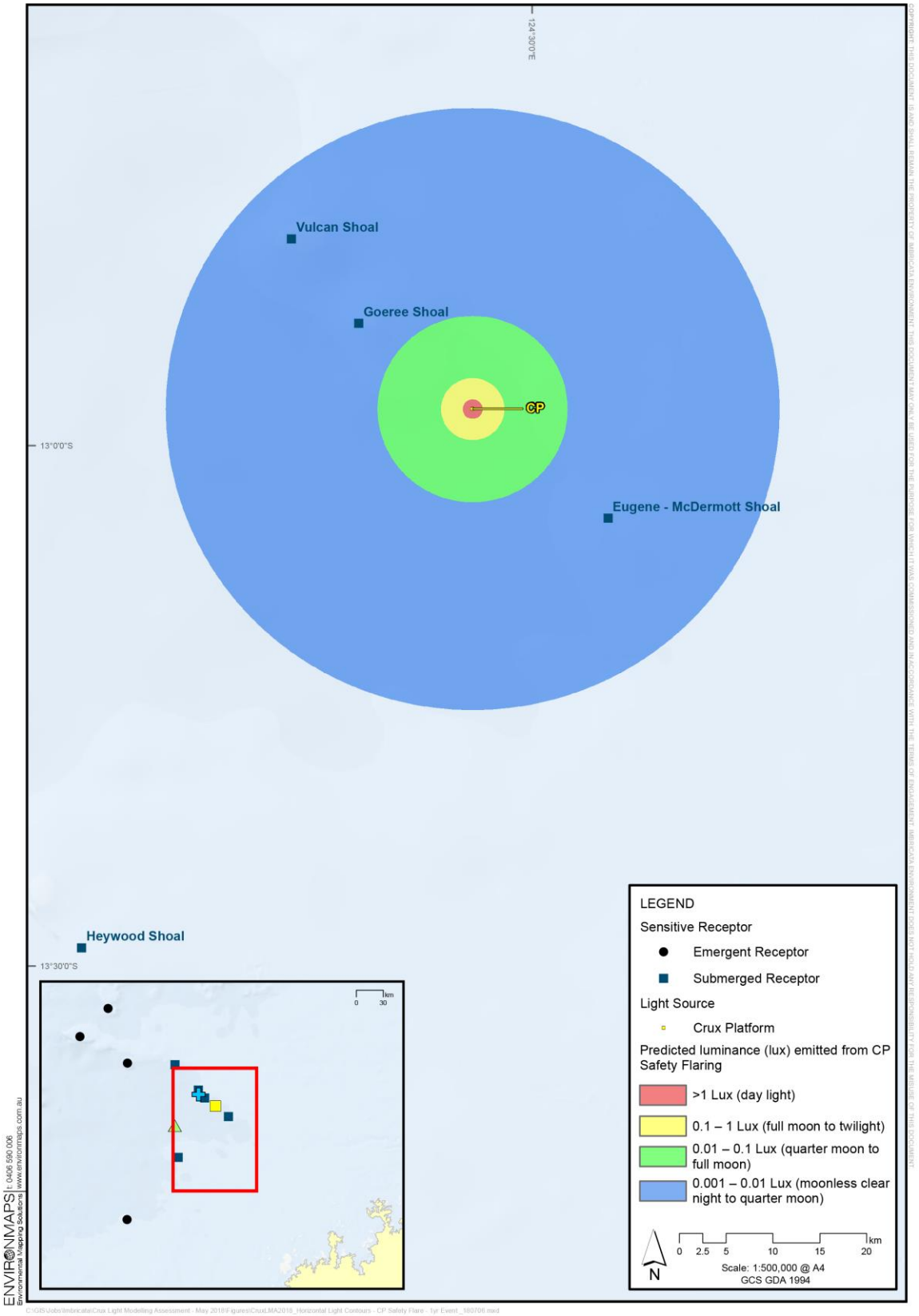


Figure 5 Horizontal light propagation during a safety flaring event from the Crux platform

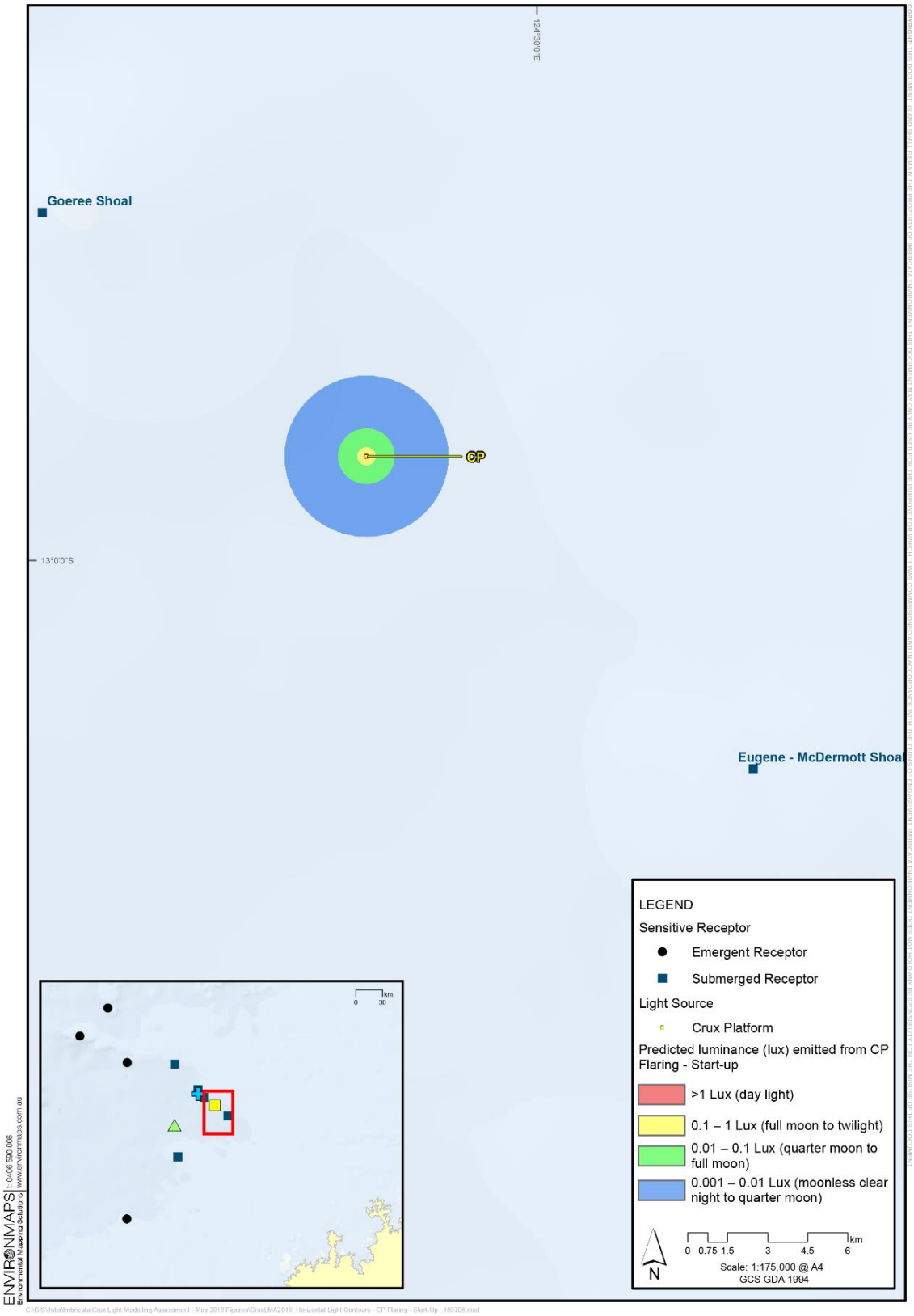


Figure 6 Horizontal light propagation during start-up flaring from the Crux platform.

4.2.1.2 Operations

The modelling outputs of the operations are shown in Figures 7 and 8. The spatial dispersal of light from the pilot flare (unmanned) is presented in Figure 9 and operations during maintenance at the Crux platform is presented in Figure 10. The modelling shows that the horizontal extent of continuous pilot flaring (assuming a period when the platform is unmanned, consistent with the NNM operational philosophy) is predicted to be 2.2 km. The functional lighting to ambient conditions is predicted to be 9 km from the Crux platform (when manned), drill rig and supply vessel (Table 5). Based on these calculations, the light from the drill rig may reach the nearest submergent receptors of Goeree Shoal (E_v= 0.0055 Lux) and Eugene McDermott Shoals (E_v= 0.0014 Lux), while the other light sources would not reach any of the key habitats at intensities greater than 0.001 Lux.

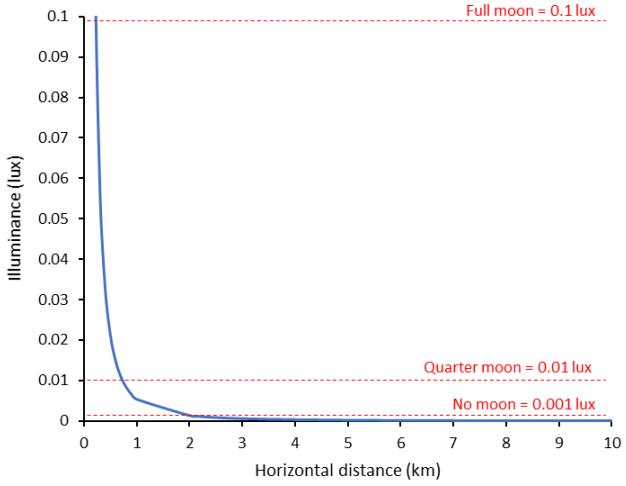


Figure 7 Modelling outputs for horizontal light propagation during pilot (unmanned) scenario from the Crux platform

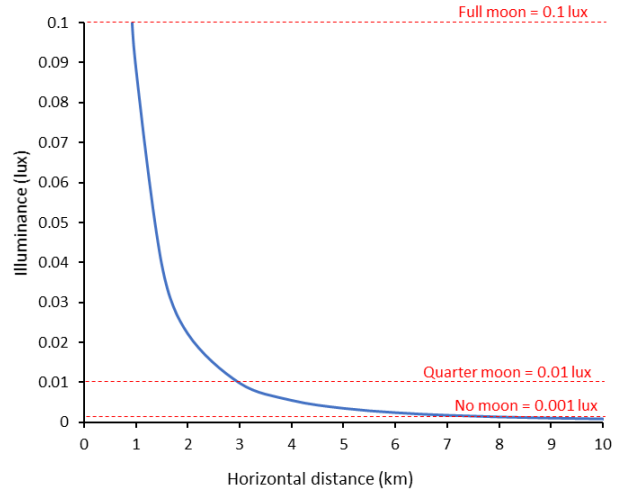


Figure 8 Modelling outputs for horizontal light projections from the Crux platform (manned), drill rig and supply vessel

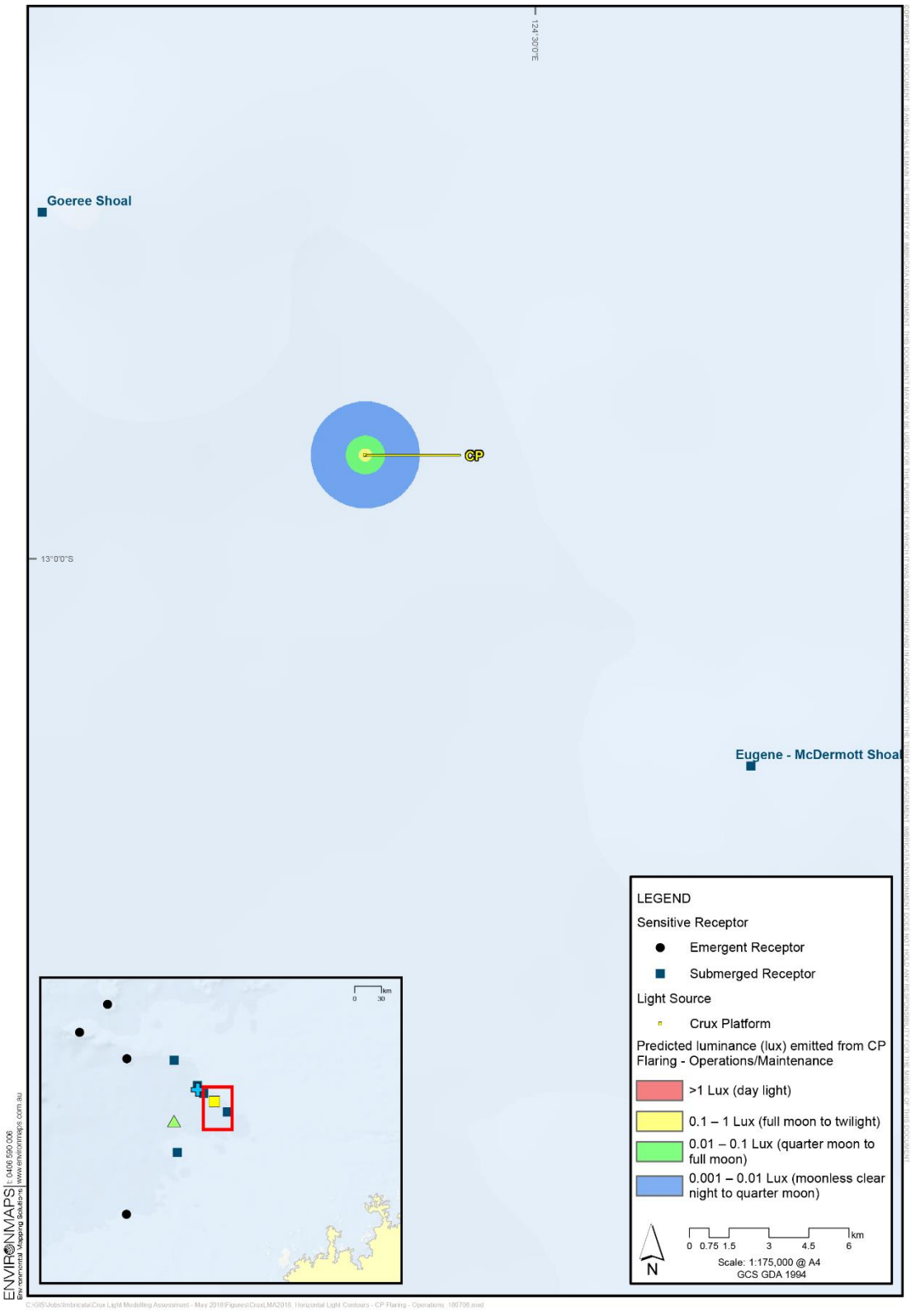


Figure 9 Horizontal light propagation during pilot flaring (unmanned) from the Crux platform

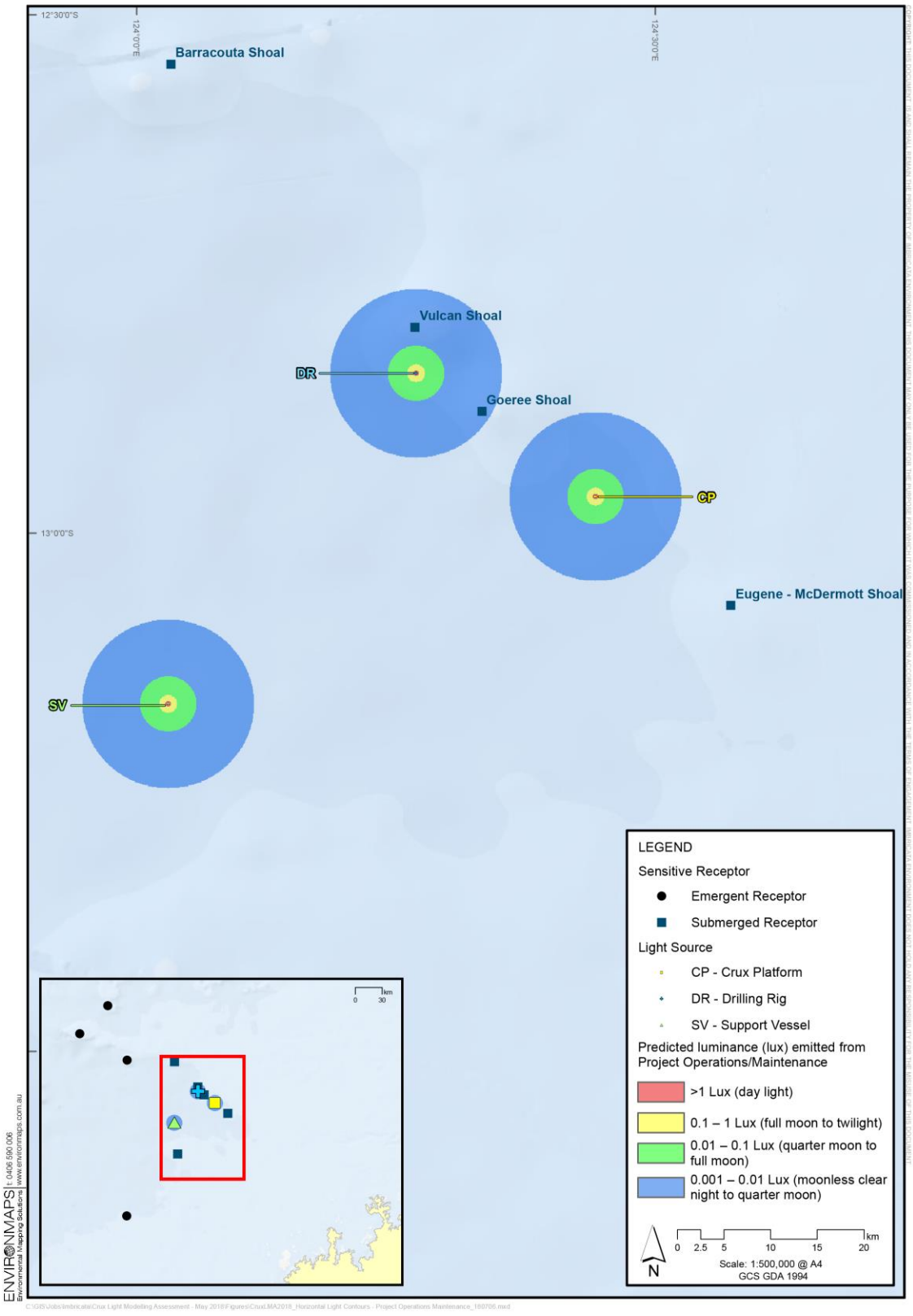


Figure 10 Horizontal light propagation during typical maintenance operations scenario including light from the Crux platform (manned), drill rig and supply vessel

5.0 DISCUSSION AND CONCLUSION

The outer area of influence from direct light is predicted to be approximately 38 km during a safety flaring event, which is expected to occur only under unanticipated rare operational conditions where the facility would need to flare to mitigate the potential for any over-pressuring of the topside infrastructure. However, the light intensity at this outer area was estimated to be less than ambient light conditions on a moonless clear night. Direct light spill from all flaring scenarios is predicted to extend over the shoals that occur in proximity to the Crux development area, including Goeree Shoal, Eugene McDermott Shoal and Vulcan Shoal. However, the light intensity is predicted to be at least an order of magnitude lower than the typical lux levels of a quarter moon on the horizon (E_v = 0.0061 Lux) at the nearest shoal.

The modelling outputs indicated that all light sources will be visible at Goeree Shoal, however only the safety flare and drill rig deck/mast will reach the shoal at intensities greater than ambient light conditions. All light sources from the Crux platform (including flaring and functional lighting) will be visible at Eugene McDermott Shoal, with no direct light visible from the drill rig or supply vessels. However, only the safety flaring will reach intensity greater than the ambient light conditions. From Vulcan Shoal, all light sources apart from the Crux platform deck and the supply vessels will be visible but only the safety flare and drill rig will reach the shoal at intensity greater than ambient light conditions.

Given the low levels of light reaching these habitats and that they are submergent features, the flaring and functional lighting scenarios would pose a low risk to sensitive receptors within the outer area of influence. The potential for increased predator activity is unlikely to result in a significant impact on the plankton population. Given the relatively small impact area surrounding the Crux Project in respect to zooplankton habitat, the potential effects are expected to be highly localised and unlikely to have a significant impact on zooplankton populations. Furthermore, the potential disturbance to fish surrounding the Crux Project is expected to be restricted to localised attraction, possibly extending up to 100 m from the light source. As such, any impacts to fish arising from light emissions are considered to be minor and localised to a small proportion of the population. The shoals surrounding the Crux Project area are not known to support large areas of coral communities, with the closest large reef system at Cartier Island (105 km from the project area). Therefore, it is unlikely that the project lighting will impede or disturb natural lighting cycles that may affect coral spawning.

Due to the high degree of variability in atmospheric conditions (e.g. cloud density, cover and ceiling height, aerosols and suspended participles), it is not feasible to accurately model the extent at which vertical skyglow will be visible at the key habitats. On a clear moonless night, the maximum vertical extent of skyglow may attenuate to 4 km above sea level (ASL) in the event of safety flaring (Imbricata 2018), which may be visible at a low angle (< 3^o) above the horizon. This skyglow will diminish exponentially over the horizon further away from the facilities and is unlikely to be visible from any emergent habitats identified within this study. Clouds can influence how skyglow is distributed at altitude by reflecting vertical light at the cloud-ceiling, which increases the perceived light across the sky at a specific observation point. The amount of light reflected off the cloud-ceiling will depend on the height, coverage and density of the clouds, and their proximity to the light source. While this factor will vary seasonally throughout the year, the worst-case scenario would be 100% cloud cover, with a cloud-ceiling height of 1 -– 4 km (e.g. altostratus, altocumulus). It is unclear the extent at which skyglow reflection on an overcast cloud-ceiling could potentially increase the outer area of attenuating light, but it would be limited to luminance less than ambient light at a low altitude angle over the horizon. Even during overcast nights, it is unlikely that the light reflected off the cloud-ceiling above the Crux Project area would reach any emergent habitat, which support nesting turtles, seabirds and migratory shorebirds, greater than ambient conditions.

Given that migratory shorebirds fly at an average altitude of 2 km (Richardson 1979), the Crux Project will be visible from a further distance than reported in this study. However, only a small number of individuals are expected to pass within the area of influence whilst in transit. Therefore, any behavioural disturbances such as disorientation, attraction and/or exhaustion are expected to affect a small proportion of the population, and not expected to result in any significant impacts on a regional or population level.

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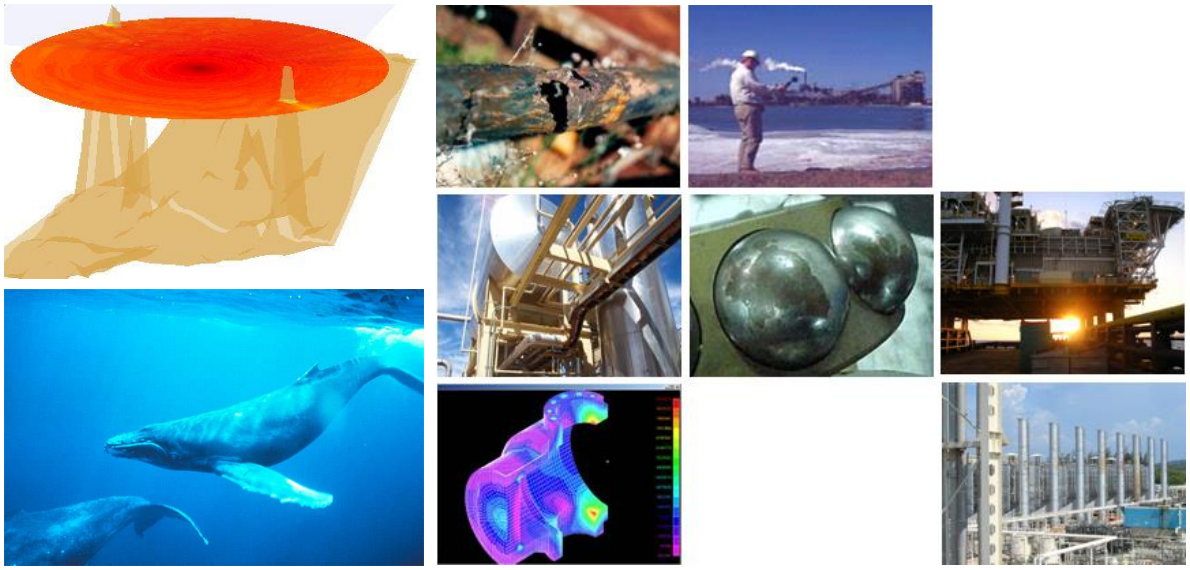
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Appendix I: Underwater Noise Modelling Study (SVT 2018)

SVT ENGINEERING CONSULTANTS
A Wood Group Company

CRUX PROJECT- UNDERWATER NOISE ASSESSMENT



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EXECUTIVE SUMMARY

Shell Australia Pty Ltd (Shell) is progressing planning for the prospective development of the Crux development area, which is located approximately 160 km north-east of the Prelude field in the northern Browse Basin, offshore Western Australia, and is located in water depths of 110m to 170m.

The current development concept is for a not normally manned platform. The reference case is currently jacket platform with piled footings. This study assesses the underwater noise levels that are likely to occur due to activities within the Crux development area, and the impact on key values and sensitivities identified by comparison with established criteria. The noise is primarily due to:

- Pile Driving for installation of the platform jacket; and
- Drilling new wells, and working over existing wells, including the use of vertical seismic profiling (VSP) activities.

As part of the validation process, measured data from the Crux baseline geophysical, geotechnical and metocean studies have been used to inform the noise assessment, to provide bathymetry, seabed type, and parameters such as temperature vs depth, salinity vs depth.

Noise modelling was undertaken of a range of scenarios to provide an early assessment of noise from key sources including:

- Underwater noise generated by pile driving – 2 scenarios (main pile - small hammer; main pile - large hammer);
- Underwater noise generated by development drilling – including 2 scenarios to conservatively assess the potential for future drilling for future tiebacks in proximity to shoals (outside a defined exclusion zone) and a scenario for drilling at the Crux platform location;
- Underwater noise generated by downhole Vertical Seismic Profiling (VSP) activities at the Crux platform location; and
- A representative worst case operational noise scenario based on a Tender / Supply Boat operating with cavitating propellers in dynamic positioning (DP) mode.

The results are summarised in Table A-1 overleaf.

Table A - 1 Calculated Maximum Range for Effects during Pile Driving Activities

Marine Species		Impulsive Sources			Non-impulsive Sources		
	Permanent Injury or Fatality	Permanent Threshold Shift (PTS)	Temporary Threshold Shift (TTS)	Behavioural Disturbance	Permanent Threshold Shift (PTS)	Temporary Threshold Shift (TTS)	Behavioural Disturbance
Fish (No Swim Bladder)	Not Exceeded	Not Exceeded	13.3 km (2)	N/A	N/A	Not Exceeded	N/A
Fish (With Swim Bladder)	Not Exceeded	390 m (1)	13.3 km (2)	N/A	N/A	Not Exceeded	N/A
Sea Turtles	Not Exceeded	390 m (1)	N/A	Not Exceeded	N/A	N/A	N/A
Low-frequency Cetaceans	Not Relevant	17.3 km (1)	57.8 km (2)	2.7 km (3)	Not Exceeded	Not Exceeded	1.6 km (3)
Mid-frequency Cetaceans	Not Relevant	14.0 km (1)	56.9 km (2)	2.7 km (3)	Not Exceeded	Not Exceeded	Not Exceeded

(1) PTS from Accumulated Daily Exposure
(2) TTS from Accumulated Daily Exposure
(3) Sound Pressure Level (L_p)

The activities will have a localised and temporary impact on the marine fauna in the surrounding area, including fish (both with and without swim bladder), eggs and larvae, sea turtles and cetaceans. The modelling and analysis undertaken shows that underwater noise levels would:

- Fall below the relevant permanent injury and fatality criteria where applicable to the marine fauna type, and the relevant instantaneous permanent hearing damage criteria, at all locations;
- Fall below the relevant permanent hearing damage criteria based on daily exposures beyond ranges of 389 m for fish and sea-turtles, 14 km for Mid-Frequency Cetaceans and 17.3 km for Low-frequency cetaceans;
- Exceed the relevant temporary hearing threshold shift criteria (strike number and exposure time dependant) at ranges up to 13.3km for fish, to up to 57.8 km for cetaceans; and
- Fall below the relevant behavioural disturbance criteria for low-frequency cetaceans at ranges beyond 2.7 km.

The limiting (longest) ranges for the impact assessment are driven in by the daily exposure criteria (L_E). This metric reflects an accumulated dose for a 24h assessment based on the assumption that an animal is exposed to such noise levels at a fixed position. The corresponding radii are significantly larger than those for peak pressure criteria, and they represent an extremely unlikely worst case scenario. More realistically, marine mammals would not stay in the same location or at the same range for 24 hours. Therefore, a reported radius of L_E criteria does not mean that any animal

travelling within this radius of the source will be injured, but rather that it there is potential for the onset of such injury if it remained in that range for 24 hours. Therefore, the cumulative 24-hour noise estimates are to be considered highly conservative and unlikely to represent the actual noise exposure by mobile transient marine fauna.

Underwater Noise Generated by Drilling

The impacts of underwater noise associated with drilling activities in the Crux development area are typical of the type of activity outlined. Minimal potential impacts are predicted.

- The modelling and analysis undertaken shows that underwater noise levels would fall below the relevant behavioural disturbance criteria for low-frequency cetaceans at ranges beyond 1.6 km; and
- Not exceed marine fauna criteria for fish, eggs and larvae, sea turtles, and mid-frequency cetaceans for any drilling scenario.

Underwater Noise Generated by Downhole VSP

No marine fauna criteria are exceeded at any location for any VSP scenario modelled. No potential impacts are predicted.

Operational Noise

The L_p criterion for behavioural disturbance to low-frequency cetaceans extends out to a range of 1.6 km (Tender on DP Scenario). No other potential impacts are predicted.

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1. INTRODUCTION

1.1 Overview of the Crux Project

Shell Australia Pty Ltd (Shell) is progressing planning for the prospective development of the Crux development area, located approximately 160km north-east of the Prelude field in the northern Browse Basin, offshore the Kimberley coast, Western Australia (WA). The Crux Project will be located in Commonwealth marine waters in the northern Browse Basin, 160km offshore north-west Australia and 620km north-north-east of Broome. The field is located in water depths of 110m to 170m.

The current development concept is for an offshore (Not Normally Manned, NNM) platform, with a potential development area for future tie-backs defined within a 30km radius around the platform (Figure 1-1). The reference case is currently jacket platform likely with piled footings.

Shell are progressing an Offshore Project Proposal (OPP) for the Crux Project for submission to the National Offshore Petroleum Safety and Environmental Management Authority (NOPSEMA) in accordance with the Commonwealth Offshore Petroleum and Greenhouse Gas Storage (Environment) Regulations 2009 (OPGGS (E) Regulations), and have requested support in developing the OPP and associated specialist studies.

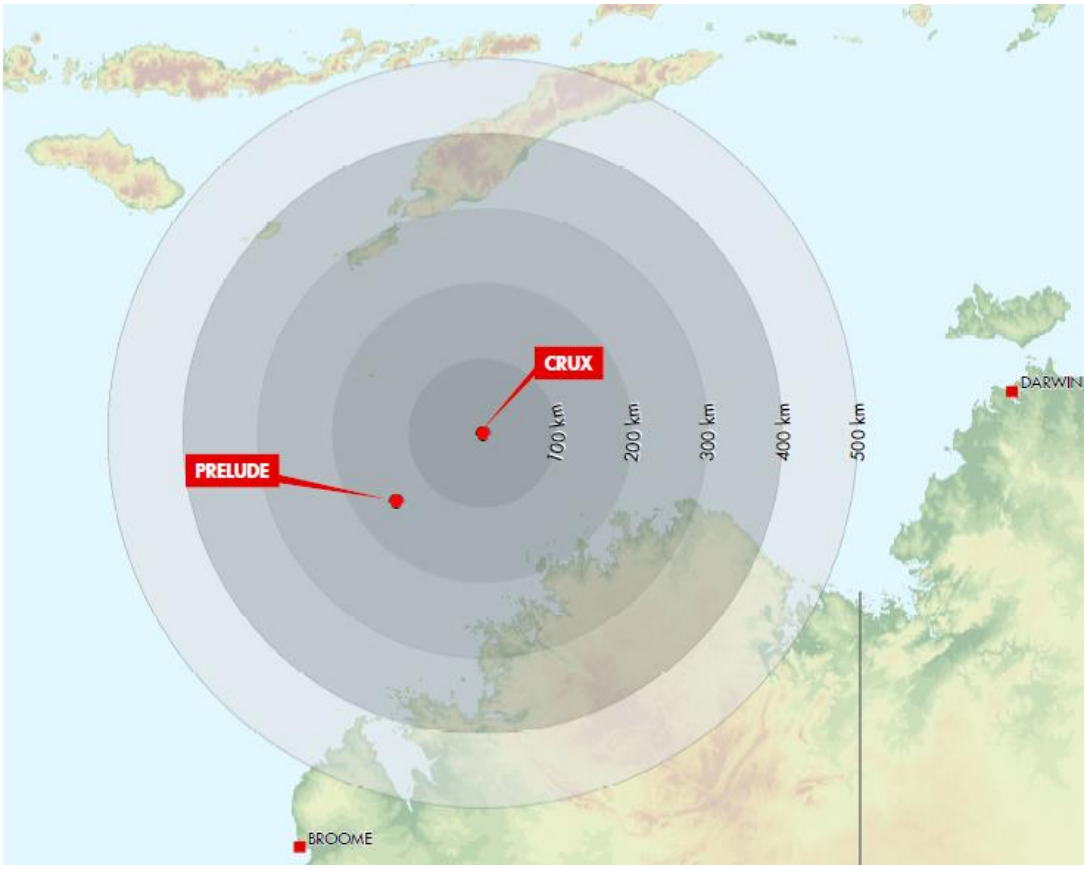


Figure 1-1 Overview of Proposed Crux Development Area

1.1.1 Noise Sources

The most significant sources of noise to be expected from the Crux Project are:

1. Pile driving during installation of the platform jacket; and
2. Development drilling - including drilling-related noise and the use of vertical seismic profiling (VSP), which involves a single noise source in the water column receiving transducers 'downhole'.

Given the nature of the development concept (NNM platform), there is little potential for significant underwater noise sources during the operational phase relative to the other project phases described above, and therefore is not a major focus of this study.

1.2 Scope

SVT was commissioned by CDM Smith, on behalf of Shell, to undertake an underwater noise impact assessment of the key noise-generating and operational activities associated with the Crux Project. This study assesses the underwater noise due to pile driving, drilling and downhole VSP activities that are likely to occur within the Crux development area, and the impact on key values and sensitivities identified by comparison with established criteria.

The scope of the study includes:

- A determination of the likely worst-case conditions for the generation of underwater noise from piling, drilling and VSP activities anticipated during the Crux Project;
- Calculation of the underwater noise levels (for 7 scenarios) from the activities expected to be conducted as part of the project, using a numerical model;
- Assessment of the modelled underwater noise levels against the marine fauna response criteria; and
- Provide a conclusion of the results and recommend underwater noise management strategies that may be considered as part of forward project planning.

1.3 Definitions, Acronyms

Table 1-1 provides a listing of acronyms used in this report. Technical terms are further defined in Appendix B.

Table 1-1 List of Acronyms

Acronym	Meaning
AHD	Australian Height Datum
BoM	Bureau of Meteorology
CF	Crest Factor – Refer Appendix B-3
DP	Dynamic Positioning
HAT	Highest Astronomical Tide

Acronym	Meaning
Mhf	High-Frequency Cetacean – A marine mammal grouping based on audiograms (sensitivity to noise). Refer also Appendix B-5
Mlf	Low-Frequency Cetacean– A marine mammal grouping based on audiograms (sensitivity to noise). Refer also Table 3-5 and Appendix B-5
Mmf	Mid-Frequency Cetacean– A marine mammal grouping based on audiograms (sensitivity to noise). Refer also Table 3-5 and Appendix B-5
MMO	Marine Mammal Observers
MMPE	Monterey Miami Parabolic Equation – Refer Appendix A-1
MPR	Modular Platform Rig
NOAA	National Oceanic and Atmospheric Administration
NNM	Not Normally Manned
PE	Parabolic Equation
PTS	Permanent Threshold Shift – Refer Appendix B-4
RMS, rms	Root Mean Squared – Refer Appendix B-3
$L_{E,p}$	Sound Exposure Level – Refer Appendix B-2
L_p	Sound Pressure Level – Refer Appendix B-1
L_{pk}	Peak Sound Pressure Levels – Refer Appendix B-3
SSP	Sound Speed Profile - – Refer Appendix B-3
TTS	Temporary Threshold Shift – Refer Appendix B-4
UTM	Universal Transverse Mercator
WA	Western Australia
WOA	World Ocean Atlas
VSP	Vertical Seismic Profiling

2. METHODOLOGY

2.1 Underwater Noise Modelling

SVT's underwater noise model (refer Appendix A for model description) predicts the transmission loss of underwater noise with changing ranges, depth, and bottom type. The model can predict transmission loss from multiple noise sources in both narrowband and broadband frequency ranges. The underlying calculation software kernel has been developed by the universities of Miami and Monterey[1] in the USA, while the front-end interface has been developed by SVT. The calculation kernel has been validated and is known as the Monterey Miami Parabolic Equation (MMPE) model.

SVT maintains a database of underwater noise sources based on field measurements and published data. This database allows SVT to directly enter the noise source frequency spectrum into the underwater noise model.

2.1.1 Data and Model Limitations

The following data and model limitations are noted:

1) **Rough Surface Scattering**. Acoustic wave scattering due to the roughness of the sea surface and seabed is not accounted for in the model, which makes the model more conservative.

2) **Vertical Launch Angles (±40°)**. The launch angle[2] of the model is limited to ±40°. The sound waves predicted at angles close to the noise source outside of this angle are evanescent waves, i.e. strongly decaying[3].

3) **Shear Speed**. As the model is based on a Parabolic Equation (PE), it does not accurately predict the effect of the high shear speed components of some bottom types, and therefore can make the model conservative in cases where the bottom type supports shear wave propagation of sound.

2.1.2 Model Validation

Underwater propagation models use bathymetric data, geo-acoustic[4] information and oceanographic parameters[5] as inputs to produce estimates of the acoustic field at any depth and distance from the source. The quality of the model's estimate is directly related to the quality of the environmental information used. For example, the geo-acoustic parameters of the seabed, such as compressional and shear sound speed, sound attenuation and sediment density, can affect acoustic propagation and can therefore affect the model predictions.

---

[1] NPS (Naval Post Graduate School) Monterey California.

[2] MMPE implements the Pade equation approximation which gives small phase error angles in the main propagation direction.

[3] It must be noted that PE models are limited in vertical launch angles. For any angles outside of this limit, the model erroneously predicts evanescent waves.

[4] Geoacoustic parameters include material density, and compressional and shear speed.

[5] Oceanographic parameters include sound speed profiles of the water column and tidal heights. It is assumed that the sound speed velocity in the water column is the same for all ranges.

Measured data from the Crux baseline geophysical, geotechnical and metocean studies have been used to inform the noise assessment, to provide bathymetry, seabed type, and parameters such as temperature vs depth, salinity vs depth and highest astronomical tide.

Four general categories of acoustic propagation models are used in underwater acoustics: ray tracing; normal mode; parabolic equation (PE); and finite difference models. Of these model types, PE models are the most capable of making reliable predictions in range dependent shallow water[6] environments with changing bottom types, and with reasonable calculation solution times. The MMPE algorithm has been used as the basis of SVT's underwater noise model. This algorithm was selected because it has been rigorously tested and validated for shallow water environments at the Shallow Water Acoustic Modelling (SWAM 99) Workshop in Monterey California.

The temperature profile from baseline data collected within the Crux development area demonstrates that that there is no isothermal layer present – even though the depth may exceed 200m in some locations within the modelled domain. Additionally, the prediction range (> 25 km) is significantly larger than the depth. These observations validate the expectation of a "shallow water" environment and indicate that the selection of a parabolic equation for noise distribution modelling is appropriate for the Crux development area.

2.1.3 Noise Source Representation

In environmental acoustics, where the range to the assessment point (point of interest) is significantly greater than the dimensions of the source, noise sources are commonly modelled as idealised point sources. In determining noise emission source strength for underwater noise, the levels are commonly quoted as a level, in dB relative to the reference pressure (1uPa), and at a reference distance (1m) from the source location (e.g. 120 dB re 1uPa @ 1m). This level is typically calculated from measurements at far-field distances (i.e. a distance at which the source can be described as a point source). This does not mean that this quoted level is what would be measured at 1m, as the source has been idealised to encompass all of its energy into a sphere of radius 1m. Most sources are significantly larger than this dimension (in this case the wetted hull area of a semi-submersible drilling rig, or the surface area of a pile 160m to 185m long with a diameter of 2.44m to 2.94m), and in actuality the total sound energy will be distributed across the full actual surface area of the source. This then means that a mathematical noise model will predict noise levels in the near field (defined as a distance where the point source characterisation does not hold, generally less than 7 times the maximum source dimension) that are higher than they would be in reality.

2.2 Underwater Noise Generated by Pile Driving

In order to install the footings for the Crux NNM Platform, piles will be driven into the seabed by hydraulic impact piling. Impact piling operations involve the hammering of a pile into the seabed using (in this case) a hydraulically driven hammer located in the water. The hammering action results in radiation of noise from the pile into the surrounding water and seabed.

At each strike of the hammer, in addition to the whole displacement of the pile further into the seabed, the pile bends elastically and then returns to its original shape. This bending takes the form of flexural waves in the pile (see Figure 2-1), which propagate along the length of the pile and into

[6] Shallow water is defined to be depths < 200 m (see Richardson et al., 1995. Marine Mammals and Noise, Academic Press).

the seafloor[7]. The transverse component of the wave creates compression waves in the water which will propagate out from the pile as noise. The compressional component of the flexural wave will propagate into the seabed.

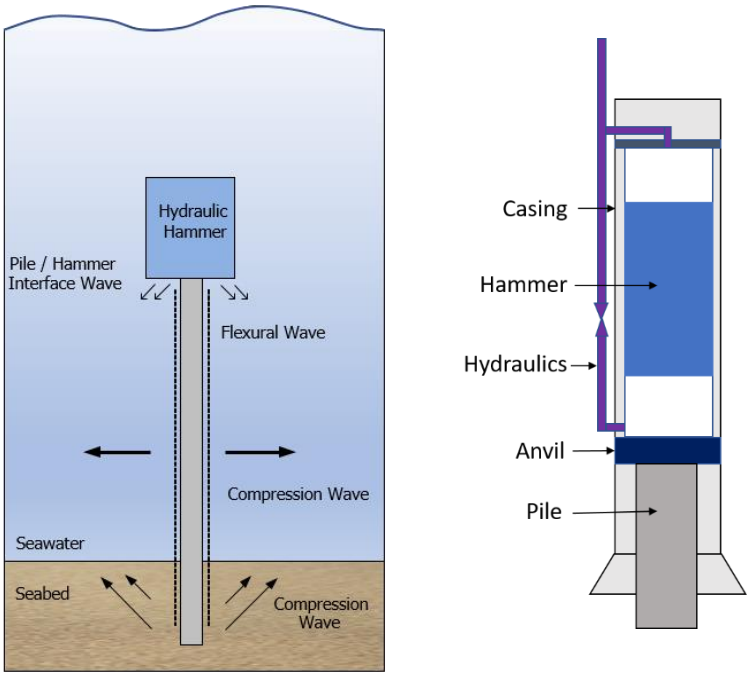


Figure 2-1 Underwater Noise Associated with Piling, and Schematic of underwater hydraulic hammer

The dominant underwater noise source from the piling activity is the compression wave generated from the surface of the pile in the water column. Studies have demonstrated that the magnitude of the noise emanating from a pile during piling is a function of the piling method (i.e. impact hammer or vibration), the pile material type (i.e. steel or concrete), the force applied to the pile (usually described by the hammer energy or hammer size), the pile size, and to lesser extent the characteristics of the substrate into which it is being driven. Selection of representative emission data for use in the model of the planned piling for the project is informed by these factors.

2.3 Pile Driving Assumptions

A piled foundation concept using main piles represents the current development concept for the Crux platform footings, in which four peripheral jacket legs will feature three rigid pile sleeves, through which a main pile is installed and secured to the sleeve. Hence, the estimated total number of piles is between 12 and 16.

2.3.1 Pile Diameter

The estimated primary pile length will be between 160m – 185m, with the insert pile being up to 260m in length. The current base case main pile configuration is 16 2.83m diameter main piles, driven to a penetration of 180m.

[7] Note: Depending on the resistivity of the soil, some of the energy will be reflected back up the length of the pile.

2.3.2 Hammer Energy

Two different hydraulic hammer types, have been modelled as separate scenarios:

- MHU-600 Hammer, 660kJ Energy, 95% efficiency; and
- MHU-2100 Hammer, 2,134kJ Energy, 95% efficiency.

2.3.3 Number of Strikes

Given the early stage of engineering definition at this OPP stage of assessment, the precise number of strikes is not feasibly known. As a conservative measure, in order to progress the assessment, estimates have been based on piling data from the Prelude FLNG project. The estimated number of strikes to full penetration that were used in the underwater noise study for the Prelude mooring piles were 6,530 for the main pile.

A detailed pile driveability analysis for Crux will not be carried out until FEED. Initial indication is that at least 100m of the total driven depth would require 'less' to 'significantly less' energy to progress than was the case for Prelude. The piles assumed in the Prelude study were significantly larger in diameter (5.5m), so assuming this number of strikes to full penetration for the Crux NNM Platform is a conservative measure.

The insert piles will be drilled and grouted.

The piles will be installed consecutively, such that only one pile will be installed per day. Therefore, the estimated maximum number of strikes per 24-hour period is 6,530 for the main pile.

2.3.4 Piling Location

The piling location used as the basis of the noise assessment is summarised in Table 2-1.

Table 2-1 Summary of Piling noise source location

Piling Location	Value
Crux Platform Location	656470 mE, 8566340 mN
Height Above Seabed	15m
Water Depth at source	168.5m

2.3.5 Estimation of Piling Source Noise Level and Spectrum

Case studies involving coastal piling or much larger offshore wind turbine piles are not considered representative of the proposed activities planned for the Crux Project.

It is theoretically reasonable that the source level for a particular hammer energy can be scaled using the relationship 10log(E2/E1). An examination of the body of published piling source values suggests that the relationship may not hold for long extrapolations, and engineering judgement suggests this scaling factor should only be applied for E2/E1 ratios that are near to 1.

MHU-2100 Hammer

CO.L.MAR [1] reported noise levels measured during the pile driving for the installation of a platform jacket in the Encana Buzzard field. The project used sub-surface piling, with 3,000 kJ hydraulic

hammer with a maximum applied efficiency of 85%, in 139m of water. This compares favourably with the project conditions when compared to other potential data sources. The report provides measured peak pressure and spectrum for the piling measured at far field distances (815m), and also states the derived attenuation from source to received location based on the observed conditions. The report also states the measured RMS pressure, and pulse length. Using this information, and scaling with respect to hammer energy, SVT derived an $L_{E,p}$ for the project piling using the 2,027 kJ Hammer, based on maximum energy at refusal.

- 2,027 kJ Hammer: 220 dB re 1μPa2.s @ 1 m

MHU-600 Hammer

More data is available for hammers of this size and they can be used to drive relatively large piles in nearshore conditions. De Jong [2] provides a calculated source level for a 700kJ hammer pile driving activity, and this has been adopted as representative for the 660kJ hammer (with 95% efficiency) used in this project (scaling with respect to energy results in an insignificant adjustment).

- 632 kJ Hammer: 214 dB re 1μPa^2.s @ 1 m

The piling source spectrum was extracted from SVT's database of measured pile driving and scaled to match the overall expected source level. Figure 2-2 shows the piling pulse $L_{E,p}$ source spectra used in the underwater noise model.

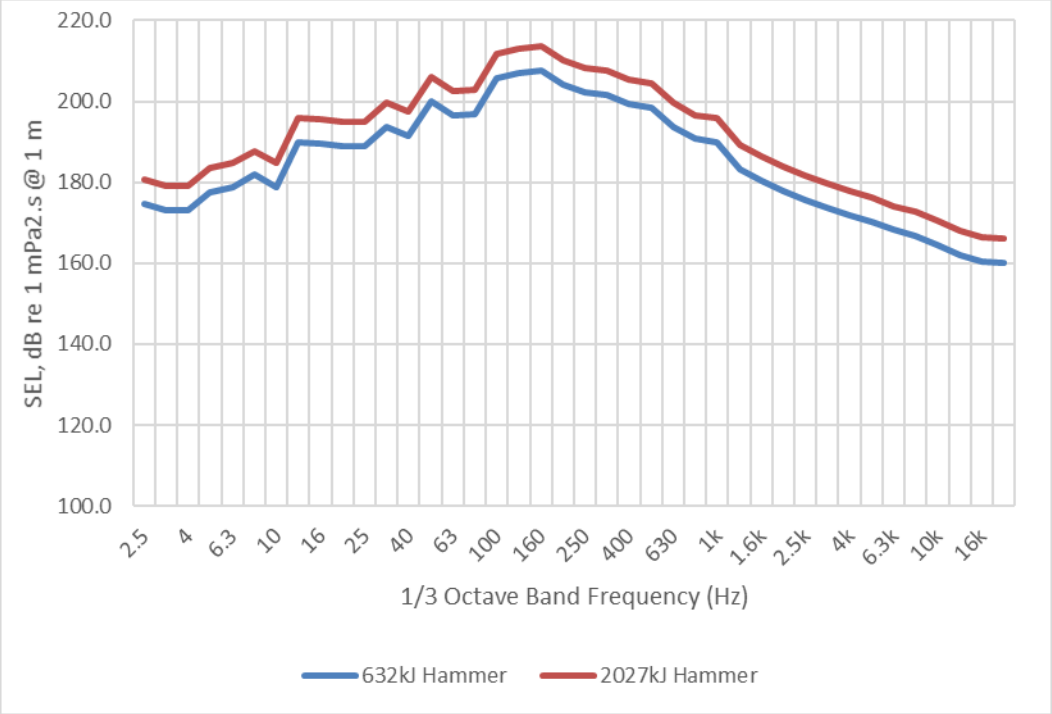


Figure 2-2 Hammer $L_{E,p}$ Source Level Spectra

2.3.6 Peak Pressure

SVT conducted an analysis of measured piling data collected during a the Ichthys project piling activities in Darwin Harbour, where both L_p and Peak noise levels were determined for each hammer strike. The data, which was collected at multiple distances and bearings from piling activity,

demonstrated a crest factor (CF) of between 15 dB and 20 dB for piling sources. Based on this data, and as a conservative assessment measure, a CF of 20 dB has been applied for the model. This CF is consistent with the data reported by CO.L.MAR discussed above.

Predicted peak pressure noise levels were calculated from the calculated sound pressure level (L_p) with range using the CF. The relationship is:

$L_{pk} = L_p + CF$.

2.3.7 Summary of Piling Source Inputs and Assumptions

The following tables summarise the key information regarding the piling sources presented in the above sections.

Table 2-2 Hammer Specifications Used in the Underwater Noise Model

Hammer Specifications	
Hammer energy	632 kJ and 2,027 kJ
Modelled number of strikes	6,530
Estimated number of strikes per day	6,530

Table 2-3 Piling scenarios used in the Underwater Noise Model

Scenario		Hammer Energy (kJ)	Source Noise Level ($L_{E,p}$ dB re 1uPa^2.s at 1m) / strike	Number of Strikes (per 24 hours)	Source Level Offset (dB)
1	Main Pile, Small Hammer	632	214	6,530	$L_{E,p}$: 38.1 L_p: 4 L_{pk}: 20
2	Main Pile, Large Hammer	2,027	220	6,530	$L_{E,p}$: 38.1 L_p: 4 L_{pk}: 20

2.4 Underwater Noise Generated by Development Drilling

2.4.1 Drilling Activity Source Levels

Offshore drilling in waters of the project depth is typically conducted by semi-submersible drilling rigs, however other drilling platforms are available. The current project concept is for the initial Crux production wells proposed to be drilled with a semi-submersible drilling rig and later completed from the Crux platform using a temporary modular platform rig (MPR). Noise is emitted by the drill string and by the vessel hull.

McCauley [3] presented measured data for the semi-submersible drill rig Ocean General under changing operational scenarios. Extrapolation of the measured data suggests a source level for the drill rig (not drilling) of 160 dB re 1uPa at 1m. McCauley also observed a 4 dB increase in noise levels

when drilling was underway. SVT has applied a 3dB safety factor (double the energy) to these levels to account for uncertainties potential differences between rigs, yielding a source level for a semi-submersible drill rig, during drilling activity, of 167 dB re 1uPa at 1m.

As drilling is a continual activity, and does not involve significant percussive elements, the peak pressure is not relevant to the assessment of noise impact. Additionally, there should be no difference between the average L_p and the $L_{E,p}$ over short periods. For drilling that occurs for 24 hours, the $L_{E,p}$ will exceed the L_p by 49.4 dB.

The drilling source levels and spectra is shown in Figure 2-3.

As part of an operational scenario, the DP of a supply boat/tender at the Crux Platform location has been modelled to conservatively represent operational noise from the facility. The drill rig has been modelled at the platform location and conservatively represents noise levels from the MPR.

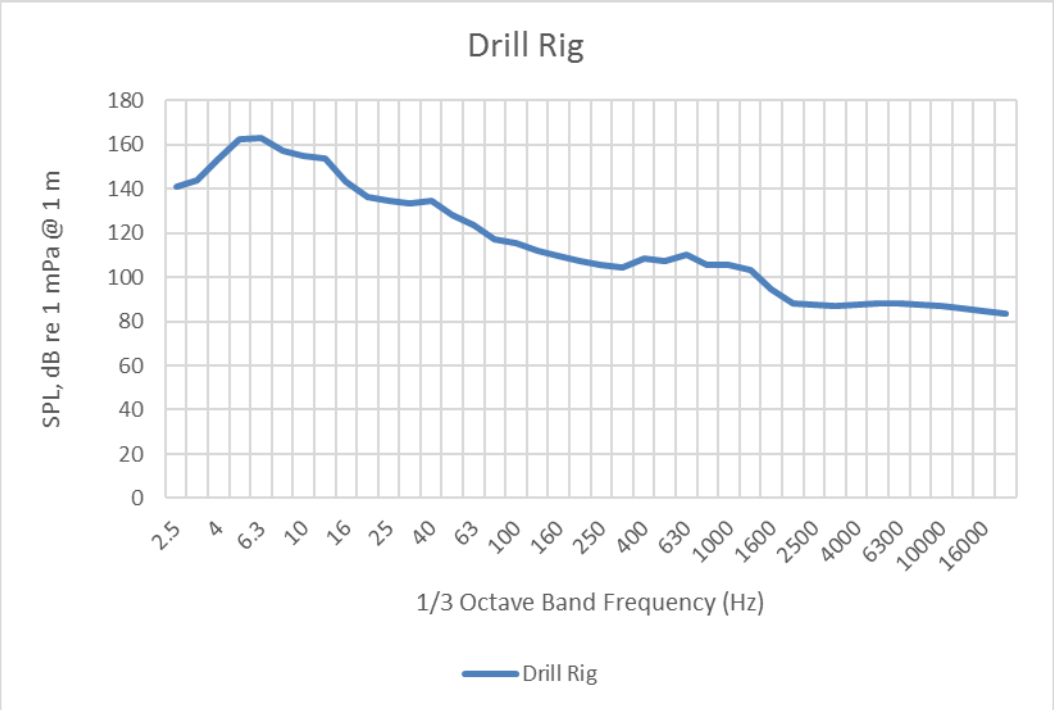


Figure 2-3 Drilling Source Spectra Used in the Underwater Noise Model

2.4.2 Summary of Drilling Source Inputs and Assumptions

Table 2-3 summarises the three drilling scenarios used in the model. This included a conservative assessment of potential drilling activity in proximity to two of the shoals that occur within the 30km radius that defines the Crux development area, outside the 1km buffer defined around these shoal features. While not part of the foundation development, the potential future tie-backs over the life of the Crux Project may define the need for future drilling activity in proximity to these shoals, and therefore have been conservatively incorporated as scenarios in this study to represent a credible worst-case location for the sound source to occur.

Table 2-4 Drilling Scenarios Used in the Underwater Noise Model

Scenario		Source location (UTM Zone 51)	Source Depth Below Surface (m)	Water Depth at Source (m)	Source Noise Level (L_p dB re 1uPa at 1m)
3	Drill Rig – in proximity to Eugene McDermott Shoal (outside 1km buffer)	674572 mE 8551496 mN	15	152	167
4	Drill Rig in proximity to Vulcan Shoal (outside 1km buffer)	635505 mE 8585910 mN	15	192	167
5	Drill Rig at Crux Platform Location	656470 mE 8566340 mN	15	168.5	167

Note: Noise emitted by temporary drilling equipment located on the Crux Platform is expected to be significantly less than that emitted by a semi-submersible rig. The use of the same source levels for this scenario also encompasses the possibility of float-over drilling rig equipment to be used.

2.4.3 Underwater Noise Generated by Vertical Seismic Profiling

VSP may be conducted during drilling activities. This involves the use of a hydrophone or geophone downhole, and the use of an airgun sound source in the water column. For downhole VSP, only one airgun is required, and therefore source levels are significantly lower than typically published for seismic survey campaigns that use arrays of airguns.

Source levels for airguns are dependent upon two critical factors: Charge pressure and charge volume, the source level being linearly proportional to charge pressure [5]. Taylor et al. [6] describe the VSP methodology used in the Offshore Drilling Program indicating an airgun volume of 300 in^3. Fewtrell et al. [7] used a single airgun with a volume of 330 in^3 and charge pressure of 1,500 psi, and stated that the source level was 192 dB re $1uPa^2s$. Typical charge pressures for airguns in the offshore industry are 2,000 psi. When scaled according to charge pressure, and rounded up to the nearest 0.5 dB the source strength for the VSP airgun is estimated at 193.5 dB re $1uPa^2s$.

Published spectra for airgun sources typically show several discrete frequencies where the source level is much lower than the adjacent frequencies – these frequencies are particular to the airgun, operating depth and observation angle, and is also influenced by the airgun array configuration. In conducting a noise prediction, based on unknown equipment, where the equipment operator has not provided specific information, a precautionary approach was taken. For this reason, a published spectrum [8] (for a single airgun) that shows a smoother frequency transition has been adopted as the source shape, and the spectrum has been shifted to match the overall source energy described above. The resulting spectrum is shown in Figure 2-4.

2.4.4 Summary of VSP Source Inputs and Assumptions

The single VSP source has been assumed to use up to 10 shots per event, with no more than one event in a day. The details of the downhole VSP source are provided in Table 2-5, and the modelled spectrum is provided in Figure 2-4.

Table 2-5 VSP Details used in the Underwater Noise Model

Item	Detail
Source Location (UTM Zone 51L)	656470 E, 8566340 N
Source Depth Below Surface (m)	15
Water Depth at Source (m)	168.5
Source Noise Level ($L_{E,p}$ dB re 1uPa^2.s at 1m)	193.5
Source Level Offset (dB)	L_{pk}: 20 L_p: 7 $L_{E,p}$: 10

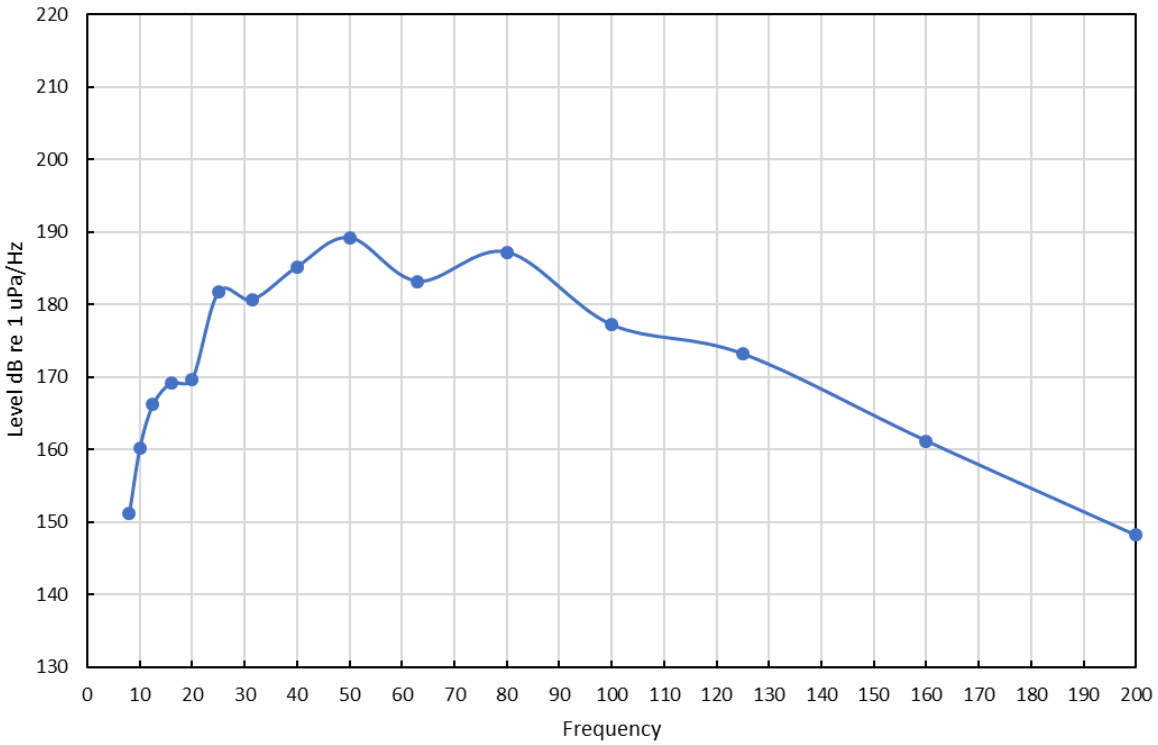


Figure 2-4 VSP Source Spectrum Used in the Underwater Noise Model

2.4.5 Other Noise Sources During Drilling

Other sources of noise are also present during pipelay and drilling activity – for example: underwater remote equipment uses sound for communication; sonar is used for depth finding; and, side-scan sonar is used for imaging equipment and the seafloor. This equipment operates at high frequencies (in the range 20 kHz to 90 kHz) and the attenuation rate will be significantly higher than the attenuation rate for the sources assessed. These sources are not expected to generate noise levels that will lead to an exceedance of the assessment criteria, and therefore do not feature as a key focus of this noise study.

2.5 Operational Noise

Noise emitted by the normal operation of the Platform is expected to be significantly less than from the drilling and construction activities. The coupling surface between the steel supports of the jacketed platform structure and the water is significantly less than that of the drill rig. As a NNM facility, normally operating mechanical equipment on the Crux platform is also expected to be minimal. The facility will occasionally require scheduled maintenance intervention, and during these times it is reasonable to expect the presence of a supply boat or tender. When operating close to facilities supply boats often maintain their position through dynamic positioning (DP), using bow and stern thrusters. Cavitation from the thruster propellers while in DP mode can be a significant source of underwater noise, the source will cycle on-off, and is not present for a majority of the time. McCauley [3] presented measured data for two tenders, which when extrapolated to 1m suggest source levels of 171 dB re1uPa at 1m and 183 dB re1uPa at 1m. The tender noise has been modelled at the higher of these two values. The octave band spectral contribution of the tender is as provided in Figure 2-5.

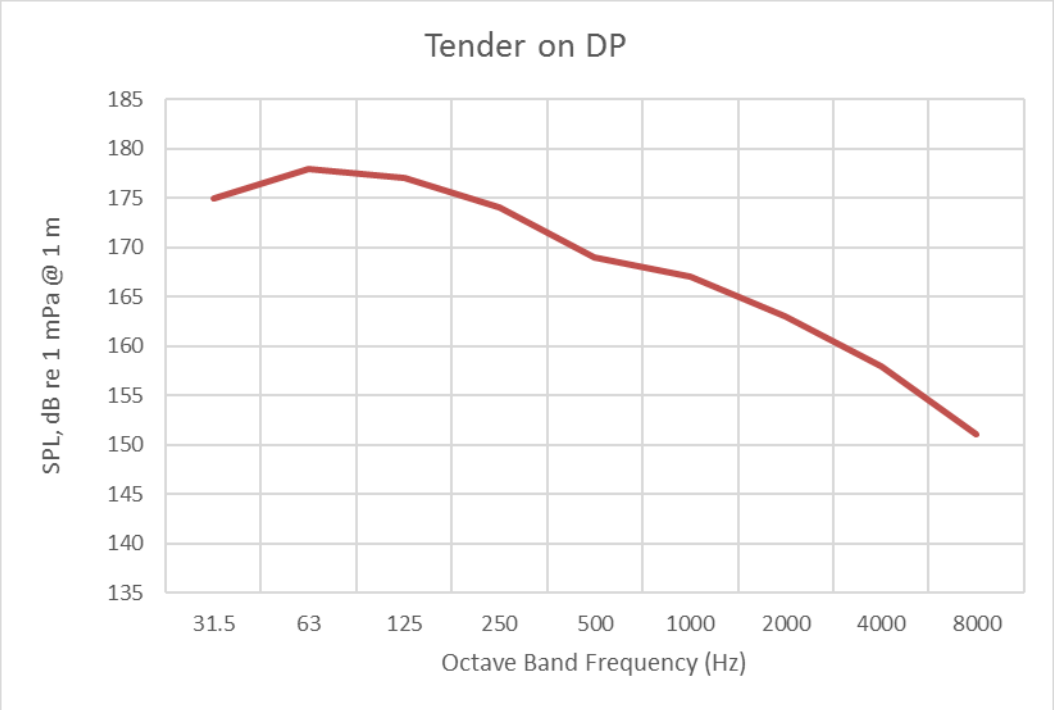


Figure 2-5 Modelled Spectrum of Supply boat / Tender on DP

2.6 Environmental Inputs

2.6.1 Important Environmental Factors

The propagation of noise through the water is dependent upon a number of environmental factors. The depth of the water limits the lowest frequency of noise that can propagate, the deeper the water the lower the cut-off frequency. Because of this, propagated noise levels may be higher in deeper water for the same source. This factor is important when conducting underwater noise assessments in shallow water, near shore, or, estuarine locations.

Temperature and salinity changes also affect the propagation of noise in water, causing refraction changes which may result in channelling of noise in the water column and also affect the reflection from the seabed. It is noted that due to the shallow depths, the Sound Speed Profile (SSP) behaves closely to pure isothermal conditions.

The type of seabed affects the fraction of noise that is reflected and transmitted at the water / sea bed boundary. This is dependent upon the impedance miss-match between the water and the seabed, and the acoustic impedance is primarily characterised by the speed of sound in the seabed. The ability of the sea bed to support compression and shear waves also influences the propagation of noise, and the transmission of noise from the sea bed into the water column.

This data, typically drawn from published research that lists sound speed and attenuation rates for various ground types, is input into the model as an attenuation rate for compression and shear wave types.

2.6.2 Model Environmental Data

The following environmental conditions were entered into the model:

Depth

The bathymetry of the project region and surrounds has been provided by Shell in the form of constant elevation lines, with depth increments of 10m. These depths ranged from 20m to 230m, with an average resolution (point to point distance) of 165m.

Tide Levels

Based on 12 months of concatenated tidal measurements recorded at the Crux location as part of the Crux baseline studies program, 18.6 years of tide heights are predicted. Analysis of these predictions indicates a Highest Astronomical Tide (HAT) of 2.81m. Therefore, a tide of 2.81m was modelled as representative of high tide conditions which are worst case for underwater noise propagation.

Seabed Types

The data from the baseline geotechnical survey undertaken as part of the Crux baseline studies program, was used to inform the derivation of seabed type, which influences the sound speed, density and attenuation rate for the seabed. The data [9] demonstrates that the seabed in the Crux development area is predominantly silt and fine sand. The geo-acoustic properties of the ground type used in the model are shown in Table 2-6[8], where sand was used to represent the ground type.

The reduced speed of sound for the bottom results in increased absorption of sound in the model, reducing the range at which adverse effects can be predicted.

[8] Note: the model uses the geo-acoustic properties to determine the attenuation and reflectivity of the waves as they travel through the seabed.

Table 2-6 Seabed Geo-Acoustic Properties

Seabed Type	Sound Speed	Density	Sound Attenuation
Sand [14]	1,650 m/s	1.9 g/cm^3	0.8 dB/m/kHz (Compressional) 2.5 dB/m/kHz (Shear)

Sound Speed Profile

The water depth in the modelling area is relatively shallow with no significant temperature gradients. Additionally, the salinity is expected to be relatively homogenous throughout the water column. The average monthly underwater sound speed profile (SSP) has been calculated based upon the monthly temperature and density data measured within the Crux development area, as presented in Figure 2-6.

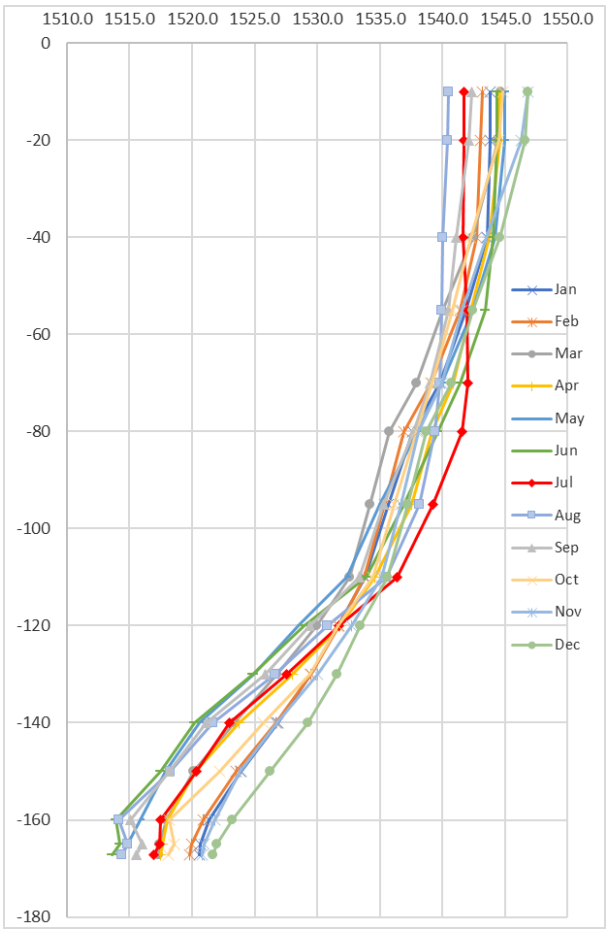


Figure 2-6 Monthly Average Sound Speed Profiles (July in Red)

Preliminary modelling was conducted to identify the conditions that could be considered representative worst-case. Analysis of modelled propagation loss for each monthly average SSP shows that at shallower water depths above 100m, the month of July can be considered the worst-case for sound propagation. The mean sound speed profile for the month of July has therefore been adopted in the model for all scenarios to provide for a conservative assessment.

Figure 2-7 shows a vertical transect of the sound propagation for the large (2,027 kJ) hammer, using the July mean SSP, with the source at the Crux NNM Platform and propagation due south (i.e. transect shown looking east). Based on this (and an examination of transects in other directions) an analysis depth of 50m has been chosen as representative of the worst-case.

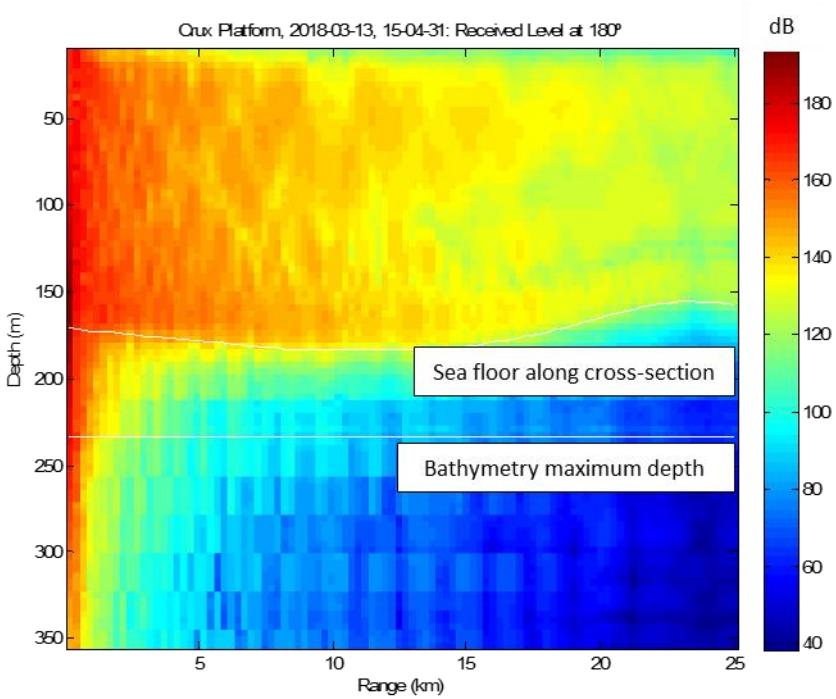


Figure 2-7 Vertical cross-section of Large Hammer Propagation, Travelling South

Model Resolution

For each noise source, additional parameters were used to generate the model results as summarised in Table 2-7.

Table 2-7 Model resolution

Noise Source	Maximum Range (km)	Angle Resolution (degrees)	Frequencies Modelled (Hz)
Piling	40	2	1/3 Octaves, 20 Hz to 4 kHz
Drilling	25	2	1/1 Octaves, 31.5 Hz to 4 kHz
VSP	25	2	1/1 Octaves, 31.5 Hz to 4 kHz

3. MARINE FAUNA ASSESSMENT CRITERIA

For the purpose of this noise assessment, the primary sensitive marine fauna that may occur, or have suitable habitat, in the Crux development area include:

- Marine Mammals;
- Marine Turtles;
- Sea Snakes;
- Fish;
- Elasmobranchs (sharks and rays); and
- Invertebrates.

The following sensitive marine fauna habitats are identified to occur in the vicinity of the Crux development area:

- Whale shark foraging area – a biologically important foraging area is recognised in open waters off the Northern WA coast, inclusive of the marine environment that overlaps the Crux development area. Due to their widespread distribution and highly migratory nature, whale sharks may occur in low numbers within the Crux development area;
- Marine turtle offshore biologically important foraging areas[9] - for flatback, green, loggerhead and olive ridley turtles (ranging from approximately 160km to 200km from the Crux NNM platform);
- Habitat critical to the survival of green turtles (nesting area) – Ashmore Reef (140km from the Crux NNM platform), Cartier Island (85km from the Crux NNM platform), and Browse Island (140km from the Crux NNM platform)[9];
- Pygmy blue whale migration corridor (approximately 121km from the Crux NNM platform at its nearest point);
- Humpback whale breeding and calving area (approximately 180km from the Crux NNM platform at its nearest point);
- Australian snubfin dolphin foraging and breeding areas (approximately 164km from the Crux NNM platform at its nearest point); and
- Indo-pacific humpback dolphin foraging areas (approximately 164km from the Crux NNM platform at its nearest point).

It should be noted that the list of relevant species has been informed by a search of the *Environment Protection and Biodiversity Conservation Act 1999* Protected Matters database and has been used as a guide only. This list is not considered exhaustive. Consideration has been given to the potential for high frequency cetacean species (pygmy sperm whale and dwarf sperm whale) to occur in the project area. A review of species distribution information was conducted and found that their distribution is

[9] Biologically important

typically in oceanic waters beyond the edge of the continental shelf. While they may occur in the broad marine environment, their occurrence in the project area in significant numbers is not expected.

Table 3-1 and Figure 3-1 summarises the significant geographical areas of interest in or near the Crux development area.

Table 3-1 Geographical Areas of Interest

Geographical Area	
Shoals	Vulcan Shoal Eugene McDermott Shoal Barracouta Shoal Heywood Shoal Echuca Shoal Goeree Shoal
Offshore reefs	Ashmore Reef Hibernia Reef
Islands	Cartier Island
Marine Parks	Kimberley Ashmore Reef Cartier Island

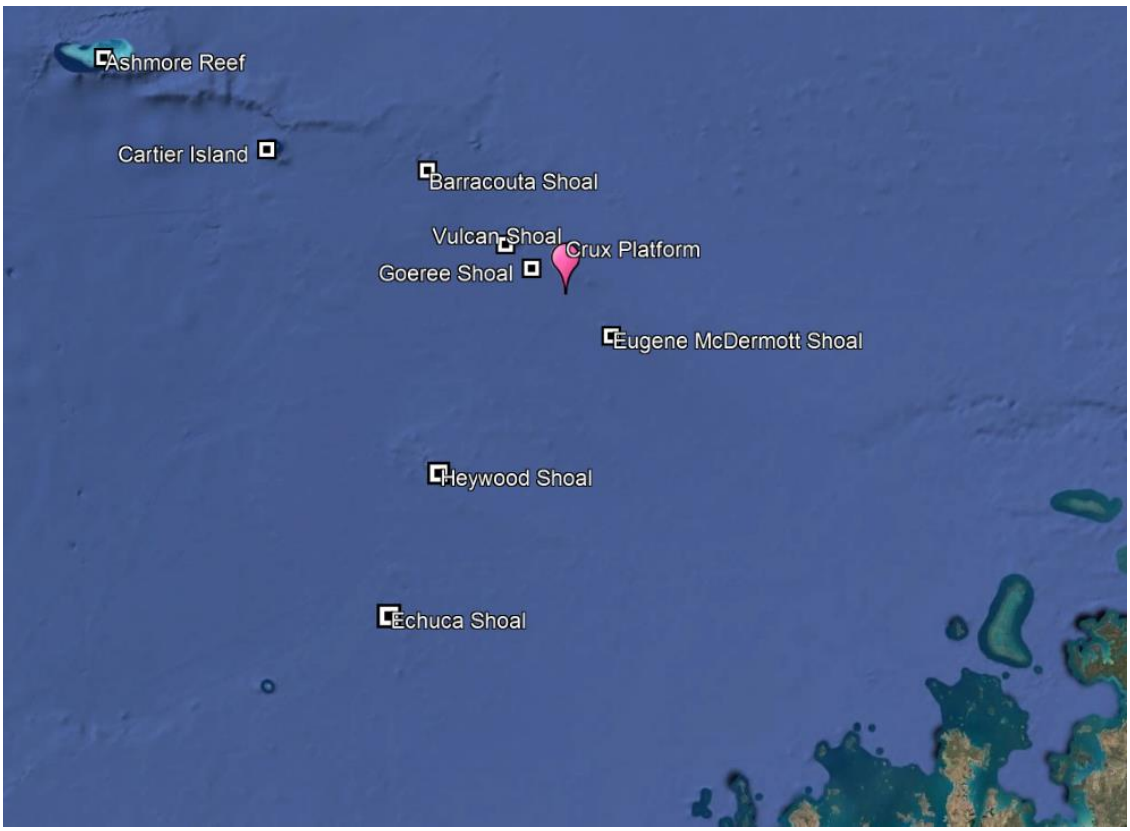


Figure 3-1 Geographical Areas of Interest Surrounding the Crux Development Area

3.1 Fish and Sea Turtles

Criteria for fish, larvae and sea turtles are defined in terms of L_p, $L_{E,p}$ and L_{pk} noise levels. The fish criteria are separated between fish with or without swim bladders, as the gas filled space increases the fish vulnerability to the changes in sound pressure. Fish eggs and larvae have been separated due to their vulnerability, reduced mobility and small size.

The physiology of turtle hatchling is different from fish. However, the air-filled cavities such as lungs of turtle hatchlings and swim bladders of fish have been found to be most susceptible to physical injury from impulsive waves such as a pile driving signal. Therefore, it is reasonable to correlate physical injury criteria for turtle hatchlings with that for fish. Due to the lack of scientific data availability, turtle hatchlings will be evaluated using both $L_{E,p}$ and L_{pk} for fish.

The criteria presented are in terms of sound pressure. Fish may also have a lateral line system which detect relative motion (displacement) between the body and the surrounding water. Popper et al. 2014 [10] states that "*relative motion only takes place very close to sound sources where there is a steep gradient of sound pressure and particle motion (Denton and Gray 1982, 1993; Kalmijn 1988). As a consequence, the operational range of the lateral line is usually restricted to no more than one or two body lengths away from the source." The guideline goes on to state "There have been no demonstrations to date of damage to lateral line systems as a result of exposure to intense man-made sounds or other signals (Hastings et al. 1996), although it is conceivable that damage may occur."* Hence as there is no evidence of impact at distance, and only very remote potential for such animals to be within a range where potential detection may occur (several body lengths), no criteria in terms of particle displacement have been presented.

3.1.1 Fish and Sea Turtles – Pile Driving Noise

Criteria for piling noise have been drawn from the Sound Exposure Guidelines for Fishes and Sea Turtles (Popper et al. 2014) [10]. The criteria are presented in Table 3-2 below.

Table 3-2 Fish, Larvae and Sea Turtle Noise Criteria for Pile Driving

Type of Animal	Mortality and Potential Mortal Injury	Impairment			Behaviour
		Recoverable Injury	TTS	Masking	
Fish: No swim bladder (particle motion detection)	> 219 dB $L_{E,p}$ or > 213 dB L_{pk}	> 216 dB $L_{E,p}$ or > 213 dB L_{pk}	> 186 dB $L_{E,p}$	(N) Moderate (I) Low (F) Low	(N) High (I) Moderate (F) Low
Fish: Swim bladder is not involved in hearing (particle motion detection)	210 dB $L_{E,p}$ or > 207 dB L_{pk}	203 dB $L_{E,p}$ or > 207 dB L_{pk}	> 186 dB $L_{E,p}$	(N) Moderate (I) Low (F) Low	(N) High (I) Moderate (F) Low
Fish: Swim bladder involved in hearing (primarily pressure detection)	207 dB $L_{E,p}$ or > 207 dB L_{pk}	203 dB $L_{E,p}$ or > 207 dB L_{pk}	186 dB $L_{E,p}$	(N) High (I) High (F) Moderate	(N) High (I) High (F) Moderate

Type of Animal	Mortality and Potential Mortal Injury	Impairment			Behaviour
		Recoverable Injury	TTS	Masking	
Eggs and larvae	210 dB $L_{E,p}$ or > 207 dB L_{pk}	(N) Moderate (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) Moderate (I) Low (F) Low
Sea turtles	>210 dB $L_{E,p}$ or >207 dB L_{pk}	(N) High (I) Low (F) Low	(N) High (I) Low (F) Low	(N) High (I) Moderate (F) Low	(N) High (I) Moderate (F) Low

Note: Where insufficient data existed to recommend objective guidelines, a subjective approach is adopted in which the relative risk (High, Moderate, Low) of an effect is placed in order of rank at three distances from the source – Near (N), Intermediate (I), and Far (F) (top to bottom within each cell of the table, respectively).
"Near" might be considered to be in the tens of metres from the source, "intermediate" in the hundreds of metres, and "far" in the thousands of meters.

Source: Popper et al. 2014 [10]

3.1.2 Fish, Larvae and Sea Turtles – VSP

The Sound Exposure Guidelines for Fishes and Sea Turtles [10] also provide criteria for exposure to seismic airguns. The criteria are presented in Table 3-3 below, and conservatively assumed to be applied for this assessment, although noting that downhole VSP generates a significantly smaller noise profile than wide array seismic activities.

Two trials [11] conducted on the response of a green and loggerhead turtle to impulsive signals (air-gun) showed that at L_p of 175 dB re 1 µPa the turtle behaviour became more erratic, which was presumed to be an avoidance response. A L_p of 175 dB re 1 µPa is equivalent to a $L_{E,p}$ of 164 dB re 1µPa^2.s, where it is assumed that a pulse length of 90ms was used during the experiment.

Table 3-3 Fish, Larvae and Sea Turtle Noise Criteria for VSP

Type of Animal	Mortality and Potential Mortal Injury	Impairment			Behaviour
		Recoverable Injury	TTS	Masking	
Fish: No swim bladder (particle motion detection)	> 219 dB $L_{E,p}$ or > 213 dB L_{pk}	> 216 dB $L_{E,p}$ or > 213 dB L_{pk}	> 186 dB $L_{E,p}$	(N) Low (I) Low (F) Low	(N) High (I) Moderate (F) Low
Fish: Swim bladder is not involved in hearing (particle motion detection)	210 dB $L_{E,p}$ or > 207 dB L_{pk}	203 dB $L_{E,p}$ or > 207 dB L_{pk}	> 186 dB $L_{E,p}$	(N) Low (I) Low (F) Low	(N) High (I) Moderate (F) Low
Fish: Swim bladder involved in hearing (primarily pressure detection)	207 dB $L_{E,p}$ or > 207 dB L_{pk}	203 dB $L_{E,p}$ or > 207 dB L_{pk}	186 dB $L_{E,p}$	(N) Low (I) Low (F) Moderate	(N) High (I) High (F) Moderate
Eggs and larvae	210 dB $L_{E,p}$ or > 207 dB L_{pk}	(N) High (I) Low (F) Low	(N) High (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) High (I) Moderate (F) Low

Type of Animal	Mortality and Potential Mortal Injury	Impairment			Behaviour
		Recoverable Injury	TTS	Masking	
Sea turtles	>210 dB $L_{E,p}$ or >207 dB L_{pk}	(N) Moderate (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) Low (I) Low (F) Low	175 dB L_p 164 dB $L_{E,p}$ [11]

Note: Where insufficient data existed to recommend objective guidelines, a subjective approach is adopted in which the relative risk (High, Moderate, Low) of an effect is placed in order of rank at three distances from the source – Near (N), Intermediate (I), and Far (F) (top to bottom within each cell of the table, respectively).
"Near" might be considered to be in the tens of metres from the source, "intermediate" in the hundreds of metres, and "far" in the thousands of metres.

Source: Popper et al. 2014 [10]

3.1.3 Fish, Larvae and Sea Turtles – Continuous Noise Sources

The Sound Exposure Guidelines for Fishes and Sea Turtles [10] also provide criteria for exposure to shipping and other continuous sources (e.g. drilling). The criteria are presented in Table 3-4 below.

Table 3-4 Fish, Larvae and Sea Turtle Noise Criteria for Shipping and Continuous Sounds

Type of Animal	Mortality and Potential Mortal Injury	Impairment			Behaviour
		Recoverable Injury	TTS	Masking	
Fish: No swim bladder (particle motion detection)	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) High (I) High (F) Moderate	(N) Moderate (I) Moderate (F) Low
Fish: Swim bladder is not involved in hearing (particle motion detection)	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) High (I) High (F) Moderate	(N) Moderate (I) Moderate (F) Low
Fish: Swim bladder involved in hearing (primarily pressure detection)	(N) Low (I) Low (F) Low	170 dB L_p for 48 h	158 dB L_p for 12 h	(N) High (I) High (F) High	(N) High (I) Moderate (F) Low
Eggs and larvae	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) High (I) High (F) Moderate	(N) High (I) Moderate (F) Low
Sea turtles	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) High (I) Moderate (F) Low	(N) Moderate (I) Moderate (F) Low

Note: Where insufficient data existed to recommend objective guidelines, a subjective approach is adopted in which the relative risk (High, Moderate, Low) of an effect is placed in order of rank at three distances from the source – Near (N), Intermediate (I), and Far (F) (top to bottom within each cell of the table, respectively).
"Near" might be considered to be in the tens of metres from the source, "intermediate" in the hundreds of metres, and "far" in the thousands of metres.

Source: Popper et al. 2014 [10]

The criteria for turtles, fish eggs and larvae, and the values in the table were derived from studies on fish.

3.2 Mammals

3.2.1 Criteria for Marine Mammals

Recent publications cited by NOPSEMA [12] have been considered in selection of marine mammal noise assessment criteria. Finneran [13] suggests that temporary and permanent threshold shifts for marine mammals should include independent criteria for both $L_{E,p}$ and L_{pk} levels. When considering behavioural disturbance thresholds for marine mammals, literature [14] generally specifies criteria in the form of $L_{E,p}$ and/or L_p. Technical guidance [15] highlights that the sensitivity of hearing differs between cetacean species, which should be considered when determining assessment criteria.

Assessment criteria for marine mammals has been drawn from the National Oceanic and Atmospheric Administration (NOAA), Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing [17]. The criteria are presented for impulsive sources (e.g. pile driving) and non-impulsive sources (e.g. drilling and vessel noise). Cumulative energy exposure criteria include the use of a weighting function, to account for the different hearing frequency ranges for marine mammals.

In the NOAA guidelines [17], cetaceans (mammals) are divided into three groups based on their hearing dominant auditory function – Low-frequency weighted cetacean (Mlf); Mid-frequency weighted cetacean (Mmf) and High-frequency weighted cetacean (Mhf). For this study Mlf and Mmf criteria and weightings are of particular relevance, based on the key marine mammal species known to occur in the marine environment in the vicinity of the Crux development area. The relevant species and respective hearing group are summarised in Table 3-5 below.

Table 3-5 Cetacean Frequency Weightings

Mammal Hearing Group	Relevant Species
Low-frequency weighted cetacean (Mlf)	Pygmy Blue Whale Humpback Whale
Mid-frequency weighted cetacean (Mmf)	Australian Snubfin Dolphin Indo-Pacific Humpback Dolphin

A chart of the frequency weightings is shown in Appendix B-5.

NOAA, in their Interim Sound Threshold Guidance for Marine Mammals [18], presented proposed behavioural response criteria for marine mammals, which were subsequently omitted in response to comments from peer reviewers from the final document when published in 2016. However, in the intervening period these suggested limits were re-published in the South Australian Underwater Piling Noise Guidelines [19]. The values can also still be found on NOAA's website.

The criteria adopted for Temporary Threshold Shift (TTS) and Permanent Threshold Shift (PTS) of hearing sensitivity in the South Australian Guidelines are less conservative than that of the NOAA Guidance, therefore they have not been considered in this study.

The NOAA guidelines provide $L_{E,p}$ and L_{pk} noise levels at which TTS and PTS may occur (at a more conservative level than South Australian guidelines) for low, mid and high frequency cetaceans. These are summarised in Table 3-6.

Table 3-6 Mammal Sound Exposure Criteria

Type of Animal	PTS - Permanent Injury [17]		TTS - Impairment [17]		Behaviour [18],[19]	
	Impulsive	Non-Impulsive	Impulsive	Non-Impulsive	Impulsive	Non-Impulsive
Low-frequency cetaceans	219 dB L_{pk} 183 dB $L_{E,p}$	199 dB $L_{E,p}$	213 dB L_{pk} 168 dB $L_{E,p}$	179 dB $L_{E,p}$	160 dB L_p	120 dB L_p
Mid-frequency cetaceans	230 dB L_{pk} 185 dB $L_{E,p}$	198 dB $L_{E,p}$	224 dB L_{pk} 170 dB $L_{E,p}$	178 dB $L_{E,p}$	160 dB L_p	120 dB L_p
High-frequency cetaceans	202 dB L_{pk} 155 dB $L_{E,p}$	173 dB $L_{E,p}$	196 dB L_{pk} 140 dB $L_{E,p}$	153 dB $L_{E,p}$	160 dB L_p	120 dB L_p

The South Australian guideline for underwater piling recommends management measures with defined observation and shutdown zones, based on the predicted $L_{E,p}$ (1 strike) at distances of either 100m or 300m. The basis for the distances is the estimation that a received single strike $L_{E,p}$ of 150 dB re 1 µPa^2.s will cumulate to the TTS limit of 183 dB (Mmf) re 1 µPa^2.s over a period of 30 minutes. The guideline is summarised in Table 3-7 for cetaceans. The modelling for this project (as shall be demonstrated later) demonstrates a L_p (which is similar to single strike $L_{E,p}$) greater than 150 dB at 300m and, therefore, the criteria in the third line of the table (shown in bold) is applicable.

Table 3-7 Summary of Safety Zones for Impact Piling

Species	Noise Exposure Threshold SEL in dB(M) re 1 µ Pa2.s	Observation Zone	Shut Down Zone	Zone of Behavioural Response
Low/Mid/High-frequency cetaceans	≤150 dB (M_{mf}/ MI_f/ Mh_f) at 100m	1 km	100 m	≤ 150 m
	≤150 dB (M_{mf}/ MI_f/ Mh_f) at 300m	1.5 km	300 m	≤ 500 m
	>150 dB (M_{mf}/ MI_f/ Mh_f) **at 300m**	**2 km**	**1 km**	**≤ 3 km**

3.3 Other Marine Fauna

3.3.1 Elasmobranchs (Sharks and Rays)

Fish species that lack a gas filled cavity, including elasmobranchs, are less vulnerable to changes in sound pressure. Therefore, whale sharks that reside (and other shark/ray species that may occur) in the surrounding area can be considered as fish without a swim bladder and can be assessed as per the criteria outlined earlier in Section 3.1.

3.3.2 Sea Snakes

SVT is not aware of any published studies or guidelines on the potential for anthropogenic noise to cause injury or disturbance to sea snakes. General information on snakes suggests that their hearing is poor and that therefore the sense of vibration the skull and associated inner ear is the more significant vector. Therefore, use of the criteria presented for fish (with no swim bladder) as per Section 3.1 is expected to be a conservative approach.

3.3.3 Invertebrates

Chan et al. [23] has shown that exposure to increased anthropogenic noise can mask the approach of predators, making invertebrate fauna such as crabs more vulnerable to predation. Wale et al. [24] showed that signs of increased oxygen consumption in crabs with exposure to anthropogenic noise indicating increased metabolic rate, and postulated that if greater energy expenditure is not matched by an increased uptake of food, decreased growth and survival may result. The same study, however, suggests the potential for habituation to the noise. In each study the noise source used was representative of general shipping, and not impulsive noise such as that generated by pile driving or seismic surveys. Several studies [25] suggest that crabs and other crustacea may use underwater sound to orient to the shore where they can settle. Stanley et al. [26] found that ambient underwater sound is likely to be an important settlement cue for the megalopae of many crab species. This may suggest that levels of continuous anthropogenic noise of sufficient magnitude to mask the 'natural' background underwater sound may result in reduction of adult crustacea recruitment into fisheries.

Day et al. [27] studied the effect of seismic noise on scallops and lobsters, finding that lobsters and scallops showed no mortality from exposure. In lobsters a reflexive response was shown and the ability to right was shown to be compromised, which was statistically correlated with damage to the statocyst sensory hairs. Additionally, the study noted that lobsters sourced from a site subject to high levels of anthropogenic aquatic noise showed substantial damage to the statocyst prior to the experiment. For scallops the study showed physiological effects described as substantial disruptions in the biochemistry of the haemolymph, and behavioural changes such as a reduction of classic behaviours and a novel velar flinch during exposure. The study used an airgun source with cumulative $L_{E,p}$'s between 190 and 200 dB re 1 µPa2·s.

Richardson et al. [29], in response to McCauley et al. [30] found substantial impacts of seismic activity on zooplankton populations within the Northwest Shelf Bioregion, with a decline in population reaching up to 22%, limited to the area of the seismic activity and within 15km; these impacts were barely discernible within 150 km of the survey area, were not discernible at the largest scale of the Northwest Shelf Bioregion. Zooplankton populations recovered quickly after seismic exposure due to their fast growth rates and the dispersal and mixing of zooplankton from both inside and outside of the area. It is noted that this is in the context of wide array seismic survey activity, which is a significantly different context to the localised downhole VSP activities which are the subject of this assessment.

No studies however have progressed to providing suggested quantitative noise exposure limitations for invertebrates. There is currently insufficient basis for the setting of interim quantitative impact assessment criteria, however qualitative criteria based on relative risk, such as those adopted by Popper et al. may be appropriate, as summarised in Table 3-8.

SVT is not aware of any published studies or guidelines on the potential invertebrate response to non-impulsive/continuous noise sources (e.g. drilling).

Table 3-8 Suggested Invertebrate Sound Exposure Assessment Criteria for Impulsive Sources

Type of Animal	Mortality and Potential Mortal Injury	Impairment Recoverable Injury	Behaviour
Invertebrates	(N) Moderate (I) Low (F) Low	(N) High (I) Low (F) Low	(N) High (I) Moderate (F) Low

4. NOISE PROPAGATION PLOTS

The following pages provide noise contour (isopleth) maps generated for each assessed scenario and each assessed noise index. These include:

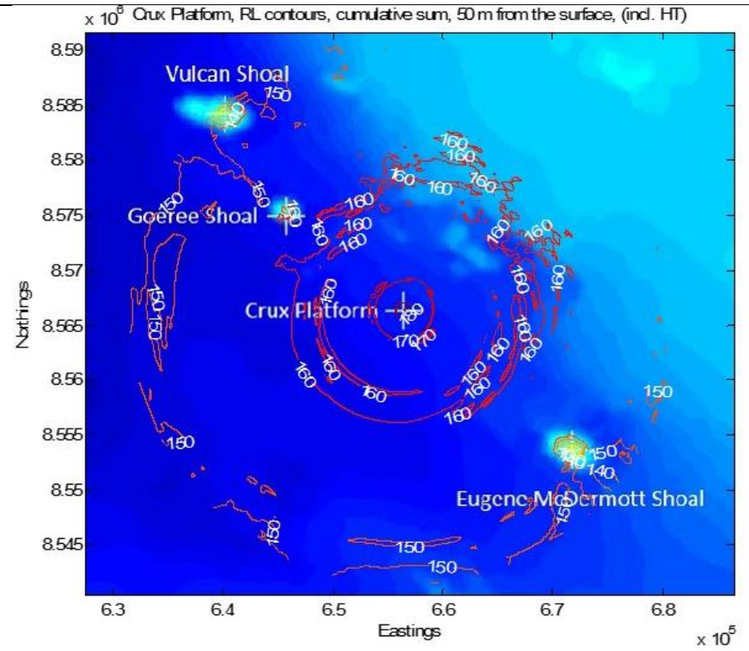
- L_{pk},
- Unweighted L_p;
- Marine Mammal weighted L_p;
- Unweighted $L_{E,p}$;
- Marine Mammal weighted $L_{E,p}$;

Adjacent to each contour plot is a plot of level with range is provided for a representative worst-case direction. On these Level-Range plots, the criteria relevant to the that particular noise index are also plotted for ease of reference.

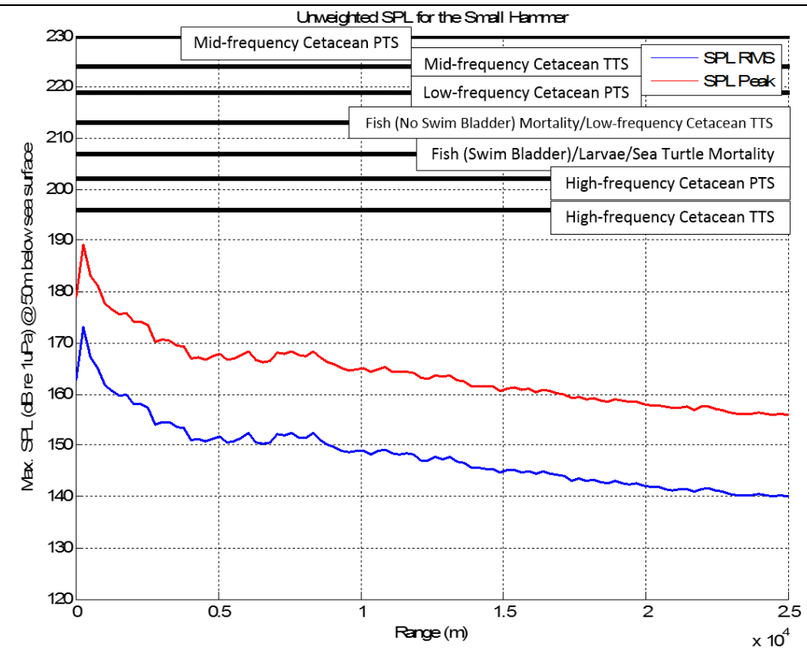
4.1 Pile Driving

4.1.1 Noise Propagation Plots for Small Hammer Pile Driving

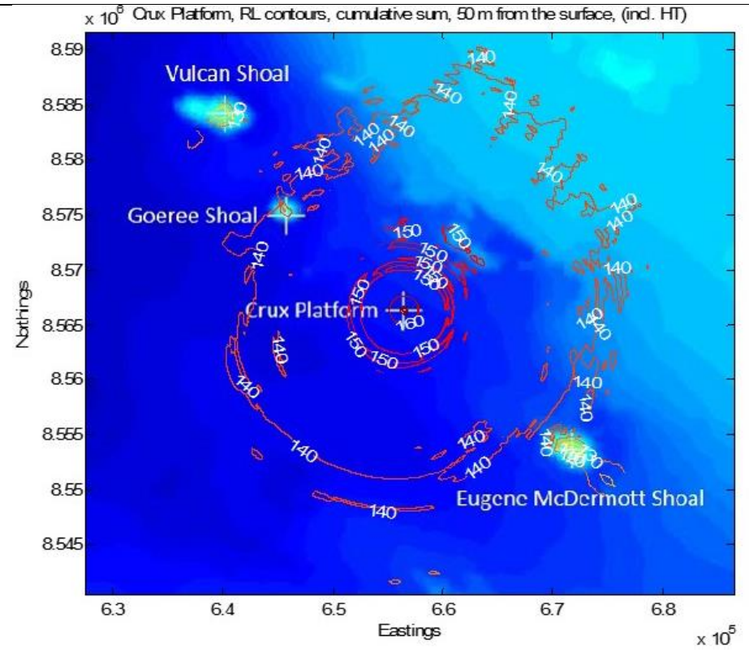
The following pages provide the noise results charts for the small hammer pile driving scenarios.



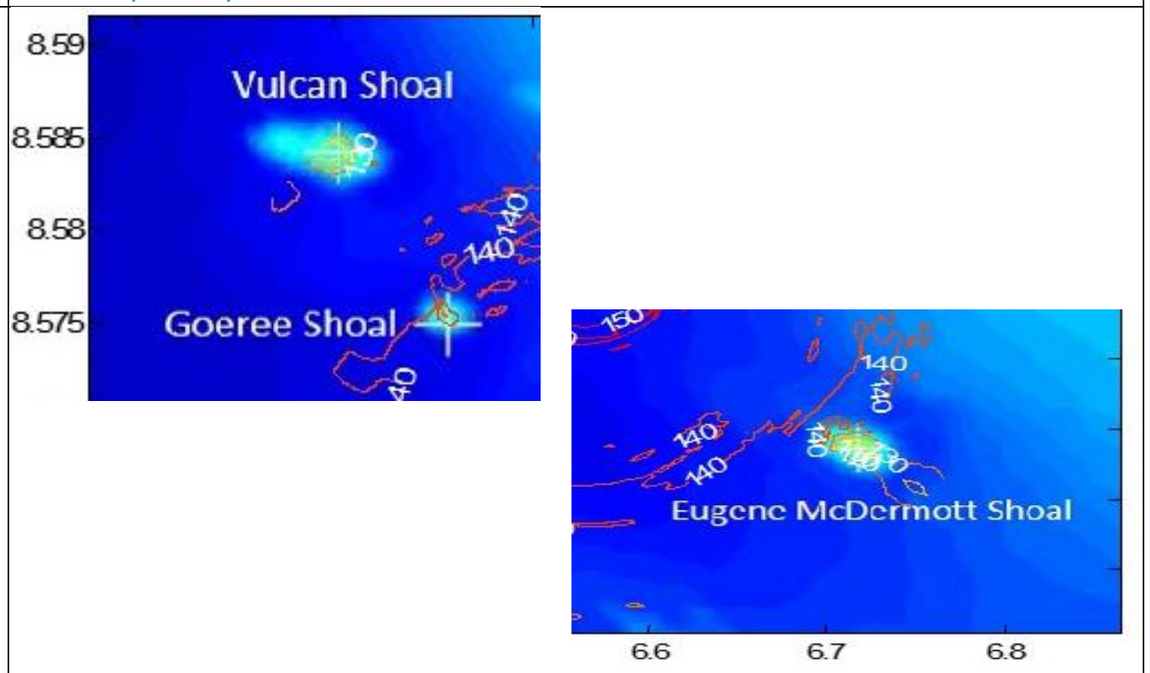
A: Contour Showing L_{pk} for Small Hammer Piling



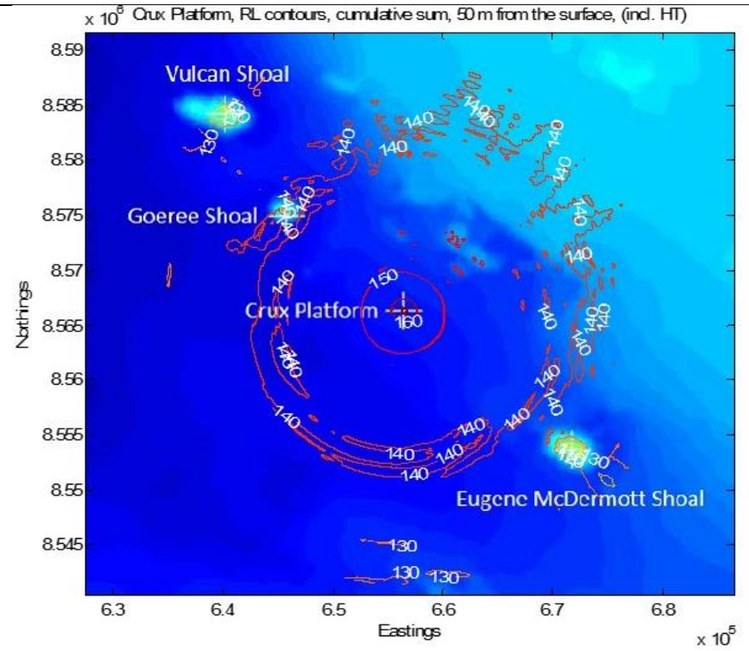
B: Maximum L_p dB and L_{pk} dB Range for Small Hammer Piling



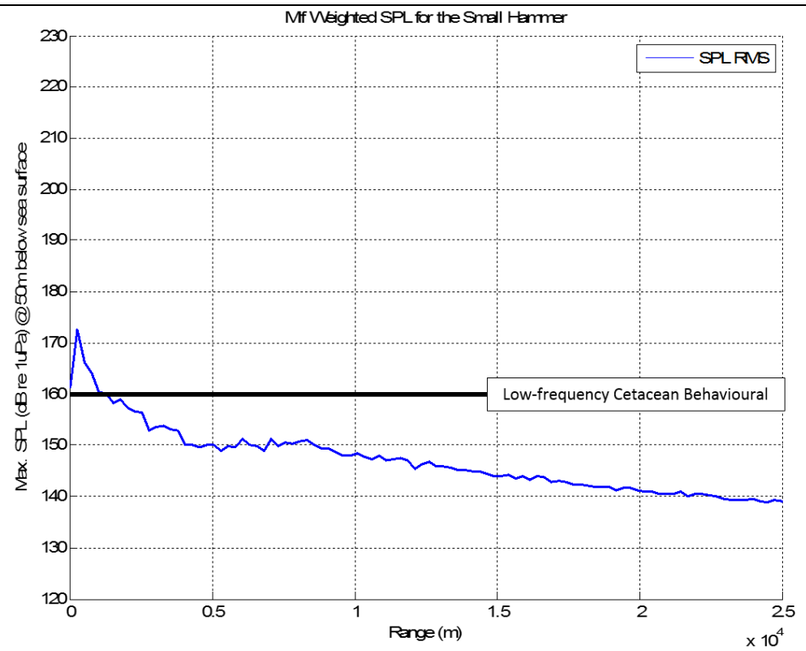
C: Noise Contour Showing Unweighted L_p for Small Hammer Piling



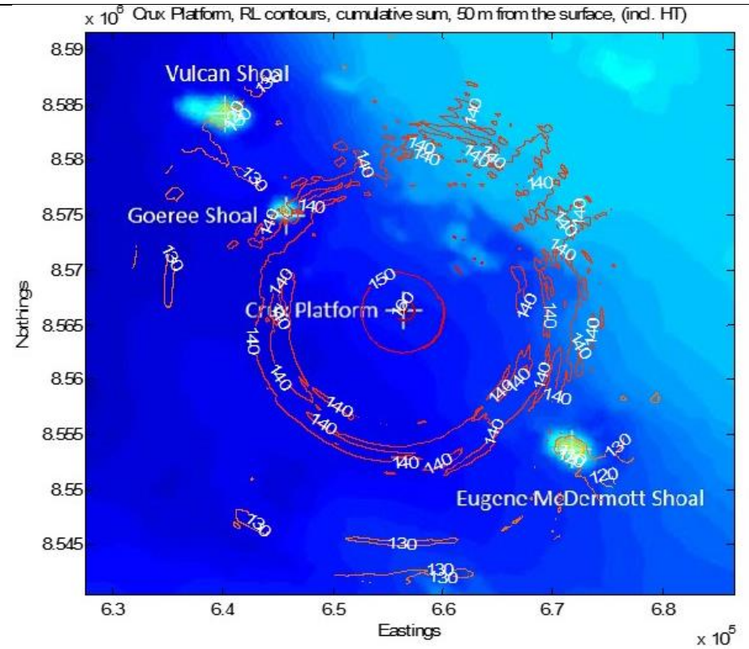
D: Zoomed Noise Contours of L_{pk} for Small Hammer Piling



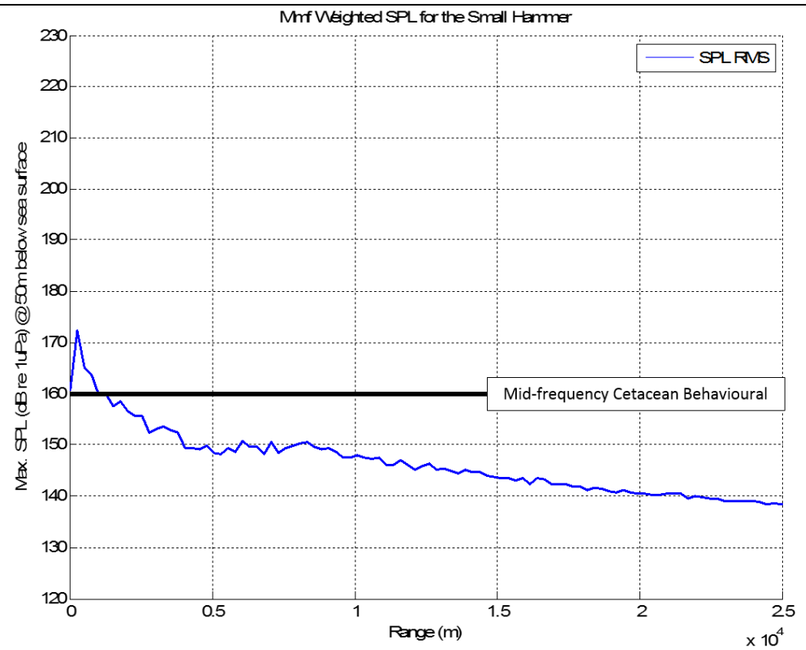
E: Noise Contour showing Mlf Weighted L_p for Small Hammer Piling



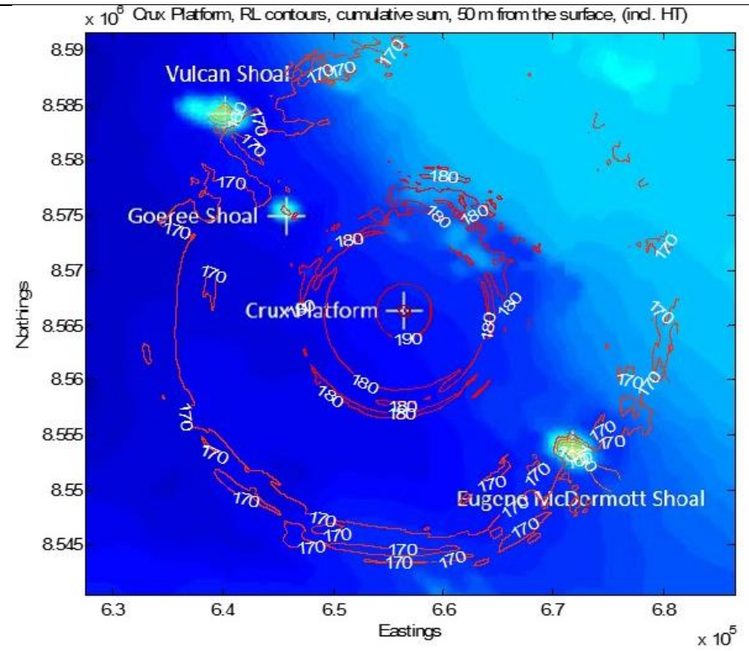
F: Maximum Mlf Weighted L_p versus Range for Small Hammer Piling



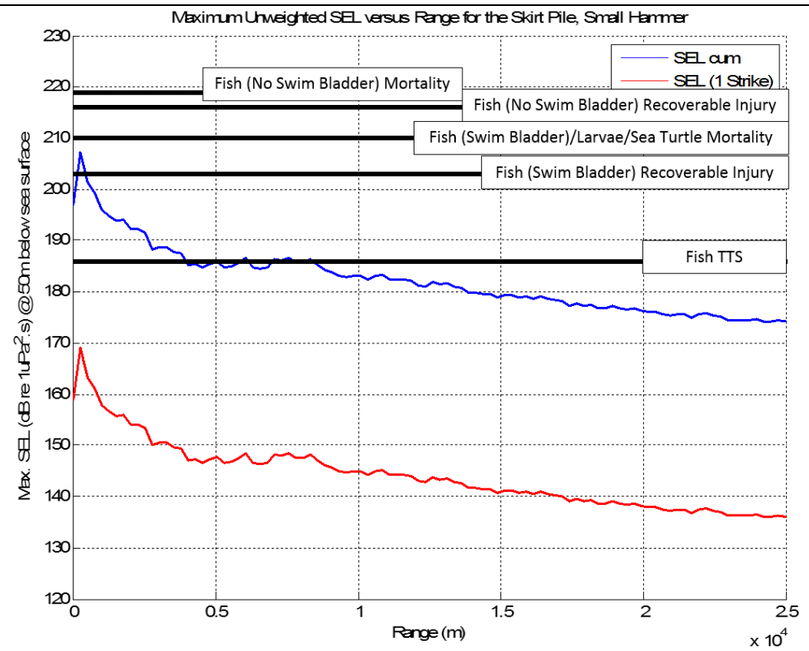
G: Noise Contour Showing Mmf Weighted L_p for Small Hammer Piling



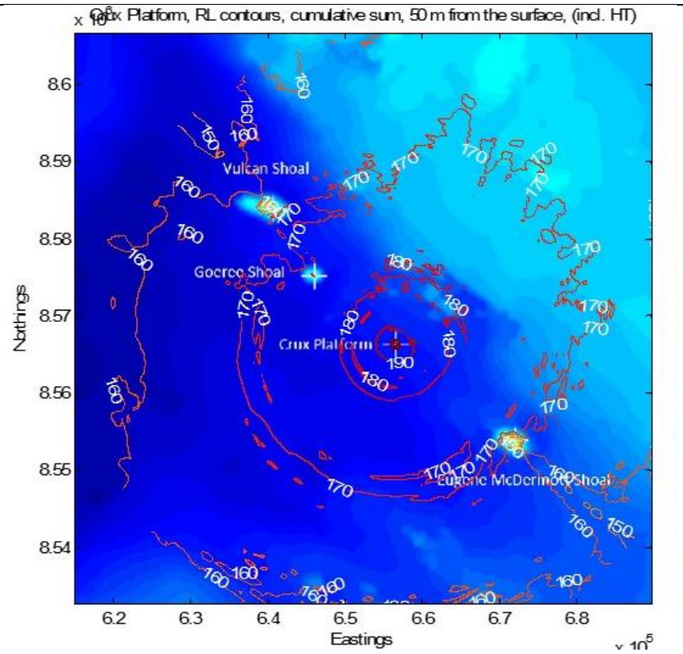
H: Maximum Mmf Weighted L_p versus Range for Small Hammer Piling



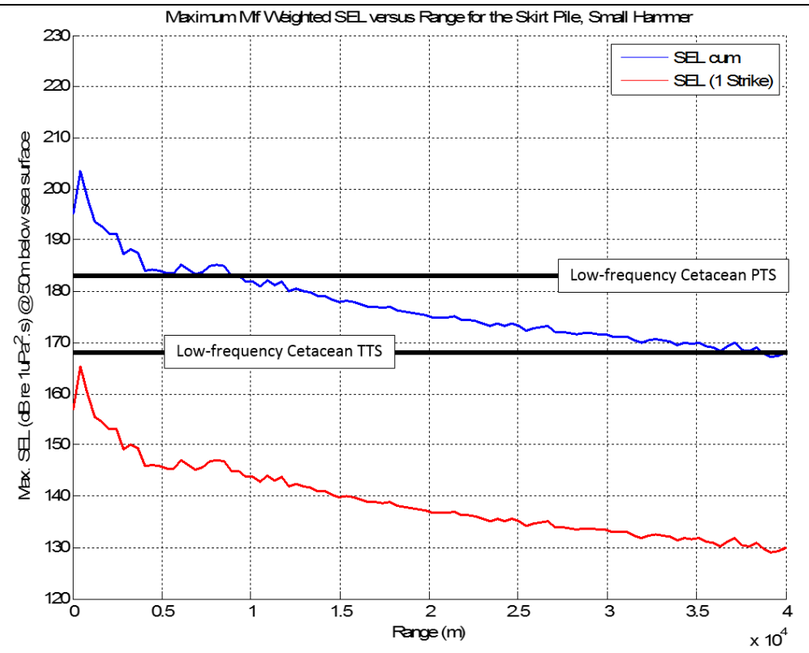
I: Noise Contour Showing Unweighted $L_{E,p}$ for Piling, Small Hammer



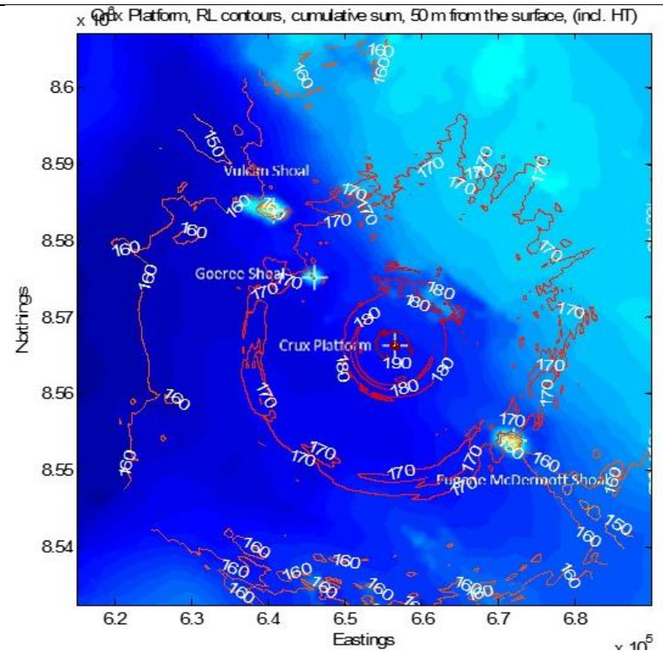
J: Maximum Unweighted $L_{E,p}$ versus Range for Piling, Small Hammer



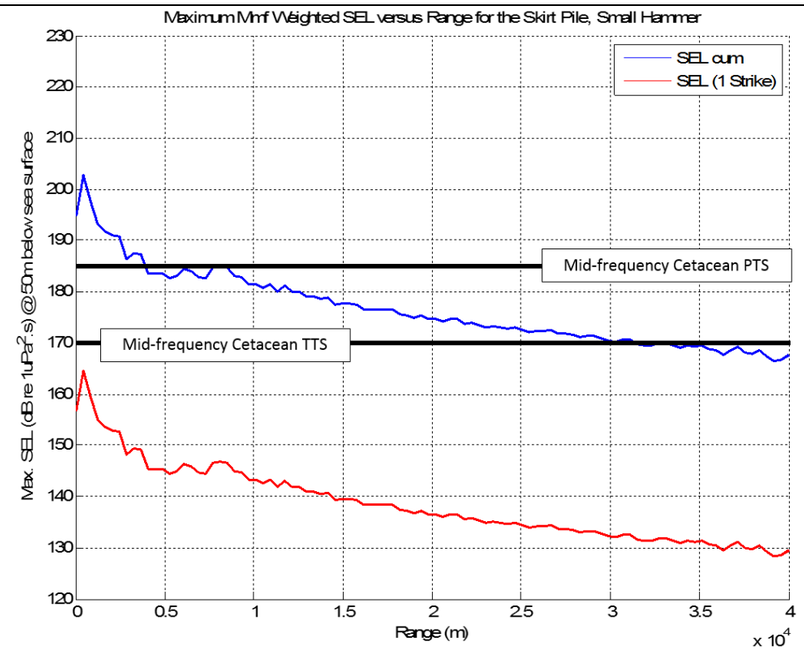
K: Noise Contour Showing Mlf Weighted $L_{E,p}$ for Piling, Small Hammer



L: Maximum Mlf Weighted $L_{E,p}$ versus Range for Piling, Small Hammer

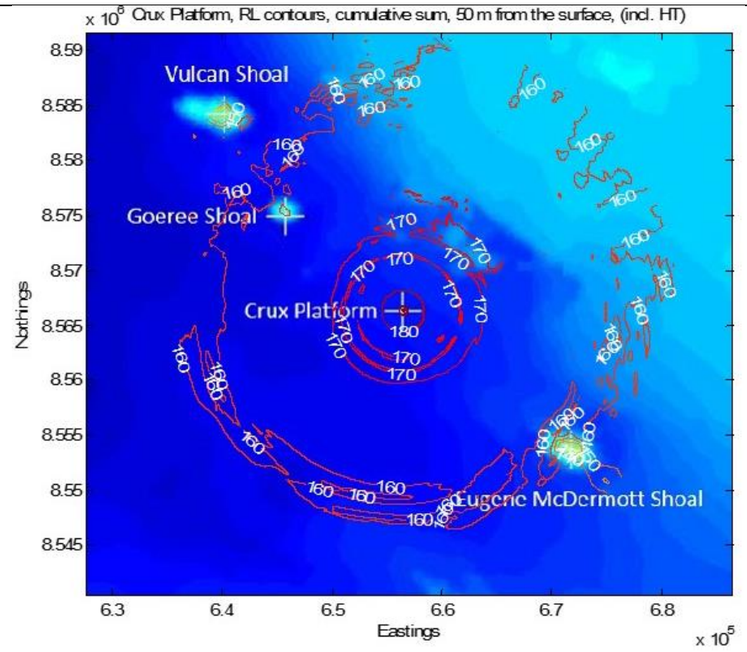


M: Noise Contour Showing Mmf Weighted $L_{E,p}$ for Piling, Small Hammer

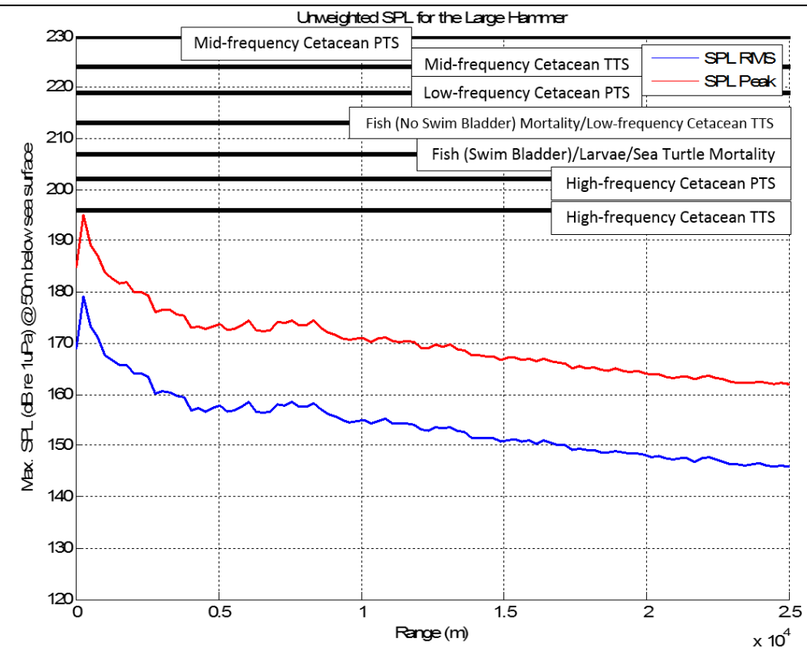


N: Maximum Mmf Weighted $L_{E,p}$ versus Range for Piling, Small Hammer

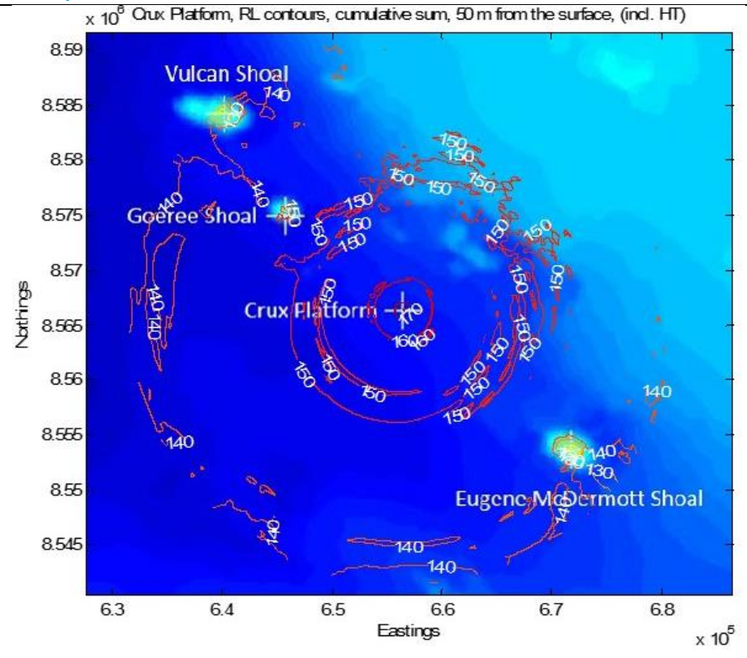
4.1.2 Noise Propagation Plots for Large Hammer Piling



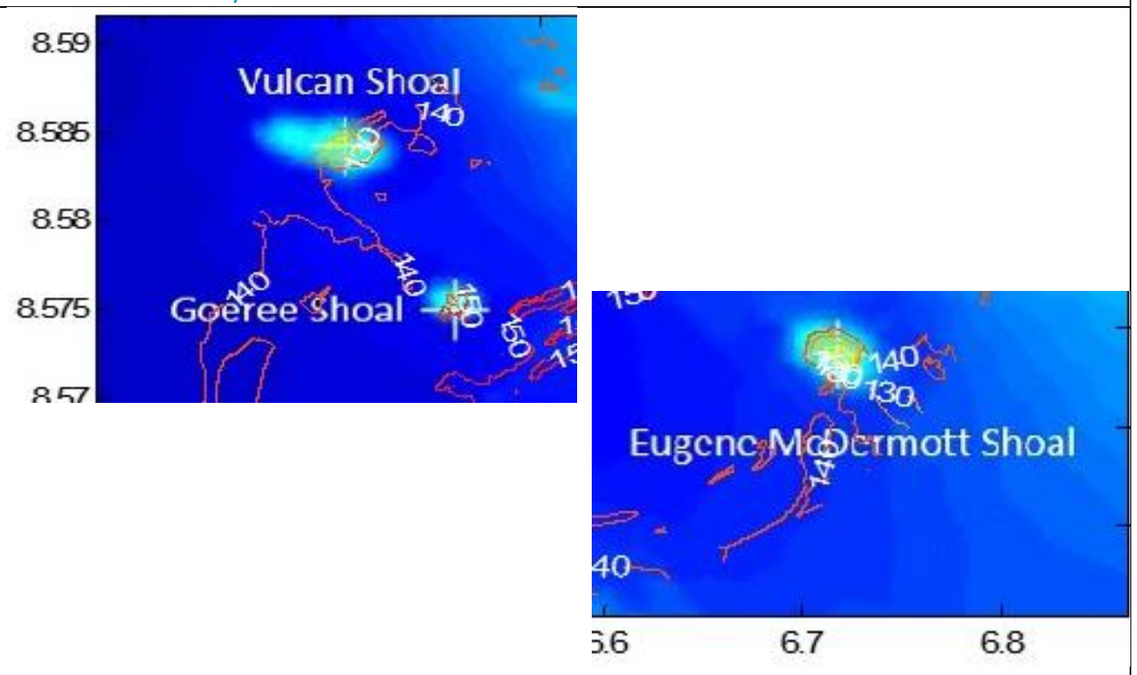
A: Noise Contour Showing L_{pk} for Large Hammer Piling



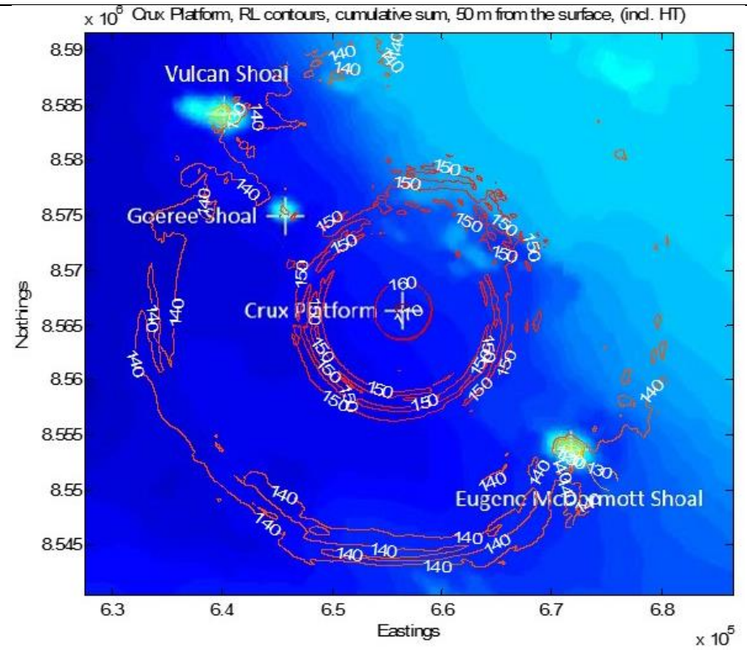
B: Maximum Unweighted L_p versus Range for Large Hammer Piling



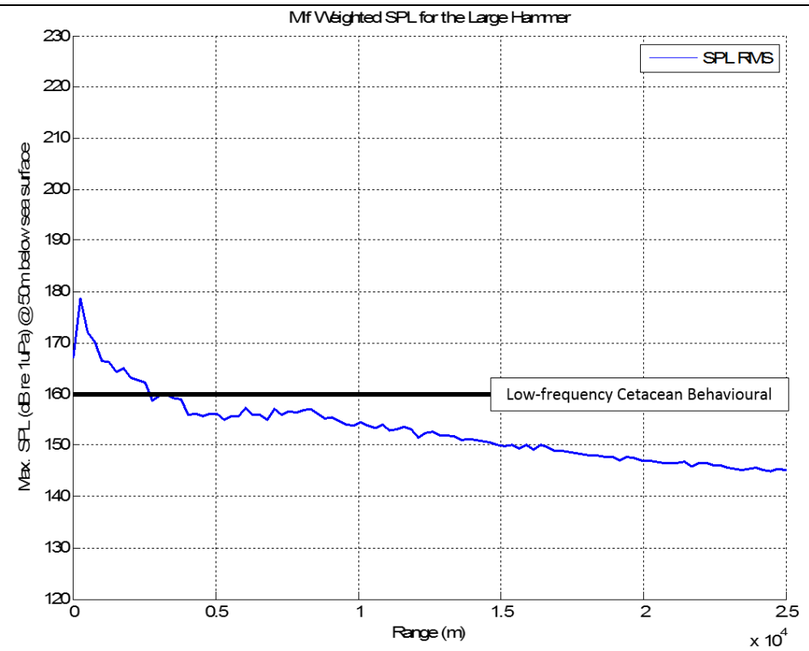
C: Noise Contour Showing Unweighted L_p for Large Hammer Piling



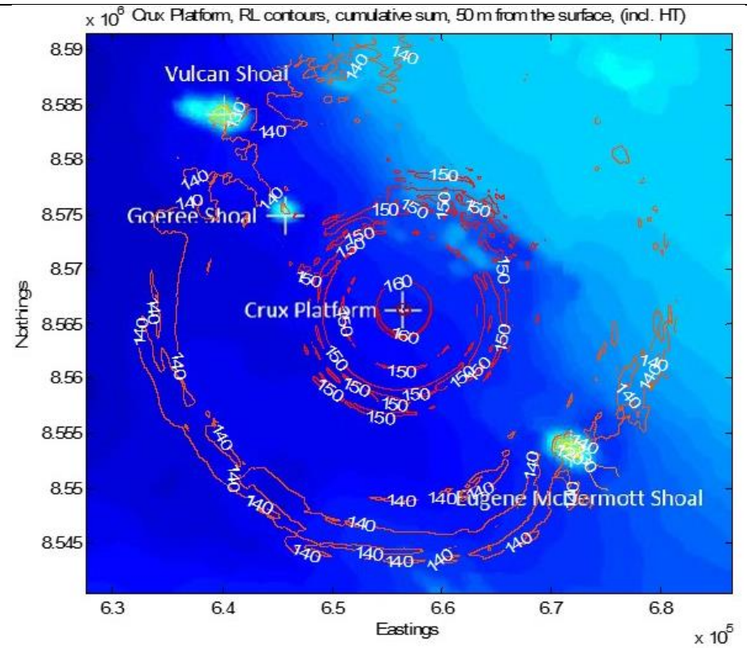
D: Zoomed Noise Contours of L_{pk} for Large Hammer Piling



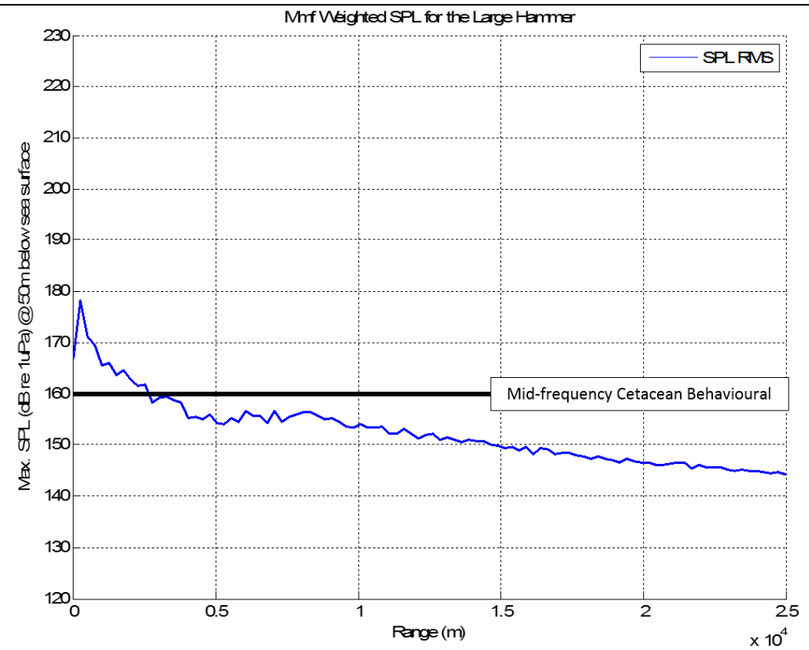
E: Noise Contour Showing Mlf Weighted L_p for Large Hammer Pilling



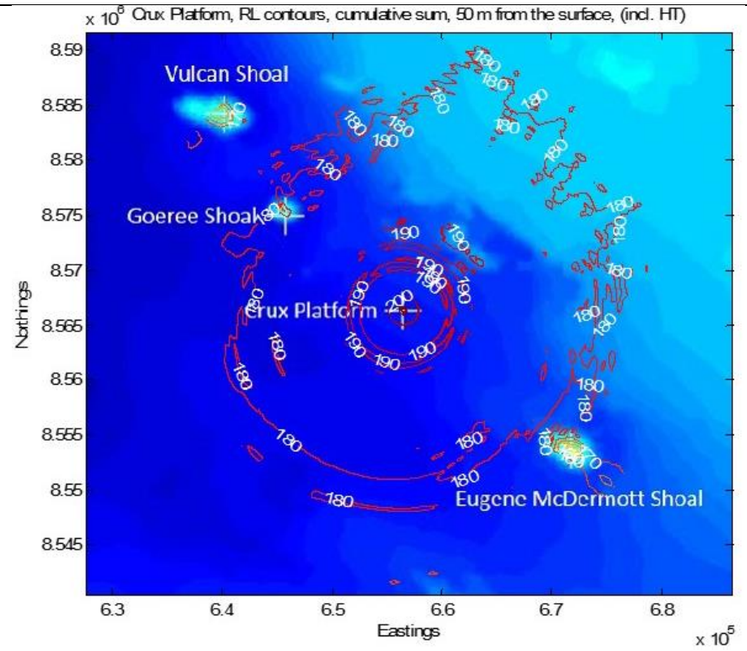
F: Maximum Mlf Weighted L_p versus Range for Large Hammer Piling



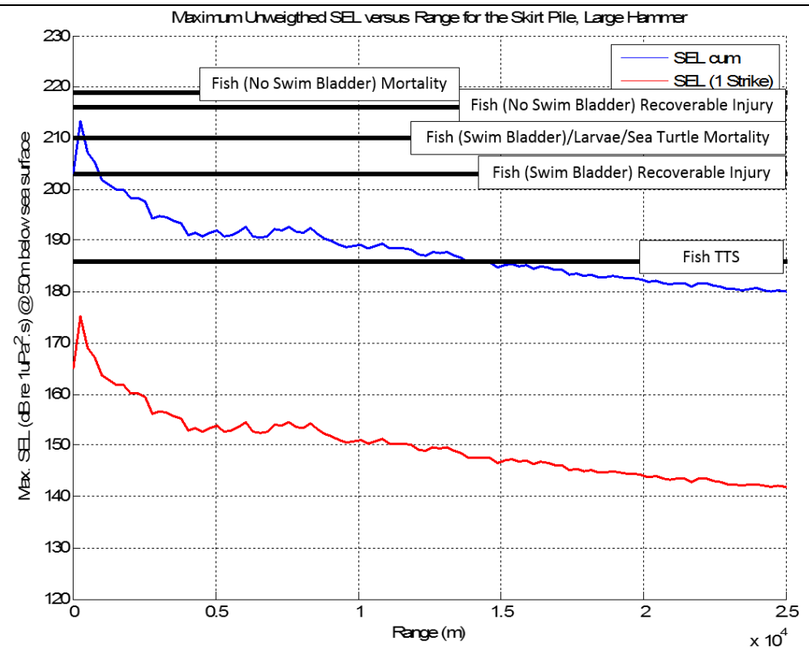
G: Noise Contour Showing Mmf Weighted L_p for Large Hammer Piling



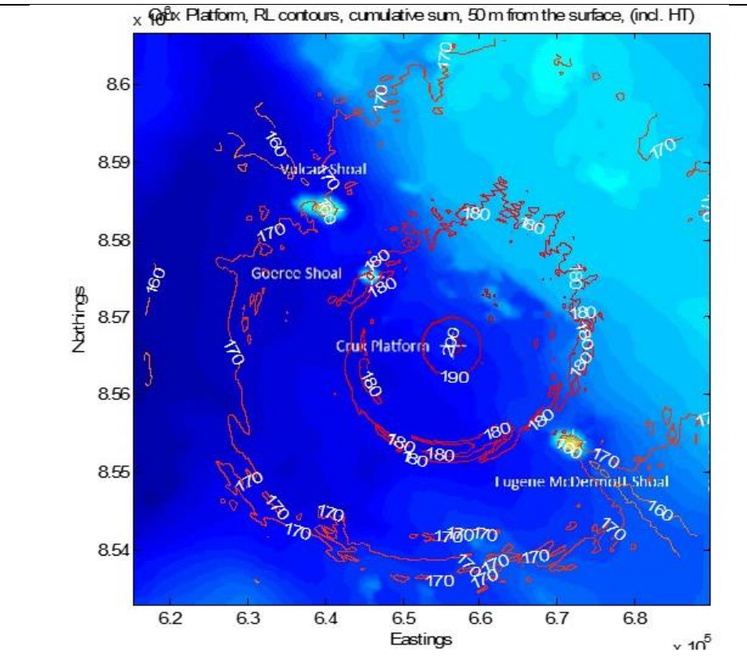
H: Maximum Mmf Weighted L_p versus Range for Large Hammer Piling



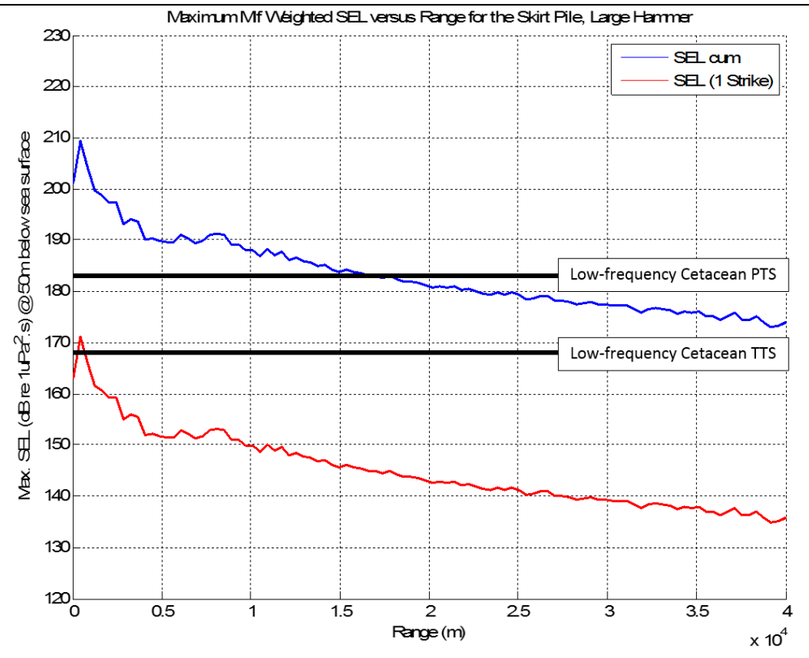
I: Noise Contour Showing Unweighted $L_{E,p}$ for Large Hammer Piling



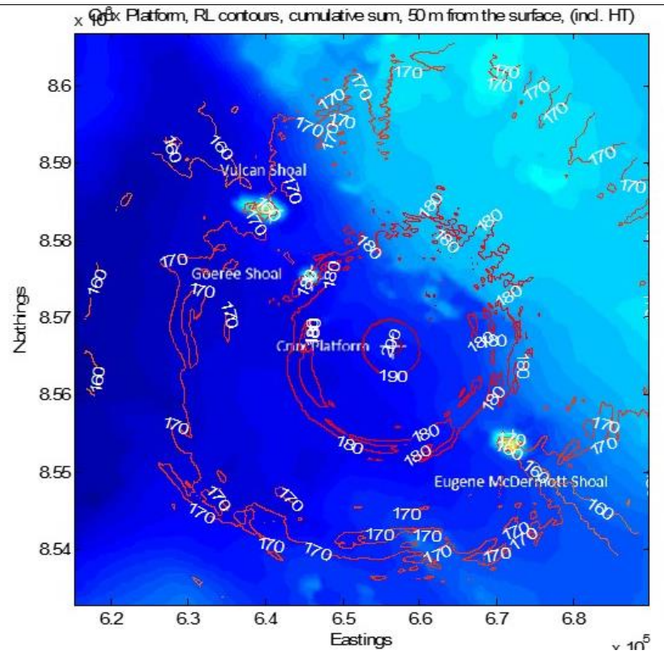
J: Maximum Unweighted $L_{E,p}$ versus Range for Large Hammer Piling



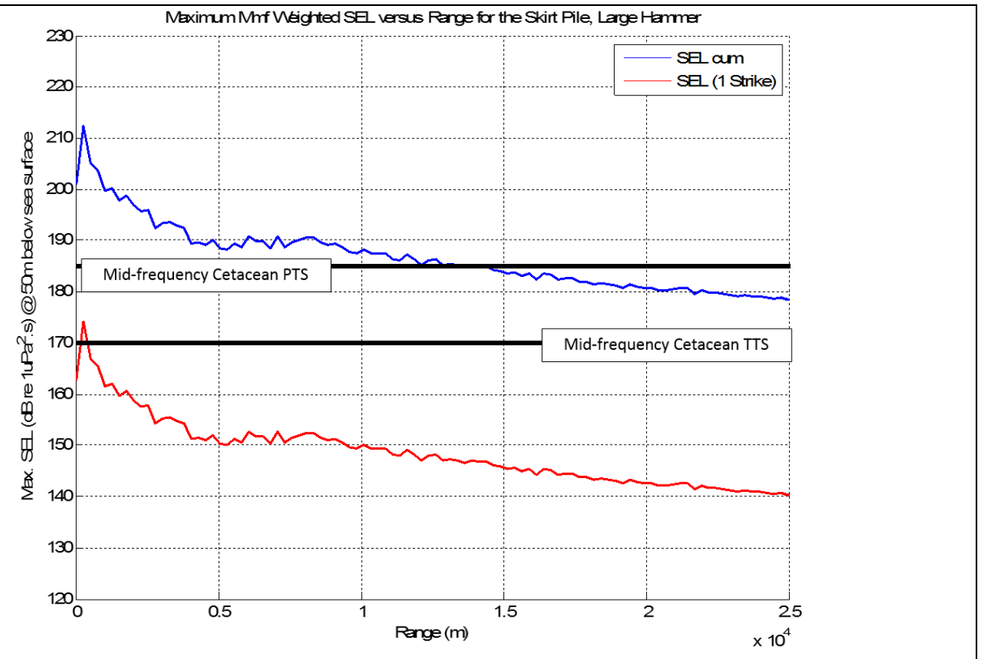
K: Noise Contour Showing Mlf Weighted $L_{E,p}$ for Large Hammer Piling



L: Maximum Mlf Weighted $L_{E,p}$ versus Range for Large Hammer Piling



M: Noise Contour Showing Mmf Weighted $L_{E,p}$ for Large Hammer Piling



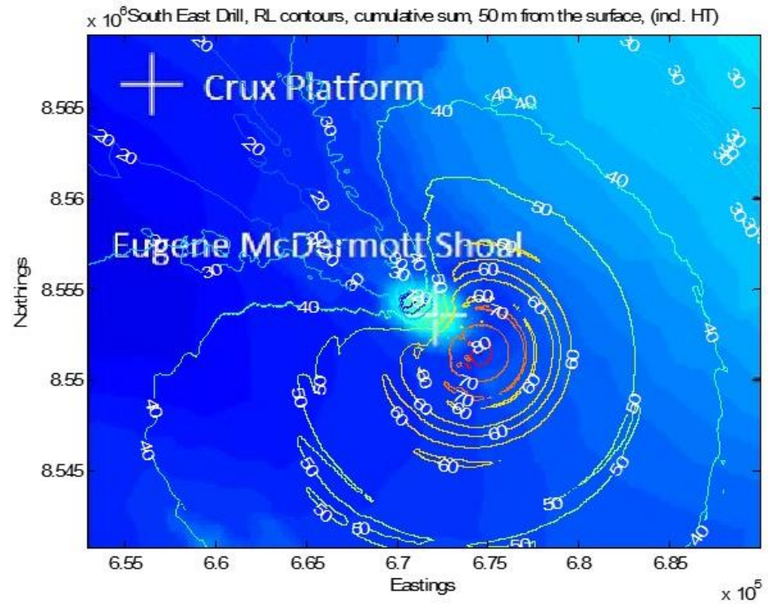
N: Maximum Mmf Weighted $L_{E,p}$ versus Range for Large Hammer Piling

4.2 Development and Operational Drilling

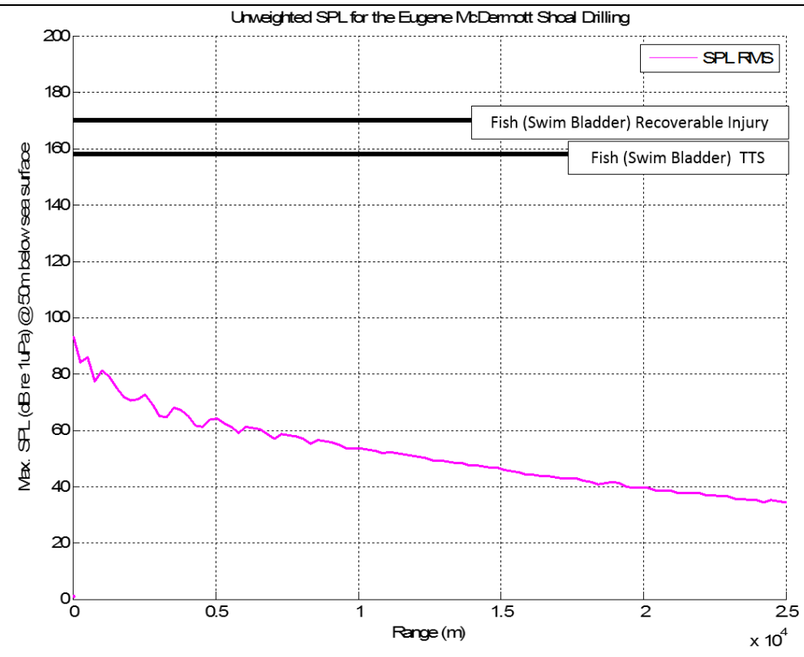
The following pages provide the noise results charts for three drilling scenarios:

1. Drill rig in proximity to Eugene McDermott Shoal
2. Drill rig in proximity to Vulcan Shoal
3. MPR on the Crux Platform

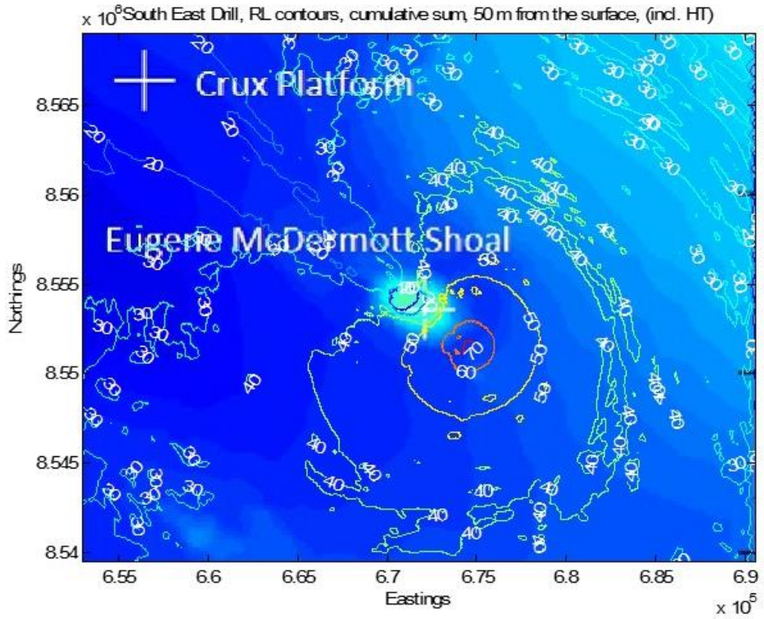
4.2.1 Drill Rig in Proximity to Eugene McDermott Shoal (Outside 1 km buffer)



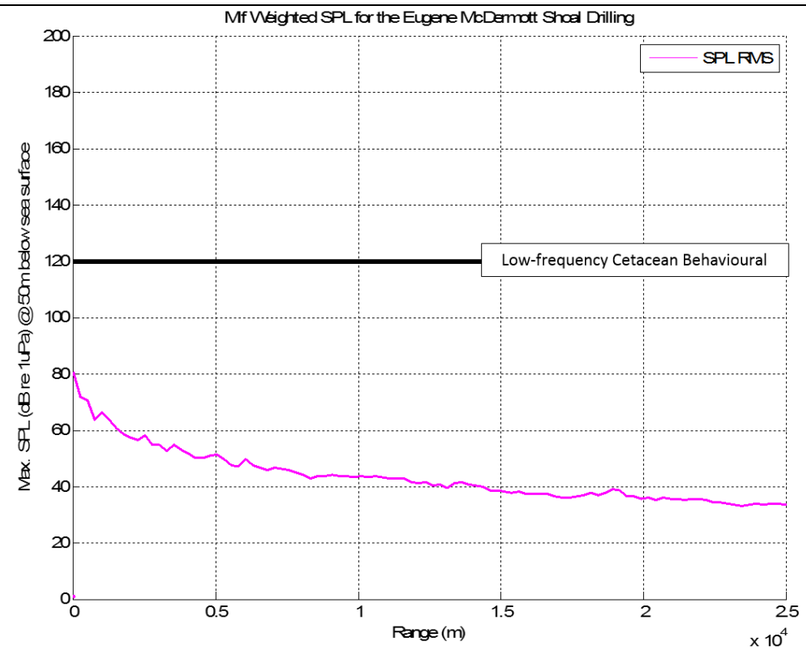
A: Noise Contour Showing Unweighted L_p for Eugene McDermott Shoal Drill Rig



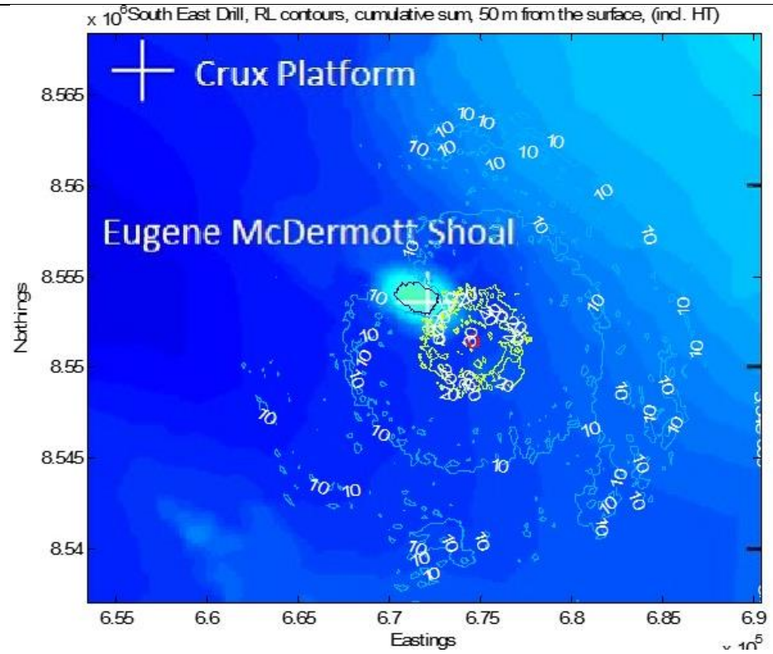
B: Maximum Unweighted L_p versus Range for Eugene McDermott Shoal Drill Rig



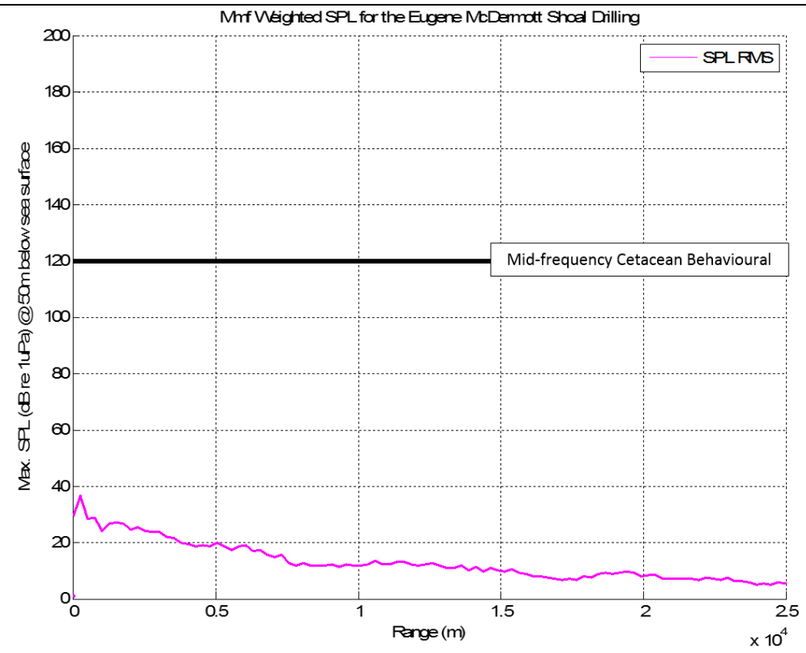
C: Noise Contour Showing Mlf-Weighted L_p for Eugene McDermott Shoal Drill Rig



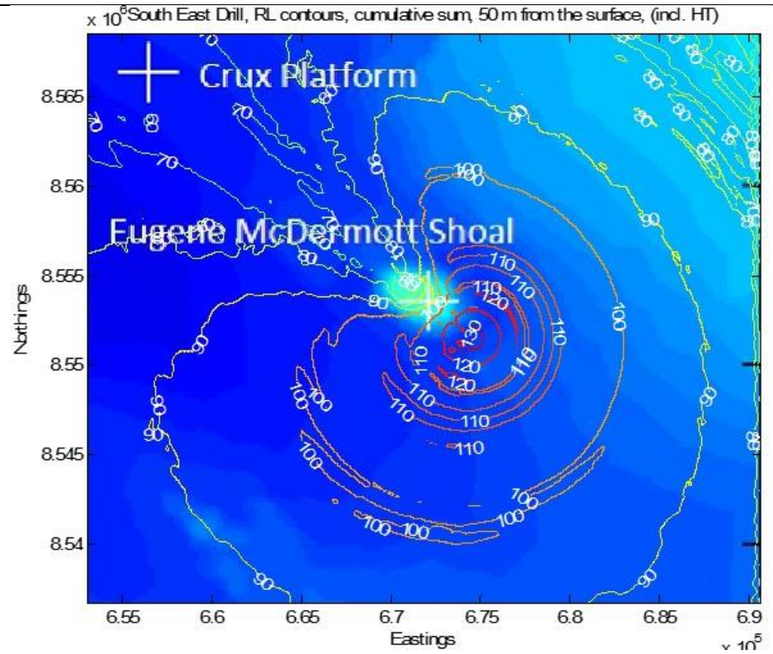
D: Maximum Mlf-Weighted L_p versus Range for Eugene McDermott Shoal Drill Rig



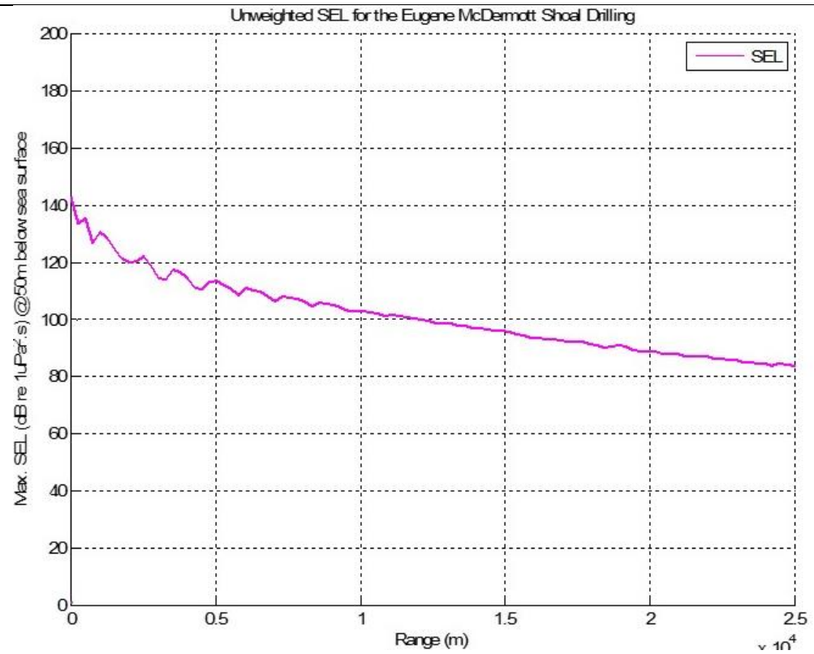
E: Noise Contour Showing Mmf-Weighted L_p for Eugene McDermott Shoal Drill Rig



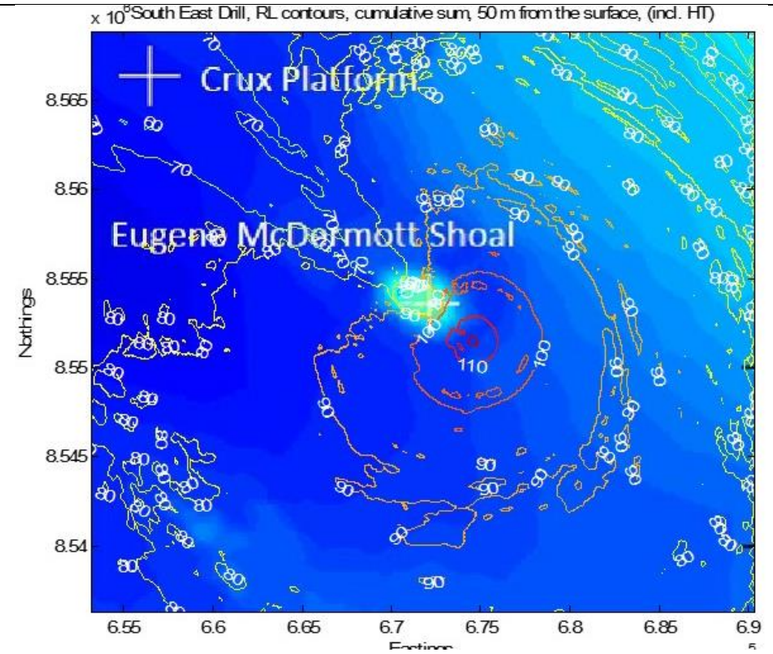
F: Maximum Mmf-Weighted L_p versus Range for Eugene McDermott Shoal Drill Rig



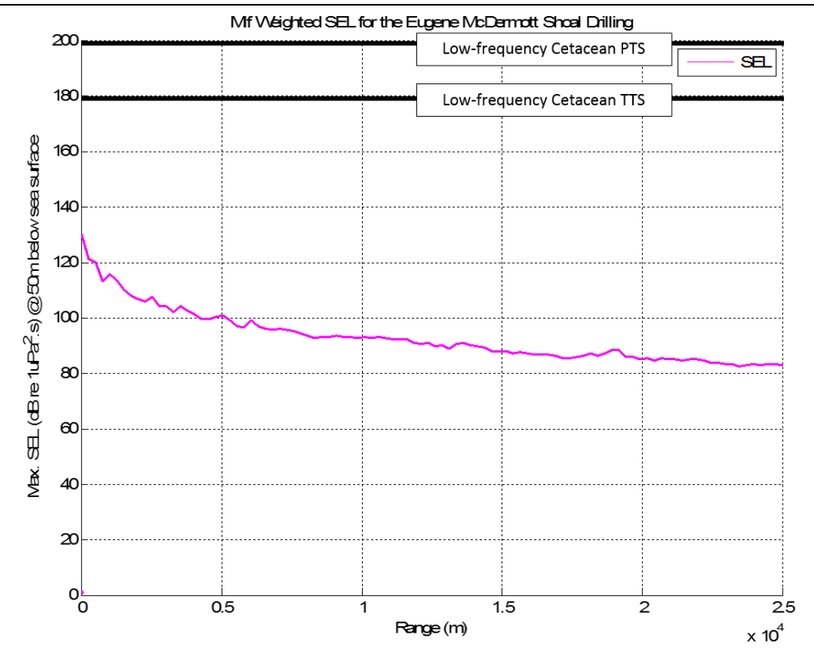
G: Noise Contour Showing Unweighted $L_{E,p}$ for Eugene McDermott Shoal Drill Rig



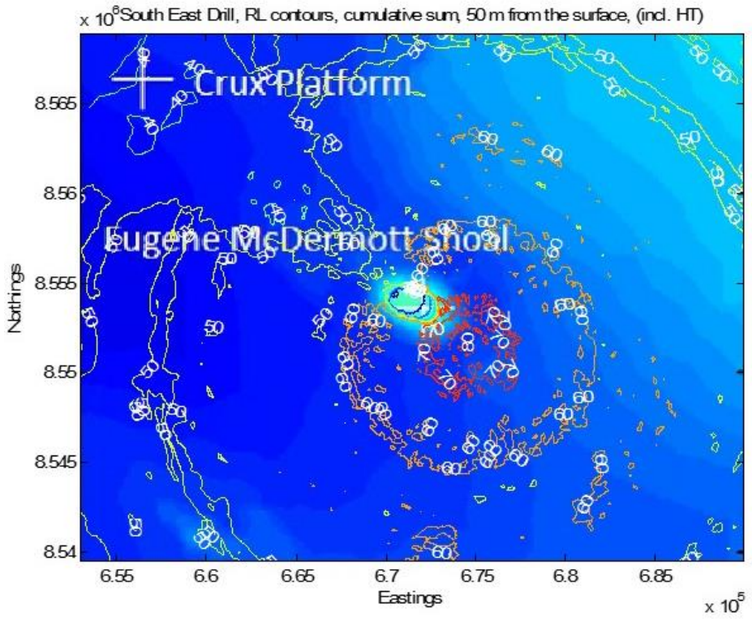
H: Maximum Unweighted $L_{E,p}$ versus Range for Eugene McDermott Shoal Drill Rig



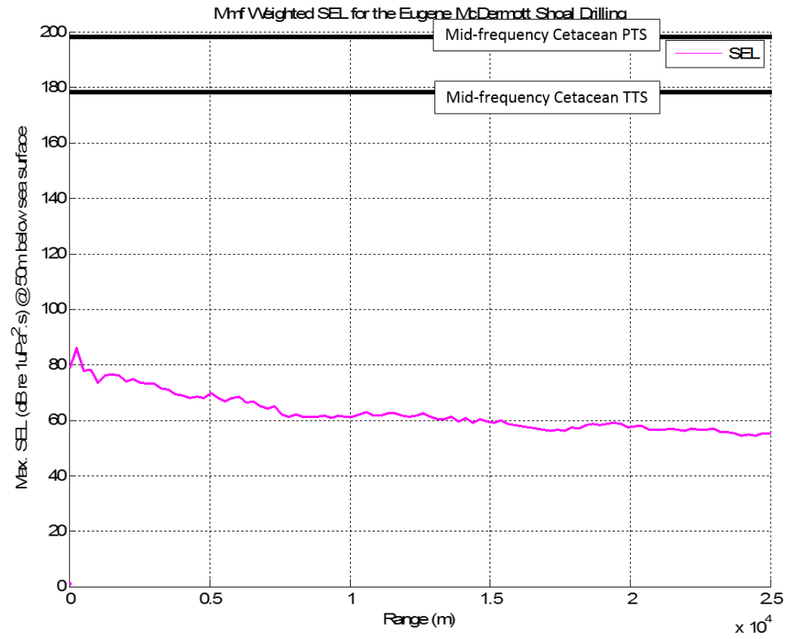
I: Noise Contour Showing Mlf-Weighted $L_{E,p}$ for Eugene McDermott Shoal Drill Rig



J: Maximum Mlf-weighted $L_{E,p}$ versus Range for Eugene McDermott Shoal Drill Rig

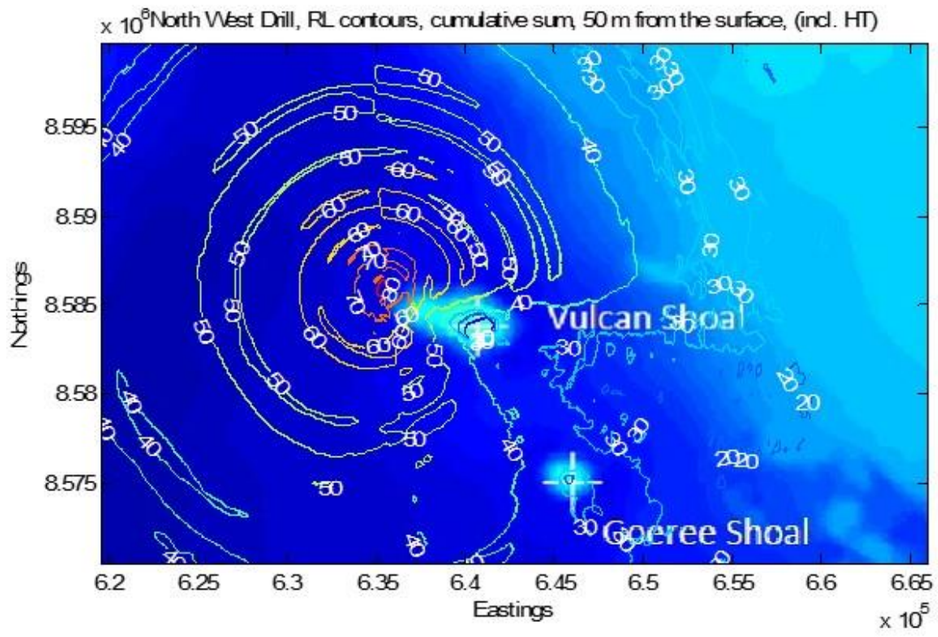


K: Noise Contour Showing Mmf-Weighted $L_{E,p}$ for Eugene McDermott Shoal Drill Rig

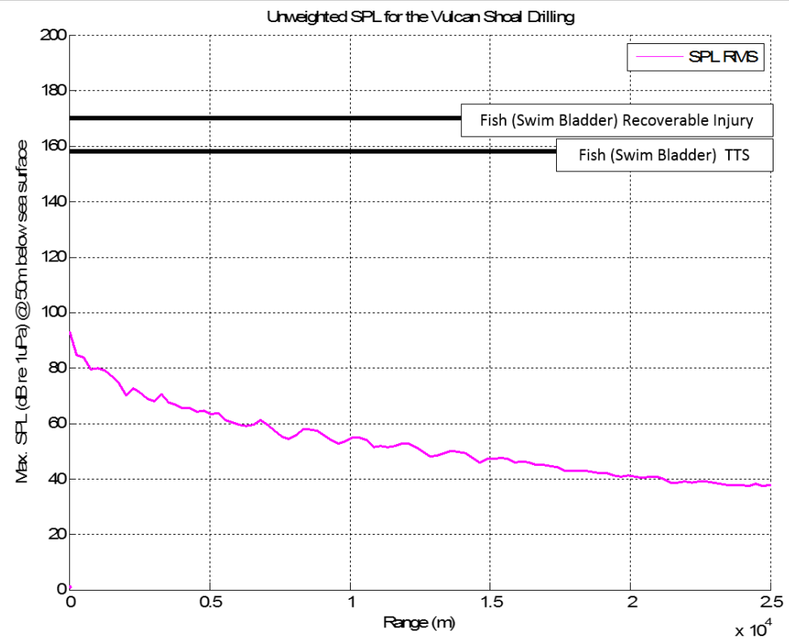


L: Maximum Mmf-Weighted $L_{E,p}$ versus Range for Eugene McDermott Shoal Drill Rig

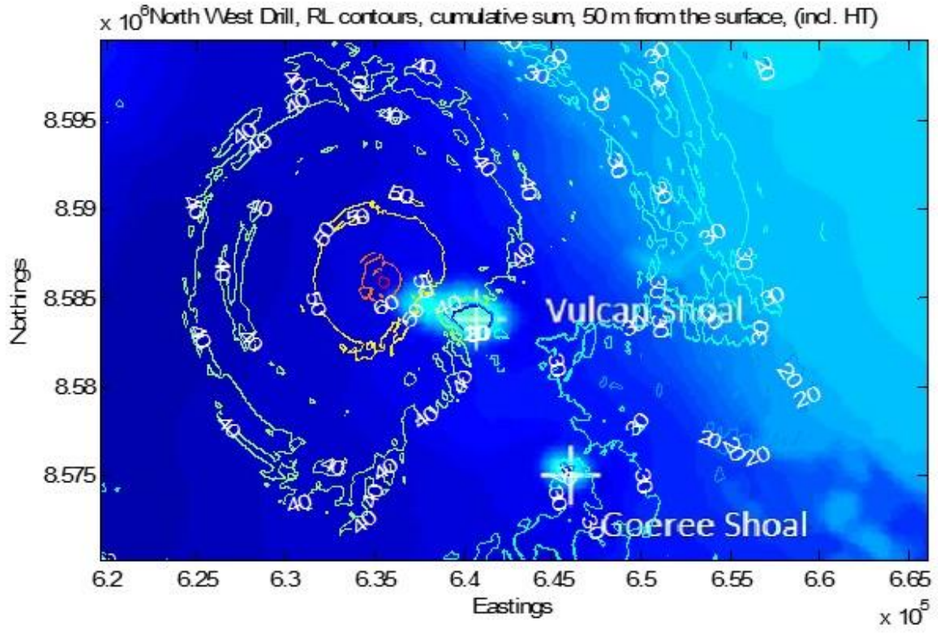
4.2.2 Drill Rig in Proximity to Vulcan Shoal (outside 1 km buffer)



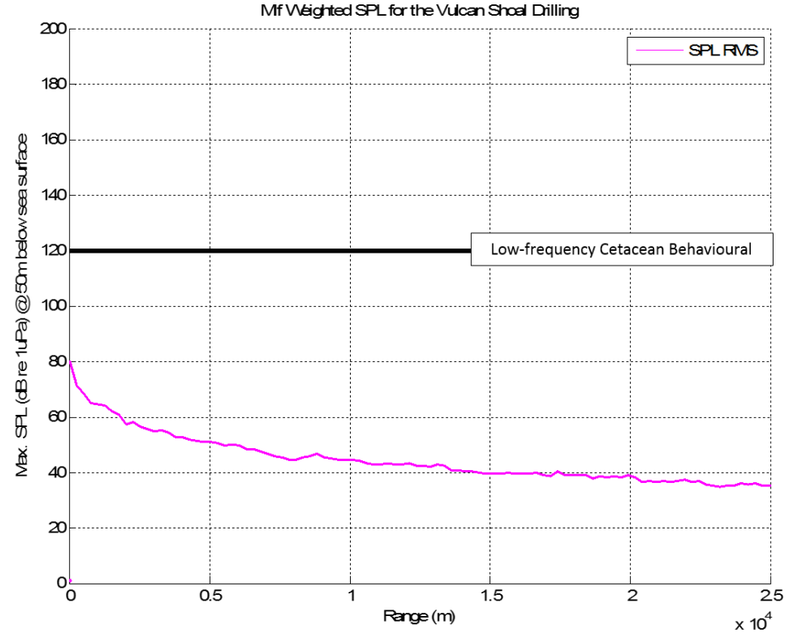
A: Noise Contour Showing Unweighted L_p for Vulcan Shoal Drill Rig



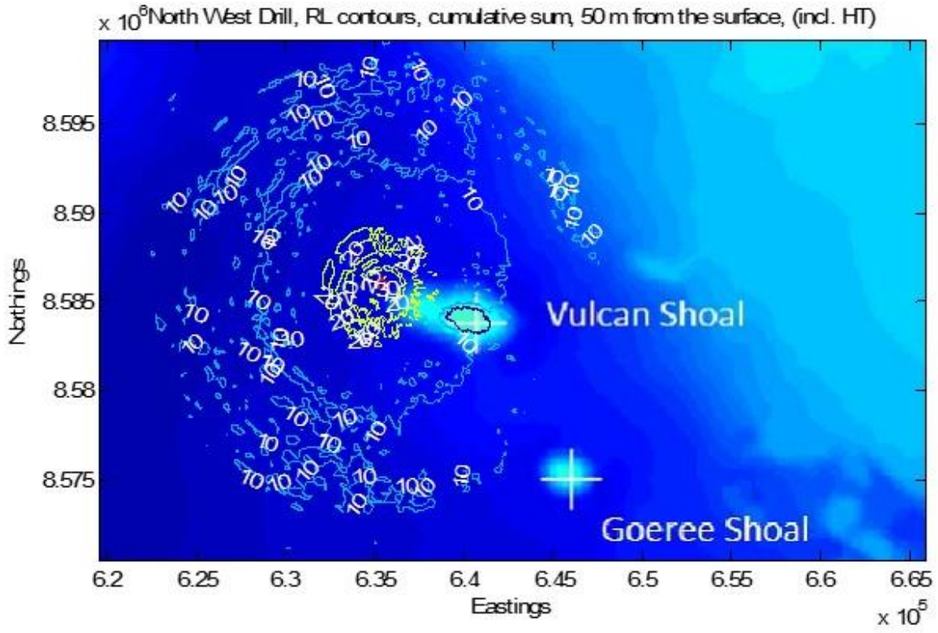
B: Maximum Unweighted L_p versus Range for Vulcan Shoal Drill Rig



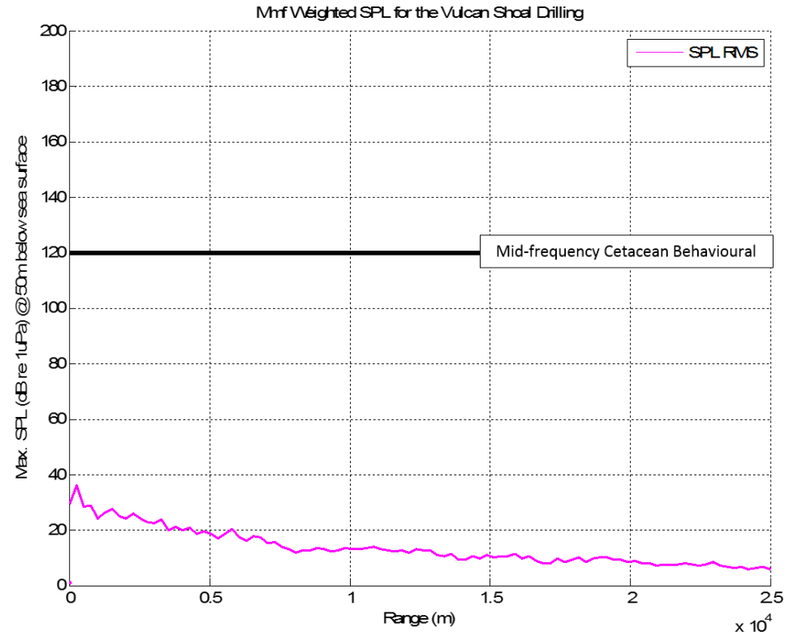
C: Noise Contour Showing Mlf-Weighted L_p for Vulcan Shoal Drill Rig



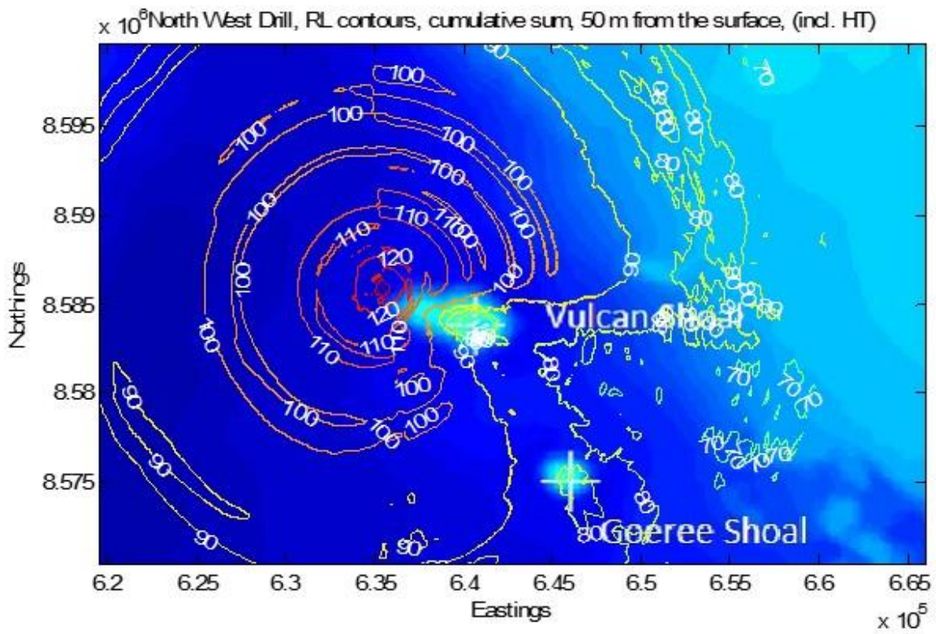
D: Maximum Mlf-Weighted L_p versus Range for Vulcan Shoal Drill Rig



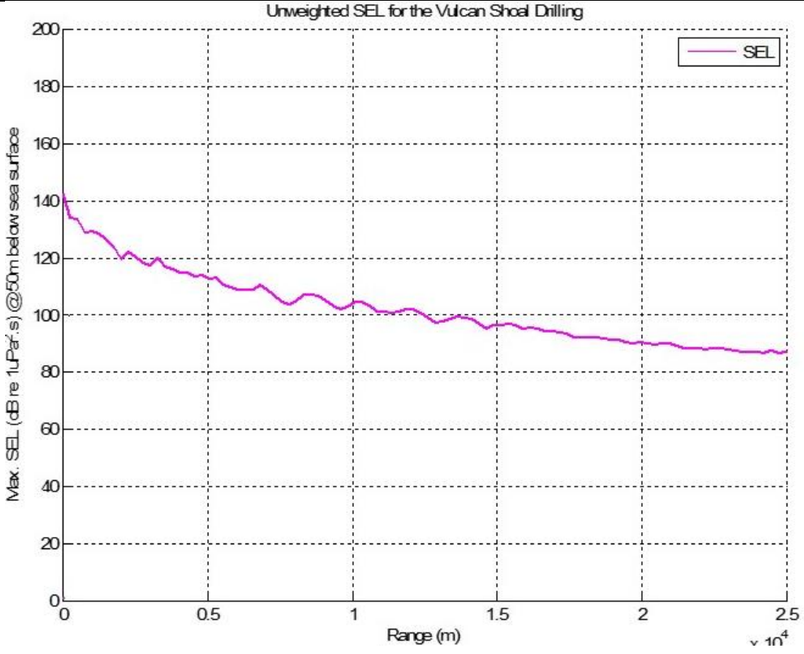
E: Noise Contour Showing Mmf-Weighted L_p for Vulcan Shoal Drill Rig



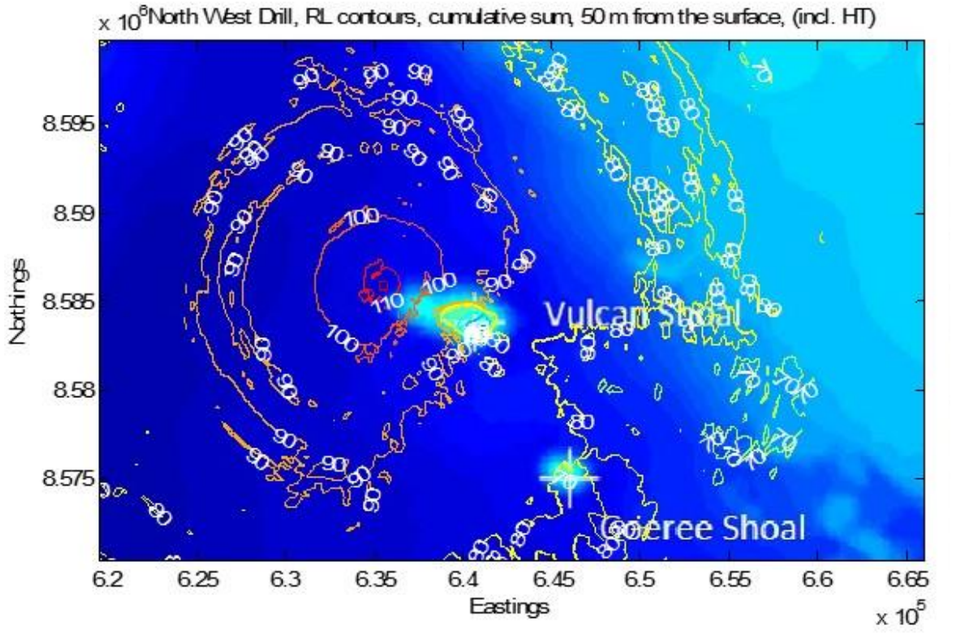
F: Maximum Mmf-Weighted L_p versus Range for Vulcan Shoal Drill Rig



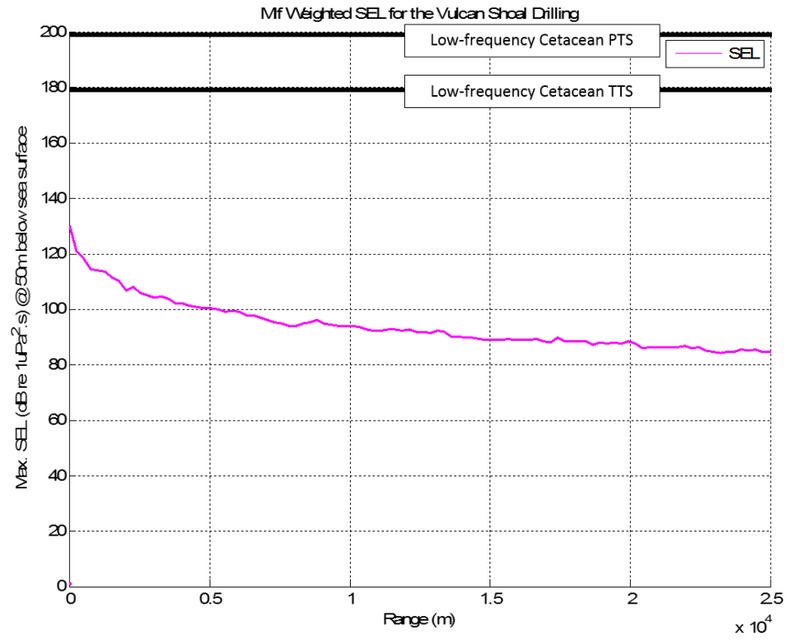
G: Noise Contour Showing Unweighted $L_{E,p}$ for Vulcan Shoal Drill Rig



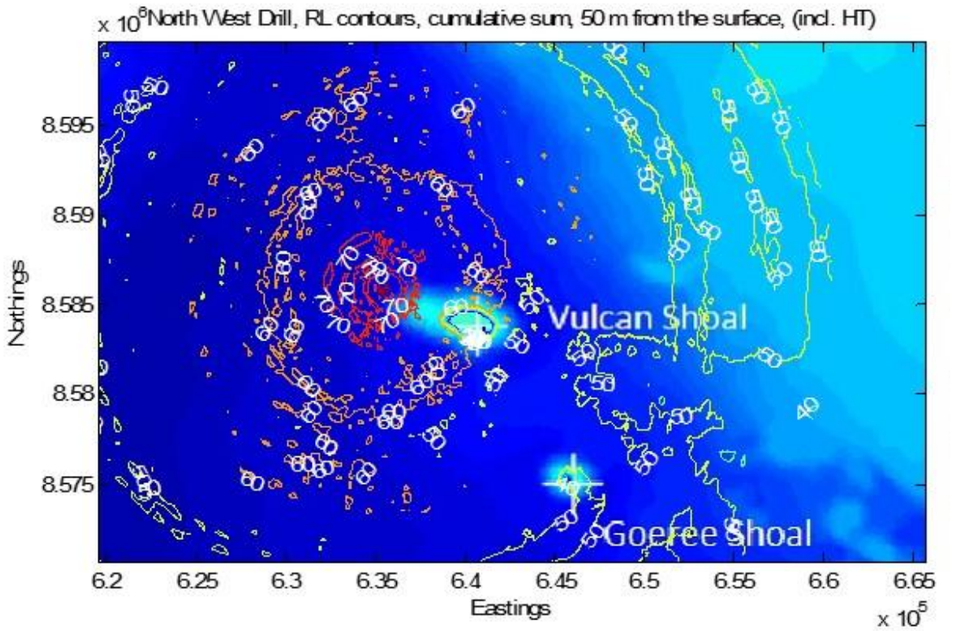
H: Maximum Unweighted $L_{E,p}$ versus Range for Vulcan Shoal Drill Rig



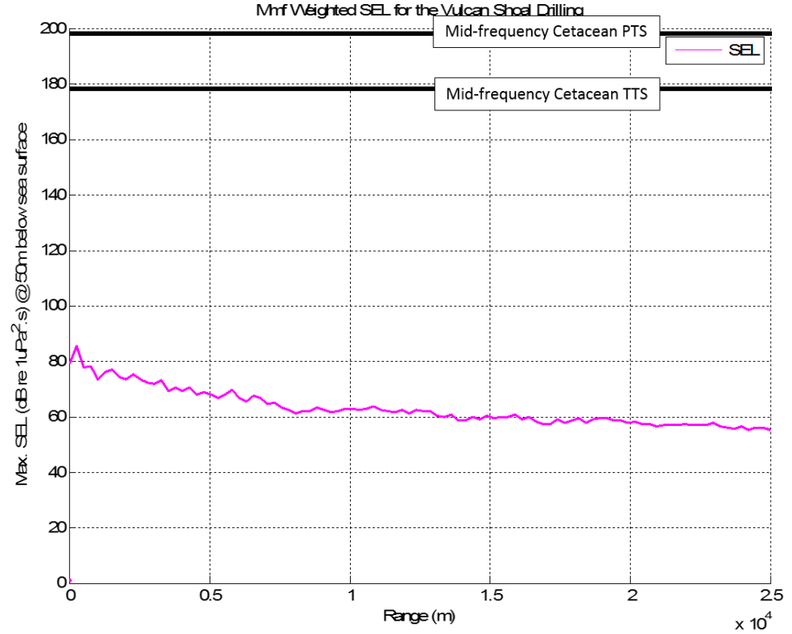
I: Noise Contour Showing MIf-Weighted $L_{E,p}$ for Vulcan Shoal Drill Rig



J: Maximum MIf-Weighted $L_{E,p}$ versus Range for Vulcan Shoal Drill Rig

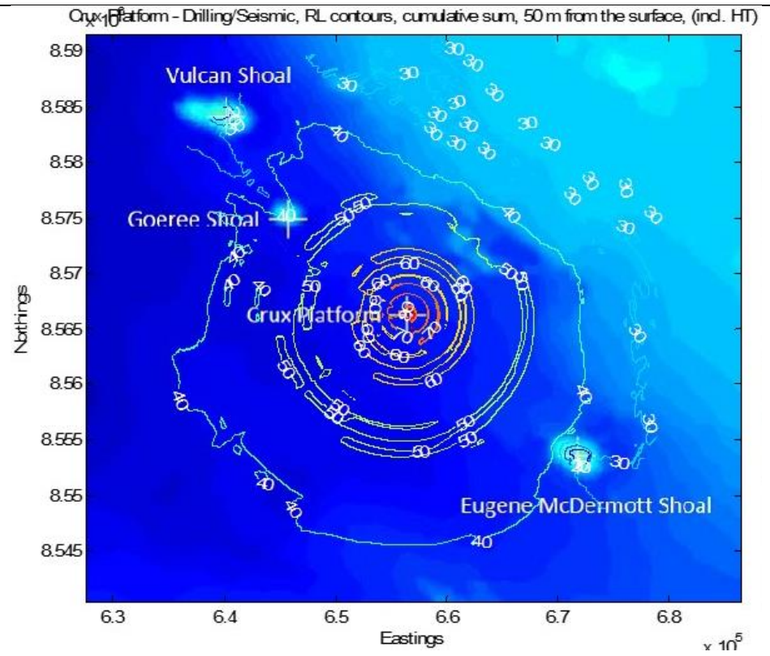


K: Noise Contour Showing Mmf-Weighted $L_{E,p}$ for Vulcan Shoal Drill Rig

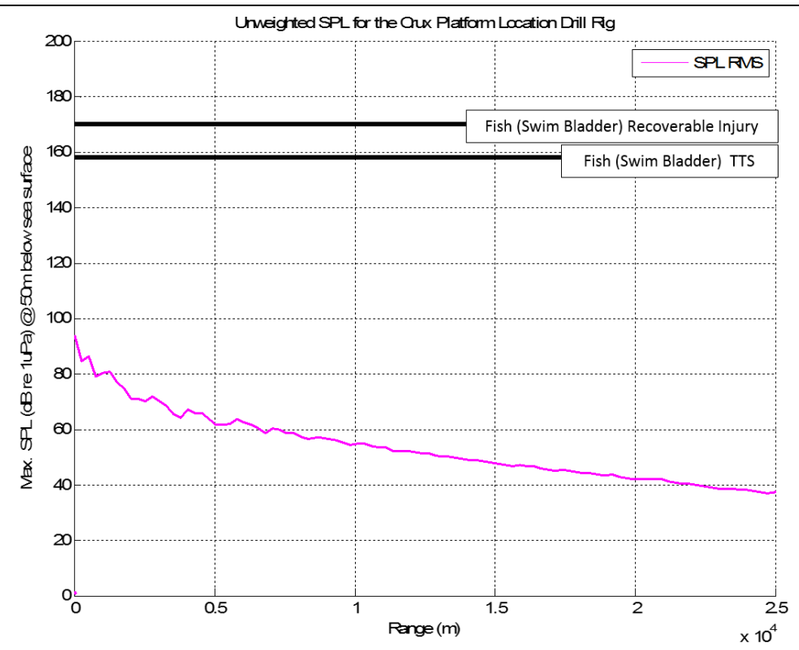


L: Maximum Mmf-Weighted $L_{E,p}$ versus Range for Vulcan Shoal Drill Rig

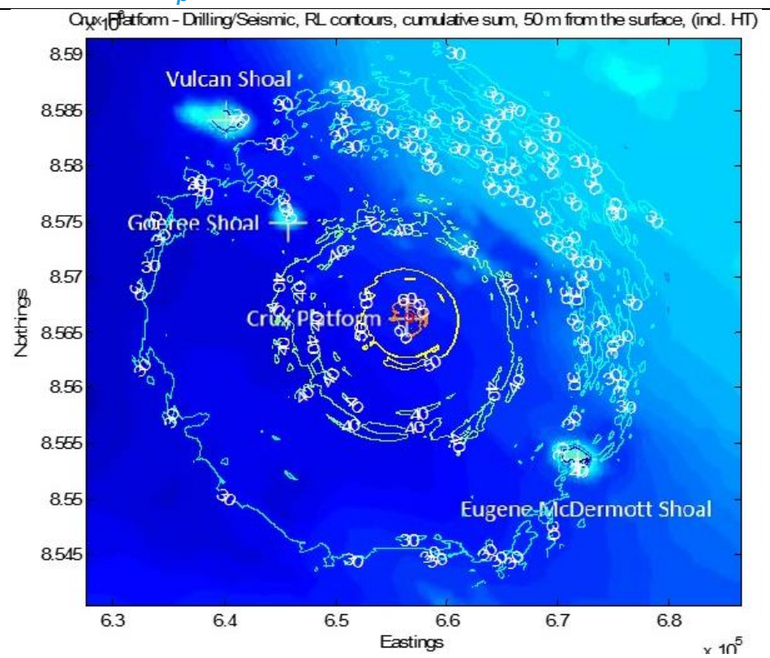
4.2.3 Drilling from Crux Platform Location



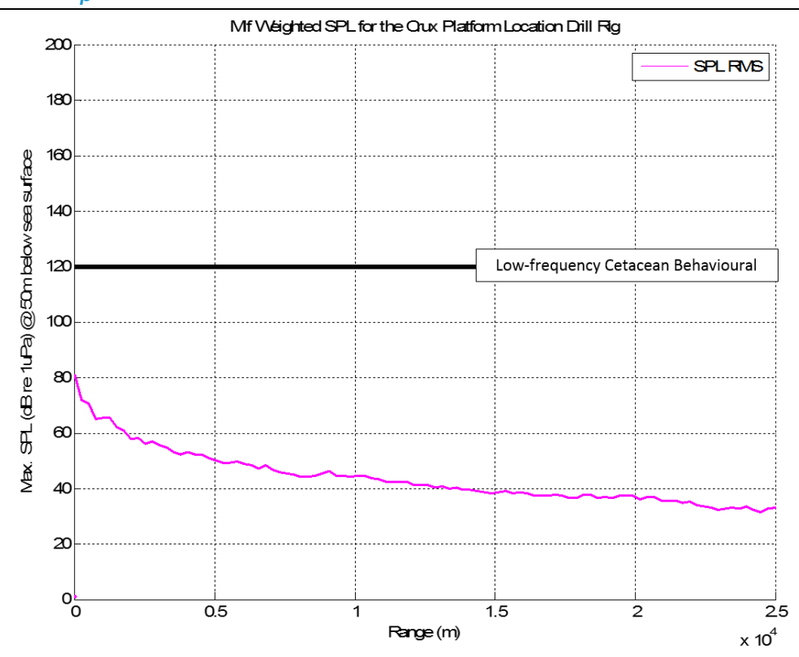
A: Noise Contour Showing Unweighted L_p for Drilling at Crux Platform



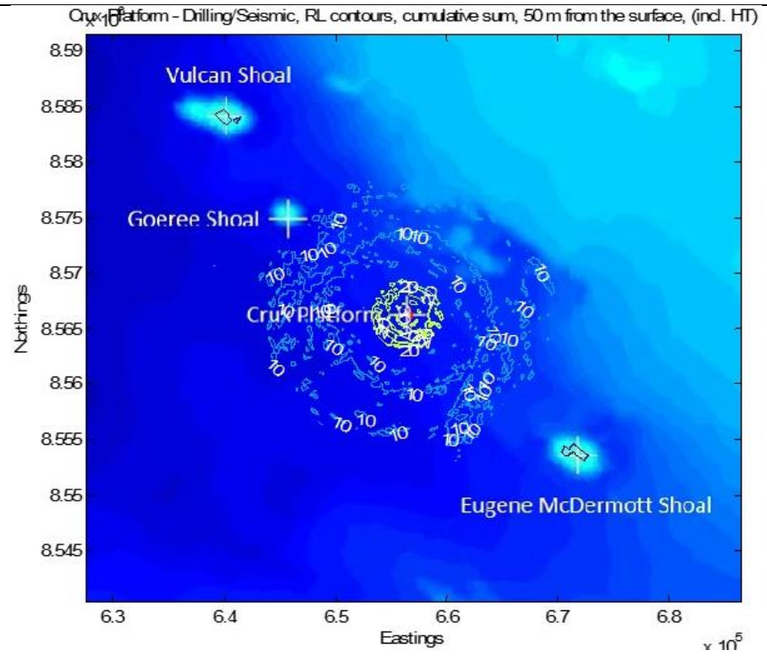
B: Maximum Unweighted L_p versus Range for Drilling at Crux Platform



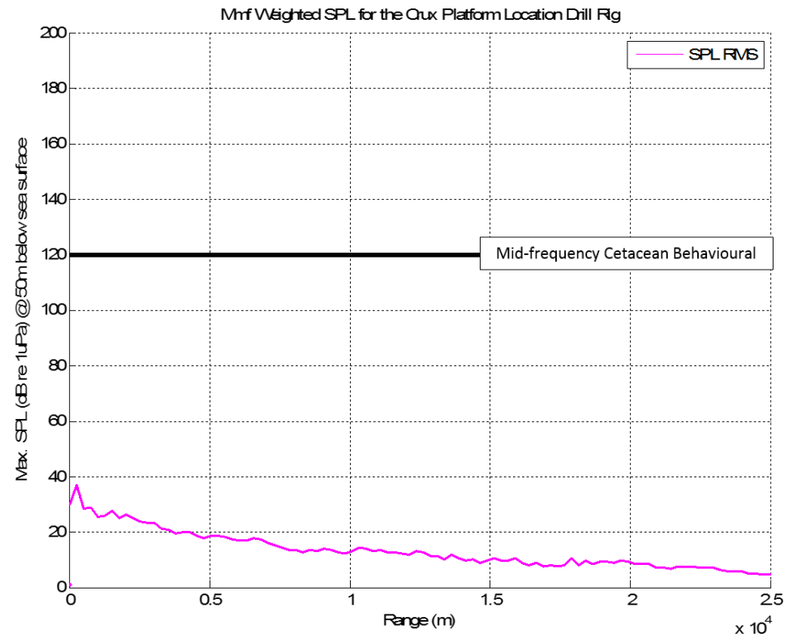
C: Noise Contour Showing Mlf-Weighted L_p for Drilling at Crux Platform



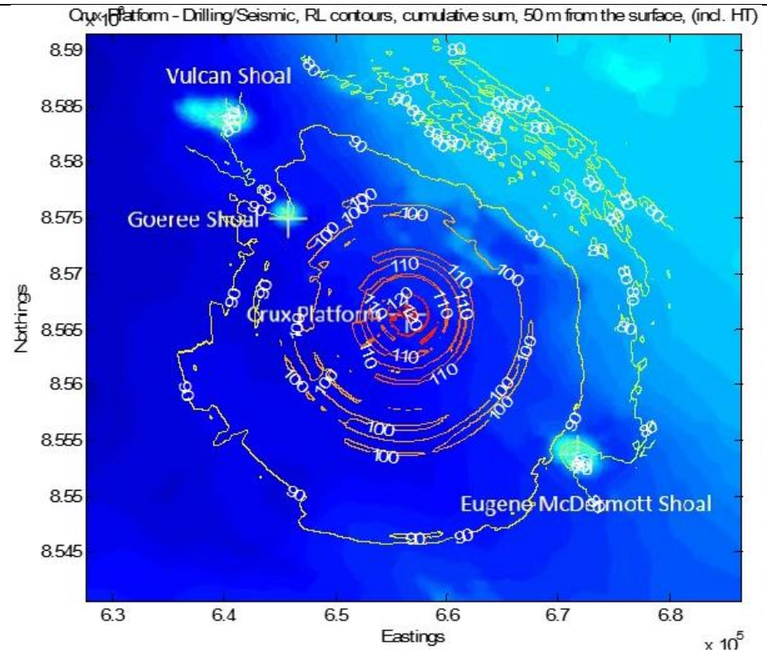
D: Maximum Mlf-Weighted L_p versus Range for Drilling at Crux Platform



E: Noise Contour Showing Mmf-Weighted L_p for Drilling at Crux Platform



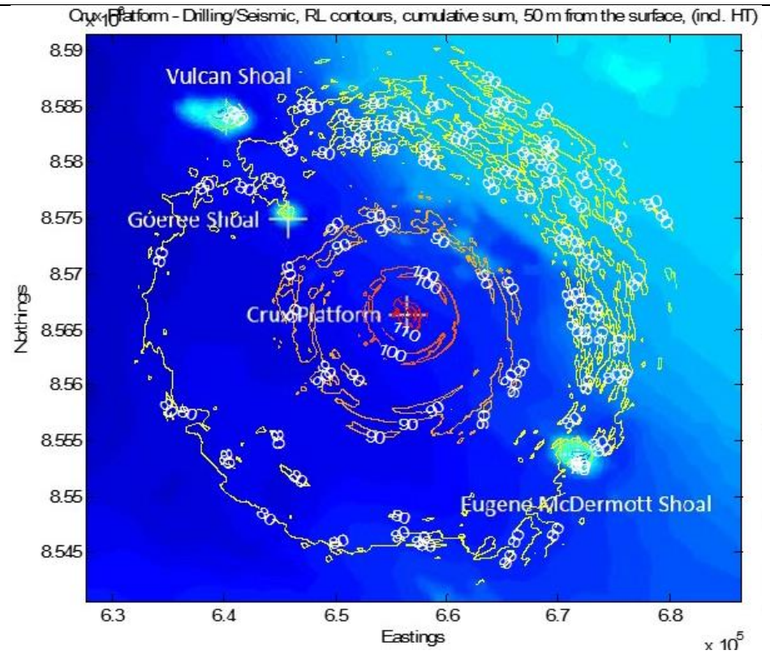
F: Maximum Mmf-Weighted L_p versus Range for Drilling at Crux Platform



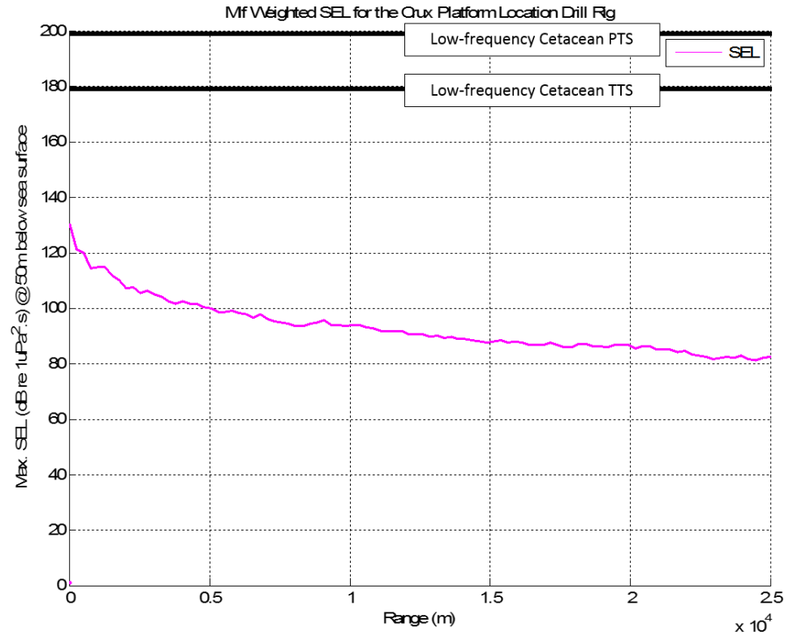
G: Noise Contour Showing Unweighted $L_{E,p}$ for Drilling at Crux Platform



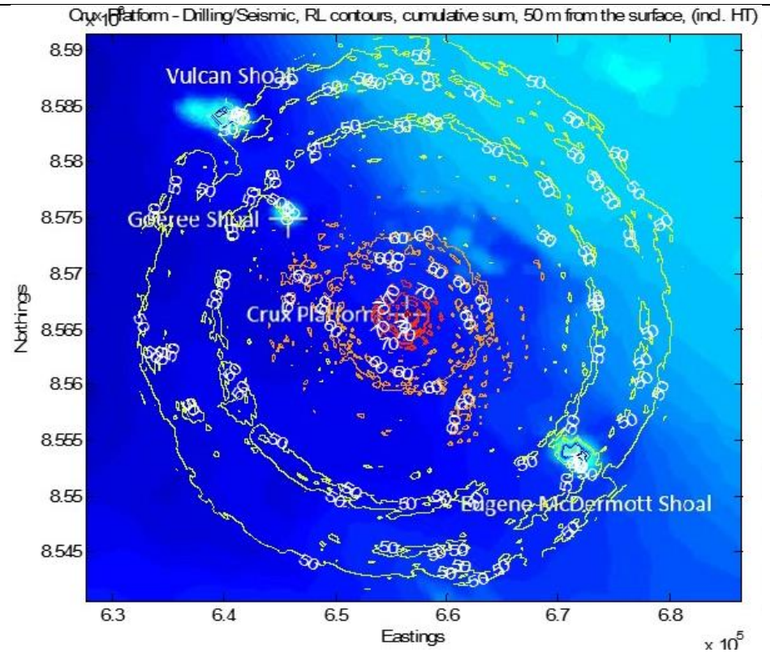
H: Maximum Unweighted $L_{E,p}$ versus Range for Drilling at Crux Platform



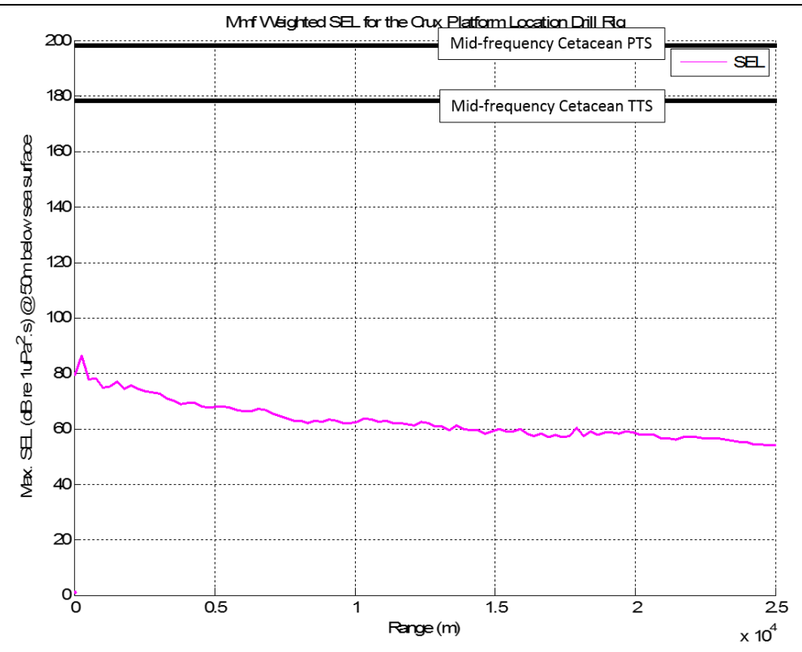
I: Noise Contour Showing Mlf-Weighted $L_{E,p}$ for Drilling at Crux Platform



J: Maximum Mlf-Weighted $L_{E,p}$ versus Range for Drilling at Crux Platform



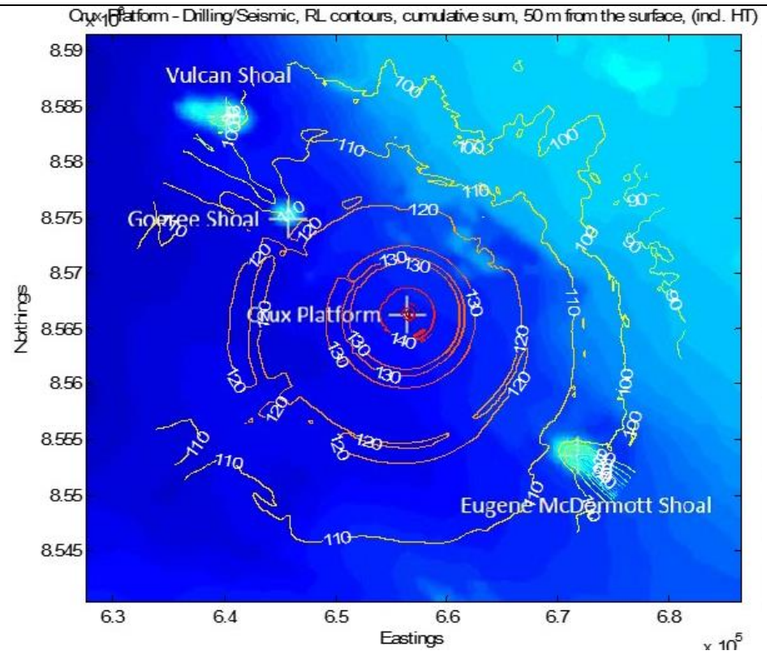
K: Noise Contour Showing Mmf-Weighted $L_{E,p}$ for Drilling at Crux Platform



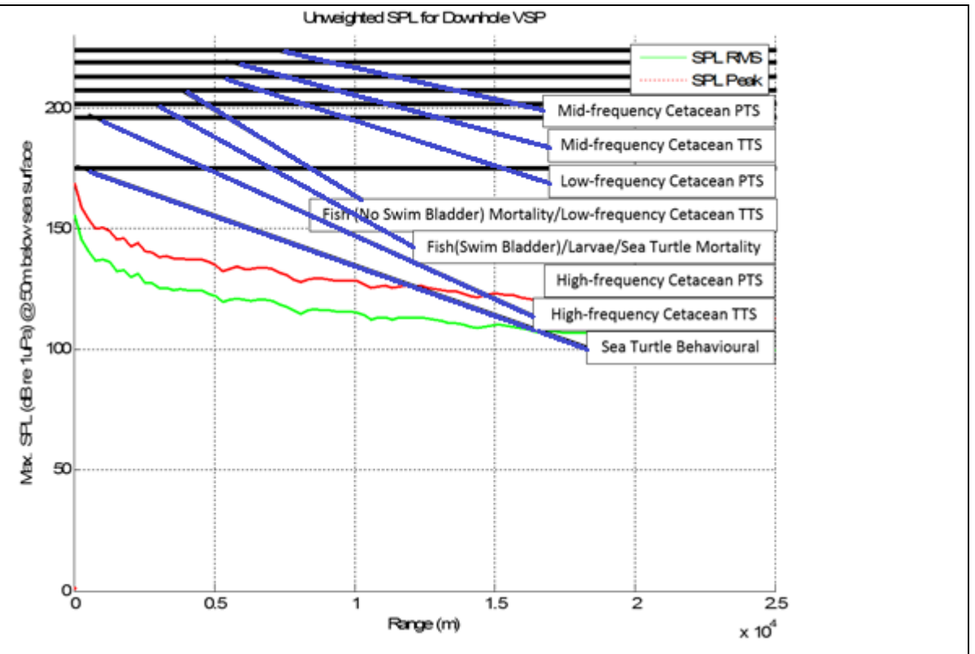
L: Maximum Mmf-Weighted $L_{E,p}$ versus Range for Drilling at Crux Platform

4.3 Downhole VSP

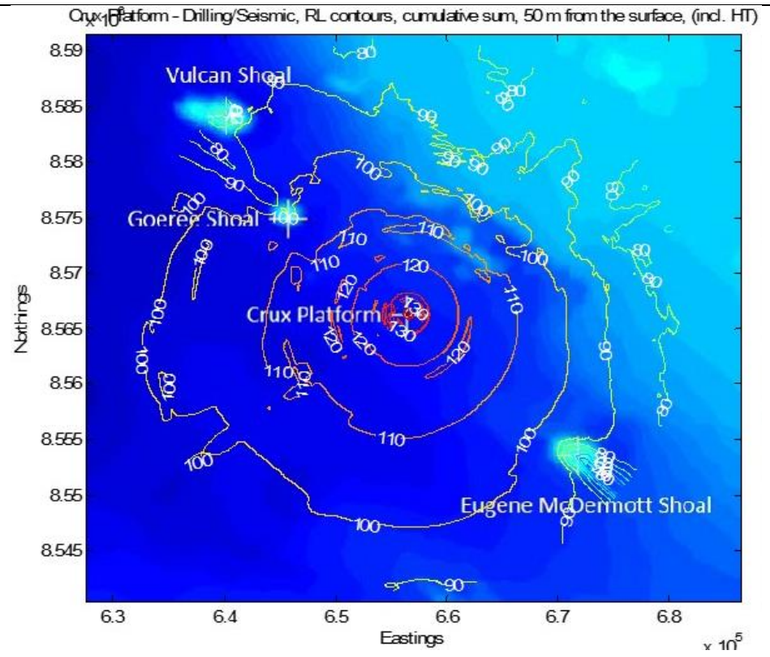
4.3.1 Sound Pressure Level for VSP activities (airgun)



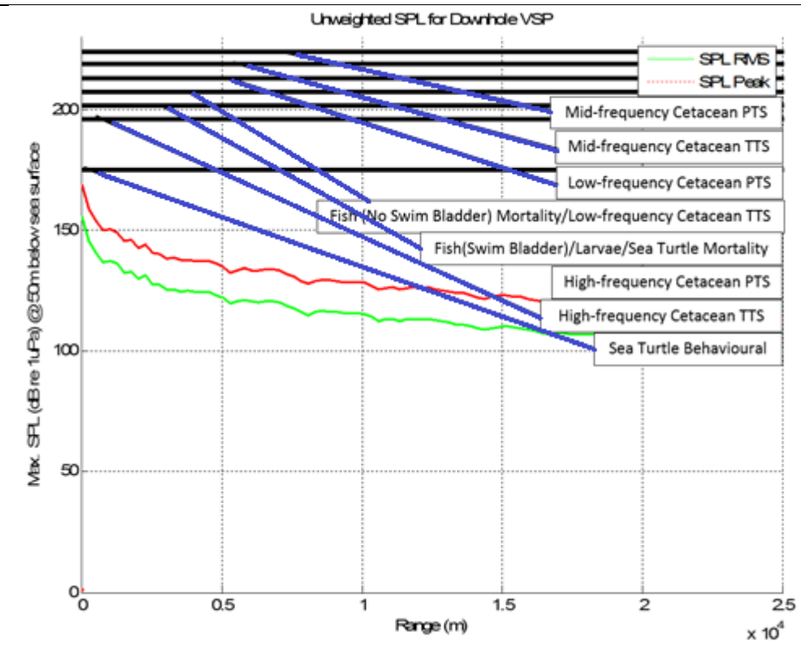
A: Noise Contour Showing L_{pk} for VSP



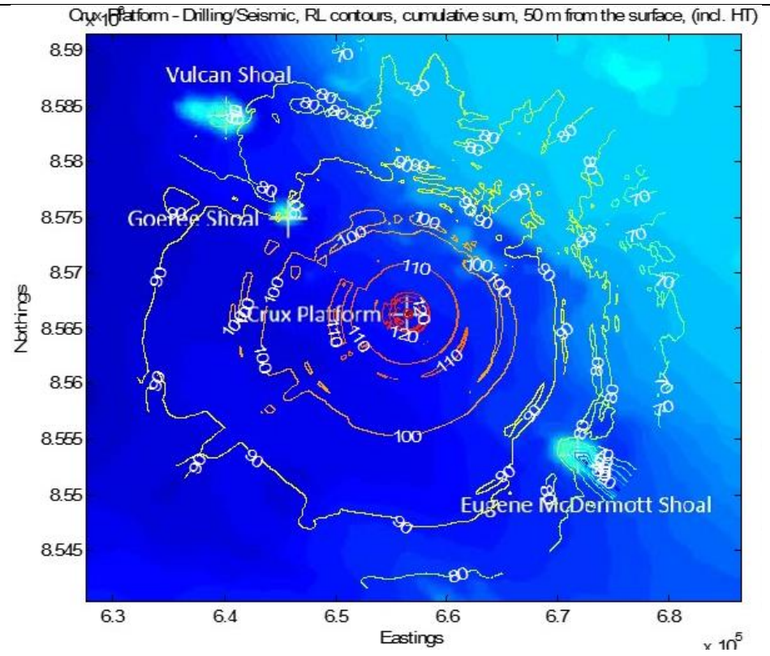
B: Maximum Unweighted L_p versus Range for VSP



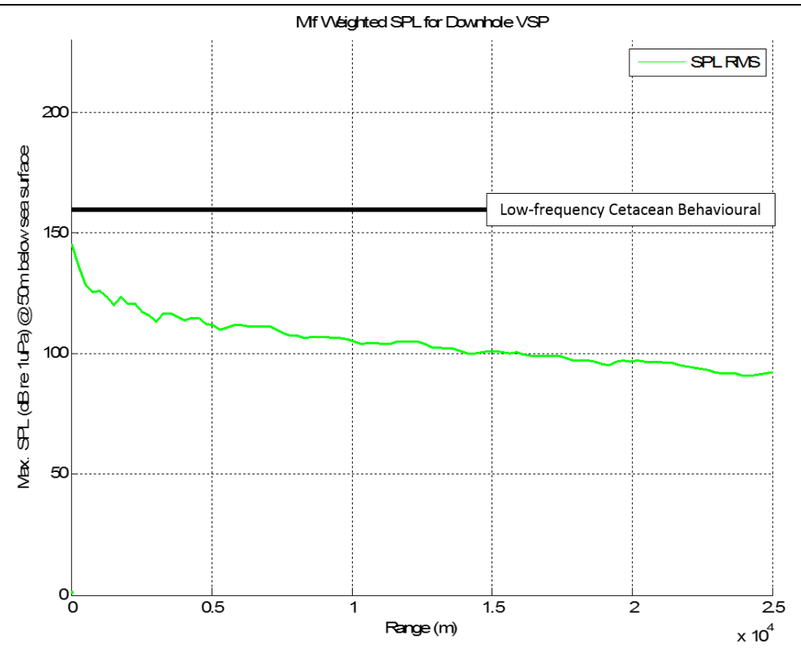
C: Noise Contour Showing Unweighted L_p for VSP



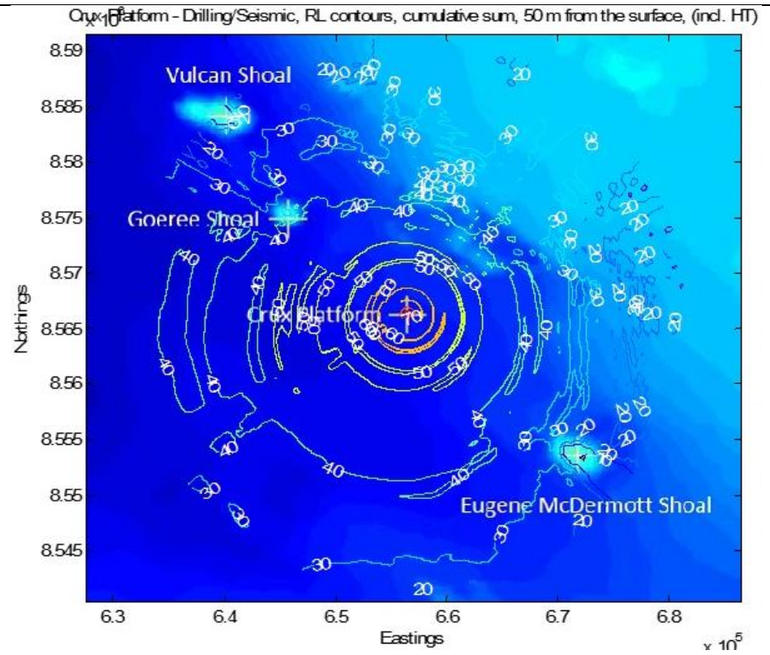
D: Maximum Unweighted L_p versus Range for VSP



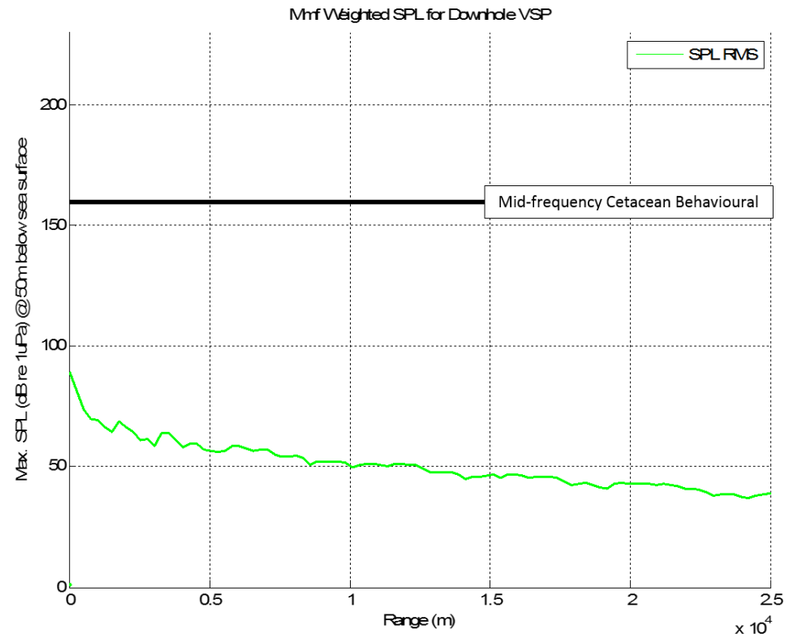
E: Noise Contour Showing Mlf-Weighted L_p for VSP



F: Maximum Mlf-Weighted L_p versus Range for VSP

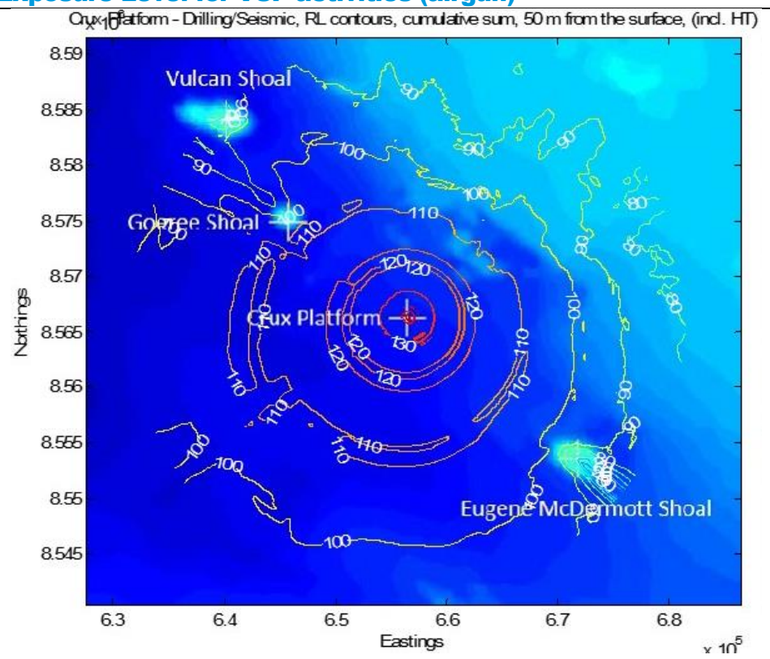


G: Noise Contour Showing Mmf-Weighted L_p for VSP

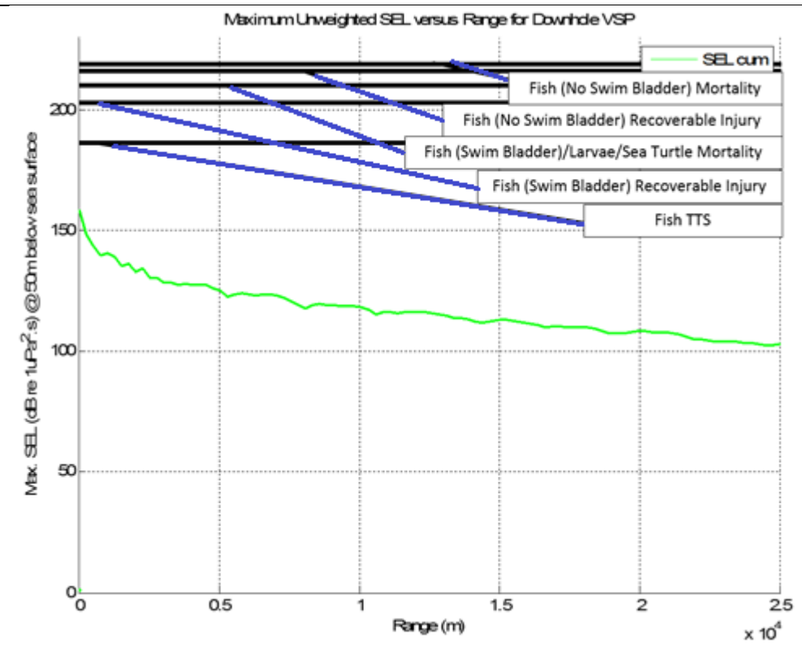


H: Maximum Mmf-Weighted L_p versus Range for VSP

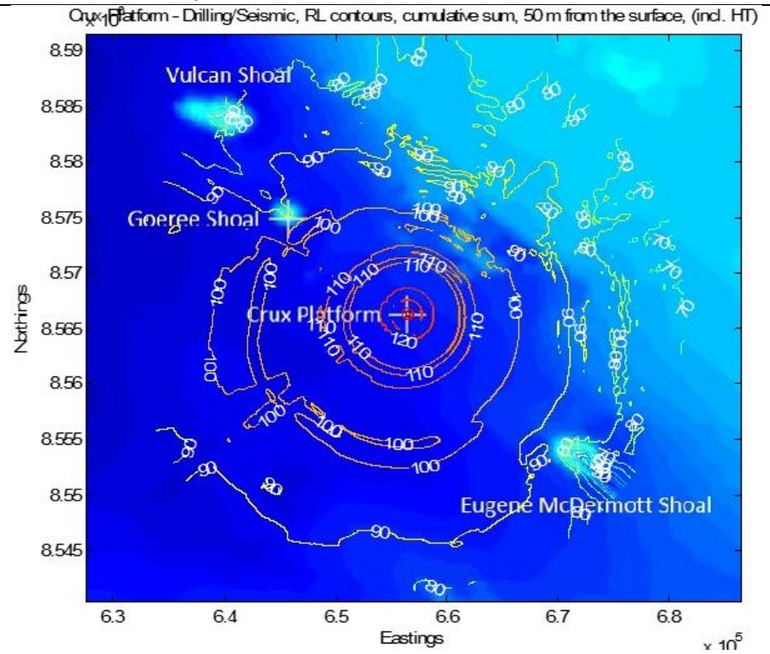
4.3.2 Sound Exposure Level for VSP activities (airgun)



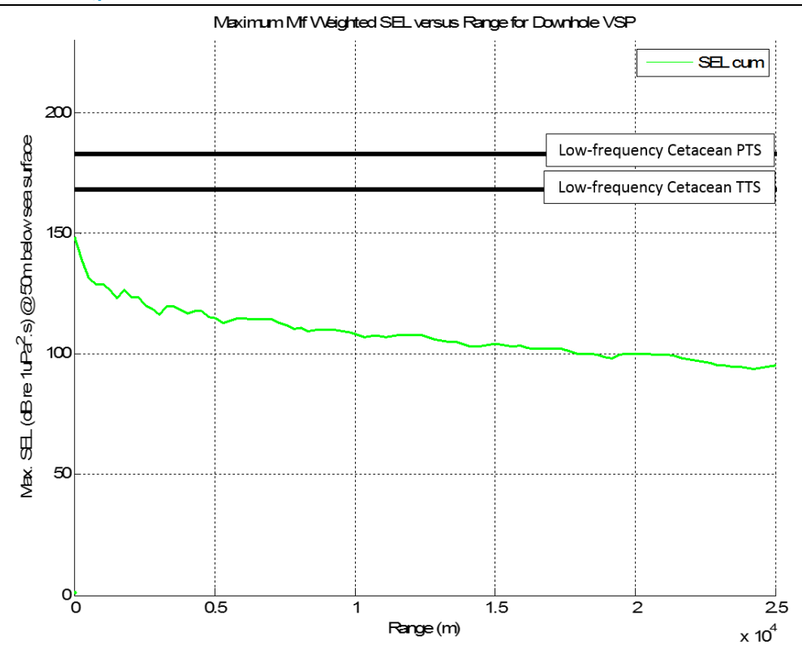
A: Noise Contour Showing Unweighted $L_{E,p}$ for VSP



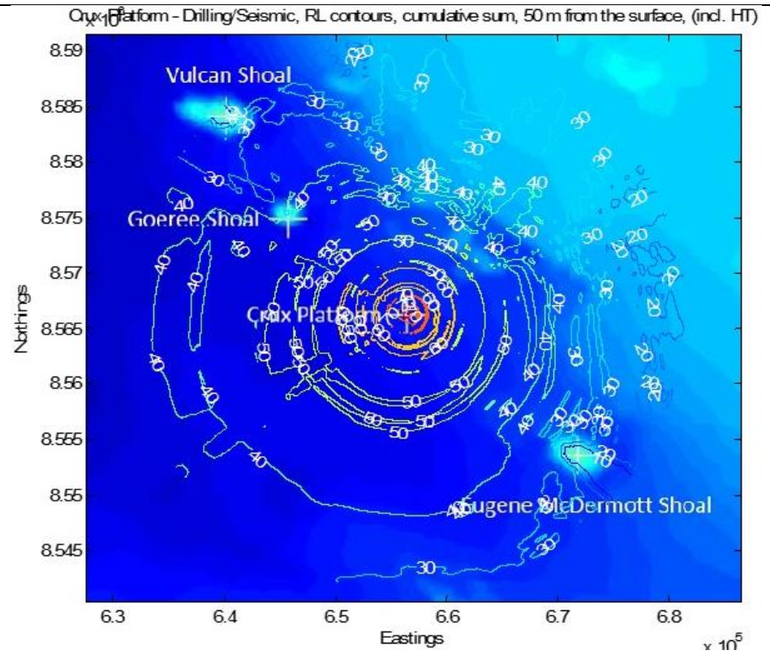
B: Maximum Unweighted $L_{E,p}$ versus Range for VSP



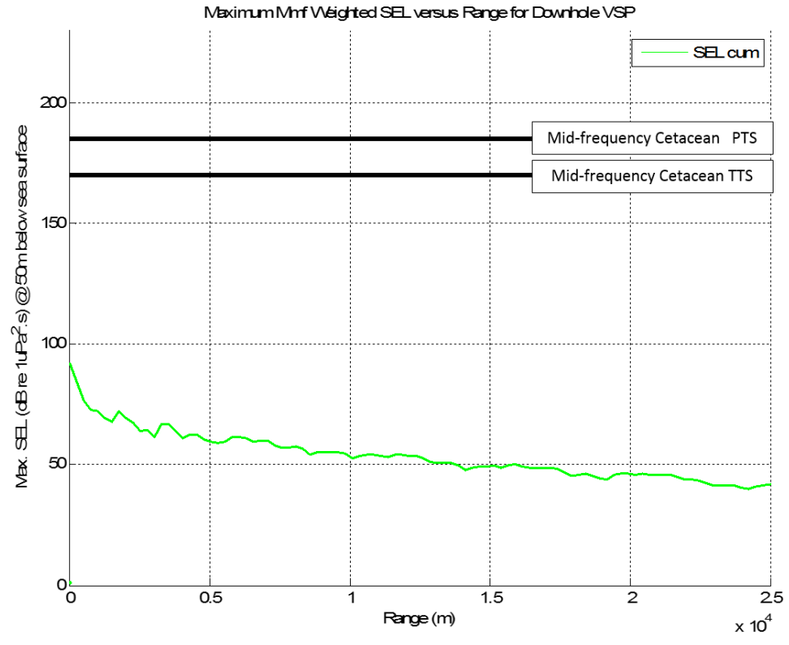
C: Noise Contour Showing MIf-Weighted $L_{E,p}$ for VSP



D: Maximum MIf-Weighted $L_{E,p}$ versus Range for VSP



E: Noise Contour Showing Mmf-Weighted $L_{E,p}$ for VSP



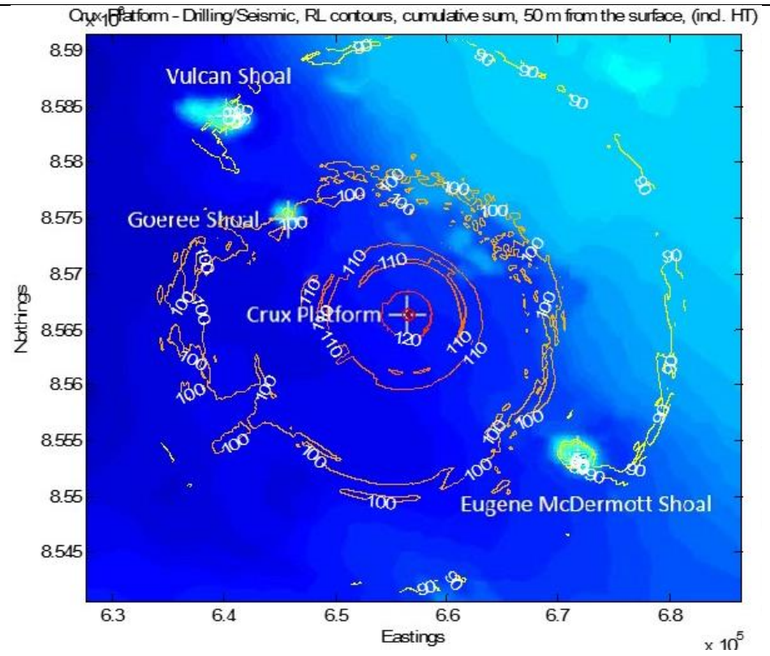
F: Maximum Mmf-Weighted $L_{E,p}$ versus Range for VSP

4.4 Operational Noise Levels

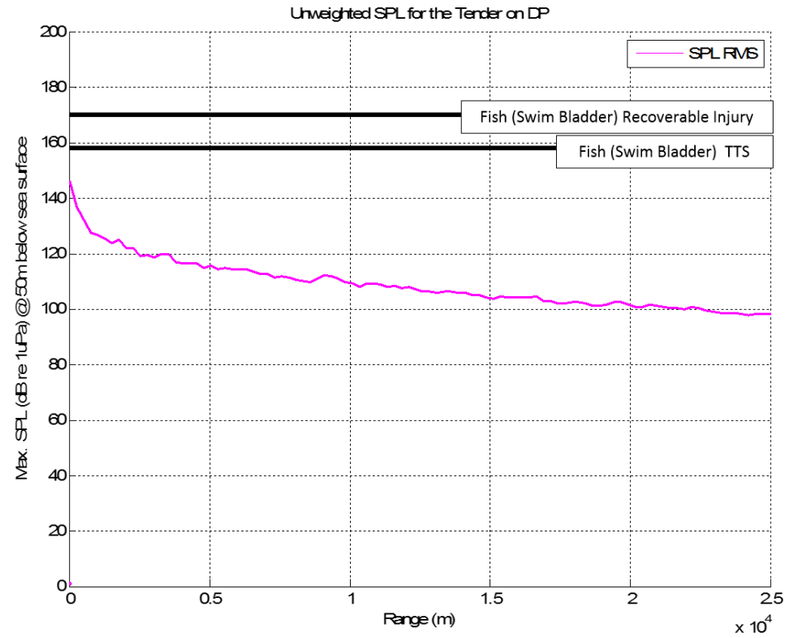
The following charts provide the noise contour (isopleth) maps for worst case operational noise levels, based on a supply boat / tender at the Crux Platform location. Adjacent to each contour plot is a plot of level with range is provided for a representative worst-case direction. On these Level-Range plots, the criteria relevant to the that particular noise index are also plotted for ease of reference.

- Unweighted L_p;
- Marine Mammal weighted L_p;
- Unweighted $L_{E,p}$ (based on 1 hr on DP); and
- Marine Mammal weighted $L_{E,p}$ (based on 1 hr on DP).

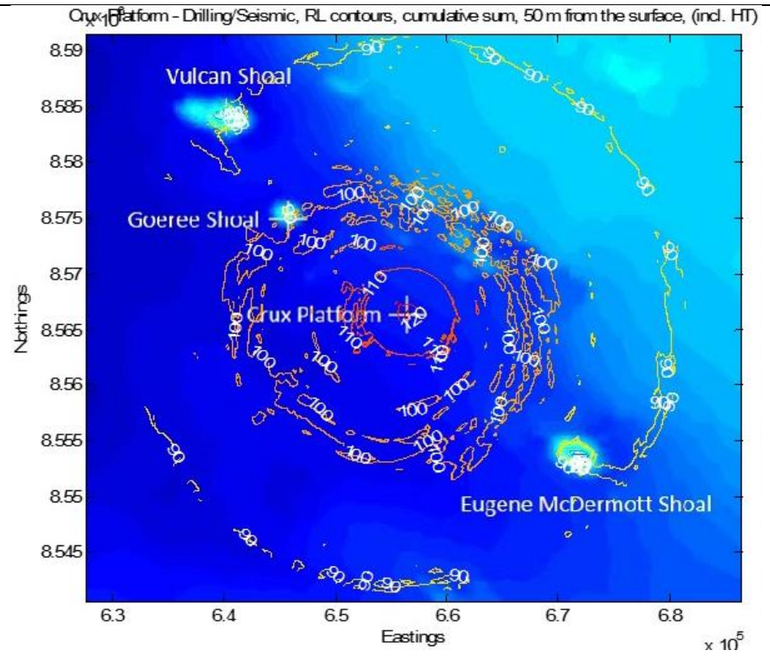
4.4.1 Scenario 8: Crux Platform Location (Tender on DP)



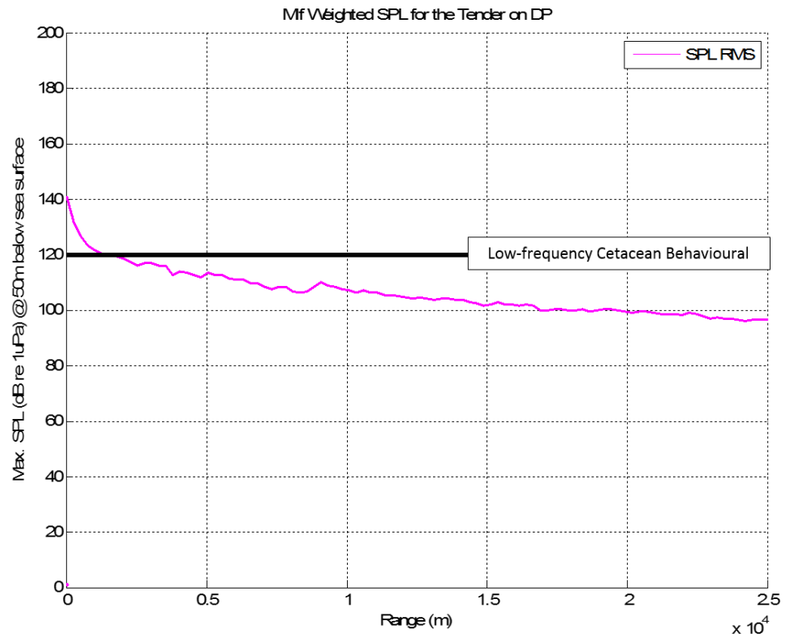
A: Noise Contour Showing Unweighted L_p for Tender on DP



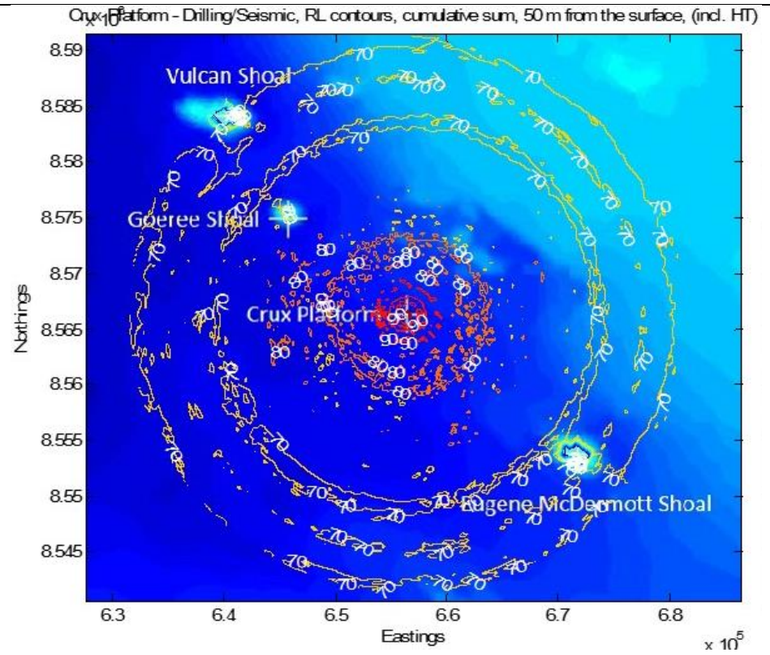
B: Maximum Unweighted L_p versus Range for Tender on DP



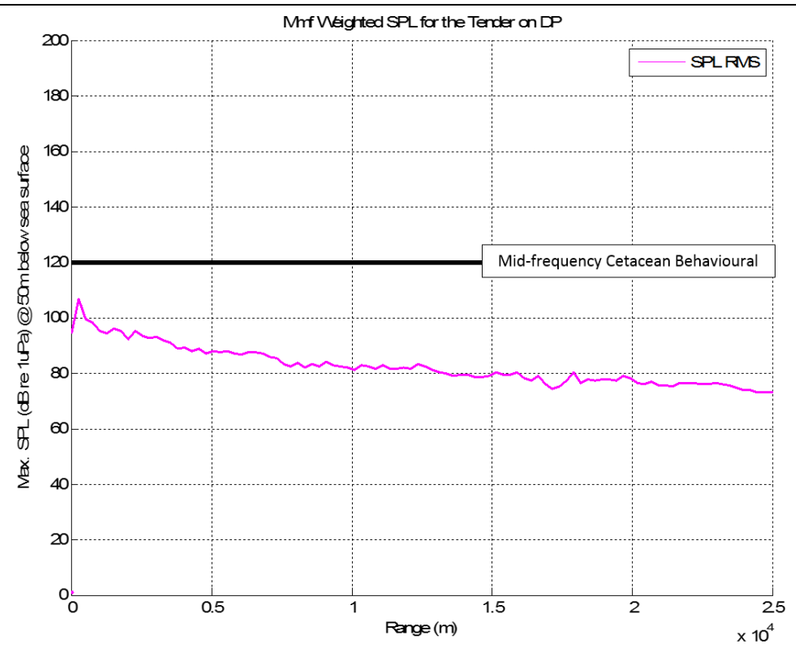
C: Noise Contour Showing Mlf-Weighted L_p for Tender on DP



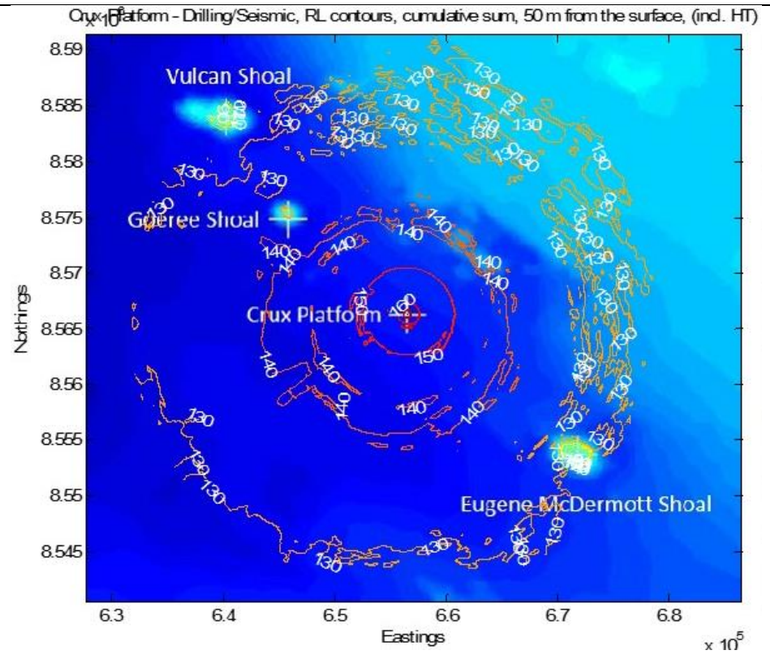
D: Maximum Mlf-Weighted L_p versus Range for Tender on DP



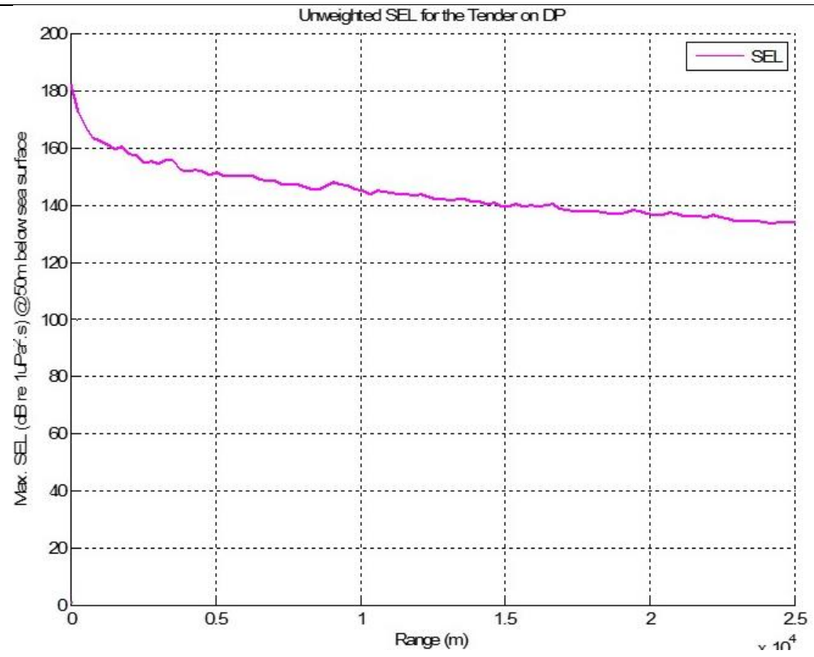
E: Noise Contour Showing Mmf-Weighted L_p for Tender on DP



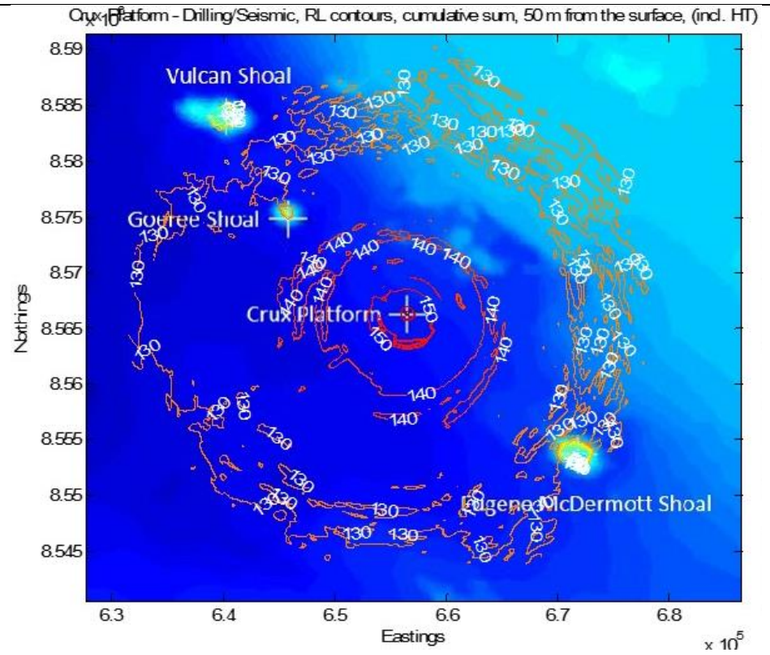
F: Maximum Mmf-Weighted L_p versus Range for Tender on DP



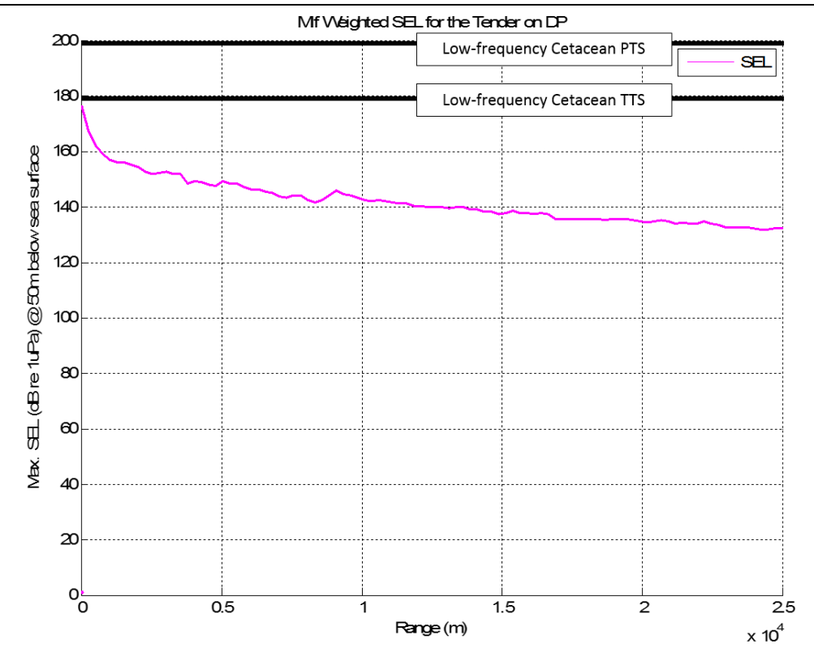
G: Noise Contour Showing Unweighted $L_{E,p}$ for Tender on DP



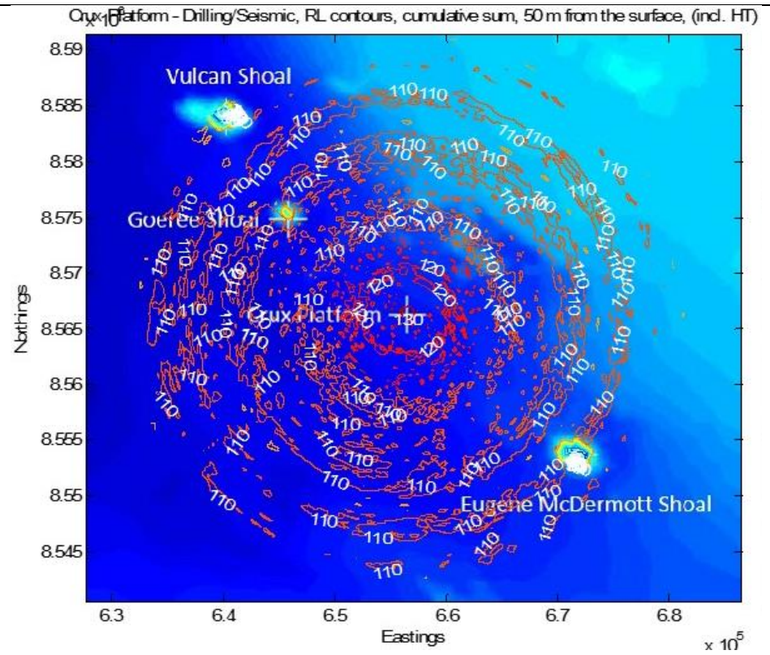
H: Maximum Unweighted $L_{E,p}$ versus Range for Tender on DP



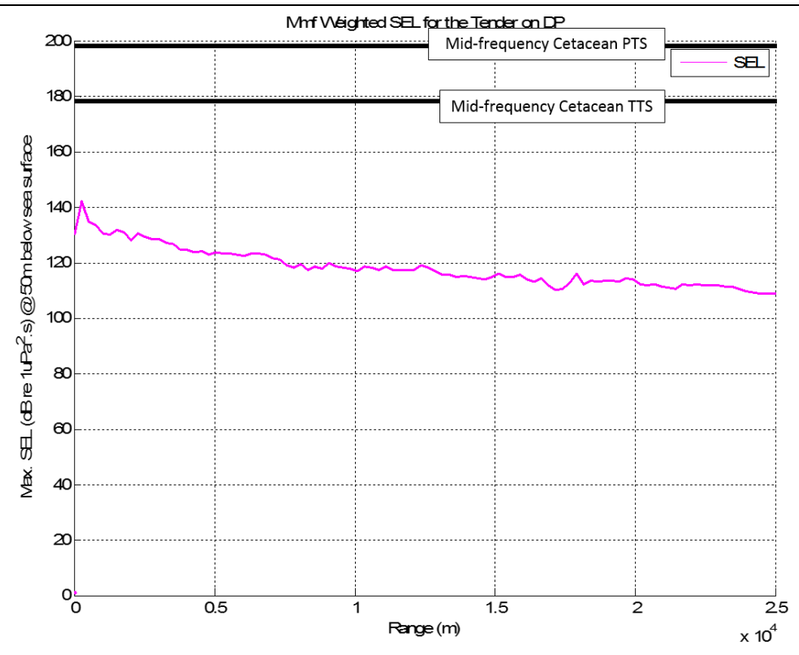
I: Noise Contour Showing Mlf-Weighted $L_{E,p}$ for Tender on DP



J: Maximum Mlf-Weighted $L_{E,p}$ versus Range for Tender on DP



K: Noise Contour Showing Mmf-Weighted $L_{E,p}$ for Tender on DP



L: Maximum Mmf-Weighted $L_{E,p}$ versus Range for Tender on DP

5. MODEL RESULTS

5.1 Overall Model Outputs

The modelled underwater noise levels have been plotted as contours for each respective piling, drilling and VSP scenarios and are presented in Section 4. Graphs of the noise levels with range (L_p, $L_{E,p}$, L_{pk}) along the worst-case bearing are also presented in Section 4.

The following tables show a summary of the range to criteria divided into three broad categories of marine fauna impacts:

- Injury or Permanent Impact;
- Temporary or Recoverable Impact; and
- Behavioural Impacts.

The range of the model predictions, extends across the supplied bathymetry, to 25 km. It should be noted that the source position for the piling has been modelled as 15m above the seabed (i.e. at a depth of 153.5m). The output data are generated for a depth of 50m as this depth correlates to the worst-case sound propagation (see Section 2.6.2). This means that the output plane does not intersect with the source location, and the nearest distance to the source represented in the results is 103.5m. Additionally, as discussed in Section 2.1.1, the model algorithm limits launching angles for sound propagation to ±40°, the effect of this at very close range can be seen in the charts.

Similarly, the sources associated with drilling have been modelled at a depth of 15m, and outputs generated for receptor depth of 50m, meaning the closest the prediction plane approached to the source position is 35m.

As discussed in Section 2.1.3 the nearfield prediction from the model will be significantly higher than the actual measured levels at close range because of the point source representation in the model. The prediction plane in each case approaches the source location to within one (1) dimension of each source, and therefore, while not as high as the model would produce if the prediction plane intersected the source point, the predictions are still expected to be higher than would be measured at these close ranges in practice.

The following conservatism in the modelling needs to be taken into account when interpreting the results:

- The prediction plane has been selected as the worst case;
- The level with range is for the worst case; and
- The point source assumption leads to high nearfield predictions.

Regarding the Sound Exposure criteria ($L_{E,p}$) the ranges assume that the assessed fauna will be stationary and present in the area for the 24 hours. In this process, NOAA acknowledges that this could lead to unrealistically large isopleths, which is a gross worst case assumption. It is possible to calculate an SEL for a moving receiver, however such a calculation requires an assumption of the receivers' path, depth(s), and speed(s) of advance. These assumptions introduce significant compounding uncertainty, especially when undertaken for open waters such as exist around this project, such that the result offers little value.

For piling, the results also assume that the pile is driven at maximum energy for the maximum number of strikes.

5.2 Pile Driving

The ranges presented in Table 5-1 to meet the $L_{E,p}$ criteria are for 6,530 strikes (1 pile) per day for the main piles. . The table shows that whales (low-frequency cetaceans) and dolphins (mid-frequency cetaceans) are the most sensitive fauna (i.e. the longest range to the criteria).

An examination of the figures in chapter 4 indicated that:

- If the number of strikes were halved, the predicted potential impact ranges for the $L_{E,p}$ criteria could reduce by 7 to 10 km; and
- If the number of strikes were reduced by a factor of 10 the predicted potential impact ranges for the $L_{E,p}$ criteria could reduce by 17 to 25 km.

Table 5-1 Ranges at which the Marine Fauna Criteria are met for Pile Driving

Marine Fauna Criteria	Main Pile, Small Hammer	Main Pile, Large Hammer
Injury or Permanent Injury Impact		
Fish (No Swim Bladder) Injury (213 dB L_{pk})	Not Reached (< 100m)	Not Reached (< 100m)
Fish (No Swim Bladder) Injury (219 dB $L_{E,p}$)	Not Reached (< 100m)	Not Reached (< 100m)
Fish, Larvae and Sea Turtle Injury (207 dB L_{pk})	Not Reached (< 100m)	Not Reached (< 100m)
Fish, Larvae and Sea Turtle Injury (210 dB $L_{E,p}$)	Not Reached (< 100m)	390 m
Low-frequency Cetacean PTS (219 dB $L_{pk)}$ dB	Not Reached (< 100m)	Not Reached (< 100m)
Low-frequency Cetacean PTS (183 $L_{E,p}$) dB(Mlf)	9.3 km	17.3 km
Mid-frequency Cetacean PTS (230 dB $L_{pk)}$ dB	Not Reached (< 100m)	Not Reached (< 100m)
Mid-frequency Cetacean PTS (185 $L_{E,p}$) dB(Mmf)	3.9 km	14 km
Invertebrates	Low Risk	Low Risk
Temporary or Recoverable Injury Impacts		
Fish TTS (186 dB $L_{E,p}$)	8.5 km	13.4 km
Fish (No Swim Bladder) Recoverable Injury[1] (216 $L_{E,p}$)	Not Reached (< 100m)	Not Reached (< 100m)
Fish (Swim Bladder) Recoverable Injury[1] (203 $L_{E,p}$)	450 m	1 km
Low-frequency Cetacean TTS (213 dB L_{pk})	Not Reached (< 100m)	Not Reached (< 100m)
Low-frequency Cetacean TTS (168 $L_{E,p}$) dB (Mlf)	38.8 km	~58 km
Mid-frequency Cetacean TTS (224 dB L_{pk})	Not Reached (< 100m)	Not Reached (< 100m)
Mid-frequency Cetacean TTS (170 $L_{E,p}$) dB (Mmf)	32.8 km	~57 km
Invertebrates	Low Risk	Low Risk
Behavioural Impacts		
Low-frequency Cetacean Behavioural (160 L_p) dB(Mlf)	1.3 km	2.7 km
Mid-frequency Cetacean Behavioural (160 L_p) dB(Mmf)	1 km	2.7 km
Invertebrates	Low Risk	Low Risk

Note 1. Recoverable injury thresholds for fish and turtles for L_{pk} are the same as those for permanent injury, and the results have therefore not been repeated in the table.
Ranges that extend beyond 40 km are based on model generated results for directions where bathymetry was available at these ranges.

5.3 Drilling Activities

5.3.1 Drilling Noise

The following table shows that all marine fauna criteria for continuous noise sources are not exceeded under any modelled drilling scenario.

Table 5-2 Ranges at Which the Marine Fauna Criteria are met during Development Drilling

Marine Fauna Criteria	Drill Rig in proximity to Eugene McDermott Shoal (1km buffer)	Drill Rig in proximity to Vulcan Shoal (1 km buffer)	Crux Platform Drilling
Injury or Permanent Injury Impact			
Low-frequency Cetacean PTS (199 $L_{E,p}$) dB(Mlf)	Not Reached (< 35m)	Not Reached (< 35m)	Not Reached (< 35m)
Mid-frequency Cetacean PTS (198 $L_{E,p}$) dB(Mmf)	Not Reached (< 35m)	Not Reached (< 35m)	Not Reached (< 35m)
Invertebrates	Low Risk	Low Risk	Low Risk
Temporary or Recoverable Injury Impacts			
Fish Recoverable Injury (170 L_p)	Not Reached (< 35m)	Not Reached (< 35m)	Not Reached (< 35m)
Fish TTS (158 L_p)	Not Reached (< 35m)	Not Reached (< 35m)	Not Reached (< 35m)
Low-frequency Cetacean TTS (179 $L_{E,p}$) dB (Mlf)	Not Reached (< 35m)	Not Reached (< 35m)	Not Reached (< 35m)
Mid-frequency Cetacean TTS (178 $L_{E,p}$) dB (Mmf)	Not Reached (< 35m)	Not Reached (< 35m)	Not Reached (< 35m)
Invertebrates	Low Risk	Low Risk	Low Risk
Behavioural Impacts			
Low-frequency Cetacean Behavioural (120 L_p) dB(Mlf)	Not Reached (< 35m)	Not Reached (< 35m)	Not Reached (< 35m)
Mid-frequency Cetacean Behavioural (120 L_p) dB(Mmf)	Not Reached (< 35m)	Not Reached (< 35m)	Not Reached (< 35m)
Invertebrates	Low Risk	Low Risk	Low Risk

5.3.2 VSP

The ranges presented in Table 5-3 to meet the $L_{E,p}$ criteria are for 10 pulses of the VSP airgun source. Ranges presented to meet L_p criteria are assuming a 0.2s signal pulse length. The following table shows that no marine fauna criteria for downhole VSP are exceeded under any modelled VSP scenario.

Table 5-3 Ranges at Which the Marine Fauna Criteria are Met during Downhole VSP

Marine Fauna Criteria	Maximum Range
Injury or Permanent Injury Impact	
Fish (No Swim Bladder) Injury (213 dB $L_{pk)}$	Not Reached (< 35m)
Fish (No Swim Bladder) Injury (219 dB $L_{E,p}$)	Not Reached (< 35m)
Fish, Larvae and Sea Turtle Injury (207 dB $L_{pk)}$	Not Reached (< 35m)
Fish, Larvae and Sea Turtle Injury (210 dB $L_{E,p}$)	Not Reached (< 35m)
Low-Frequency Cetacean PTS (219 dB $L_{pk)}$ dB	Not Reached (< 35m)
Low-frequency Cetacean PTS (183 $L_{E,p}$) dB(Mlf)	Not Reached (< 35m)
Mid-frequency Cetacean PTS (230 dB $L_{pk)}$ dB	Not Reached (< 35m)
Mid-frequency Cetacean PTS (185 $L_{E,p}$) dB(Mmf)	Not Reached (< 35m)
Invertebrates	Low Risk
Temporary or Recoverable Injury Impacts	
Fish TTS (186 dB $L_{E,p}$)	Not Reached (< 35m)
Fish (No Swim Bladder) Recoverable Injury (216 $L_{E,p}$)	Not Reached (< 35m)
Fish (Swim Bladder) Recoverable Injury (203 $L_{E,p}$)	Not Reached (< 35m)
Low-frequency Cetacean TTS (213 dB L_{pk})	Not Reached(< 35m)
Low-frequency Cetacean TTS (168 $L_{E,p}$) dB (Mlf)	Not Reached (< 35m)
Mid-frequency Cetacean TTS (224 dB L_{pk})	Not Reached (< 35m)
Mid-frequency Cetacean TTS (170 $L_{E,p}$) dB (Mmf)	Not Reached (< 35m)
Invertebrates	Low risk
Behavioural Impacts	
Low-frequency Cetacean Behavioural (160 L_p) dB(Mlf)	Not Reached (< 35m)
Mid-frequency Cetacean Behavioural (160 L_p) dB(Mmf)	Not Reached (< 35m)
Sea Turtle Behavioural (175 L_p) dB	Not Reached (< 35m)
Invertebrates	Moderate to low risk

5.3.3 Operational Noise

The ranges presented in Table 5-3 to meet the $L_{E,p}$ criteria are for the tender operating on DP, (at high propeller rates inducing significant cavitation), for a total of 1 hour. The following table shows that no marine fauna injury criteria for are exceeded under any modelled operational scenario. However, the low-frequency cetacean behavioural criterion may be exceeded by a tender on DP, provided that the animal remains within this range for the entire event.

Table 5-4 Ranges at Which the Marine Fauna Criteria are Met During Facility Operations

Marine Fauna Criteria	Tender on DP
Low-frequency Cetacean PTS (199 $L_{E,p}$) dB(Mlf)	Not Reached (< 35m)
Mid-frequency Cetacean PTS (198 $L_{E,p}$) dB(Mmf)	Not Reached (< 35m)
Invertebrates	Low Risk
Fish Recoverable Injury (170 L_p)	Not Reached (< 35m)
Fish TTS (158 L_p)	Not Reached (< 35m)
Low-frequency Cetacean TTS (179 $L_{E,p}$) dB (Mlf)	Not Reached (< 35m)
Mid-frequency Cetacean TTS (178 $L_{E,p}$) dB (Mmf)	Not Reached (< 35m)
Invertebrates	Low Risk
Low-frequency Cetacean Behavioural (120 L_p) dB(Mlf)	1.6 km
Mid-frequency Cetacean Behavioural (120 L_p) dB(Mmf)	Not Reached (< 35m)
Invertebrates	Low Risk

6. CONCLUSION

An assessment of the underwater noise generated by the piling, and drilling operations planned in the Crux development area has been undertaken. The results are summarised below.

The limiting (longest) ranges for the impact assessment are drawn in each case from the daily exposure criteria. The criteria sum the overall sound energy (from the source) received by the animal for a 24-hour period, and in this case, are calculated for 6,530 pile driving strikes. The calculation does not take account of the potential for the animal to flee outside of the affected area during the course of the activity, or the change in range inherent in the activities of a mobile receiver. Nor does the calculation take account of the possibility for the activity to be completed in a lesser number of strikes. Furthermore, the modelled sound energy per strike is based on the maximum energy expected at refusal. Therefore, the results are considered to be conservative worst-case.

6.1 Pile Driving

Permanent Injury or fatality, or Permanent Threshold Shift

Using the instantaneous assessment criteria (L_{pk} and L_p) the following results are obtained:

- The limit for onset of potential Permanent Threshold Shift for low-frequency cetaceans of 219 dB L_{pk} is not reached at any location;
- The limit for onset of potential Permanent Threshold Shift criterion for mid-frequency cetaceans of 230 dB L_{pk} is not reached at any location;
- The instantaneous permanent injury criterion for both fish (with swim bladder), larvae and sea turtles of 207 dB L_{pk} is not reached at any location; and
- The instantaneous permanent injury criterion for fish (no swim bladder) of 213 dB L_{pk} is not reached at any location.

Using the daily exposure criteria ($L_{E,p}$), which are dependent upon the number of pile driving strikes in a day and upon the presence of the receiving animal remaining in the area for the 24-hour period assessed, the following results are identified:

- The criterial for permanent injury to fish (no swim bladder) for a likely daily exposure is not reached at any location;
- There is potential for onset of permanent threshold shift in low-frequency cetaceans within a range of up to 17.3 km based on the daily exposure criterion;
- There is potential for onset of permanent threshold shift in mid-frequency cetaceans within a range of up to 14 km based on the daily exposure criterion; and
- There is potential for permanent injury to fish (with swim bladder), larvae and sea turtles within a range of up to 390 m, based on the daily exposure criterion.

The $L_{E,p}$ is a 24-hour cumulative metric that reflects the accumulated 'dose' impact of noise levels within 24 hours based on the assumption that an animal is consistently exposed to such noise levels at a fixed position. The corresponding radii are significantly larger than those for peak pressure criteria, or behavioural disturbance, but they represent an extremely unlikely worst-case scenario. More realistically, marine mammals would not stay in the same location or at the same range for 24 hours. Therefore, a reported radius of $L_{E,p}$ criteria does not mean that any animal travelling within

this radius of the source will be injured, but rather that it could be injured if it remained in that range for 24 hours. Therefore the cumulative 24-hour noise estimates are to be considered highly conservative and unlikely to represent the actual noise exposure by mobile transient marine fauna.

An examination of the noise model results indicates that:

- If the number of strikes were halved, the predicted potential impact ranges for the $L_{E,p}$ criteria could reduce by 7 to 10 km; and
- If the number of strikes were reduced by a factor of 10 the predicted potential impact ranges for the $L_{E,p}$ criteria could reduce by 17 to 25 km.

Recoverable Injury and TTS

Using the instantaneous assessment criteria (L_{pk} and L_p) the following results are obtained:

- The instantaneous recoverable injury and TTS criterion for low-frequency cetaceans of 213 dB L_{pk} is not reached at any location; and
- instantaneous recoverable injury and TTS criterion for mid-frequency cetaceans of 224 dB L_{pk} is not reached at any location.

Using the daily exposure criteria, which are dependent upon the number of pile driving strikes in a day and upon the presence of the receiving animal for the 24-hour period assessed (and taking note of the discussion above regarding the application of this criteria), the following results are identified:

- The potential for onset of TTS in low-frequency cetaceans using the daily exposure criterion extends out to a range of 57.8 km;
- The potential for onset of TTS in mid-frequency cetaceans using the daily exposure criterion extends out to a range of 56.9 km;
- The range for onset of recoverable injury for fish (with swim bladder) is met at 1 km using the daily exposure criterion;
- The range for recoverable injury for fish (no swim bladder) using the daily exposure criterion is not reached at any location; and
- There is potential for onset of TTS in fish within a range of 13.4 km using the daily exposure criterion.

Behavioural Disturbance

- The single strike (L_p) criterion for onset of behavioural disturbance to low-frequency cetaceans extends out to a range of 2.7 km; and
- The single strike (L_p) criterion for onset of mid-frequency cetacean behavioural disturbance also extends out to 2.7 km.

6.2 Drilling

6.2.1 Drilling Noise

Permanent Injury or fatality

No marine fauna PTS or permanent injury criteria are exceeded at any location for any drilling scenario modelled.

Recoverable Injury and TTS

No marine fauna Recoverable injury or TTS criteria are exceeded at any location for any drilling scenario modelled.

Behavioural Disturbance

No marine fauna behavioural disturbance criteria are exceeded at any location for any drilling scenario modelled.

6.2.2 VSP

No marine fauna criteria are exceeded at any location for any VSP scenario modelled.

6.3 Operational Noise

Permanent Injury or fatality

No marine fauna criteria PTS or permanent injury are exceeded at any location for any drilling scenario modelled.

Recoverable Injury and TTS

- There is potential for permanent injury to low-frequency cetaceans within a range of up to 350 m based on the daily exposure criterion (Tender on DP scenario), if the animal remains with this range for the duration of the event.

Marine fauna criteria for fish, larvae, sea turtles and mid-frequency cetaceans are not exceeded at any location for any operational scenario modelled.

Behavioural Disturbance

- The L_p criterion for behavioural disturbance to low-frequency cetaceans extends out to a range of 1.6 km (Tender on DP Scenario).

Marine fauna criteria for fish, larvae, sea turtles and mid-frequency cetaceans are not exceeded at any location for any operational scenario modelled.

7. REFERENCES

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APPENDIX A UNDERWATER NOISE MODEL

Appendix A-1 Underwater Noise Model Selection

Various numerical techniques are used to develop underwater acoustic propagation models, including wavenumber integration, ray theory, normal modes, parabolic equation (PE) and finite differences/finite elements. When determining which model is to be used for the modelling prediction, it is necessary to define the application for which it is to be used and the type of underwater environment it is going to simulate. For the model applied in this assessment, the underwater environment has the following characteristics:

- Strong range dependence
- A deep and shallow water ocean environment
- Differing bottom types

Parabolic Equation (PE) models are capable of making predictions in various conditions: shallow water, areas that have changing bottom types and under environmental conditions that are range dependent. A PE model called the Monterey Miami Parabolic Equation (MMPE) model was selected because it has been benchmark-tested for shallow water environments. The PE model is a well-recognized algorithm for transmission loss prediction and is widely used in the field of underwater acoustics. SVT have validated the model in multiple instances, for example: seismic survey modelling in Bassett Field (SVT for Total, 'Underwater Noise Modelling Validation and Results for 3D Seismic Survey in Bassett Field', 2010, Job Ref: 1052786-3-200).

The MMPE is a broadband model, and makes use of transmission loss calculations at multiple frequencies. With higher frequency comes greater computational overhead, and therefore to speed up the modelling process an upper-bound on frequency must be chosen. SVT chose to model frequencies from 20 Hz to 4 kHz, which is considered as being reasonable since most of the pile energy is in the first 4 kHz. This is a standard approach that has been followed by others such as, for example, the Centre for Marine Science and Technology (CMST) at Curtin University.

Furthermore, the absorption of sound in sea water increases significantly with high frequencies. Jensen et al. [14] provide the well-recognised expression for the frequency dependence of attenuation (see equation A.1), where α is the attenuation in dB/km and f is the frequency of the sound in kHz.

$$\alpha = (3.3)(10^{-3}) + \frac{0.11f^2}{1+f^2} + \frac{44f^2}{4100+f^2} + (3.0)(10^{-4}) \qquad \text{(A.1)}$$

Using this equation will result in 4.1 dB/km attenuation for a sound wave at 20 kHz, compared to 0.8 dB/km at 8 kHz and 0.1 dB/km at 2 kHz.

Appendix A-2 Seabed Sound Propagation Effects

Sound propagates both through the water and through the sea bed due to efficient transmission due to their similar acoustic impedances. This is not the case with the air-water boundary at the sea surface. Therefore the effect of airborne propagation can be assumed insignificant, and more importantly the surface will act as a near perfect reflector of underwater sound. Bottom loss must also be considered and is a function of the bottom type and the grazing angle. The limiting frequency f_0 below which no propagation is possible within the sediment is given by equation B.6:

$$f_0 = \frac{c_{water}}{4h}\sqrt{\frac{1}{1-(c_{water}/\,c_{sediment})^2}} \qquad \text{(B.6)}$$

APPENDIX B PRINCIPLES OF UNDERWATER NOISE

Appendix B-1 Sound Pressure Level

Sound Pressure Level – The RMS level of sound at the instant (or in practice within one second) of the noise occurring. Since sound travels as a pressure wave, with high and low pressure amplitudes, the sound pressure level is always varying in time. Sound pressure level is expressed in dB, with relation to a reference sound pressure p_{ref}. The mathematical definition of sound pressure level (L_p) is:

$$L_P = 10 \log_{10}\left(\frac{\overline{p^2}}{p_{ref}^2}\right) \quad \text{(B.1)}$$

(SPL is the commonly used descriptor for sound pressure level in a number of historical published documents, however the official standard descriptor is L_p. For clarity and consistency with ISO 18405:2007 SVT uses L_p in this report.)

Because sound pressure is a continuously varying value, it is useful to average the sound pressure over a certain time period, to provide a reliable and meaningful comparison of the amplitude of sound. This averaging is conducted on an energy basis, and because sound pressure is varying about a zero mean pressure, the root mean square (rms) is used. In airborne acoustics, this averaging yields a value commonly referred to as the *Equivalent Level*, or L_{eq}. While L_{eq} is the commonly accepted and used notation, the official standard term and notation for this value is *Time Averaged Level*, L_T.

In a number of publications regarding the impact of underwater noise, "SPL" has been used as the descriptor for continuous received noise upon which the proposed assessment criteria are based. In these documents the term sound pressure level has been defined as an *averaged* sound pressure. This definition, mathematically, is the same as that for the Time Averaged Level, discussed above.

Additional opportunity for confusion has arisen in the field since the NOAA guidelines (2016) [17] have reverted to the original definition of "SPL".

Since SVT is referring in this document to criteria that use the "SPL descriptor", and this descriptor was intended to mean an averaged level by the author of the publication, SVT will use L_p in this document to mean a time averaged level of rms sound pressure. Therefore, for this document, the following definition of Sound Pressure Level is adopted:

Sound Pressure Level (L_p) is defined as the sound pressure, relative to some reference pressure, averaged over the time period T. For underwater acoustics, the reference pressure is generally taken to be p_{ref} = 1 µPa. Mathematically this is expressed as:

$$L_p = 10 \log_{10}\left(\frac{1}{T}\int_0^T \frac{p(t)^2}{p_{ref}^2} dt\right) \quad \text{(B.2)}$$

Appendix B-2 Sound Exposure Level

The Sound Exposure Level ($L_{E,p}$), also known as the energy flux density, the constant sound pressure level that if maintained for one second, would deliver the same total sound energy as the original source. It is usually used to describe discrete noise events. SEL is the commonly used (ANSI defined) descriptor for sound exposure level such as it is used in the NOAA guidelines [17], however the official standard descriptor is $L_{E,p}$,. For conformity to ISO 18405:2007 SVT has used the $L_{E,p}$ notation in this study.

The Sound Exposure Level is especially useful as it can be used in an accumulative context by summing all energy over an extended time period T, or over N discrete events, to find the total received sound energy level. The disturbance and injury criteria for marine life is commonly given in $L_{E,p}$ for impulsive noise sources such as pile-driving, and $L_{E,p}$ (i.e. SEL) is also used by NOAA [17] for newer criteria even for non-impulsive sources.

$$L_{E,p} = 10\ \log_{10}\left(\int_0^T \frac{p(t)^2}{p_{ref}^2} dt\right) \quad \text{(B.3)}$$

In deriving the $L_{E,p}$ for a continuous source, the time T should be taken as 1 second.

The Cumulative $L_{E,p}$ (denoted SEL_{cum} in ANSI standards and ANSI compliant publications such as the NOAA guidelines) is the total sound energy for a set number of discrete events, or in the instance of a continuous source, for the total period under consideration.

For *n* pulses, the cumulative $L_{E,p}$ can be derived from the single pulse $L_{E,p}$ by equation B.4:

$$L_{E,p} = L_{E,p\ (single\ event)} + 10\log(n) \quad \text{(B.4)}$$

For *a continuous source*, the cumulative $L_{E,p}$ for a defined exposure time T can be can be derived from the $L_{E,p}$ by equation B.5:

$$L_{E,p} = L_{E,p}\ + 10\log(T) \quad \text{(B.5)}$$

Appendix B-3 Other Descriptors of Sound

Hz — Hertz, the SI unit of frequency, meaning cycles per second.

Impulsive — Sound sources that produce sounds that are typically transient, brief (less than 1 second), broadband, and consist of high peak sound pressure with rapid rise time and rapid decay (ANSI 1986; NIOSH 1998; ANSI 2005). They can occur in repetition or as a single event. Examples of impulsive sound sources include: explosives, seismic airguns, and impact pile drivers [17].

L_{pk} — The absolute maximum peak pressure level (not RMS or mean level) reached at any time within the measurement period. L_{pk} gives a true representation of the actual maximum physical pressure of an acoustic wave.

Crest Factor — The peak amplitude of the waveform divided by the RMS value of the waveform. The Crest Factor describes the how the peak of a wave form relates the average (rms) level. The Crest Factor is also sometimes called the Peak to Average Ratio (PAR) when expressed in engineering units (i.e. for sound when expressed as

pressure (Pa). Because sound is typically expressed in dB, (a logarithmic unit) and log(ab) = Log(a) + Log(b), when the crest factor is expressed in dB it is the difference between the peak value and the mean value, i.e. CF = L_{pk} - L_p

Octave Band — A 'constant percentage bandwidth' where each successive band centre frequency is double the previous one. International standards define nominal centre frequencies of 16 Hz, 31.5Hz, 63Hz, 125Hz, 250Hz, 500Hz, 1kHz, 2kHz, 4kHz, 8kHz, and 16kHz. Each octave band has a bandwidth which is proportional to the frequency so that there are no gaps or overlaps between bands. A separate noise level can be measured for each band, allowing definition of the frequency content of the noise.

Non-Impulsive — Sound sources that produce sounds that can be broadband, narrowband or tonal, brief or prolonged, continuous or intermittent) and typically do not have a high peak sound pressure with rapid rise time that impulsive sounds do. Examples of non-impulsive sound sources include: marine vessels, machinery operations/construction (e.g., drilling), and vibratory pile drivers [17].

Pa — Pascal, the SI unit for pressure.

RMS — Root Mean Square – the mathematical means by which a regularly oscillating signal is 'averaged' such that the result is not zero.

SSP — Sound Speed Profile – A table or graph showing how the speed of sound varies in a fluid (usually a body of water). The speed of sound in water is dependent upon temperature, pressure, and salinity. Differing speeds of sound through the water column causes refraction and in some cases reflection of the sound waves, and is therefore an important consideration in underwater noise propagation modelling.

Tonality — A qualitative term used to identify when a noticeable tone or series of tones are detectable. In environmental noise this can be used to can be used describe noise that may be more annoying (due to its frequency content), than other noise of a similar overall level – when it is so used, the appropriate authority will usually define a quantitative means for determining when a noise demonstrates 'tonality'.

Appendix B-4 Effects of Noise

PTS — Permanent Threshold Shift - A permanent, irreversible increase in the threshold of audibility at a specified frequency or portion of an individual's hearing range above a previously established reference level [17]. Noise-induced PTS represents tissue injury [16].

TTS — A temporary, reversible increase in the threshold of audibility at a specified frequency or portion of an individual's hearing range above a previously established reference level [17]. Although TTS involves reduced hearing sensitivity following exposure, it results primarily from the fatigue (as opposed to loss) of cochlear hair cells and supporting structures and is, by definition, reversible. Since TTS represents a temporary change in sensitivity without permanent damage to sensory cells or support structures, it is not considered to represent tissue injury [16].

Behavioural Disturbance — Encompasses a broad range of potential responses to noise, including but not limited to: orienting to hear it; investigating it; changes or interruptions to normal behaviour (feeding, breeding, communicating etc), and panic or fleeing.

Appendix B-5 M Weighting

To account for the different hearing frequency ranges for marine mammals, particularly when criteria are set for cumulative energy exposure (such as L_p or $L_{E,p}$) and for disturbance criteria, weightings have been developed for each species group. The weightings provided by NOAA as applied in this report are presented below.

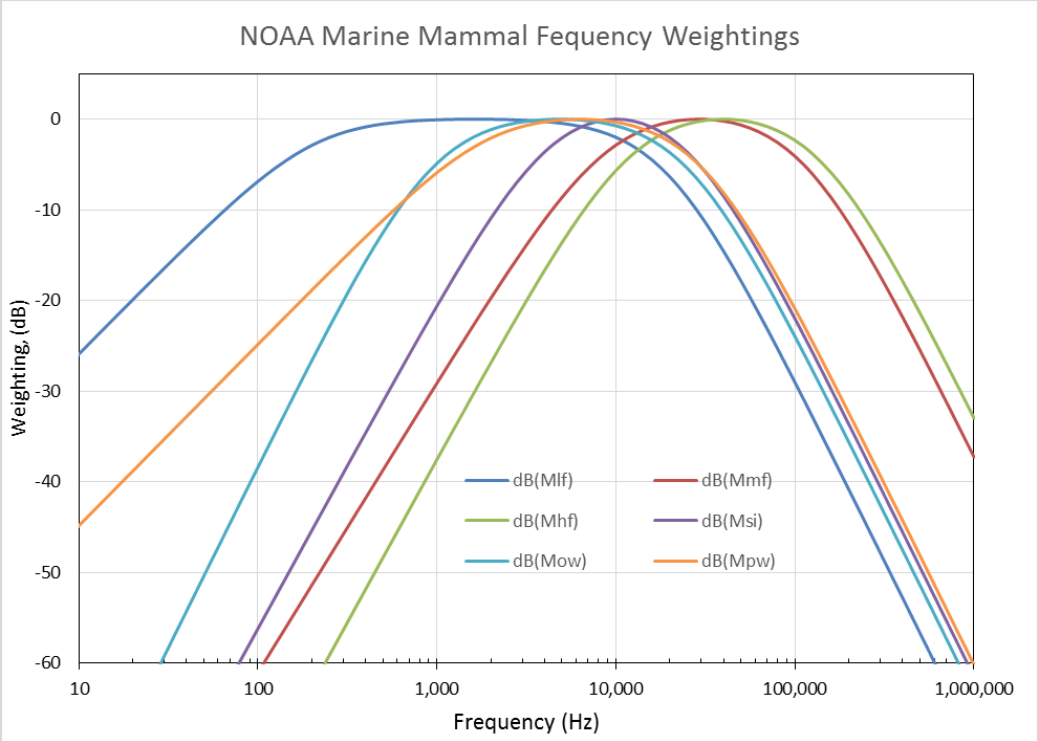


Figure B - 1 NOAA Marine Mammal Frequency Weightings

Appendix J: EPBC Protected Matter Search Results

Australian Government
Department of the Environment and Energy

EPBC Act Protected Matters Report

This report provides general guidance on matters of national environmental significance and other matters protected by the EPBC Act in the area you have selected.

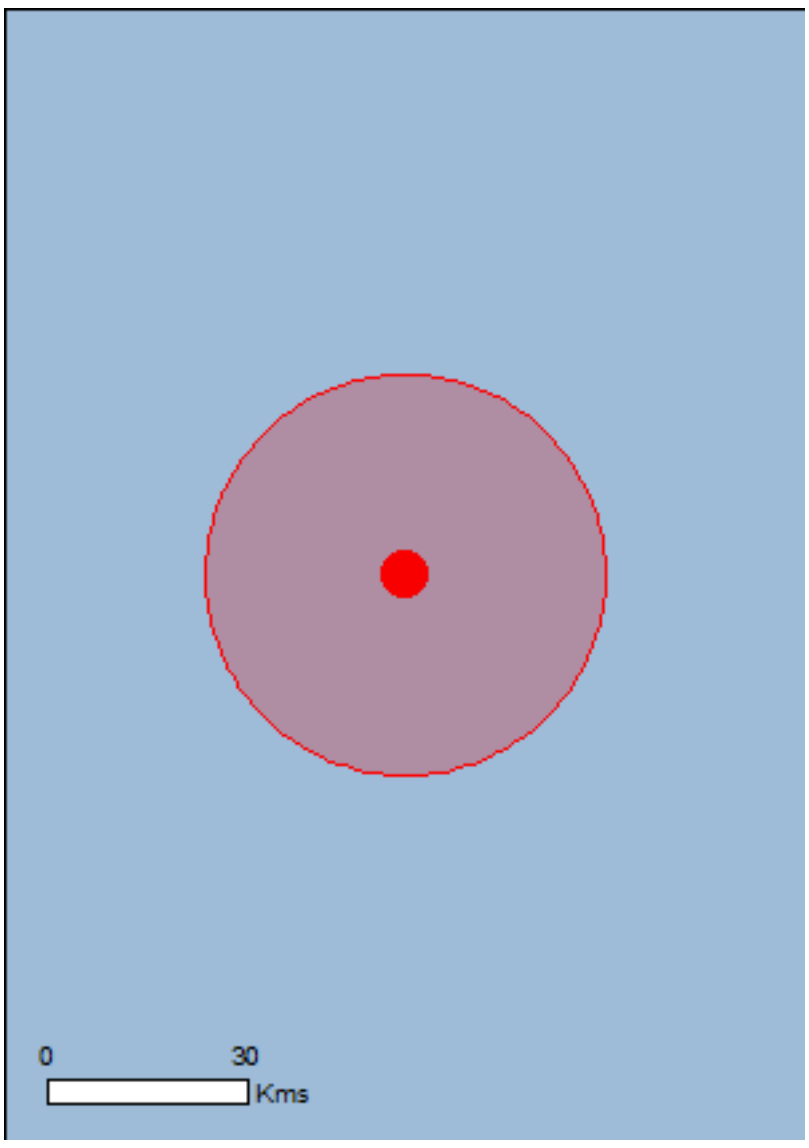
Information on the coverage of this report and qualifications on data supporting this report are contained in the caveat at the end of the report.

Information is available about Environment Assessments and the EPBC Act including significance guidelines, forms and application process details.

Report created: 21/08/18 11:34:02

Summary
Details
- Matters of NES
- Other Matters Protected by the EPBC Act
- Extra Information

Caveat
Acknowledgements



This map may contain data which are ©Commonwealth of Australia (Geoscience Australia), ©PSMA 2010

Coordinates
Buffer: 30.0Km



Summary

Matters of National Environmental Significance

This part of the report summarises the matters of national environmental significance that may occur in, or may relate to, the area you nominated. Further information is available in the detail part of the report, which can be accessed by scrolling or following the links below. If you are proposing to undertake an activity that may have a significant impact on one or more matters of national environmental significance then you should consider the Administrative Guidelines on Significance.

World Heritage Properties:	None
National Heritage Places:	None
Wetlands of International Importance:	None
Great Barrier Reef Marine Park:	None
Commonwealth Marine Area:	1
Listed Threatened Ecological Communities:	None
Listed Threatened Species:	20
Listed Migratory Species:	33

Other Matters Protected by the EPBC Act

This part of the report summarises other matters protected under the Act that may relate to the area you nominated. Approval may be required for a proposed activity that significantly affects the environment on Commonwealth land, when the action is outside the Commonwealth land, or the environment anywhere when the action is taken on Commonwealth land. Approval may also be required for the Commonwealth or Commonwealth agencies proposing to take an action that is likely to have a significant impact on the environment anywhere.

The EPBC Act protects the environment on Commonwealth land, the environment from the actions taken on Commonwealth land, and the environment from actions taken by Commonwealth agencies. As heritage values of a place are part of the 'environment', these aspects of the EPBC Act protect the Commonwealth Heritage values of a Commonwealth Heritage place. Information on the new heritage laws can be found at http://www.environment.gov.au/heritage

A permit may be required for activities in or on a Commonwealth area that may affect a member of a listed threatened species or ecological community, a member of a listed migratory species, whales and other cetaceans, or a member of a listed marine species.

Commonwealth Land:	None
Commonwealth Heritage Places:	None
Listed Marine Species:	61
Whales and Other Cetaceans:	25
Critical Habitats:	None
Commonwealth Reserves Terrestrial:	None
Australian Marine Parks:	None

Extra Information

This part of the report provides information that may also be relevant to the area you have nominated.

State and Territory Reserves:	None
Regional Forest Agreements:	None
Invasive Species:	None
Nationally Important Wetlands:	None
Key Ecological Features (Marine)	1

Details

Matters of National Environmental Significance

Commonwealth Marine Area [Resource Information]

Approval is required for a proposed activity that is located within the Commonwealth Marine Area which has, will have, or is likely to have a significant impact on the environment. Approval may be required for a proposed action taken outside the Commonwealth Marine Area but which has, may have or is likely to have a significant impact on the environment in the Commonwealth Marine Area. Generally the Commonwealth Marine Area stretches from three nautical miles to two hundred nautical miles from the coast.

Name

EEZ and Territorial Sea

Marine Regions [Resource Information]

If you are planning to undertake action in an area in or close to the Commonwealth Marine Area, and a marine bioregional plan has been prepared for the Commonwealth Marine Area in that area, the marine bioregional plan may inform your decision as to whether to refer your proposed action under the EPBC Act.

Name

North-west

Listed Threatened Species [Resource Information]

Name	Status	Type of Presence
Birds		
Anous tenuirostris melanops Australian Lesser Noddy [26000]	Vulnerable	Species or species habitat may occur within area
Calidris canutus Red Knot, Knot [855]	Endangered	Species or species habitat may occur within area
Calidris ferruginea Curlew Sandpiper [856]	Critically Endangered	Species or species habitat may occur within area
Numenius madagascariensis Eastern Curlew, Far Eastern Curlew [847]	Critically Endangered	Species or species habitat may occur within area
Papasula abbotti Abbott's Booby [59297]	Endangered	Species or species habitat may occur within area
Mammals		
Balaenoptera borealis Sei Whale [34]	Vulnerable	Species or species habitat likely to occur within area
Balaenoptera musculus Blue Whale [36]	Endangered	Species or species habitat likely to occur within area
Balaenoptera physalus Fin Whale [37]	Vulnerable	Species or species habitat likely to occur within area
Megaptera novaeangliae Humpback Whale [38]	Vulnerable	Species or species

Name	Status	Type of Presence
		habitat likely to occur within area
Reptiles		
Caretta caretta Loggerhead Turtle [1763]	Endangered	Foraging, feeding or related behaviour likely to occur within area
Chelonia mydas Green Turtle [1765]	Vulnerable	Foraging, feeding or related behaviour known to occur within area
Dermochelys coriacea Leatherback Turtle, Leathery Turtle, Luth [1768]	Endangered	Foraging, feeding or related behaviour likely to occur within area
Eretmochelys imbricata Hawksbill Turtle [1766]	Vulnerable	Foraging, feeding or related behaviour likely to occur within area
Lepidochelys olivacea Olive Ridley Turtle, Pacific Ridley Turtle [1767]	Endangered	Foraging, feeding or related behaviour likely to occur within area
Natator depressus Flatback Turtle [59257]	Vulnerable	Species or species habitat known to occur within area
Sharks		
Carcharodon carcharias White Shark, Great White Shark [64470]	Vulnerable	Species or species habitat may occur within area
Glyphis garricki Northern River Shark, New Guinea River Shark [82454]	Endangered	Species or species habitat may occur within area
Pristis pristis Freshwater Sawfish, Largetooth Sawfish, River Sawfish, Leichhardt's Sawfish, Northern Sawfish [60756]	Vulnerable	Species or species habitat known to occur within area
Pristis zijsron Green Sawfish, Dindagubba, Narrowsnout Sawfish [68442]	Vulnerable	Species or species habitat known to occur within area
Rhincodon typus Whale Shark [66680]	Vulnerable	Foraging, feeding or related behaviour known to occur within area

Listed Migratory Species		[Resource Information]
* Species is listed under a different scientific name on the EPBC Act - Threatened Species list.		
Name	Threatened	Type of Presence
Migratory Marine Birds		
Anous stolidus Common Noddy [825]		Species or species habitat may occur within area
Calonectris leucomelas Streaked Shearwater [1077]		Species or species habitat likely to occur within area
Fregata ariel Lesser Frigatebird, Least Frigatebird [1012]		Species or species habitat likely to occur within area
Fregata minor Great Frigatebird, Greater Frigatebird [1013]		Species or species habitat may occur within area
Migratory Marine Species		
Anoxypristis cuspidata Narrow Sawfish, Knifetooth Sawfish [68448]		Species or species

Name	Threatened	Type of Presence
		habitat may occur within area
[Balaenoptera borealis](#) Sei Whale [34]	Vulnerable	Species or species habitat likely to occur within area
[Balaenoptera edeni](#) Bryde's Whale [35]		Species or species habitat likely to occur within area
[Balaenoptera musculus](#) Blue Whale [36]	Endangered	Species or species habitat likely to occur within area
[Balaenoptera physalus](#) Fin Whale [37]	Vulnerable	Species or species habitat likely to occur within area
[Carcharodon carcharias](#) White Shark, Great White Shark [64470]	Vulnerable	Species or species habitat may occur within area
[Caretta caretta](#) Loggerhead Turtle [1763]	Endangered	Foraging, feeding or related behaviour likely to occur within area
[Chelonia mydas](#) Green Turtle [1765]	Vulnerable	Foraging, feeding or related behaviour known to occur within area
[Dermochelys coriacea](#) Leatherback Turtle, Leathery Turtle, Luth [1768]	Endangered	Foraging, feeding or related behaviour likely to occur within area
[Eretmochelys imbricata](#) Hawksbill Turtle [1766]	Vulnerable	Foraging, feeding or related behaviour likely to occur within area
[Isurus oxyrinchus](#) Shortfin Mako, Mako Shark [79073]		Species or species habitat likely to occur within area
[Isurus paucus](#) Longfin Mako [82947]		Species or species habitat likely to occur within area
[Lepidochelys olivacea](#) Olive Ridley Turtle, Pacific Ridley Turtle [1767]	Endangered	Foraging, feeding or related behaviour likely to occur within area
[Manta alfredi](#) Reef Manta Ray, Coastal Manta Ray, Inshore Manta Ray, Prince Alfred's Ray, Resident Manta Ray [84994]		Species or species habitat likely to occur within area
[Manta birostris](#) Giant Manta Ray, Chevron Manta Ray, Pacific Manta Ray, Pelagic Manta Ray, Oceanic Manta Ray [84995]		Species or species habitat likely to occur within area
[Megaptera novaeangliae](#) Humpback Whale [38]	Vulnerable	Species or species habitat likely to occur within area
[Natator depressus](#) Flatback Turtle [59257]	Vulnerable	Species or species habitat known to occur within area
[Orcinus orca](#) Killer Whale, Orca [46]		Species or species habitat may occur within area
[Physeter macrocephalus](#) Sperm Whale [59]		Species or species habitat may occur within

Name	Threatened	Type of Presence
		area
Pristis pristis Freshwater Sawfish, Largetooth Sawfish, River Sawfish, Leichhardt's Sawfish, Northern Sawfish [60756]	Vulnerable	Species or species habitat known to occur within area
Pristis zijsron Green Sawfish, Dindagubba, Narrowsnout Sawfish [68442]	Vulnerable	Species or species habitat known to occur within area
Rhincodon typus Whale Shark [66680]	Vulnerable	Foraging, feeding or related behaviour known to occur within area
Tursiops aduncus (Arafura/Timor Sea populations) Spotted Bottlenose Dolphin (Arafura/Timor Sea populations) [78900]		Species or species habitat may occur within area
Migratory Wetlands Species		
Actitis hypoleucos Common Sandpiper [59309]		Species or species habitat may occur within area
Calidris acuminata Sharp-tailed Sandpiper [874]		Species or species habitat may occur within area
Calidris canutus Red Knot, Knot [855]	Endangered	Species or species habitat may occur within area
Calidris ferruginea Curlew Sandpiper [856]	Critically Endangered	Species or species habitat may occur within area
Calidris melanotos Pectoral Sandpiper [858]		Species or species habitat may occur within area
Numenius madagascariensis Eastern Curlew, Far Eastern Curlew [847]	Critically Endangered	Species or species habitat may occur within area

Other Matters Protected by the EPBC Act

Listed Marine Species		[Resource Information]
* Species is listed under a different scientific name on the EPBC Act - Threatened Species list.		
Name	Threatened	Type of Presence
Birds		
Actitis hypoleucos Common Sandpiper [59309]		Species or species habitat may occur within area
Anous stolidus Common Noddy [825]		Species or species habitat may occur within area
Anous tenuirostris melanops Australian Lesser Noddy [26000]	Vulnerable	Species or species habitat may occur within area
Calidris acuminata Sharp-tailed Sandpiper [874]		Species or species habitat may occur within area
Calidris canutus Red Knot, Knot [855]	Endangered	Species or species habitat may occur within

Name	Threatened	Type of Presence
		area
Calidris ferruginea Curlew Sandpiper [856]	Critically Endangered	Species or species habitat may occur within area
Calidris melanotos Pectoral Sandpiper [858]		Species or species habitat may occur within area
Calonectris leucomelas Streaked Shearwater [1077]		Species or species habitat likely to occur within area
Fregata ariel Lesser Frigatebird, Least Frigatebird [1012]		Species or species habitat likely to occur within area
Fregata minor Great Frigatebird, Greater Frigatebird [1013]		Species or species habitat may occur within area
Numenius madagascariensis Eastern Curlew, Far Eastern Curlew [847]	Critically Endangered	Species or species habitat may occur within area
Papasula abbotti Abbott's Booby [59297]	Endangered	Species or species habitat may occur within area
Fish		
Bhanotia fasciolata Corrugated Pipefish, Barbed Pipefish [66188]		Species or species habitat may occur within area
Campichthys tricarinatus Three-keel Pipefish [66192]		Species or species habitat may occur within area
Choeroichthys brachysoma Pacific Short-bodied Pipefish, Short-bodied Pipefish [66194]		Species or species habitat may occur within area
Choeroichthys suillus Pig-snouted Pipefish [66198]		Species or species habitat may occur within area
Corythoichthys amplexus Fijian Banded Pipefish, Brown-banded Pipefish [66199]		Species or species habitat may occur within area
Corythoichthys flavofasciatus Reticulate Pipefish, Yellow-banded Pipefish, Network Pipefish [66200]		Species or species habitat may occur within area
Corythoichthys intestinalis Australian Messmate Pipefish, Banded Pipefish [66202]		Species or species habitat may occur within area
Corythoichthys schultzi Schultz's Pipefish [66205]		Species or species habitat may occur within area
Cosmocampus banneri Roughridge Pipefish [66206]		Species or species habitat may occur within area
Doryrhamphus dactyliophorus Banded Pipefish, Ringed Pipefish [66210]		Species or species habitat may occur within area
Doryrhamphus excisus Bluestripe Pipefish, Indian Blue-stripe Pipefish, Pacific Blue-stripe Pipefish [66211]		Species or species habitat may occur within

Name	Threatened	Type of Presence
		area
Doryrhamphus janssi Cleaner Pipefish, Janss' Pipefish [66212]		Species or species habitat may occur within area
Filicampus tigris Tiger Pipefish [66217]		Species or species habitat may occur within area
Halicampus brocki Brock's Pipefish [66219]		Species or species habitat may occur within area
Halicampus dunckeri Red-hair Pipefish, Duncker's Pipefish [66220]		Species or species habitat may occur within area
Halicampus grayi Mud Pipefish, Gray's Pipefish [66221]		Species or species habitat may occur within area
Halicampus spinirostris Spiny-snout Pipefish [66225]		Species or species habitat may occur within area
Haliichthys taeniophorus Ribboned Pipehorse, Ribboned Seadragon [66226]		Species or species habitat may occur within area
Hippichthys penicillus Beady Pipefish, Steep-nosed Pipefish [66231]		Species or species habitat may occur within area
Hippocampus histrix Spiny Seahorse, Thorny Seahorse [66236]		Species or species habitat may occur within area
Hippocampus kuda Spotted Seahorse, Yellow Seahorse [66237]		Species or species habitat may occur within area
Hippocampus planifrons Flat-face Seahorse [66238]		Species or species habitat may occur within area
Hippocampus spinosissimus Hedgehog Seahorse [66239]		Species or species habitat may occur within area
Micrognathus micronotopterus Tidepool Pipefish [66255]		Species or species habitat may occur within area
Solegnathus hardwickii Pallid Pipehorse, Hardwick's Pipehorse [66272]		Species or species habitat may occur within area
Solegnathus lettiensis Gunther's Pipehorse, Indonesian Pipefish [66273]		Species or species habitat may occur within area
Solenostomus cyanopterus Robust Ghostpipefish, Blue-finned Ghost Pipefish, [66183]		Species or species habitat may occur within area
Syngnathoides biaculeatus Double-end Pipehorse, Double-ended Pipehorse, Alligator Pipefish [66279]		Species or species habitat may occur within area
Trachyrhamphus bicoarctatus Bentstick Pipefish, Bend Stick Pipefish, Short-tailed Pipefish [66280]		Species or species habitat may occur within area

Name	Threatened	Type of Presence
Trachyrhamphus longirostris Straightstick Pipefish, Long-nosed Pipefish, Straight Stick Pipefish [66281]		Species or species habitat may occur within area
Reptiles		
Acalyptophis peronii Horned Seasnake [1114]		Species or species habitat may occur within area
Aipysurus duboisii Dubois' Seasnake [1116]		Species or species habitat may occur within area
Aipysurus eydouxii Spine-tailed Seasnake [1117]		Species or species habitat may occur within area
Aipysurus laevis Olive Seasnake [1120]		Species or species habitat may occur within area
Astrotia stokesii Stokes' Seasnake [1122]		Species or species habitat may occur within area
Caretta caretta Loggerhead Turtle [1763]	Endangered	Foraging, feeding or related behaviour likely to occur within area
Chelonia mydas Green Turtle [1765]	Vulnerable	Foraging, feeding or related behaviour known to occur within area
Dermochelys coriacea Leatherback Turtle, Leathery Turtle, Luth [1768]	Endangered	Foraging, feeding or related behaviour likely to occur within area
Disteira kingii Spectacled Seasnake [1123]		Species or species habitat may occur within area
Disteira major Olive-headed Seasnake [1124]		Species or species habitat may occur within area
Enhydrina schistosa Beaked Seasnake [1126]		Species or species habitat may occur within area
Eretmochelys imbricata Hawksbill Turtle [1766]	Vulnerable	Foraging, feeding or related behaviour likely to occur within area
Hydrophis coggeri Slender-necked Seasnake [25925]		Species or species habitat may occur within area
Hydrophis elegans Elegant Seasnake [1104]		Species or species habitat may occur within area
Hydrophis ornatus Spotted Seasnake, Ornate Reef Seasnake [1111]		Species or species habitat may occur within area
Lapemis hardwickii Spine-bellied Seasnake [1113]		Species or species habitat may occur within area
Lepidochelys olivacea Olive Ridley Turtle, Pacific Ridley Turtle [1767]	Endangered	Foraging, feeding or related behaviour likely to occur within area

Name	Threatened	Type of Presence
Natator depressus Flatback Turtle [59257]	Vulnerable	Species or species habitat known to occur within area
Pelamis platurus Yellow-bellied Seasnake [1091]		Species or species habitat may occur within area

Whales and other Cetaceans [Resource Information]

Name	Status	Type of Presence
Mammals		
Balaenoptera borealis Sei Whale [34]	Vulnerable	Species or species habitat likely to occur within area
Balaenoptera edeni Bryde's Whale [35]		Species or species habitat likely to occur within area
Balaenoptera musculus Blue Whale [36]	Endangered	Species or species habitat likely to occur within area
Balaenoptera physalus Fin Whale [37]	Vulnerable	Species or species habitat likely to occur within area
Delphinus delphis Common Dophin, Short-beaked Common Dolphin [60]		Species or species habitat may occur within area
Feresa attenuata Pygmy Killer Whale [61]		Species or species habitat may occur within area
Globicephala macrorhynchus Short-finned Pilot Whale [62]		Species or species habitat may occur within area
Grampus griseus Risso's Dolphin, Grampus [64]		Species or species habitat may occur within area
Kogia breviceps Pygmy Sperm Whale [57]		Species or species habitat may occur within area
Kogia simus Dwarf Sperm Whale [58]		Species or species habitat may occur within area
Lagenodelphis hosei Fraser's Dolphin, Sarawak Dolphin [41]		Species or species habitat may occur within area
Megaptera novaeangliae Humpback Whale [38]	Vulnerable	Species or species habitat likely to occur within area
Mesoplodon densirostris Blainville's Beaked Whale, Dense-beaked Whale [74]		Species or species habitat may occur within area
Orcinus orca Killer Whale, Orca [46]		Species or species habitat may occur within area
Peponocephala electra Melon-headed Whale [47]		Species or species habitat may occur within area

Name	Status	Type of Presence
Physeter macrocephalus Sperm Whale [59]		Species or species habitat may occur within area
Pseudorca crassidens False Killer Whale [48]		Species or species habitat likely to occur within area
Stenella attenuata Spotted Dolphin, Pantropical Spotted Dolphin [51]		Species or species habitat may occur within area
Stenella coeruleoalba Striped Dolphin, Euphrosyne Dolphin [52]		Species or species habitat may occur within area
Stenella longirostris Long-snouted Spinner Dolphin [29]		Species or species habitat may occur within area
Steno bredanensis Rough-toothed Dolphin [30]		Species or species habitat may occur within area
Tursiops aduncus Indian Ocean Bottlenose Dolphin, Spotted Bottlenose Dolphin [68418]		Species or species habitat may occur within area
Tursiops aduncus (Arafura/Timor Sea populations) Spotted Bottlenose Dolphin (Arafura/Timor Sea populations) [78900]		Species or species habitat may occur within area
Tursiops truncatus s. str. Bottlenose Dolphin [68417]		Species or species habitat may occur within area
Ziphius cavirostris Cuvier's Beaked Whale, Goose-beaked Whale [56]		Species or species habitat may occur within area

Extra Information

Key Ecological Features (Marine) [Resource Information]

Key Ecological Features are the parts of the marine ecosystem that are considered to be important for the biodiversity or ecosystem functioning and integrity of the Commonwealth Marine Area.

Name	Region
Ancient coastline at 125 m depth contour	North-west

Caveat

The information presented in this report has been provided by a range of data sources as acknowledged at the end of the report.

This report is designed to assist in identifying the locations of places which may be relevant in determining obligations under the Environment Protection and Biodiversity Conservation Act 1999. It holds mapped locations of World and National Heritage properties, Wetlands of International and National Importance, Commonwealth and State/Territory reserves, listed threatened, migratory and marine species and listed threatened ecological communities. Mapping of Commonwealth land is not complete at this stage. Maps have been collated from a range of sources at various resolutions.

Not all species listed under the EPBC Act have been mapped (see below) and therefore a report is a general guide only. Where available data supports mapping, the type of presence that can be determined from the data is indicated in general terms. People using this information in making a referral may need to consider the qualifications below and may need to seek and consider other information sources.

For threatened ecological communities where the distribution is well known, maps are derived from recovery plans, State vegetation maps, remote sensing imagery and other sources. Where threatened ecological community distributions are less well known, existing vegetation maps and point location data are used to produce indicative distribution maps.

Threatened, migratory and marine species distributions have been derived through a variety of methods. Where distributions are well known and if time permits, maps are derived using either thematic spatial data (i.e. vegetation, soils, geology, elevation, aspect, terrain, etc) together with point locations and described habitat; or environmental modelling (MAXENT or BIOCLIM habitat modelling) using point locations and environmental data layers.

Where very little information is available for species or large number of maps are required in a short time-frame, maps are derived either from 0.04 or 0.02 decimal degree cells; by an automated process using polygon capture techniques (static two kilometre grid cells, alpha-hull and convex hull); or captured manually or by using topographic features (national park boundaries, islands, etc). In the early stages of the distribution mapping process (1999-early 2000s) distributions were defined by degree blocks, 100K or 250K map sheets to rapidly create distribution maps. More reliable distribution mapping methods are used to update these distributions as time permits.

Only selected species covered by the following provisions of the EPBC Act have been mapped:

- migratory and
- marine

The following species and ecological communities have not been mapped and do not appear in reports produced from this database:

- threatened species listed as extinct or considered as vagrants
- some species and ecological communities that have only recently been listed
- some terrestrial species that overfly the Commonwealth marine area
- migratory species that are very widespread, vagrant, or only occur in small numbers

The following groups have been mapped, but may not cover the complete distribution of the species:

- non-threatened seabirds which have only been mapped for recorded breeding sites
- seals which have only been mapped for breeding sites near the Australian continent

Such breeding sites may be important for the protection of the Commonwealth Marine environment.

Coordinates

-12.96444 124.4425

Acknowledgements

This database has been compiled from a range of data sources. The department acknowledges the following custodians who have contributed valuable data and advice:

-Office of Environment and Heritage, New South Wales
-Department of Environment and Primary Industries, Victoria
-Department of Primary Industries, Parks, Water and Environment, Tasmania
-Department of Environment, Water and Natural Resources, South Australia
-Department of Land and Resource Management, Northern Territory
-Department of Environmental and Heritage Protection, Queensland
-Department of Parks and Wildlife, Western Australia
-Environment and Planning Directorate, ACT
-Birdlife Australia
-Australian Bird and Bat Banding Scheme
-Australian National Wildlife Collection
-Natural history museums of Australia
-Museum Victoria
-Australian Museum
-South Australian Museum
-Queensland Museum
-Online Zoological Collections of Australian Museums
-Queensland Herbarium
-National Herbarium of NSW
-Royal Botanic Gardens and National Herbarium of Victoria
-Tasmanian Herbarium
-State Herbarium of South Australia
-Northern Territory Herbarium
-Western Australian Herbarium
-Australian National Herbarium, Canberra
-University of New England
-Ocean Biogeographic Information System
-Australian Government, Department of Defence
Forestry Corporation, NSW
-Geoscience Australia
-CSIRO
-Australian Tropical Herbarium, Cairns
-eBird Australia
-Australian Government – Australian Antarctic Data Centre
-Museum and Art Gallery of the Northern Territory
-Australian Government National Environmental Science Program
-Australian Institute of Marine Science
-Reef Life Survey Australia
-American Museum of Natural History
-Queen Victoria Museum and Art Gallery, Inveresk, Tasmania
-Tasmanian Museum and Art Gallery, Hobart, Tasmania
-Other groups and individuals

The Department is extremely grateful to the many organisations and individuals who provided expert advice and information on numerous draft distributions.

Please feel free to provide feedback via the Contact Us page.

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Australian Government
Department of the Environment and Energy

EPBC Act Protected Matters Report

This report provides general guidance on matters of national environmental significance and other matters protected by the EPBC Act in the area you have selected.

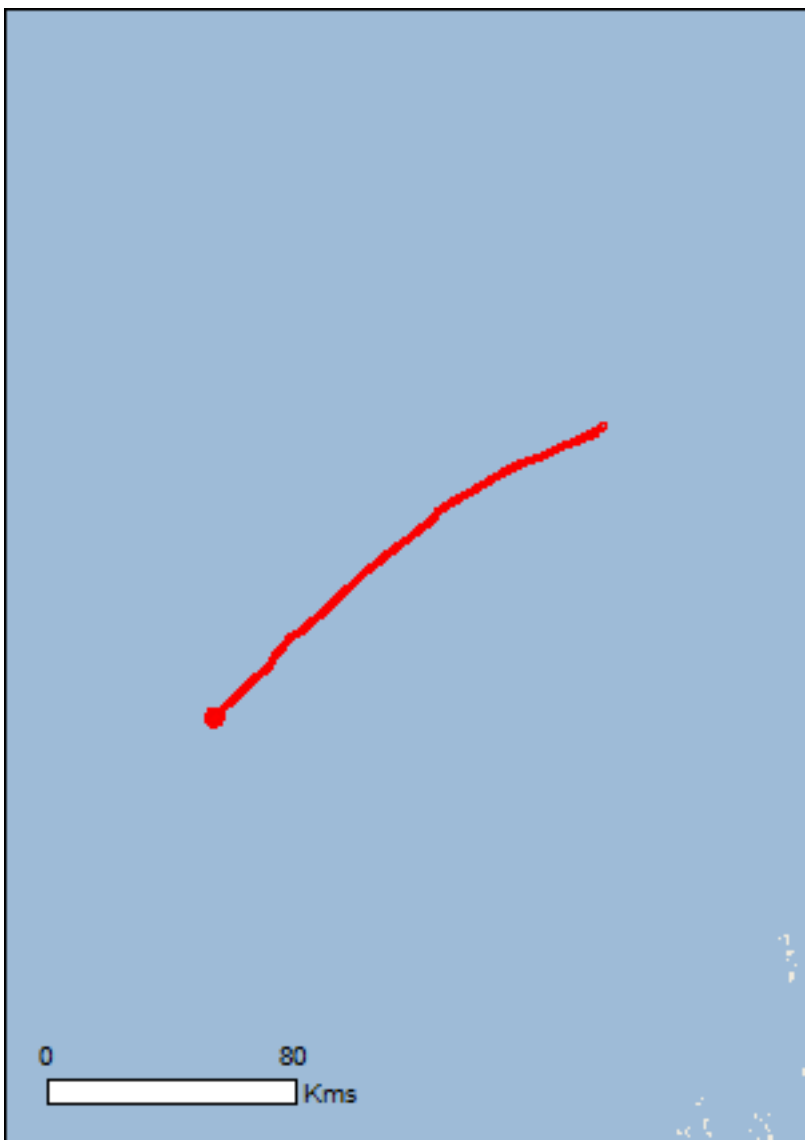
Information on the coverage of this report and qualifications on data supporting this report are contained in the caveat at the end of the report.

Information is available about Environment Assessments and the EPBC Act including significance guidelines, forms and application process details.

Report created: 21/08/18 11:29:32

Summary
Details
- Matters of NES
- Other Matters Protected by the EPBC Act
- Extra Information

Caveat
Acknowledgements



This map may contain data which are ©Commonwealth of Australia (Geoscience Australia), ©PSMA 2010

Coordinates
Buffer: 1.0Km



Summary

Matters of National Environmental Significance

This part of the report summarises the matters of national environmental significance that may occur in, or may relate to, the area you nominated. Further information is available in the detail part of the report, which can be accessed by scrolling or following the links below. If you are proposing to undertake an activity that may have a significant impact on one or more matters of national environmental significance then you should consider the Administrative Guidelines on Significance.

World Heritage Properties:	None
National Heritage Places:	None
Wetlands of International Importance:	None
Great Barrier Reef Marine Park:	None
Commonwealth Marine Area:	1
Listed Threatened Ecological Communities:	None
Listed Threatened Species:	20
Listed Migratory Species:	33

Other Matters Protected by the EPBC Act

This part of the report summarises other matters protected under the Act that may relate to the area you nominated. Approval may be required for a proposed activity that significantly affects the environment on Commonwealth land, when the action is outside the Commonwealth land, or the environment anywhere when the action is taken on Commonwealth land. Approval may also be required for the Commonwealth or Commonwealth agencies proposing to take an action that is likely to have a significant impact on the environment anywhere.

The EPBC Act protects the environment on Commonwealth land, the environment from the actions taken on Commonwealth land, and the environment from actions taken by Commonwealth agencies. As heritage values of a place are part of the 'environment', these aspects of the EPBC Act protect the Commonwealth Heritage values of a Commonwealth Heritage place. Information on the new heritage laws can be found at http://www.environment.gov.au/heritage

A permit may be required for activities in or on a Commonwealth area that may affect a member of a listed threatened species or ecological community, a member of a listed migratory species, whales and other cetaceans, or a member of a listed marine species.

Commonwealth Land:	None
Commonwealth Heritage Places:	None
Listed Marine Species:	61
Whales and Other Cetaceans:	22
Critical Habitats:	None
Commonwealth Reserves Terrestrial:	None
Australian Marine Parks:	None

Extra Information

This part of the report provides information that may also be relevant to the area you have nominated.

State and Territory Reserves:	None
Regional Forest Agreements:	None
Invasive Species:	None
Nationally Important Wetlands:	None
Key Ecological Features (Marine)	1

Details

Matters of National Environmental Significance

Commonwealth Marine Area [Resource Information]

Approval is required for a proposed activity that is located within the Commonwealth Marine Area which has, will have, or is likely to have a significant impact on the environment. Approval may be required for a proposed action taken outside the Commonwealth Marine Area but which has, may have or is likely to have a significant impact on the environment in the Commonwealth Marine Area. Generally the Commonwealth Marine Area stretches from three nautical miles to two hundred nautical miles from the coast.

Name

EEZ and Territorial Sea

Marine Regions [Resource Information]

If you are planning to undertake action in an area in or close to the Commonwealth Marine Area, and a marine bioregional plan has been prepared for the Commonwealth Marine Area in that area, the marine bioregional plan may inform your decision as to whether to refer your proposed action under the EPBC Act.

Name

North-west

Listed Threatened Species [Resource Information]

Name	Status	Type of Presence
Birds		
Anous tenuirostris melanops Australian Lesser Noddy [26000]	Vulnerable	Species or species habitat may occur within area
Calidris canutus Red Knot, Knot [855]	Endangered	Species or species habitat may occur within area
Calidris ferruginea Curlew Sandpiper [856]	Critically Endangered	Species or species habitat may occur within area
Numenius madagascariensis Eastern Curlew, Far Eastern Curlew [847]	Critically Endangered	Species or species habitat may occur within area
Papasula abbotti Abbott's Booby [59297]	Endangered	Species or species habitat may occur within area
Mammals		
Balaenoptera borealis Sei Whale [34]	Vulnerable	Species or species habitat likely to occur within area
Balaenoptera musculus Blue Whale [36]	Endangered	Species or species habitat likely to occur within area
Balaenoptera physalus Fin Whale [37]	Vulnerable	Species or species habitat likely to occur within area
Megaptera novaeangliae Humpback Whale [38]	Vulnerable	Species or species

Name	Status	Type of Presence
		habitat likely to occur within area
Reptiles		
Caretta caretta Loggerhead Turtle [1763]	Endangered	Species or species habitat likely to occur within area
Chelonia mydas Green Turtle [1765]	Vulnerable	Species or species habitat known to occur within area
Dermochelys coriacea Leatherback Turtle, Leathery Turtle, Luth [1768]	Endangered	Species or species habitat likely to occur within area
Eretmochelys imbricata Hawksbill Turtle [1766]	Vulnerable	Species or species habitat likely to occur within area
Lepidochelys olivacea Olive Ridley Turtle, Pacific Ridley Turtle [1767]	Endangered	Species or species habitat likely to occur within area
Natator depressus Flatback Turtle [59257]	Vulnerable	Species or species habitat known to occur within area
Sharks		
Carcharodon carcharias White Shark, Great White Shark [64470]	Vulnerable	Species or species habitat may occur within area
Glyphis garricki Northern River Shark, New Guinea River Shark [82454]	Endangered	Species or species habitat may occur within area
Pristis pristis Freshwater Sawfish, Largetooth Sawfish, River Sawfish, Leichhardt's Sawfish, Northern Sawfish [60756]	Vulnerable	Species or species habitat known to occur within area
Pristis zijsron Green Sawfish, Dindagubba, Narrowsnout Sawfish [68442]	Vulnerable	Species or species habitat known to occur within area
Rhincodon typus Whale Shark [66680]	Vulnerable	Foraging, feeding or related behaviour known to occur within area

Listed Migratory Species		[Resource Information]
* Species is listed under a different scientific name on the EPBC Act - Threatened Species list.		
Name	Threatened	Type of Presence
Migratory Marine Birds		
Anous stolidus Common Noddy [825]		Species or species habitat may occur within area
Calonectris leucomelas Streaked Shearwater [1077]		Species or species habitat known to occur within area
Fregata ariel Lesser Frigatebird, Least Frigatebird [1012]		Species or species habitat likely to occur within area
Fregata minor Great Frigatebird, Greater Frigatebird [1013]		Foraging, feeding or related behaviour likely to occur within area
Migratory Marine Species		
Anoxypristis cuspidata Narrow Sawfish, Knifetooth Sawfish [68448]		Species or species

Name	Threatened	Type of Presence
		habitat may occur within area
[Balaenoptera borealis](#) Sei Whale [34]	Vulnerable	Species or species habitat likely to occur within area
[Balaenoptera edeni](#) Bryde's Whale [35]		Species or species habitat likely to occur within area
[Balaenoptera musculus](#) Blue Whale [36]	Endangered	Species or species habitat likely to occur within area
[Balaenoptera physalus](#) Fin Whale [37]	Vulnerable	Species or species habitat likely to occur within area
[Carcharodon carcharias](#) White Shark, Great White Shark [64470]	Vulnerable	Species or species habitat may occur within area
[Caretta caretta](#) Loggerhead Turtle [1763]	Endangered	Species or species habitat likely to occur within area
[Chelonia mydas](#) Green Turtle [1765]	Vulnerable	Species or species habitat known to occur within area
[Dermochelys coriacea](#) Leatherback Turtle, Leathery Turtle, Luth [1768]	Endangered	Species or species habitat likely to occur within area
[Eretmochelys imbricata](#) Hawksbill Turtle [1766]	Vulnerable	Species or species habitat likely to occur within area
[Isurus oxyrinchus](#) Shortfin Mako, Mako Shark [79073]		Species or species habitat likely to occur within area
[Isurus paucus](#) Longfin Mako [82947]		Species or species habitat likely to occur within area
[Lepidochelys olivacea](#) Olive Ridley Turtle, Pacific Ridley Turtle [1767]	Endangered	Species or species habitat likely to occur within area
[Manta alfredi](#) Reef Manta Ray, Coastal Manta Ray, Inshore Manta Ray, Prince Alfred's Ray, Resident Manta Ray [84994]		Species or species habitat may occur within area
[Manta birostris](#) Giant Manta Ray, Chevron Manta Ray, Pacific Manta Ray, Pelagic Manta Ray, Oceanic Manta Ray [84995]		Species or species habitat may occur within area
[Megaptera novaeangliae](#) Humpback Whale [38]	Vulnerable	Species or species habitat likely to occur within area
[Natator depressus](#) Flatback Turtle [59257]	Vulnerable	Species or species habitat known to occur within area
[Orcinus orca](#) Killer Whale, Orca [46]		Species or species habitat may occur within area
[Physeter macrocephalus](#) Sperm Whale [59]		Species or species habitat may occur within

Name	Threatened	Type of Presence
		area
Pristis pristis Freshwater Sawfish, Largetooth Sawfish, River Sawfish, Leichhardt's Sawfish, Northern Sawfish [60756]	Vulnerable	Species or species habitat known to occur within area
Pristis zijsron Green Sawfish, Dindagubba, Narrowsnout Sawfish [68442]	Vulnerable	Species or species habitat known to occur within area
Rhincodon typus Whale Shark [66680]	Vulnerable	Foraging, feeding or related behaviour known to occur within area
Tursiops aduncus (Arafura/Timor Sea populations) Spotted Bottlenose Dolphin (Arafura/Timor Sea populations) [78900]		Species or species habitat may occur within area
Migratory Wetlands Species		
Actitis hypoleucos Common Sandpiper [59309]		Species or species habitat may occur within area
Calidris acuminata Sharp-tailed Sandpiper [874]		Species or species habitat may occur within area
Calidris canutus Red Knot, Knot [855]	Endangered	Species or species habitat may occur within area
Calidris ferruginea Curlew Sandpiper [856]	Critically Endangered	Species or species habitat may occur within area
Calidris melanotos Pectoral Sandpiper [858]		Species or species habitat may occur within area
Numenius madagascariensis Eastern Curlew, Far Eastern Curlew [847]	Critically Endangered	Species or species habitat may occur within area

Other Matters Protected by the EPBC Act

Listed Marine Species		[Resource Information]
* Species is listed under a different scientific name on the EPBC Act - Threatened Species list.		
Name	Threatened	Type of Presence
Birds		
Actitis hypoleucos Common Sandpiper [59309]		Species or species habitat may occur within area
Anous stolidus Common Noddy [825]		Species or species habitat may occur within area
Anous tenuirostris melanops Australian Lesser Noddy [26000]	Vulnerable	Species or species habitat may occur within area
Calidris acuminata Sharp-tailed Sandpiper [874]		Species or species habitat may occur within area
Calidris canutus Red Knot, Knot [855]	Endangered	Species or species habitat may occur within

Name	Threatened	Type of Presence
		area
Calidris ferruginea Curlew Sandpiper [856]	Critically Endangered	Species or species habitat may occur within area
Calidris melanotos Pectoral Sandpiper [858]		Species or species habitat may occur within area
Calonectris leucomelas Streaked Shearwater [1077]		Species or species habitat known to occur within area
Fregata ariel Lesser Frigatebird, Least Frigatebird [1012]		Species or species habitat likely to occur within area
Fregata minor Great Frigatebird, Greater Frigatebird [1013]		Foraging, feeding or related behaviour likely to occur within area
Numenius madagascariensis Eastern Curlew, Far Eastern Curlew [847]	Critically Endangered	Species or species habitat may occur within area
Papasula abbotti Abbott's Booby [59297]	Endangered	Species or species habitat may occur within area
Fish		
Bhanotia fasciolata Corrugated Pipefish, Barbed Pipefish [66188]		Species or species habitat may occur within area
Campichthys tricarinatus Three-keel Pipefish [66192]		Species or species habitat may occur within area
Choeroichthys brachysoma Pacific Short-bodied Pipefish, Short-bodied Pipefish [66194]		Species or species habitat may occur within area
Choeroichthys suillus Pig-snouted Pipefish [66198]		Species or species habitat may occur within area
Corythoichthys amplexus Fijian Banded Pipefish, Brown-banded Pipefish [66199]		Species or species habitat may occur within area
Corythoichthys flavofasciatus Reticulate Pipefish, Yellow-banded Pipefish, Network Pipefish [66200]		Species or species habitat may occur within area
Corythoichthys intestinalis Australian Messmate Pipefish, Banded Pipefish [66202]		Species or species habitat may occur within area
Corythoichthys schultzi Schultz's Pipefish [66205]		Species or species habitat may occur within area
Cosmocampus banneri Roughridge Pipefish [66206]		Species or species habitat may occur within area
Doryrhamphus dactyliophorus Banded Pipefish, Ringed Pipefish [66210]		Species or species habitat may occur within area
Doryrhamphus excisus Bluestripe Pipefish, Indian Blue-stripe Pipefish, Pacific Blue-stripe Pipefish [66211]		Species or species habitat may occur within

Name	Threatened	Type of Presence
		area
Doryrhamphus janssi Cleaner Pipefish, Janss' Pipefish [66212]		Species or species habitat may occur within area
Filicampus tigris Tiger Pipefish [66217]		Species or species habitat may occur within area
Halicampus brocki Brock's Pipefish [66219]		Species or species habitat may occur within area
Halicampus dunckeri Red-hair Pipefish, Duncker's Pipefish [66220]		Species or species habitat may occur within area
Halicampus grayi Mud Pipefish, Gray's Pipefish [66221]		Species or species habitat may occur within area
Halicampus spinirostris Spiny-snout Pipefish [66225]		Species or species habitat may occur within area
Haliichthys taeniophorus Ribboned Pipehorse, Ribboned Seadragon [66226]		Species or species habitat may occur within area
Hippichthys penicillus Beady Pipefish, Steep-nosed Pipefish [66231]		Species or species habitat may occur within area
Hippocampus histrix Spiny Seahorse, Thorny Seahorse [66236]		Species or species habitat may occur within area
Hippocampus kuda Spotted Seahorse, Yellow Seahorse [66237]		Species or species habitat may occur within area
Hippocampus planifrons Flat-face Seahorse [66238]		Species or species habitat may occur within area
Hippocampus spinosissimus Hedgehog Seahorse [66239]		Species or species habitat may occur within area
Micrognathus micronotopterus Tidepool Pipefish [66255]		Species or species habitat may occur within area
Solegnathus hardwickii Pallid Pipehorse, Hardwick's Pipehorse [66272]		Species or species habitat may occur within area
Solegnathus lettiensis Gunther's Pipehorse, Indonesian Pipefish [66273]		Species or species habitat may occur within area
Solenostomus cyanopterus Robust Ghostpipefish, Blue-finned Ghost Pipefish, [66183]		Species or species habitat may occur within area
Syngnathoides biaculeatus Double-end Pipehorse, Double-ended Pipehorse, Alligator Pipefish [66279]		Species or species habitat may occur within area
Trachyrhamphus bicoarctatus Bentstick Pipefish, Bend Stick Pipefish, Short-tailed Pipefish [66280]		Species or species habitat may occur within area

Name	Threatened	Type of Presence
Trachyrhamphus longirostris Straightstick Pipefish, Long-nosed Pipefish, Straight Stick Pipefish [66281]		Species or species habitat may occur within area
Reptiles		
Acalyptophis peronii Horned Seasnake [1114]		Species or species habitat may occur within area
Aipysurus duboisii Dubois' Seasnake [1116]		Species or species habitat may occur within area
Aipysurus eydouxii Spine-tailed Seasnake [1117]		Species or species habitat may occur within area
Aipysurus laevis Olive Seasnake [1120]		Species or species habitat may occur within area
Astrotia stokesii Stokes' Seasnake [1122]		Species or species habitat may occur within area
Caretta caretta Loggerhead Turtle [1763]	Endangered	Species or species habitat likely to occur within area
Chelonia mydas Green Turtle [1765]	Vulnerable	Species or species habitat known to occur within area
Dermochelys coriacea Leatherback Turtle, Leathery Turtle, Luth [1768]	Endangered	Species or species habitat likely to occur within area
Disteira kingii Spectacled Seasnake [1123]		Species or species habitat may occur within area
Disteira major Olive-headed Seasnake [1124]		Species or species habitat may occur within area
Enhydrina schistosa Beaked Seasnake [1126]		Species or species habitat may occur within area
Eretmochelys imbricata Hawksbill Turtle [1766]	Vulnerable	Species or species habitat likely to occur within area
Hydrophis coggeri Slender-necked Seasnake [25925]		Species or species habitat may occur within area
Hydrophis elegans Elegant Seasnake [1104]		Species or species habitat may occur within area
Hydrophis ornatus Spotted Seasnake, Ornate Reef Seasnake [1111]		Species or species habitat may occur within area
Lapemis hardwickii Spine-bellied Seasnake [1113]		Species or species habitat may occur within area
Lepidochelys olivacea Olive Ridley Turtle, Pacific Ridley Turtle [1767]	Endangered	Species or species habitat likely to occur within area

Name	Threatened	Type of Presence
Natator depressus Flatback Turtle [59257]	Vulnerable	Species or species habitat known to occur within area
Pelamis platurus Yellow-bellied Seasnake [1091]		Species or species habitat may occur within area

Whales and other Cetaceans [Resource Information]

Name	Status	Type of Presence
Mammals		
Balaenoptera borealis Sei Whale [34]	Vulnerable	Species or species habitat likely to occur within area
Balaenoptera edeni Bryde's Whale [35]		Species or species habitat likely to occur within area
Balaenoptera musculus Blue Whale [36]	Endangered	Species or species habitat likely to occur within area
Balaenoptera physalus Fin Whale [37]	Vulnerable	Species or species habitat likely to occur within area
Delphinus delphis Common Dophin, Short-beaked Common Dolphin [60]		Species or species habitat may occur within area
Feresa attenuata Pygmy Killer Whale [61]		Species or species habitat may occur within area
Globicephala macrorhynchus Short-finned Pilot Whale [62]		Species or species habitat may occur within area
Grampus griseus Risso's Dolphin, Grampus [64]		Species or species habitat may occur within area
Kogia breviceps Pygmy Sperm Whale [57]		Species or species habitat may occur within area
Kogia simus Dwarf Sperm Whale [58]		Species or species habitat may occur within area
Megaptera novaeangliae Humpback Whale [38]	Vulnerable	Species or species habitat likely to occur within area
Orcinus orca Killer Whale, Orca [46]		Species or species habitat may occur within area
Peponocephala electra Melon-headed Whale [47]		Species or species habitat may occur within area
Physeter macrocephalus Sperm Whale [59]		Species or species habitat may occur within area
Pseudorca crassidens False Killer Whale [48]		Species or species habitat likely to occur within area

Name	Status	Type of Presence
Stenella attenuata Spotted Dolphin, Pantropical Spotted Dolphin [51]		Species or species habitat may occur within area
Stenella coeruleoalba Striped Dolphin, Euphrosyne Dolphin [52]		Species or species habitat may occur within area
Stenella longirostris Long-snouted Spinner Dolphin [29]		Species or species habitat may occur within area
Steno bredanensis Rough-toothed Dolphin [30]		Species or species habitat may occur within area
Tursiops aduncus (Arafura/Timor Sea populations) Spotted Bottlenose Dolphin (Arafura/Timor Sea populations) [78900]		Species or species habitat may occur within area
Tursiops truncatus s. str. Bottlenose Dolphin [68417]		Species or species habitat may occur within area
Ziphius cavirostris Cuvier's Beaked Whale, Goose-beaked Whale [56]		Species or species habitat may occur within area

Extra Information

Key Ecological Features (Marine) [Resource Information]

Key Ecological Features are the parts of the marine ecosystem that are considered to be important for the biodiversity or ecosystem functioning and integrity of the Commonwealth Marine Area.

Name	Region
Continental Slope Demersal Fish Communities	North-west

Caveat

The information presented in this report has been provided by a range of data sources as acknowledged at the end of the report.

This report is designed to assist in identifying the locations of places which may be relevant in determining obligations under the Environment Protection and Biodiversity Conservation Act 1999. It holds mapped locations of World and National Heritage properties, Wetlands of International and National Importance, Commonwealth and State/Territory reserves, listed threatened, migratory and marine species and listed threatened ecological communities. Mapping of Commonwealth land is not complete at this stage. Maps have been collated from a range of sources at various resolutions.

Not all species listed under the EPBC Act have been mapped (see below) and therefore a report is a general guide only. Where available data supports mapping, the type of presence that can be determined from the data is indicated in general terms. People using this information in making a referral may need to consider the qualifications below and may need to seek and consider other information sources.

For threatened ecological communities where the distribution is well known, maps are derived from recovery plans, State vegetation maps, remote sensing imagery and other sources. Where threatened ecological community distributions are less well known, existing vegetation maps and point location data are used to produce indicative distribution maps.

Threatened, migratory and marine species distributions have been derived through a variety of methods. Where distributions are well known and if time permits, maps are derived using either thematic spatial data (i.e. vegetation, soils, geology, elevation, aspect, terrain, etc) together with point locations and described habitat; or environmental modelling (MAXENT or BIOCLIM habitat modelling) using point locations and environmental data layers.

Where very little information is available for species or large number of maps are required in a short time-frame, maps are derived either from 0.04 or 0.02 decimal degree cells; by an automated process using polygon capture techniques (static two kilometre grid cells, alpha-hull and convex hull); or captured manually or by using topographic features (national park boundaries, islands, etc). In the early stages of the distribution mapping process (1999-early 2000s) distributions were defined by degree blocks, 100K or 250K map sheets to rapidly create distribution maps. More reliable distribution mapping methods are used to update these distributions as time permits.

Only selected species covered by the following provisions of the EPBC Act have been mapped:

- migratory and
- marine

The following species and ecological communities have not been mapped and do not appear in reports produced from this database:

- threatened species listed as extinct or considered as vagrants
- some species and ecological communities that have only recently been listed
- some terrestrial species that overfly the Commonwealth marine area
- migratory species that are very widespread, vagrant, or only occur in small numbers

The following groups have been mapped, but may not cover the complete distribution of the species:

- non-threatened seabirds which have only been mapped for recorded breeding sites
- seals which have only been mapped for breeding sites near the Australian continent

Such breeding sites may be important for the protection of the Commonwealth Marine environment.

Coordinates

-12.96457328 124.4425573,-12.980711 124.422349,-12.98835507 124.403823,-13.00617302 124.3614609,-13.02398469 124.3190922,-13.04179 124.2767168,-13.05958892 124.2343348,-13.07766666 124.1920825,-13.0982701 124.151036,-13.11886753 124.1099823,-13.14162199 124.0701503,-13.16500011 124.0306688,-13.18837258 123.9911794,-13.201448 123.969315,-13.2163022 123.9555142,-13.239519 123.934575,-13.24821913 123.923067,-13.27578419 123.8864877,-13.30334446 123.8499,-13.33089982 123.8133039,-13.35845037 123.7766993,-13.38633339 123.7403818,-13.41780521 123.7072292,-13.44927301 123.674068,-13.48073683 123.6408982,-13.51190777 123.6074377,-13.541795 123.574827,-13.54253608 123.5735049,-13.553699 123.545957,-13.5652534 123.5345412,-13.59808675 123.5027706,-13.608522 123.492848,-13.633529 123.480741,-13.63583033 123.4782671,-13.66715518 123.4449327,-13.69847383 123.4115875,-13.72978816 123.3782336,-13.7610981 123.3448707,-13.771196 123.334085,-13.777889 123.340333,-13.795463 123.335632,-13.799533 123.315711,-13.78722 123.304605,-13.7681 123.31165,-13.765217 123.327122

Acknowledgements

This database has been compiled from a range of data sources. The department acknowledges the following custodians who have contributed valuable data and advice:

-Office of Environment and Heritage, New South Wales
-Department of Environment and Primary Industries, Victoria
-Department of Primary Industries, Parks, Water and Environment, Tasmania
-Department of Environment, Water and Natural Resources, South Australia
-Department of Land and Resource Management, Northern Territory
-Department of Environmental and Heritage Protection, Queensland
-Department of Parks and Wildlife, Western Australia
-Environment and Planning Directorate, ACT
-Birdlife Australia
-Australian Bird and Bat Banding Scheme
-Australian National Wildlife Collection
-Natural history museums of Australia
-Museum Victoria
-Australian Museum
-South Australian Museum
-Queensland Museum
-Online Zoological Collections of Australian Museums
-Queensland Herbarium
-National Herbarium of NSW
-Royal Botanic Gardens and National Herbarium of Victoria
-Tasmanian Herbarium
-State Herbarium of South Australia
-Northern Territory Herbarium
-Western Australian Herbarium
-Australian National Herbarium, Canberra
-University of New England
-Ocean Biogeographic Information System
-Australian Government, Department of Defence
Forestry Corporation, NSW
-Geoscience Australia
-CSIRO
-Australian Tropical Herbarium, Cairns
-eBird Australia
-Australian Government – Australian Antarctic Data Centre
-Museum and Art Gallery of the Northern Territory
-Australian Government National Environmental Science Program
-Australian Institute of Marine Science
-Reef Life Survey Australia
-American Museum of Natural History
-Queen Victoria Museum and Art Gallery, Inveresk, Tasmania
-Tasmanian Museum and Art Gallery, Hobart, Tasmania
-Other groups and individuals

The Department is extremely grateful to the many organisations and individuals who provided expert advice and information on numerous draft distributions.

Please feel free to provide feedback via the Contact Us page.

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Department of the Environment and Energy

EPBC Act Protected Matters Report

This report provides general guidance on matters of national environmental significance and other matters protected by the EPBC Act in the area you have selected.

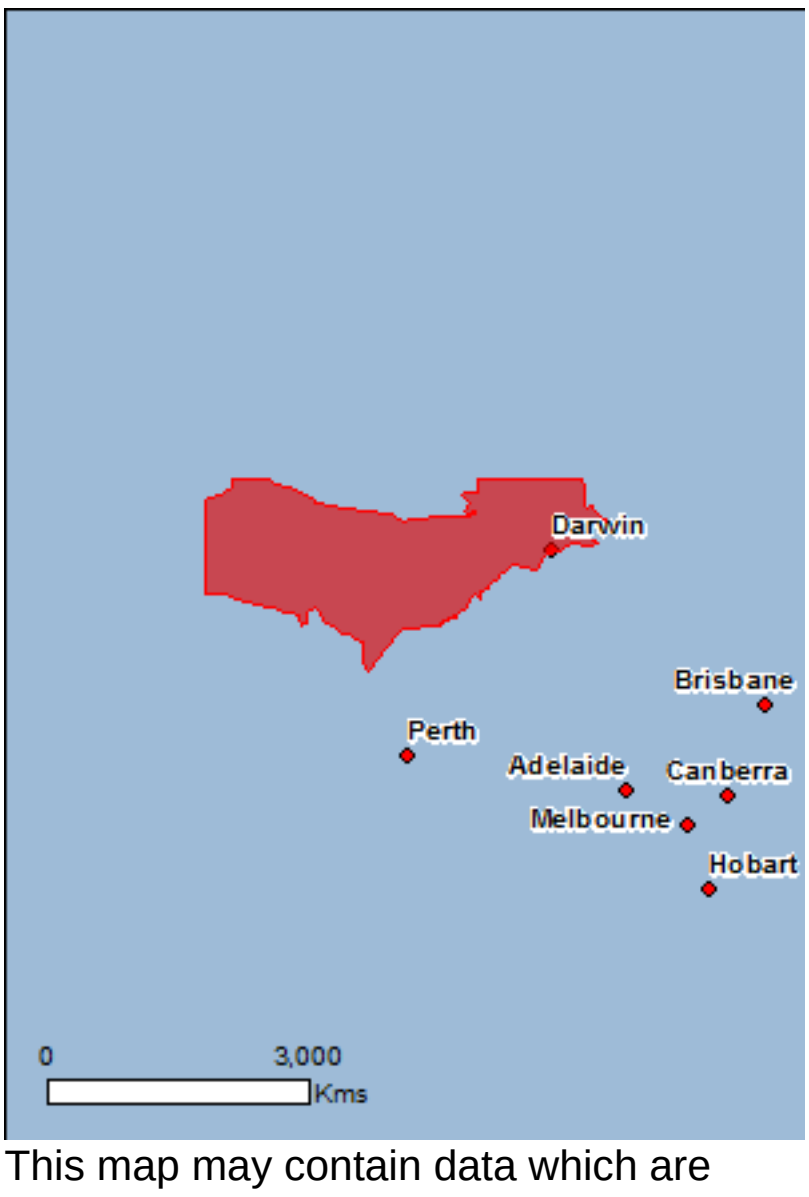
Information on the coverage of this report and qualifications on data supporting this report are contained in the caveat at the end of the report.

Information is available about Environment Assessments and the EPBC Act including significance guidelines, forms and application process details.

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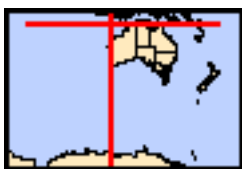
Summary
Details
- Matters of NES
- Other Matters Protected by the EPBC Act
- Extra Information

Caveat
Acknowledgements



This map may contain data which are ©Commonwealth of Australia (Geoscience Australia), ©PSMA 2010

Coordinates
Buffer: 1.0Km



Summary

Matters of National Environmental Significance

This part of the report summarises the matters of national environmental significance that may occur in, or may relate to, the area you nominated. Further information is available in the detail part of the report, which can be accessed by scrolling or following the links below. If you are proposing to undertake an activity that may have a significant impact on one or more matters of national environmental significance then you should consider the Administrative Guidelines on Significance.

World Heritage Properties:	None
National Heritage Places:	1
Wetlands of International Importance:	5
Great Barrier Reef Marine Park:	None
Commonwealth Marine Area:	2
Listed Threatened Ecological Communities:	1
Listed Threatened Species:	96
Listed Migratory Species:	95

Other Matters Protected by the EPBC Act

This part of the report summarises other matters protected under the Act that may relate to the area you nominated. Approval may be required for a proposed activity that significantly affects the environment on Commonwealth land, when the action is outside the Commonwealth land, or the environment anywhere when the action is taken on Commonwealth land. Approval may also be required for the Commonwealth or Commonwealth agencies proposing to take an action that is likely to have a significant impact on the environment anywhere.

The EPBC Act protects the environment on Commonwealth land, the environment from the actions taken on Commonwealth land, and the environment from actions taken by Commonwealth agencies. As heritage values of a place are part of the 'environment', these aspects of the EPBC Act protect the Commonwealth Heritage values of a Commonwealth Heritage place. Information on the new heritage laws can be found at http://www.environment.gov.au/heritage

A permit may be required for activities in or on a Commonwealth area that may affect a member of a listed threatened species or ecological community, a member of a listed migratory species, whales and other cetaceans, or a member of a listed marine species.

Commonwealth Land:	6
Commonwealth Heritage Places:	35
Listed Marine Species:	169
Whales and Other Cetaceans:	32
Critical Habitats:	None
Commonwealth Reserves Terrestrial:	None
Australian Marine Parks:	25

Extra Information

This part of the report provides information that may also be relevant to the area you have nominated.

State and Territory Reserves:	30
Regional Forest Agreements:	None
Invasive Species:	37
Nationally Important Wetlands:	9
Key Ecological Features (Marine)	15

Details

Matters of National Environmental Significance

National Heritage Properties		[Resource Information]
Name	State	Status
Natural		
The West Kimberley	WA	Listed place

Wetlands of International Importance (Ramsar)	[Resource Information]
Name	Proximity
Ashmore reef national nature reserve	Within Ramsar site
Cobourg peninsula	Within Ramsar site
Hosnies spring	Within Ramsar site
Pulu keeling national park	Within Ramsar site
The dales	Within Ramsar site

Commonwealth Marine Area [Resource Information]

Approval is required for a proposed activity that is located within the Commonwealth Marine Area which has, will have, or is likely to have a significant impact on the environment. Approval may be required for a proposed action taken outside the Commonwealth Marine Area but which has, may have or is likely to have a significant impact on the environment in the Commonwealth Marine Area. Generally the Commonwealth Marine Area stretches from three nautical miles to two hundred nautical miles from the coast.

Name

EEZ and Territorial Sea

Extended Continental Shelf

Marine Regions [Resource Information]

If you are planning to undertake action in an area in or close to the Commonwealth Marine Area, and a marine bioregional plan has been prepared for the Commonwealth Marine Area in that area, the marine bioregional plan may inform your decision as to whether to refer your proposed action under the EPBC Act.

Name

North

North-west

Listed Threatened Ecological Communities [Resource Information]

For threatened ecological communities where the distribution is well known, maps are derived from recovery plans, State vegetation maps, remote sensing imagery and other sources. Where threatened ecological community distributions are less well known, existing vegetation maps and point location data are used to produce indicative distribution maps.

Name	Status	Type of Presence
Monsoon vine thickets on the coastal sand dunes of Dampier Peninsula	Endangered	Community likely to occur within area

Listed Threatened Species [Resource Information]

Name	Status	Type of Presence
Birds		
Accipiter hiogaster natalis		
Christmas Island Goshawk [82408]	Endangered	Species or species habitat known to occur within area
Anous tenuirostris melanops		
Australian Lesser Noddy [26000]	Vulnerable	Breeding known to occur within area
Calidris canutus		
Red Knot, Knot [855]	Endangered	Species or species habitat known to occur within area
Calidris ferruginea		
Curlew Sandpiper [856]	Critically Endangered	Species or species habitat known to occur within area

Name	Status	Type of Presence
Calidris tenuirostris Great Knot [862]	Critically Endangered	Foraging, feeding or related behaviour known to occur within area
Chalcophaps indica natalis Christmas Island Emerald Dove, Emerald Dove (Christmas Island) [67030]	Endangered	Species or species habitat known to occur within area
Charadrius leschenaultii Greater Sand Plover, Large Sand Plover [877]	Vulnerable	Foraging, feeding or related behaviour known to occur within area
Charadrius mongolus Lesser Sand Plover, Mongolian Plover [879]	Endangered	Foraging, feeding or related behaviour known to occur within area
Epthianura crocea tunneyi Alligator Rivers Yellow Chat, Yellow Chat (Alligator Rivers) [67089]	Endangered	Species or species habitat may occur within area
Erythrotriorchis radiatus Red Goshawk [942]	Vulnerable	Species or species habitat known to occur within area
Erythrura gouldiae Gouldian Finch [413]	Endangered	Species or species habitat known to occur within area
Falcunculus frontatus whitei Crested Shrike-tit (northern), Northern Shrike-tit [26013]	Vulnerable	Species or species habitat likely to occur within area
Fregata andrewsi Christmas Island Frigatebird, Andrew's Frigatebird [1011]	Endangered	Breeding known to occur within area
Geophaps smithii blaauwi Partridge Pigeon (western) [66501]	Vulnerable	Species or species habitat likely to occur within area
Geophaps smithii smithii Partridge Pigeon (eastern) [64441]	Vulnerable	Species or species habitat known to occur within area
Hypotaenidia philippensis andrewsi Buff-banded Rail (Cocos (Keeling) Islands), Ayam Hutan [88994]	Endangered	Translocated population known to occur within area
Limosa lapponica baueri Bar-tailed Godwit (baueri), Western Alaskan Bar-tailed Godwit [86380]	Vulnerable	Species or species habitat likely to occur within area
Limosa lapponica menzbieri Northern Siberian Bar-tailed Godwit, Bar-tailed Godwit (menzbieri) [86432]	Critically Endangered	Species or species habitat likely to occur within area
Macronectes giganteus Southern Giant-Petrel, Southern Giant Petrel [1060]	Endangered	Species or species habitat may occur within area
Melanodryas cucullata melvillensis Tiwi Islands Hooded Robin, Hooded Robin (Tiwi Islands) [67092]	Critically Endangered	Species or species habitat known to occur within area
Mirafra javanica melvillensis Horsfield's Bushlark (Tiwi Islands) [81011]	Vulnerable	Species or species habitat known to occur within area
Ninox natalis Christmas Island Hawk-Owl, Christmas Boobook [66671]	Vulnerable	Species or species habitat known to occur within area
Numenius madagascariensis Eastern Curlew, Far Eastern Curlew [847]	Critically Endangered	Species or species

Name	Status	Type of Presence
		habitat known to occur within area
Papasula abbotti Abbott's Booby [59297]	Endangered	Species or species habitat known to occur within area
Pezoporus occidentalis Night Parrot [59350]	Endangered	Species or species habitat may occur within area
Phaethon lepturus fulvus Christmas Island White-tailed Tropicbird, Golden Bosunbird [26021]	Endangered	Breeding likely to occur within area
Polytelis alexandrae Princess Parrot, Alexandra's Parrot [758]	Vulnerable	Species or species habitat known to occur within area
Pterodroma arminjoniana Round Island Petrel, Trinidade Petrel [89284]	Critically Endangered	Breeding likely to occur within area
Pterodroma mollis Soft-plumaged Petrel [1036]	Vulnerable	Foraging, feeding or related behaviour likely to occur within area
Rostratula australis Australian Painted-snipe, Australian Painted Snipe [77037]	Endangered	Species or species habitat may occur within area
Sternula nereis nereis Australian Fairy Tern [82950]	Vulnerable	Foraging, feeding or related behaviour likely to occur within area
Thalassarche cauta cauta Shy Albatross, Tasmanian Shy Albatross [82345]	Vulnerable	Species or species habitat may occur within area
Thalassarche cauta steadi White-capped Albatross [82344]	Vulnerable	Species or species habitat may occur within area
Thalassarche impavida Campbell Albatross, Campbell Black-browed Albatross [64459]	Vulnerable	Species or species habitat may occur within area
Thalassarche melanophris Black-browed Albatross [66472]	Vulnerable	Species or species habitat may occur within area
Turdus poliocephalus erythropleurus Christmas Island Thrush [67122]	Endangered	Species or species habitat likely to occur within area
Tyto novaehollandiae kimberli Masked Owl (northern) [26048]	Vulnerable	Species or species habitat known to occur within area
Tyto novaehollandiae melvillensis Tiwi Masked Owl, Tiwi Islands Masked Owl [26049]	Endangered	Species or species habitat known to occur within area
Mammals		
Antechinus bellus Fawn Antechinus [344]	Vulnerable	Species or species habitat known to occur within area
Balaenoptera borealis Sei Whale [34]	Vulnerable	Foraging, feeding or related behaviour likely to occur within area
Balaenoptera musculus Blue Whale [36]	Endangered	Migration route known to occur within area

Name	Status	Type of Presence
Balaenoptera physalus Fin Whale [37]	Vulnerable	Foraging, feeding or related behaviour likely to occur within area
Conilurus penicillatus Brush-tailed Rabbit-rat, Brush-tailed Tree-rat, Pakooma [132]	Vulnerable	Species or species habitat known to occur within area
Crocidura trichura Christmas Island Shrew [86568]	Critically Endangered	Species or species habitat likely to occur within area
Dasyurus hallucatus Northern Quoll, Digul [Gogo-Yimidir], Wijingadda [Dambimangari], Wiminji [Martu] [331]	Endangered	Species or species habitat known to occur within area
Eubalaena australis Southern Right Whale [40]	Endangered	Species or species habitat may occur within area
Isoodon auratus auratus Golden Bandicoot (mainland) [66665]	Vulnerable	Species or species habitat likely to occur within area
Macroderma gigas Ghost Bat [174]	Vulnerable	Species or species habitat known to occur within area
Macrotis lagotis Greater Bilby [282]	Vulnerable	Species or species habitat likely to occur within area
Megaptera novaeangliae Humpback Whale [38]	Vulnerable	Breeding known to occur within area
Mesembriomys gouldii gouldii Black-footed Tree-rat (Kimberley and mainland Northern Territory), Djintamoonga, Manbul [87618]	Endangered	Species or species habitat known to occur within area
Mesembriomys gouldii melvillensis Black-footed Tree-rat (Melville Island) [87619]	Vulnerable	Species or species habitat known to occur within area
Mesembriomys macrurus Golden-backed Tree-rat, Koorrawal [119]	Vulnerable	Species or species habitat known to occur within area
Notomys aquilo Northern Hopping-mouse, Woorrentinta [123]	Vulnerable	Species or species habitat may occur within area
Petrogale concinna canescens Nabarlek (Top End) [87606]	Endangered	Species or species habitat may occur within area
Petrogale concinna monastria Nabarlek (Kimberley) [87607]	Endangered	Species or species habitat known to occur within area
Phascogale pirata Northern Brush-tailed Phascogale [82954]	Vulnerable	Species or species habitat known to occur within area
Phascogale tapoatafa kimberleyensis Kimberley brush-tailed phascogale, Brush-tailed Phascogale (Kimberley) [88453]	Vulnerable	Species or species habitat known to occur within area
Pipistrellus murrayi Christmas Island Pipistrelle [64383]	Critically Endangered	Species or species habitat known to occur within area
Pteropus natalis Christmas Island Flying-fox, Christmas Island	Critically Endangered	Roosting known to occur

Name	Status	Type of Presence
Fruit-bat [87611]		within area
Saccolaimus saccolaimus nudicluniatus Bare-rumped Sheath-tailed Bat, Bare-rumped Sheathtail Bat [66889]	Vulnerable	Species or species habitat known to occur within area
Sminthopsis butleri Butler's Dunnart [302]	Vulnerable	Species or species habitat known to occur within area
Xeromys myoides Water Mouse, False Water Rat, Yirrkoo [66]	Vulnerable	Species or species habitat known to occur within area
Plants		
Asplenium listeri Christmas Island Spleenwort [65865]	Critically Endangered	Species or species habitat known to occur within area
Burmannia sp. Bathurst Island (R.Fensham 1021) [82017]	Endangered	Species or species habitat likely to occur within area
Hoya australis subsp. oramicola a vine [55436]	Vulnerable	Species or species habitat known to occur within area
Mitrella tiwiensis a vine [82029]	Vulnerable	Species or species habitat likely to occur within area
Pneumatopteris truncata fern [68812]	Critically Endangered	Species or species habitat known to occur within area
Stylidium ensatum a triggerplant [86366]	Endangered	Species or species habitat likely to occur within area
Tectaria devexa [14767]	Endangered	Species or species habitat likely to occur within area
Typhonium jonesii a herb [62412]	Endangered	Species or species habitat known to occur within area
Typhonium mirabile a herb [79227]	Endangered	Species or species habitat known to occur within area
Xylopia monosperma a shrub [82030]	Endangered	Species or species habitat known to occur within area
Reptiles		
Acanthophis hawkei Plains Death Adder [83821]	Vulnerable	Species or species habitat known to occur within area
Aipysurus apraefrontalis Short-nosed Seasnake [1115]	Critically Endangered	Species or species habitat known to occur within area
Aipysurus foliosquama Leaf-scaled Seasnake [1118]	Critically Endangered	Species or species habitat known to occur within area
Caretta caretta Loggerhead Turtle [1763]	Endangered	Foraging, feeding or related behaviour known to occur within area
Chelonia mydas Green Turtle [1765]	Vulnerable	Breeding known to occur

Name	Status	Type of Presence
		within area
Cryptoblepharus egeriae		
Christmas Island Blue-tailed Skink, Blue-tailed Snake-eyed Skink [1526]	Critically Endangered	Species or species habitat likely to occur within area
Cryptoblepharus gurrmul		
Arafura Snake-eyed Skink [83106]	Endangered	Species or species habitat known to occur within area
Cyrtodactylus sadleiri		
Christmas Island Giant Gecko [86865]	Endangered	Species or species habitat known to occur within area
Dermochelys coriacea		
Leatherback Turtle, Leathery Turtle, Luth [1768]	Endangered	Foraging, feeding or related behaviour known to occur within area
Emoia nativitatis		
Christmas Island Forest Skink, Christmas Island Whiptail-skink [1400]	Critically Endangered	Species or species habitat known to occur within area
Eretmochelys imbricata		
Hawksbill Turtle [1766]	Vulnerable	Breeding known to occur within area
Lepidochelys olivacea		
Olive Ridley Turtle, Pacific Ridley Turtle [1767]	Endangered	Breeding known to occur within area
Lepidodactylus listeri		
Christmas Island Gecko, Lister's Gecko [1711]	Critically Endangered	Species or species habitat known to occur within area
Natator depressus		
Flatback Turtle [59257]	Vulnerable	Breeding known to occur within area
Ramphotyphlops exocoeti		
Christmas Island Blind Snake, Christmas Island Pink Blind Snake [1262]	Vulnerable	Species or species habitat likely to occur within area
Sharks		
Carcharias taurus (west coast population)		
Grey Nurse Shark (west coast population) [68752]	Vulnerable	Species or species habitat known to occur within area
Carcharodon carcharias		
White Shark, Great White Shark [64470]	Vulnerable	Species or species habitat known to occur within area
Glyphis garricki		
Northern River Shark, New Guinea River Shark [82454]	Endangered	Breeding known to occur within area
Glyphis glyphis		
Speartooth Shark [82453]	Critically Endangered	Species or species habitat known to occur within area
Pristis clavata		
Dwarf Sawfish, Queensland Sawfish [68447]	Vulnerable	Breeding known to occur within area
Pristis pristis		
Freshwater Sawfish, Largetooth Sawfish, River Sawfish, Leichhardt's Sawfish, Northern Sawfish [60756]	Vulnerable	Species or species habitat known to occur within area
Pristis zijsron		
Green Sawfish, Dindagubba, Narrowsnout Sawfish [68442]	Vulnerable	Breeding known to occur within area
Rhincodon typus		
Whale Shark [66680]	Vulnerable	Foraging, feeding or related behaviour known to occur within area

Listed Migratory Species		[Resource Information]
* Species is listed under a different scientific name on the EPBC Act - Threatened Species list.		
Name	Threatened	Type of Presence

Name	Threatened	Type of Presence
Migratory Marine Birds		
Anous stolidus Common Noddy [825]		Breeding known to occur within area
Apus pacificus Fork-tailed Swift [678]		Species or species habitat likely to occur within area
Ardenna carneipes Flesh-footed Shearwater, Fleshy-footed Shearwater [82404]		Species or species habitat may occur within area
Ardenna pacifica Wedge-tailed Shearwater [84292]		Breeding known to occur within area
Calonectris leucomelas Streaked Shearwater [1077]		Species or species habitat known to occur within area
Fregata andrewsi Christmas Island Frigatebird, Andrew's Frigatebird [1011]	Endangered	Breeding known to occur within area
Fregata ariel Lesser Frigatebird, Least Frigatebird [1012]		Breeding known to occur within area
Fregata minor Great Frigatebird, Greater Frigatebird [1013]		Breeding known to occur within area
Hydroprogne caspia Caspian Tern [808]		Breeding known to occur within area
Macronectes giganteus Southern Giant-Petrel, Southern Giant Petrel [1060]	Endangered	Species or species habitat may occur within area
Onychoprion anaethetus Bridled Tern [82845]		Breeding known to occur within area
Phaethon lepturus White-tailed Tropicbird [1014]		Breeding known to occur within area
Phaethon rubricauda Red-tailed Tropicbird [994]		Breeding known to occur within area
Sterna dougallii Roseate Tern [817]		Breeding known to occur within area
Sternula albifrons Little Tern [82849]		Breeding known to occur within area
Sula dactylatra Masked Booby [1021]		Breeding known to occur within area
Sula leucogaster Brown Booby [1022]		Breeding known to occur within area
Sula sula Red-footed Booby [1023]		Breeding known to occur within area
Thalassarche cauta Tasmanian Shy Albatross [89224]	Vulnerable*	Species or species habitat may occur within area
Thalassarche impavida Campbell Albatross, Campbell Black-browed Albatross [64459]	Vulnerable	Species or species habitat may occur within area
Thalassarche melanophris Black-browed Albatross [66472]	Vulnerable	Species or species habitat may occur within area

Name	Threatened	Type of Presence
Thalassarche steadi White-capped Albatross [64462]	Vulnerable*	Species or species habitat may occur within area
Migratory Marine Species		
Anoxypristis cuspidata Narrow Sawfish, Knifetooth Sawfish [68448]		Species or species habitat known to occur within area
Balaena glacialis australis Southern Right Whale [75529]	Endangered*	Species or species habitat may occur within area
Balaenoptera bonaerensis Antarctic Minke Whale, Dark-shoulder Minke Whale [67812]		Species or species habitat likely to occur within area
Balaenoptera borealis Sei Whale [34]	Vulnerable	Foraging, feeding or related behaviour likely to occur within area
Balaenoptera edeni Bryde's Whale [35]		Species or species habitat likely to occur within area
Balaenoptera musculus Blue Whale [36]	Endangered	Migration route known to occur within area
Balaenoptera physalus Fin Whale [37]	Vulnerable	Foraging, feeding or related behaviour likely to occur within area
Carcharodon carcharias White Shark, Great White Shark [64470]	Vulnerable	Species or species habitat known to occur within area
Caretta caretta Loggerhead Turtle [1763]	Endangered	Foraging, feeding or related behaviour known to occur within area
Chelonia mydas Green Turtle [1765]	Vulnerable	Breeding known to occur within area
Crocodylus porosus Salt-water Crocodile, Estuarine Crocodile [1774]		Species or species habitat likely to occur within area
Dermochelys coriacea Leatherback Turtle, Leathery Turtle, Luth [1768]	Endangered	Foraging, feeding or related behaviour known to occur within area
Dugong dugon Dugong [28]		Breeding known to occur within area
Eretmochelys imbricata Hawksbill Turtle [1766]	Vulnerable	Breeding known to occur within area
Isurus oxyrinchus Shortfin Mako, Mako Shark [79073]		Species or species habitat likely to occur within area
Isurus paucus Longfin Mako [82947]		Species or species habitat likely to occur within area
Lamna nasus Porbeagle, Mackerel Shark [83288]		Species or species habitat may occur within area
Lepidochelys olivacea Olive Ridley Turtle, Pacific Ridley Turtle [1767]	Endangered	Breeding known to occur within area

Name	Threatened	Type of Presence
Manta alfredi Reef Manta Ray, Coastal Manta Ray, Inshore Manta Ray, Prince Alfred's Ray, Resident Manta Ray [84994]		Species or species habitat known to occur within area
Manta birostris Giant Manta Ray, Chevron Manta Ray, Pacific Manta Ray, Pelagic Manta Ray, Oceanic Manta Ray [84995]		Species or species habitat known to occur within area
Megaptera novaeangliae Humpback Whale [38]	Vulnerable	Breeding known to occur within area
Natator depressus Flatback Turtle [59257]	Vulnerable	Breeding known to occur within area
Orcaella brevirostris Irrawaddy Dolphin [45]		Species or species habitat known to occur within area
Orcinus orca Killer Whale, Orca [46]		Species or species habitat may occur within area
Physeter macrocephalus Sperm Whale [59]		Species or species habitat may occur within area
Pristis clavata Dwarf Sawfish, Queensland Sawfish [68447]	Vulnerable	Breeding known to occur within area
Pristis pristis Freshwater Sawfish, Largetooth Sawfish, River Sawfish, Leichhardt's Sawfish, Northern Sawfish [60756]	Vulnerable	Species or species habitat known to occur within area
Pristis zijsron Green Sawfish, Dindagubba, Narrowsnout Sawfish [68442]	Vulnerable	Breeding known to occur within area
Rhincodon typus Whale Shark [66680]	Vulnerable	Foraging, feeding or related behaviour known to occur within area
Sousa chinensis Indo-Pacific Humpback Dolphin [50]		Breeding known to occur within area
Tursiops aduncus (Arafura/Timor Sea populations) Spotted Bottlenose Dolphin (Arafura/Timor Sea populations) [78900]		Species or species habitat known to occur within area
Migratory Terrestrial Species		
Cecropis daurica Red-rumped Swallow [80610]		Species or species habitat known to occur within area
Cuculus optatus Oriental Cuckoo, Horsfield's Cuckoo [86651]		Species or species habitat known to occur within area
Hirundo rustica Barn Swallow [662]		Species or species habitat known to occur within area
Motacilla cinerea Grey Wagtail [642]		Species or species habitat known to occur within area
Motacilla flava Yellow Wagtail [644]		Species or species habitat known to occur within area
Rhipidura rufifrons Rufous Fantail [592]		Species or species habitat known to occur within area
Migratory Wetlands Species		

Name	Threatened	Type of Presence
Acrocephalus orientalis Oriental Reed-Warbler [59570]		Species or species habitat known to occur within area
Actitis hypoleucos Common Sandpiper [59309]		Species or species habitat known to occur within area
Arenaria interpres Ruddy Turnstone [872]		Foraging, feeding or related behaviour known to occur within area
Calidris acuminata Sharp-tailed Sandpiper [874]		Foraging, feeding or related behaviour known to occur within area
Calidris alba Sanderling [875]		Foraging, feeding or related behaviour known to occur within area
Calidris canutus Red Knot, Knot [855]	Endangered	Species or species habitat known to occur within area
Calidris ferruginea Curlew Sandpiper [856]	Critically Endangered	Species or species habitat known to occur within area
Calidris melanotos Pectoral Sandpiper [858]		Species or species habitat known to occur within area
Calidris ruficollis Red-necked Stint [860]		Foraging, feeding or related behaviour known to occur within area
Calidris subminuta Long-toed Stint [861]		Foraging, feeding or related behaviour known to occur within area
Calidris tenuirostris Great Knot [862]	Critically Endangered	Foraging, feeding or related behaviour known to occur within area
Charadrius dubius Little Ringed Plover [896]		Foraging, feeding or related behaviour known to occur within area
Charadrius leschenaultii Greater Sand Plover, Large Sand Plover [877]	Vulnerable	Foraging, feeding or related behaviour known to occur within area
Charadrius mongolus Lesser Sand Plover, Mongolian Plover [879]	Endangered	Foraging, feeding or related behaviour known to occur within area
Charadrius veredus Oriental Plover, Oriental Dotterel [882]		Foraging, feeding or related behaviour known to occur within area
Gallinago megala Swinhoe's Snipe [864]		Foraging, feeding or related behaviour known to occur within area
Gallinago stenura Pin-tailed Snipe [841]		Foraging, feeding or related behaviour likely to occur within area
Glareola maldivarum Oriental Pratincole [840]		Foraging, feeding or related behaviour known to occur within area

Name	Threatened	Type of Presence
Limicola falcinellus Broad-billed Sandpiper [842]		Foraging, feeding or related behaviour known to occur within area
Limnodromus semipalmatus Asian Dowitcher [843]		Foraging, feeding or related behaviour known to occur within area
Limosa lapponica Bar-tailed Godwit [844]		Species or species habitat known to occur within area
Limosa limosa Black-tailed Godwit [845]		Foraging, feeding or related behaviour known to occur within area
Numenius madagascariensis Eastern Curlew, Far Eastern Curlew [847]	Critically Endangered	Species or species habitat known to occur within area
Numenius minutus Little Curlew, Little Whimbrel [848]		Foraging, feeding or related behaviour known to occur within area
Numenius phaeopus Whimbrel [849]		Foraging, feeding or related behaviour known to occur within area
Pandion haliaetus Osprey [952]		Breeding known to occur within area
Pluvialis fulva Pacific Golden Plover [25545]		Foraging, feeding or related behaviour known to occur within area
Pluvialis squatarola Grey Plover [865]		Foraging, feeding or related behaviour known to occur within area
Thalasseus bergii Crested Tern [83000]		Breeding known to occur within area
Tringa brevipes Grey-tailed Tattler [851]		Foraging, feeding or related behaviour known to occur within area
Tringa glareola Wood Sandpiper [829]		Foraging, feeding or related behaviour known to occur within area
Tringa incana Wandering Tattler [831]		Foraging, feeding or related behaviour known to occur within area
Tringa nebularia Common Greenshank, Greenshank [832]		Species or species habitat known to occur within area
Tringa stagnatilis Marsh Sandpiper, Little Greenshank [833]		Foraging, feeding or related behaviour known to occur within area
Tringa totanus Common Redshank, Redshank [835]		Species or species habitat known to occur within area
Xenus cinereus Terek Sandpiper [59300]		Foraging, feeding or related behaviour known to occur within area

Other Matters Protected by the EPBC Act

Commonwealth Land [Resource Information]

The Commonwealth area listed below may indicate the presence of Commonwealth land in this vicinity. Due to the unreliability of the data source, all proposals should be checked as to whether it impacts on a Commonwealth area, before making a definitive decision. Contact the State or Territory government land department for further information.

Name
Commonwealth Land -
Commonwealth Land - Australian Government Solicitor
Commonwealth Land - Christmas Island National Park
Commonwealth Land - Pulu Keeling National Park
Defence - QUAIL ISLAND BOMBING RANGE
Defence - YAMPI SOUND TRAINING AREA

Commonwealth Heritage Places [Resource Information]

Name	State	Status
Natural		
Ashmore Reef National Nature Reserve	EXT	Listed place
Christmas Island Natural Areas	EXT	Listed place
Mermaid Reef - Rowley Shoals	WA	Listed place
North Keeling Island	EXT	Listed place
Scott Reef and Surrounds - Commonwealth Area	EXT	Listed place
Yampi Defence Area	WA	Listed place
Historic		
Administration Building Forecourt	EXT	Listed place
Administrators House Precinct	EXT	Listed place
Bungalow 702	EXT	Listed place
Captain Ballards Grave	EXT	Listed place
Direction Island (DI) Houses	EXT	Listed place
Drumsite Industrial Area	EXT	Listed place
Early Settlers Graves	EXT	Listed place
Government House	EXT	Listed place
Home Island Cemetery	EXT	Listed place
Home Island Foreshore	EXT	Listed place
Home Island Industrial Precinct	EXT	Listed place
Industrial and Administrative Group	EXT	Listed place
Malay Kampong Group	EXT	Listed place
Malay Kampong Precinct	EXT	Listed place
Oceania House and Surrounds	EXT	Listed place
Old Co-op Shop (Canteen)	EXT	Listed place
Phosphate Hill Historic Area	EXT	Listed place
Poon Saan Group	EXT	Listed place
Qantas Huts (former)	EXT	Listed place
RAAF Memorial	EXT	Listed place
Settlement Christmas Island	EXT	Listed place
Six Inch Guns	EXT	Listed place
Slipway and Tank	EXT	Listed place
South Point Settlement Remains	EXT	Listed place
Type 2 Residences	EXT	Listed place
Type T Houses Precinct	EXT	Listed place
West Island Elevated Houses	EXT	Listed place
West Island Housing Precinct	EXT	Listed place
West Island Mosque	EXT	Listed place

Listed Marine Species [Resource Information]

* Species is listed under a different scientific name on the EPBC Act - Threatened Species list.

Name	Threatened	Type of Presence
Birds		
Acrocephalus orientalis Oriental Reed-Warbler [59570]		Species or species habitat known to occur within area
Actitis hypoleucos Common Sandpiper [59309]		Species or species habitat known to occur within area

Name	Threatened	Type of Presence
Anous minutus Black Noddy [824]		Breeding known to occur within area
Anous stolidus Common Noddy [825]		Breeding known to occur within area
Anous tenuirostris melanops Australian Lesser Noddy [26000]	Vulnerable	Breeding known to occur within area
Anseranas semipalmata Magpie Goose [978]		Species or species habitat may occur within area
Apus pacificus Fork-tailed Swift [678]		Species or species habitat likely to occur within area
Ardea alba Great Egret, White Egret [59541]		Species or species habitat known to occur within area
Ardea ibis Cattle Egret [59542]		Species or species habitat may occur within area
Arenaria interpres Ruddy Turnstone [872]		Foraging, feeding or related behaviour known to occur within area
Calidris acuminata Sharp-tailed Sandpiper [874]		Foraging, feeding or related behaviour known to occur within area
Calidris alba Sanderling [875]		Foraging, feeding or related behaviour known to occur within area
Calidris canutus Red Knot, Knot [855]	Endangered	Species or species habitat known to occur within area
Calidris ferruginea Curlew Sandpiper [856]	Critically Endangered	Species or species habitat known to occur within area
Calidris melanotos Pectoral Sandpiper [858]		Species or species habitat known to occur within area
Calidris ruficollis Red-necked Stint [860]		Foraging, feeding or related behaviour known to occur within area
Calidris subminuta Long-toed Stint [861]		Foraging, feeding or related behaviour known to occur within area
Calidris tenuirostris Great Knot [862]	Critically Endangered	Foraging, feeding or related behaviour known to occur within area
Calonectris leucomelas Streaked Shearwater [1077]		Species or species habitat known to occur within area
Charadrius dubius Little Ringed Plover [896]		Foraging, feeding or related behaviour known to occur within area
Charadrius leschenaultii Greater Sand Plover, Large Sand Plover [877]	Vulnerable	Foraging, feeding or related behaviour known to occur within area

Name	Threatened	Type of Presence
Charadrius mongolus Lesser Sand Plover, Mongolian Plover [879]	Endangered	Foraging, feeding or related behaviour known to occur within area
Charadrius ruficapillus Red-capped Plover [881]		Foraging, feeding or related behaviour known to occur within area
Charadrius veredus Oriental Plover, Oriental Dotterel [882]		Foraging, feeding or related behaviour known to occur within area
Chrysococcyx osculans Black-eared Cuckoo [705]		Species or species habitat known to occur within area
Fregata andrewsi Christmas Island Frigatebird, Andrew's Frigatebird [1011]	Endangered	Breeding known to occur within area
Fregata ariel Lesser Frigatebird, Least Frigatebird [1012]		Breeding known to occur within area
Fregata minor Great Frigatebird, Greater Frigatebird [1013]		Breeding known to occur within area
Gallinago megala Swinhoe's Snipe [864]		Foraging, feeding or related behaviour known to occur within area
Gallinago stenura Pin-tailed Snipe [841]		Foraging, feeding or related behaviour likely to occur within area
Glareola maldivarum Oriental Pratincole [840]		Foraging, feeding or related behaviour known to occur within area
Haliaeetus leucogaster White-bellied Sea-Eagle [943]		Species or species habitat known to occur within area
Heteroscelus brevipes Grey-tailed Tattler [59311]		Foraging, feeding or related behaviour known to occur within area
Heteroscelus incanus Wandering Tattler [59547]		Foraging, feeding or related behaviour known to occur within area
Himantopus himantopus Pied Stilt, Black-winged Stilt [870]		Foraging, feeding or related behaviour known to occur within area
Hirundo daurica Red-rumped Swallow [59480]		Species or species habitat known to occur within area
Hirundo rustica Barn Swallow [662]		Species or species habitat known to occur within area
Larus novaehollandiae Silver Gull [810]		Breeding known to occur within area
Limicola falcinellus Broad-billed Sandpiper [842]		Foraging, feeding or related behaviour known to occur within area
Limnodromus semipalmatus Asian Dowitcher [843]		Foraging, feeding or related behaviour known to occur within area

Name	Threatened	Type of Presence
Limosa lapponica Bar-tailed Godwit [844]		Species or species habitat known to occur within area
Limosa limosa Black-tailed Godwit [845]		Foraging, feeding or related behaviour known to occur within area
Macronectes giganteus Southern Giant-Petrel, Southern Giant Petrel [1060]	Endangered	Species or species habitat may occur within area
Merops ornatus Rainbow Bee-eater [670]		Species or species habitat may occur within area
Motacilla cinerea Grey Wagtail [642]		Species or species habitat known to occur within area
Motacilla flava Yellow Wagtail [644]		Species or species habitat known to occur within area
Numenius madagascariensis Eastern Curlew, Far Eastern Curlew [847]	Critically Endangered	Species or species habitat known to occur within area
Numenius minutus Little Curlew, Little Whimbrel [848]		Foraging, feeding or related behaviour known to occur within area
Numenius phaeopus Whimbrel [849]		Foraging, feeding or related behaviour known to occur within area
Pandion haliaetus Osprey [952]		Breeding known to occur within area
Papasula abbotti Abbott's Booby [59297]	Endangered	Species or species habitat known to occur within area
Phaethon lepturus White-tailed Tropicbird [1014]		Breeding known to occur within area
Phaethon lepturus fulvus Christmas Island White-tailed Tropicbird, Golden Bosunbird [26021]	Endangered	Breeding likely to occur within area
Phaethon rubricauda Red-tailed Tropicbird [994]		Breeding known to occur within area
Pluvialis fulva Pacific Golden Plover [25545]		Foraging, feeding or related behaviour known to occur within area
Pluvialis squatarola Grey Plover [865]		Foraging, feeding or related behaviour known to occur within area
Pterodroma mollis Soft-plumaged Petrel [1036]	Vulnerable	Foraging, feeding or related behaviour likely to occur within area
Puffinus carneipes Flesh-footed Shearwater, Fleshy-footed Shearwater [1043]		Species or species habitat may occur within area
Puffinus pacificus Wedge-tailed Shearwater [1027]		Breeding known to occur within area
Rhipidura rufifrons Rufous Fantail [592]		Species or species

Name	Threatened	Type of Presence
		habitat known to occur within area
Rostratula benghalensis (sensu lato) Painted Snipe [889]	Endangered*	Species or species habitat may occur within area
Sterna albifrons Little Tern [813]		Breeding known to occur within area
Sterna anaethetus Bridled Tern [814]		Breeding known to occur within area
Sterna bengalensis Lesser Crested Tern [815]		Breeding known to occur within area
Sterna bergii Crested Tern [816]		Breeding known to occur within area
Sterna caspia Caspian Tern [59467]		Breeding known to occur within area
Sterna dougallii Roseate Tern [817]		Breeding known to occur within area
Sterna fuscata Sooty Tern [794]		Breeding known to occur within area
Sterna nereis Fairy Tern [796]		Breeding known to occur within area
Stiltia isabella Australian Pratincole [818]		Foraging, feeding or related behaviour known to occur within area
Sula dactylatra Masked Booby [1021]		Breeding known to occur within area
Sula leucogaster Brown Booby [1022]		Breeding known to occur within area
Sula sula Red-footed Booby [1023]		Breeding known to occur within area
Thalassarche cauta Tasmanian Shy Albatross [89224]	Vulnerable*	Species or species habitat may occur within area
Thalassarche impavida Campbell Albatross, Campbell Black-browed Albatross [64459]	Vulnerable	Species or species habitat may occur within area
Thalassarche melanophris Black-browed Albatross [66472]	Vulnerable	Species or species habitat may occur within area
Thalassarche steadi White-capped Albatross [64462]	Vulnerable*	Species or species habitat may occur within area
Tringa glareola Wood Sandpiper [829]		Foraging, feeding or related behaviour known to occur within area
Tringa nebularia Common Greenshank, Greenshank [832]		Species or species habitat known to occur within area
Tringa stagnatilis Marsh Sandpiper, Little Greenshank [833]		Foraging, feeding or related behaviour known to occur within area

Name	Threatened	Type of Presence
Tringa totanus Common Redshank, Redshank [835]		Species or species habitat known to occur within area
Xenus cinereus Terek Sandpiper [59300]		Foraging, feeding or related behaviour known to occur within area
Fish		
Acentronura larsonae Helen's Pygmy Pipehorse [66186]		Species or species habitat may occur within area
Bhanotia fasciolata Corrugated Pipefish, Barbed Pipefish [66188]		Species or species habitat may occur within area
Bulbonaricus brauni Braun's Pughead Pipefish, Pug-headed Pipefish [66189]		Species or species habitat may occur within area
Campichthys tricarinatus Three-keel Pipefish [66192]		Species or species habitat may occur within area
Choeroichthys brachysoma Pacific Short-bodied Pipefish, Short-bodied Pipefish [66194]		Species or species habitat may occur within area
Choeroichthys latispinosus Muiron Island Pipefish [66196]		Species or species habitat may occur within area
Choeroichthys sculptus Sculptured Pipefish [66197]		Species or species habitat may occur within area
Choeroichthys suillus Pig-snouted Pipefish [66198]		Species or species habitat may occur within area
Corythoichthys amplexus Fijian Banded Pipefish, Brown-banded Pipefish [66199]		Species or species habitat may occur within area
Corythoichthys flavofasciatus Reticulate Pipefish, Yellow-banded Pipefish, Network Pipefish [66200]		Species or species habitat may occur within area
Corythoichthys haematopterus Reef-top Pipefish [66201]		Species or species habitat may occur within area
Corythoichthys intestinalis Australian Messmate Pipefish, Banded Pipefish [66202]		Species or species habitat may occur within area
Corythoichthys schultzi Schultz's Pipefish [66205]		Species or species habitat may occur within area
Cosmocampus banneri Roughridge Pipefish [66206]		Species or species habitat may occur within area
Cosmocampus maxweberi Maxweber's Pipefish [66209]		Species or species habitat may occur within area
Doryrhamphus baldwini Redstripe Pipefish [66718]		Species or species habitat may occur within area

Name	Threatened	Type of Presence
Doryrhamphus dactyliophorus Banded Pipefish, Ringed Pipefish [66210]		Species or species habitat may occur within area
Doryrhamphus excisus Bluestripe Pipefish, Indian Blue-stripe Pipefish, Pacific Blue-stripe Pipefish [66211]		Species or species habitat may occur within area
Doryrhamphus janssi Cleaner Pipefish, Janss' Pipefish [66212]		Species or species habitat may occur within area
Doryrhamphus multiannulatus Many-banded Pipefish [66717]		Species or species habitat may occur within area
Doryrhamphus negrosensis Flagtail Pipefish, Masthead Island Pipefish [66213]		Species or species habitat may occur within area
Festucalex cinctus Girdled Pipefish [66214]		Species or species habitat may occur within area
Festucalex scalaris Ladder Pipefish [66216]		Species or species habitat may occur within area
Filicampus tigris Tiger Pipefish [66217]		Species or species habitat may occur within area
Halicampus brocki Brock's Pipefish [66219]		Species or species habitat may occur within area
Halicampus dunckeri Red-hair Pipefish, Duncker's Pipefish [66220]		Species or species habitat may occur within area
Halicampus grayi Mud Pipefish, Gray's Pipefish [66221]		Species or species habitat may occur within area
Halicampus macrorhynchus Whiskered Pipefish, Ornate Pipefish [66222]		Species or species habitat may occur within area
Halicampus mataafae Samoan Pipefish [66223]		Species or species habitat may occur within area
Halicampus nitidus Glittering Pipefish [66224]		Species or species habitat may occur within area
Halicampus spinirostris Spiny-snout Pipefish [66225]		Species or species habitat may occur within area
Haliichthys taeniophorus Ribboned Pipehorse, Ribboned Seadragon [66226]		Species or species habitat may occur within area
Hippichthys cyanospilos Blue-speckled Pipefish, Blue-spotted Pipefish [66228]		Species or species habitat may occur within area
Hippichthys heptagonus Madura Pipefish, Reticulated Freshwater Pipefish [66229]		Species or species habitat may occur within area

Name	Threatened	Type of Presence
Hippichthys parvicarinatus Short-keel Pipefish, Short-keeled Pipefish [66230]		Species or species habitat may occur within area
Hippichthys penicillus Beady Pipefish, Steep-nosed Pipefish [66231]		Species or species habitat may occur within area
Hippichthys spicifer Belly-barred Pipefish, Banded Freshwater Pipefish [66232]		Species or species habitat may occur within area
Hippocampus angustus Western Spiny Seahorse, Narrow-bellied Seahorse [66234]		Species or species habitat may occur within area
Hippocampus histrix Spiny Seahorse, Thorny Seahorse [66236]		Species or species habitat may occur within area
Hippocampus kuda Spotted Seahorse, Yellow Seahorse [66237]		Species or species habitat may occur within area
Hippocampus planifrons Flat-face Seahorse [66238]		Species or species habitat may occur within area
Hippocampus spinosissimus Hedgehog Seahorse [66239]		Species or species habitat may occur within area
Hippocampus trimaculatus Three-spot Seahorse, Low-crowned Seahorse, Flat-faced Seahorse [66720]		Species or species habitat may occur within area
Micrognathus brevirostris thorntail Pipefish, Thorn-tailed Pipefish [66254]		Species or species habitat may occur within area
Micrognathus micronotopterus Tidepool Pipefish [66255]		Species or species habitat may occur within area
Phoxocampus belcheri Black Rock Pipefish [66719]		Species or species habitat may occur within area
Solegnathus hardwickii Pallid Pipehorse, Hardwick's Pipehorse [66272]		Species or species habitat may occur within area
Solegnathus lettiensis Gunther's Pipehorse, Indonesian Pipefish [66273]		Species or species habitat may occur within area
Solenostomus cyanopterus Robust Ghostpipefish, Blue-finned Ghost Pipefish, [66183]		Species or species habitat may occur within area
Syngnathoides biaculeatus Double-end Pipehorse, Double-ended Pipehorse, Alligator Pipefish [66279]		Species or species habitat may occur within area
Trachyrhamphus bicoarctatus Bentstick Pipefish, Bend Stick Pipefish, Short-tailed Pipefish [66280]		Species or species habitat may occur within area
Trachyrhamphus longirostris Straightstick Pipefish, Long-nosed Pipefish, Straight Stick Pipefish [66281]		Species or species habitat may occur within area
Mammals		

Name	Threatened	Type of Presence
Dugong dugon Dugong [28]		Breeding known to occur within area
Reptiles		
Acalyptophis peronii Horned Seasnake [1114]		Species or species habitat may occur within area
Aipysurus apraefrontalis Short-nosed Seasnake [1115]	Critically Endangered	Species or species habitat known to occur within area
Aipysurus duboisii Dubois' Seasnake [1116]		Species or species habitat may occur within area
Aipysurus eydouxii Spine-tailed Seasnake [1117]		Species or species habitat may occur within area
Aipysurus foliosquama Leaf-scaled Seasnake [1118]	Critically Endangered	Species or species habitat known to occur within area
Aipysurus fuscus Dusky Seasnake [1119]		Species or species habitat known to occur within area
Aipysurus laevis Olive Seasnake [1120]		Species or species habitat may occur within area
Aipysurus tenuis Brown-lined Seasnake [1121]		Species or species habitat may occur within area
Astrotia stokesii Stokes' Seasnake [1122]		Species or species habitat may occur within area
Caretta caretta Loggerhead Turtle [1763]	Endangered	Foraging, feeding or related behaviour known to occur within area
Chelonia mydas Green Turtle [1765]	Vulnerable	Breeding known to occur within area
Crocodylus johnstoni Freshwater Crocodile, Johnston's Crocodile, Johnston's River Crocodile [1773]		Species or species habitat may occur within area
Crocodylus porosus Salt-water Crocodile, Estuarine Crocodile [1774]		Species or species habitat likely to occur within area
Dermochelys coriacea Leatherback Turtle, Leathery Turtle, Luth [1768]	Endangered	Foraging, feeding or related behaviour known to occur within area
Disteira kingii Spectacled Seasnake [1123]		Species or species habitat may occur within area
Disteira major Olive-headed Seasnake [1124]		Species or species habitat may occur within area
Emydocephalus annulatus Turtle-headed Seasnake [1125]		Species or species habitat may occur within area
Enhydrina schistosa Beaked Seasnake [1126]		Species or species

Name	Threatened	Type of Presence
		habitat may occur within area
Ephalophis greyi North-western Mangrove Seasnake [1127]		Species or species habitat may occur within area
Eretmochelys imbricata Hawksbill Turtle [1766]	Vulnerable	Breeding known to occur within area
Hydrelaps darwiniensis Black-ringed Seasnake [1100]		Species or species habitat may occur within area
Hydrophis atriceps Black-headed Seasnake [1101]		Species or species habitat may occur within area
Hydrophis coggeri Slender-necked Seasnake [25925]		Species or species habitat may occur within area
Hydrophis czeblukovi Fine-spined Seasnake [59233]		Species or species habitat may occur within area
Hydrophis elegans Elegant Seasnake [1104]		Species or species habitat may occur within area
Hydrophis inornatus Plain Seasnake [1107]		Species or species habitat may occur within area
Hydrophis mcdowelli null [25926]		Species or species habitat may occur within area
Hydrophis ornatus Spotted Seasnake, Ornate Reef Seasnake [1111]		Species or species habitat may occur within area
Hydrophis pacificus Large-headed Seasnake, Pacific Seasnake [1112]		Species or species habitat may occur within area
Lapemis hardwickii Spine-bellied Seasnake [1113]		Species or species habitat may occur within area
Lepidochelys olivacea Olive Ridley Turtle, Pacific Ridley Turtle [1767]	Endangered	Breeding known to occur within area
Natator depressus Flatback Turtle [59257]	Vulnerable	Breeding known to occur within area
Parahydrophis mertoni Northern Mangrove Seasnake [1090]		Species or species habitat may occur within area
Pelamis platurus Yellow-bellied Seasnake [1091]		Species or species habitat may occur within area

Whales and other Cetaceans		[Resource Information]
Name	Status	Type of Presence
Mammals		
Balaenoptera acutorostrata Minke Whale [33]		Species or species habitat may occur within area
Balaenoptera bonaerensis Antarctic Minke Whale, Dark-shoulder Minke		Species or species

Name	Status	Type of Presence
Whale [67812]		habitat likely to occur within area
Balaenoptera borealis Sei Whale [34]	Vulnerable	Foraging, feeding or related behaviour likely to occur within area
Balaenoptera edeni Bryde's Whale [35]		Species or species habitat likely to occur within area
Balaenoptera musculus Blue Whale [36]	Endangered	Migration route known to occur within area
Balaenoptera physalus Fin Whale [37]	Vulnerable	Foraging, feeding or related behaviour likely to occur within area
Delphinus delphis Common Dophin, Short-beaked Common Dolphin [60]		Species or species habitat may occur within area
Eubalaena australis Southern Right Whale [40]	Endangered	Species or species habitat may occur within area
Feresa attenuata Pygmy Killer Whale [61]		Species or species habitat may occur within area
Globicephala macrorhynchus Short-finned Pilot Whale [62]		Species or species habitat may occur within area
Grampus griseus Risso's Dolphin, Grampus [64]		Species or species habitat may occur within area
Indopacetus pacificus Longman's Beaked Whale [72]		Species or species habitat may occur within area
Kogia breviceps Pygmy Sperm Whale [57]		Species or species habitat may occur within area
Kogia simus Dwarf Sperm Whale [58]		Species or species habitat may occur within area
Lagenodelphis hosei Fraser's Dolphin, Sarawak Dolphin [41]		Species or species habitat may occur within area
Megaptera novaeangliae Humpback Whale [38]	Vulnerable	Breeding known to occur within area
Mesoplodon densirostris Blainville's Beaked Whale, Dense-beaked Whale [74]		Species or species habitat may occur within area
Mesoplodon ginkgodens Gingko-toothed Beaked Whale, Gingko-toothed Whale, Gingko Beaked Whale [59564]		Species or species habitat may occur within area
Orcaella brevirostris Irrawaddy Dolphin [45]		Species or species habitat known to occur within area
Orcinus orca Killer Whale, Orca [46]		Species or species habitat may occur within area

Name	Status	Type of Presence
Peponocephala electra Melon-headed Whale [47]		Species or species habitat may occur within area
Physeter macrocephalus Sperm Whale [59]		Species or species habitat may occur within area
Pseudorca crassidens False Killer Whale [48]		Species or species habitat likely to occur within area
Sousa chinensis Indo-Pacific Humpback Dolphin [50]		Breeding known to occur within area
Stenella attenuata Spotted Dolphin, Pantropical Spotted Dolphin [51]		Species or species habitat may occur within area
Stenella coeruleoalba Striped Dolphin, Euphrosyne Dolphin [52]		Species or species habitat may occur within area
Stenella longirostris Long-snouted Spinner Dolphin [29]		Species or species habitat may occur within area
Steno bredanensis Rough-toothed Dolphin [30]		Species or species habitat may occur within area
Tursiops aduncus Indian Ocean Bottlenose Dolphin, Spotted Bottlenose Dolphin [68418]		Species or species habitat likely to occur within area
Tursiops aduncus (Arafura/Timor Sea populations) Spotted Bottlenose Dolphin (Arafura/Timor Sea populations) [78900]		Species or species habitat known to occur within area
Tursiops truncatus s. str. Bottlenose Dolphin [68417]		Species or species habitat may occur within area
Ziphius cavirostris Cuvier's Beaked Whale, Goose-beaked Whale [56]		Species or species habitat may occur within area

Australian Marine Parks [Resource Information]

Name	Label
Arafura	Multiple Use Zone (IUCN VI)
Arafura	Special Purpose Zone (IUCN VI)
Arafura	Special Purpose Zone (Trawl) (IUCN VI)
Argo-Rowley Terrace	Multiple Use Zone (IUCN VI)
Argo-Rowley Terrace	National Park Zone (IUCN II)
Argo-Rowley Terrace	Special Purpose Zone (Trawl) (IUCN VI)
Arnhem	Special Purpose Zone (IUCN VI)
Ashmore Reef	Recreational Use Zone (IUCN IV)
Ashmore Reef	Sanctuary Zone (IUCN Ia)
Cartier Island	Sanctuary Zone (IUCN Ia)
Eighty Mile Beach	Multiple Use Zone (IUCN VI)
Gascoyne	Habitat Protection Zone (IUCN IV)
Gascoyne	Multiple Use Zone (IUCN VI)
Gascoyne	National Park Zone (IUCN II)
Joseph Bonaparte Gulf	Multiple Use Zone (IUCN VI)
Joseph Bonaparte Gulf	Special Purpose Zone (IUCN VI)
Kimberley	Habitat Protection Zone (IUCN IV)

Name	Label
Kimberley	Multiple Use Zone (IUCN VI)
Kimberley	National Park Zone (IUCN II)
Mermaid Reef	National Park Zone (IUCN II)
Montebello	Multiple Use Zone (IUCN VI)
Oceanic Shoals	Habitat Protection Zone (IUCN IV)
Oceanic Shoals	Multiple Use Zone (IUCN VI)
Oceanic Shoals	National Park Zone (IUCN II)
Oceanic Shoals	Special Purpose Zone (Trawl) (IUCN VI)

Extra Information

State and Territory Reserves [Resource Information]

Name	State
Adele Island	WA
Balanggarra	WA
Bardi Jawi	WA
Bedout Island	WA
Browse Island	WA
Casuarina	NT
Christmas Island	EXT
Coulomb Point	WA
Dambimangari	WA
Djukbinj	NT
Garig Gunak Barlu	NT
Indian Island	NT
Lacepede Islands	WA
Lawley River	WA
Lesueur Island	WA
Low Rocks	WA
Prince Regent	WA
Pulu Keeling	EXT
Swan Island	WA
Tanner Island	WA
Unnamed WA28968	WA
Unnamed WA37168	WA
Unnamed WA41775	WA
Unnamed WA44669	WA
Unnamed WA44672	WA
Unnamed WA44673	WA
Unnamed WA44674	WA
Unnamed WA44677	WA
Uunguu	WA
Vernon Islands	NT

Invasive Species [Resource Information]

Weeds reported here are the 20 species of national significance (WoNS), along with other introduced plants that are considered by the States and Territories to pose a particularly significant threat to biodiversity. The following feral animals are reported: Goat, Red Fox, Cat, Rabbit, Pig, Water Buffalo and Cane Toad. Maps from Landscape Health Project, National Land and Water Resouces Audit, 2001.

Name	Status	Type of Presence
Birds		
Anas platyrhynchos Mallard [974]		Species or species habitat likely to occur within area
Columba livia Rock Pigeon, Rock Dove, Domestic Pigeon [803]		Species or species habitat likely to occur

Name	Status	Type of Presence
		within area
Gallus gallus Red Junglefowl, Domestic Fowl [917]		Species or species habitat likely to occur within area
Gallus varius Green Junglefowl [81207]		Species or species habitat likely to occur within area
Lonchura oryzivora Java Sparrow [59586]		Species or species habitat likely to occur within area
Meleagris gallopavo Wild Turkey [64380]		Species or species habitat likely to occur within area
Passer montanus Eurasian Tree Sparrow [406]		Species or species habitat likely to occur within area
Frogs		
Rhinella marina Cane Toad [83218]		Species or species habitat known to occur within area
Mammals		
Bos javanicus Banteng, Bali Cattle [15]		Species or species habitat likely to occur within area
Bos taurus Domestic Cattle [16]		Species or species habitat likely to occur within area
Bubalus bubalis Water Buffalo, Swamp Buffalo [1]		Species or species habitat likely to occur within area
Canis lupus familiaris Domestic Dog [82654]		Species or species habitat likely to occur within area
Capra hircus Goat [2]		Species or species habitat likely to occur within area
Equus asinus Donkey, Ass [4]		Species or species habitat likely to occur within area
Equus caballus Horse [5]		Species or species habitat likely to occur within area
Felis catus Cat, House Cat, Domestic Cat [19]		Species or species habitat likely to occur within area
Mus musculus House Mouse [120]		Species or species habitat likely to occur within area
Rattus exulans Pacific Rat, Polynesian Rat [79]		Species or species habitat likely to occur within area
Rattus rattus Black Rat, Ship Rat [84]		Species or species habitat likely to occur within area
Sus scrofa Pig [6]		Species or species

Name	Status	Type of Presence
		habitat likely to occur within area
Plants		
Andropogon gayanus Gamba Grass [66895]		Species or species habitat likely to occur within area
Brachiaria mutica Para Grass [5879]		Species or species habitat likely to occur within area
Cabomba caroliniana Cabomba, Fanwort, Carolina Watershield, Fish Grass, Washington Grass, Watershield, Carolina Fanwort, Common Cabomba [5171]		Species or species habitat likely to occur within area
Cenchrus ciliaris Buffel-grass, Black Buffel-grass [20213]		Species or species habitat likely to occur within area
Hymenachne amplexicaulis Hymenachne, Olive Hymenachne, Water Stargrass, West Indian Grass, West Indian Marsh Grass [31754]		Species or species habitat likely to occur within area
Jatropha gossypifolia Cotton-leaved Physic-Nut, Bellyache Bush, Cotton-leaf Physic Nut, Cotton-leaf Jatropha, Black Physic Nut [7507]		Species or species habitat likely to occur within area
Lantana camara Lantana, Common Lantana, Kamara Lantana, Large-leaf Lantana, Pink Flowered Lantana, Red Flowered Lantana, Red-Flowered Sage, White Sage, Wild Sage [10892]		Species or species habitat likely to occur within area
Mimosa pigra Mimosa, Giant Mimosa, Giant Sensitive Plant, ThornySensitive Plant, Black Mimosa, Catclaw Mimosa, Bashful Plant [11223]		Species or species habitat likely to occur within area
Opuntia spp. Prickly Pears [82753]		Species or species habitat likely to occur within area
Parkinsonia aculeata Parkinsonia, Jerusalem Thorn, Jelly Bean Tree, Horse Bean [12301]		Species or species habitat likely to occur within area
Pennisetum polystachyon Mission Grass, Perennial Mission Grass, Missiongrass, Feathery Pennisetum, Feather Pennisetum, Thin Napier Grass, West Indian Pennisetum, Blue Buffel Grass [21194]		Species or species habitat likely to occur within area
Salvinia molesta Salvinia, Giant Salvinia, Aquarium Watermoss, Kariba Weed [13665]		Species or species habitat likely to occur within area
Reptiles		
Hemidactylus frenatus Asian House Gecko [1708]		Species or species habitat likely to occur within area
Lepidodactylus lugubris Mourning Gecko [1712]		Species or species habitat likely to occur within area
Lycodon aulicus Wolf Snake, Common Wolf Snake, Asian Wolf Snake [83178]		Species or species habitat likely to occur within area
Lygosoma bowringii Christmas Island Grass-skink [1312]		Species or species habitat likely to occur within area
Ramphotyphlops braminus Flowerpot Blind Snake, Brahminy Blind Snake, Cacing Besi [1258]		Species or species habitat known to occur

Name	Status	Type of Presence within area

Nationally Important Wetlands [Resource Information]

Name	State
"The Dales", Christmas Island	EXT
Adelaide River Floodplain System	NT
Ashmore Reef	EXT
Cobourg Peninsula System	NT
Finniss Floodplain and Fog Bay Systems	NT
Hosine's Spring, Christmas Island	EXT
Mermaid Reef	EXT
Pulu Keeling National Park	EXT
Yampi Sound Training Area	WA

Key Ecological Features (Marine) [Resource Information]

Key Ecological Features are the parts of the marine ecosystem that are considered to be important for the biodiversity or ecosystem functioning and integrity of the Commonwealth Marine Area.

Name	Region
Carbonate bank and terrace system of the Van	North
Pinnacles of the Bonaparte Basin	North
Shelf break and slope of the Arafura Shelf	North
Tributary Canyons of the Arafura Depression	North
Ancient coastline at 125 m depth contour	North-west
Ashmore Reef and Cartier Island and surrounding	North-west
Canyons linking the Argo Abyssal Plain with the	North-west
Canyons linking the Cuvier Abyssal Plain and the	North-west
Carbonate bank and terrace system of the Sahul	North-west
Continental Slope Demersal Fish Communities	North-west
Exmouth Plateau	North-west
Glomar Shoals	North-west
Mermaid Reef and Commonwealth waters	North-west
Pinnacles of the Bonaparte Basin	North-west
Seringapatam Reef and Commonwealth waters in	North-west

Caveat

The information presented in this report has been provided by a range of data sources as acknowledged at the end of the report.

This report is designed to assist in identifying the locations of places which may be relevant in determining obligations under the Environment Protection and Biodiversity Conservation Act 1999. It holds mapped locations of World and National Heritage properties, Wetlands of International and National Importance, Commonwealth and State/Territory reserves, listed threatened, migratory and marine species and listed threatened ecological communities. Mapping of Commonwealth land is not complete at this stage. Maps have been collated from a range of sources at various resolutions.

Not all species listed under the EPBC Act have been mapped (see below) and therefore a report is a general guide only. Where available data supports mapping, the type of presence that can be determined from the data is indicated in general terms. People using this information in making a referral may need to consider the qualifications below and may need to seek and consider other information sources.

For threatened ecological communities where the distribution is well known, maps are derived from recovery plans, State vegetation maps, remote sensing imagery and other sources. Where threatened ecological community distributions are less well known, existing vegetation maps and point location data are used to produce indicative distribution maps.

Threatened, migratory and marine species distributions have been derived through a variety of methods. Where distributions are well known and if time permits, maps are derived using either thematic spatial data (i.e. vegetation, soils, geology, elevation, aspect, terrain, etc) together with point locations and described habitat; or environmental modelling (MAXENT or BIOCLIM habitat modelling) using point locations and environmental data layers.

Where very little information is available for species or large number of maps are required in a short time-frame, maps are derived either from 0.04 or 0.02 decimal degree cells; by an automated process using polygon capture techniques (static two kilometre grid cells, alpha-hull and convex hull); or captured manually or by using topographic features (national park boundaries, islands, etc). In the early stages of the distribution mapping process (1999-early 2000s) distributions were defined by degree blocks, 100K or 250K map sheets to rapidly create distribution maps. More reliable distribution mapping methods are used to update these distributions as time permits.

Only selected species covered by the following provisions of the EPBC Act have been mapped:

- migratory and
- marine

The following species and ecological communities have not been mapped and do not appear in reports produced from this database:

- threatened species listed as extinct or considered as vagrants
- some species and ecological communities that have only recently been listed
- some terrestrial species that overfly the Commonwealth marine area
- migratory species that are very widespread, vagrant, or only occur in small numbers

The following groups have been mapped, but may not cover the complete distribution of the species:

- non-threatened seabirds which have only been mapped for recorded breeding sites
- seals which have only been mapped for breeding sites near the Australian continent

Such breeding sites may be important for the protection of the Commonwealth Marine environment.

Coordinates

-7.825 95.017,-7.258 95.057,-6.889 95.237,-6.546 96.79,-5.888 97.702,-5.082 97.709,-5.082 101.768,-5.414 102.196,-5.93 103.76,-7.147 106.451,-7.373 106.405,-7.371 106.464,-7.442 106.953,-7.744 107.995,-7.905 109.722,-8.356 111.662,-8.658 114.361,-9.316 115.483,-9.106 116.195,-9.15 116.927,-8.821 119.311,-8.755 122.28,-8.452 122.881,-8.181 122.864,-8.618 122.351,-8.542 122.084,-8.149 121.927,-7.45 122.23,-6.573 121.494,-6.268 121.687,-6.441 122.623,-6.416 123.13,-5.113 123.133,-5.113 133.938,-5.756 134.147,-7.713 134.118,-7.969 134.501,-7.815 135.134,-8.241 135.302,-8.909 135.884,-9.195 136.427,-9.473 136.375,-9.844 136.011,-9.831 135.131,-10.246 134.206,-10.601 134.135,-10.823 135.421,-10.709 134.224,-11.029 134.456,-11.348 135.339,-11.563 135.522,-11.768 134.789,-11.405 132.823,-12.258 131.691,-12.208 131.004,-12.913 130.189,-14.271 129.243,-13.816 126.757,-13.977 126.369,-14.59 125.843,-14.391 125.612,-14.655 125.271,-14.96 125.273,-15.436 124.511,-16.112 124.318,-16.25 123.58,-17.181 123.449,-16.508 122.977,-17.191 122.224,-17.832 121.993,-18.363 121.112,-18.861 120.844,-19.26 119.724,-19.711 119.219,-20.146 115.456,-22.107 113.387,-23.866 112.25,-24.037 111.896,-23.478 111.438,-22.327 111.418,-21.302 111.244,-21.164 110.494,-20.578 110.015,-20.556 109.025,-19.69 108.376,-19.261 107.083,-18.477 106.843,-17.955 106.373,-18.429 105.463,-19.468 105.407,-19.652 105.038,-18.834 104.781,-18.465 104.174,-18.39 103.302,-17.903 102.18,-18.024 101.627,-17.698 100.31,-17.302 99.413,-17.054 98.178,-16.713 97.326,-16.574 96.068,-16.593 95.119,-7.825 95.017

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-Department of Land and Resource Management, Northern Territory
-Department of Environmental and Heritage Protection, Queensland
-Department of Parks and Wildlife, Western Australia
-Environment and Planning Directorate, ACT
-Birdlife Australia
-Australian Bird and Bat Banding Scheme
-Australian National Wildlife Collection
-Natural history museums of Australia
-Museum Victoria
-Australian Museum
-South Australian Museum
-Queensland Museum
-Online Zoological Collections of Australian Museums
-Queensland Herbarium
-National Herbarium of NSW
-Royal Botanic Gardens and National Herbarium of Victoria
-Tasmanian Herbarium
-State Herbarium of South Australia
-Northern Territory Herbarium
-Western Australian Herbarium
-Australian National Herbarium, Canberra
-University of New England
-Ocean Biogeographic Information System
-Australian Government, Department of Defence
Forestry Corporation, NSW
-Geoscience Australia
-CSIRO
-Australian Tropical Herbarium, Cairns
-eBird Australia
-Australian Government – Australian Antarctic Data Centre
-Museum and Art Gallery of the Northern Territory
-Australian Government National Environmental Science Program
-Australian Institute of Marine Science
-Reef Life Survey Australia
-American Museum of Natural History
-Queen Victoria Museum and Art Gallery, Inveresk, Tasmania
-Tasmanian Museum and Art Gallery, Hobart, Tasmania
-Other groups and individuals

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Please feel free to provide feedback via the Contact Us page.

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