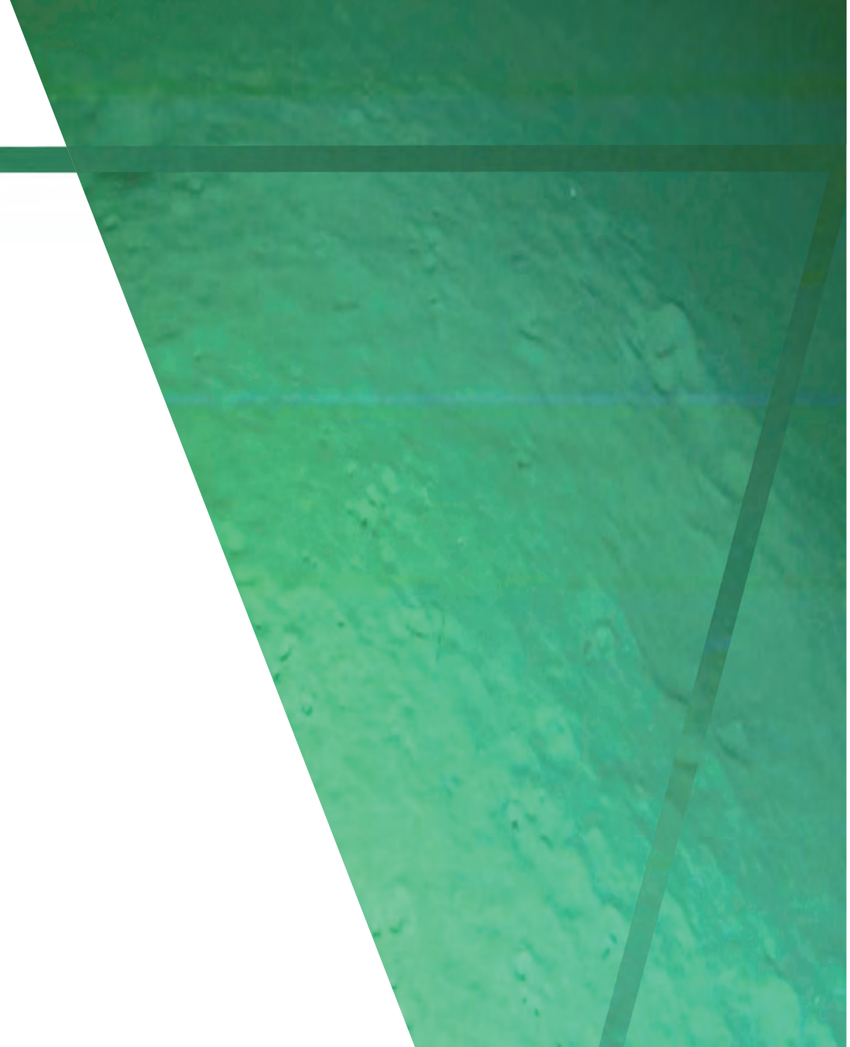
# Appendix A

## Scarborough Offshore Benthic Marine Habitat Assessment



# Scarborough

## Offshore Benthic Marine Habitat Assessment

1 February 2019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## Disclaimer



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# Executive Summary

The Scarborough gas resource is located approximately 375 km west-north-west off the Burrup Peninsula and is part of the Greater Scarborough gas fields which are estimated to hold 9.2 Tcf (2C, 100%) of dry gas. Woodside is proposing to develop the Scarborough gas resource through new offshore facilities connected by an approximately 430 km pipeline onshore. The proposal is to initially develop the Scarborough gas field with wells, tied back to a semi-submersible floating production unit (FPU) moored in 900 m of water close to the Scarborough field. This report has been developed in support of environmental approvals associated with the Scarborough Project.

This report is a summary of relevant information on benthic habitats from the offshore slope and deeper development area and is based on survey work previously completed in the permit area (>950 m water depth), on the escarpment of the continental shelf (300-950m water depth) and on the shelf (<300 m water depth). The data used in the assessment is based on video recordings and still images collected from ROV footage obtained during industry operations at a range of locations from the offshore project area as well as project specific surveys for the Scarborough Development.

Regional and site specific studies reviewed indicate that seabed material along the proposed trunkline alignment (and around the gas field) is predominantly flat and featureless and comprises thick, unconsolidated fine grained sands. The sediments support soft sediment benthic communities dominated by infauna (including molluscs, crustaceans and worms) and isolated larger fauna (free swimming cnidarian, demersal fish and benthic crustaceans).

Sedimentary infauna associated with soft unconsolidated sediments of the general area is widespread and well represented throughout the North West Shelf (NWS) region. In the context of the broader extent of habitats across the region, benthic habitat along the proposed trunkline corridor and within the Scarborough field consists primarily of soft unconsolidated sediments and is considered to be of relatively low environmental sensitivity.

Benthic communities of filter feeders generally live in areas that have strong currents and hard substratum and are closely associated with substrate type, with areas of hard substrate typically supporting more diverse epibenthic communities. The only natural habitat within the offshore permit area and trunkline corridor that is not classified as soft sediment is the pinnacle field that lies in about 300m water depth, on the continental slope. The pinnacle field covers an area that is less than 3 $km^2$ in size and at its closest point is more than 350m away from the proposed trunkline. Furthermore, the pinnacles are isolated forms and do not constitute continuous reef. It remains unclear what the rock pinnacles are constructed from, however the structures provide habitat for a diverse range of epifaunal and demersal species that commonly occur elsewhere in the NWS.

Interestingly, the habitats containing the greatest biodiversity in these offshore environments are the habitats formed by colonising invertebrates on oil and gas subsea infrastructure including the well heads and pipelines. These habitats and the species present on these structures in the NWS of Western Australia have been recently subject to detailed quantitative and qualitative assessment

(McLean et al. (2018), McLean et al. (2017), Bond et al (2018)). These habitats not only have structural complexity but also create habitat for a large diversity of fish species that commonly occur elsewhere in the NWS but do not occur over soft unconsolidated sediments.

# 1 Introduction

## 1.1 Background

The Scarborough gas resource is located approximately 375 km west-north-west off the Burrup Peninsula and is part of the Greater Scarborough gas fields which are estimated to hold 9.2 Tcf (2C, 100%) of dry gas. Woodside is proposing to develop the Scarborough gas resource through new offshore facilities connected by an approximately 430 km pipeline onshore. The proposal is to initially develop the Scarborough gas field with wells, tied back to a semi-submersible floating production unit (FPU) moored in 900 m of water close to the Scarborough field.

WEL engaged Advisian to undertake an offshore marine habitat assessment to further the understanding of the environmental conditions of permit area WA-1-R. Findings from the marine studies will support the Scarborough Project environmental approvals.

The report is a summary of relevant information on benthic habitats from the offshore slope and deeper development area and is based on survey work previously completed in the permit area (>950 m water depth), on the escarpment of the continental shelf (300-950m water depth) and on the shelf (<300 m water depth).

## 1.2 Scope of Work

The objectives of the offshore marine habitat assessment were:

- To provide sufficiently detailed background information to enable the existing benthic habitat to be adequately described, particularly for benthic species and habitats of conservation significance, and
- To assess and interpret the available benthic habitat data which will be used to inform environmental approvals documentation for the Scarborough Development.

# 2 Method of Assessment

## 2.1 Review of Existing Literature

The offshore marine habitat assessment was undertaken by reviewing relevant literature from the areas of interest. This includes use of site specific environmental survey data that were commissioned to investigate the environmental conditions at both the Scarborough and Pluto field developments. Additional information was sourced from geophysical investigations, ROV surveys and sub-sea infrastructure inspections in the areas of interest.

An environmental characterisation report based on seasonal marine surveys was undertaken within Permit Area WA-1-R by ERM (2013). The surveys were completed in November 2012 (wet season) and July/August 2013 (dry season) and included sampling of water, sediment, plankton and infauna communities. Characterisation of seabed habitat was undertaken using multibeam.

The offshore marine environmental survey for the Pluto LNG development (SKM 2006) was also reviewed as the trunkline alignment from Scarborough will follow a similar route as that taken by the Pluto gas trunkline. The Pluto survey included infauna and epifauna sampling, sediment sampling for particle size analysis and sediment chemistry, ROV / video investigations of benthic habitats and anecdotal recordings of seabirds, cetaceans and other marine mammals, sea turtles and other reptiles. Detailed AUV and ROV survey data for Pluto were also reviewed as part of a comprehensive geophysical and geotechnical survey of the Pluto field (Geoconsult 2005).

The historical marine survey work was supplemented by a series of more recent marine surveys, including geophysical and ROV surveys that filmed the proposed trunkline route through the Scarborough field. These include the ROV survey of the export pipeline route (Ocean Affinity, July 2018) along a section of the continental slope between Scarborough and Pluto.

## 2.2 Report Layout

For the purpose of this report, the offshore marine habitat assessment has been divided into three sections according to water depth. These include describing habitats in the:

- Deeper Water (>950m depth), which includes the seabed where the Scarborough gas field is located;
- Continental Slope (300-950m water depth), which includes the section of seabed between the Scarborough gas field and the Pluto tieback;
- Continental Shelf (<300m water depth), which covers the seabed around the Pluto platform

For the purpose of this report, survey scopes that involved water quality, plankton and other surveys of the open water environment are not included in this report.

# 3 Deepwater Habitat

Much of the following section has been adapted from the Scarborough marine studies completed by ERM in 2013.

## 3.1 Background

The Scarborough Development is located on the Exmouth Plateau, within the North-west Marine Bioregion (Figure 3-1), as defined by DoE's framework for coordinating conservation and sustainable management (DoE 2013). The region comprises Commonwealth waters from the Western Australian/ Northern Territory border to Kalbarri, south of Shark Bay and covers 1.07 million square kilometres (km$^2$) of tropical and sub-tropical waters (DEWHA 2008). The Exmouth Plateau is located within the region's Northwest Province, which covers an area of 178,651 km$^2$ and is situated entirely on the continental slope (DEWHA 2008). The water depths of the North-west Province predominantly range between 1,000 m and 3,000 m reaching a maximum depth of 5,170 m.

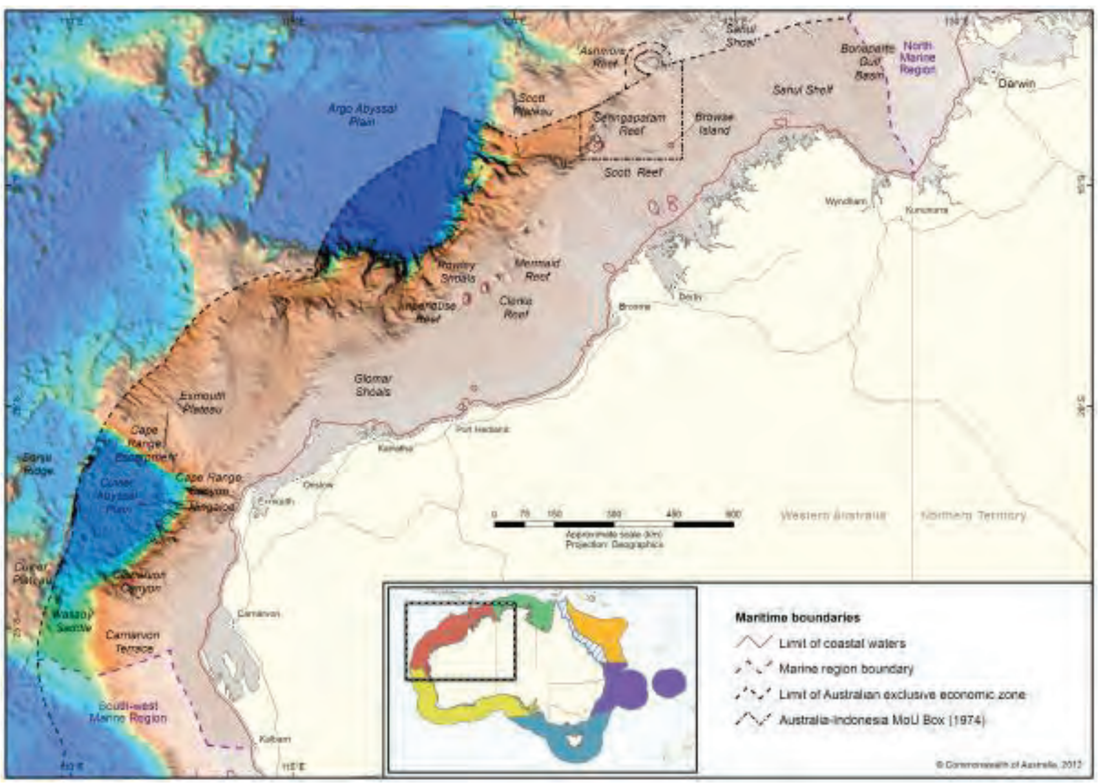


**Figure 3-1 The North West Marine Bioregion, showing location of the Exmouth Plateau**

The Exmouth Plateau, a deepwater plateau adjacent to the continental slope, is a dominant geomorphic feature of the region Figure 3-2. The Montebello Trough along the south-east edge of the plateau drains into the Cape Range Canyon, while the northern portion of the plateau comprises the Dampier Ridge and Swan Canyon. The Exmouth Plateau peaks at approximately 1,000 m deep with a narrow, steep southern slope and a wider, less steep northern slope. WA-1-R is located in the north-central section of the Exmouth Plateau in water depths of approximately 900 m to 970 m.

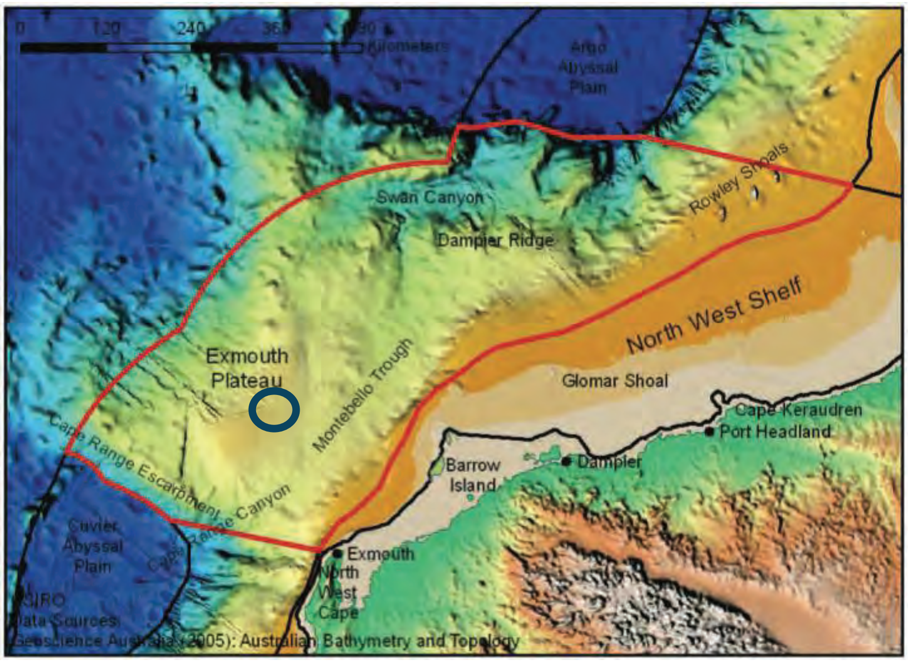


**Figure 3-2 The Exmouth Plateau (showing location of Scarborough Development)**

### 3.1.1 Seabed Characteristics

The region comprises bio-clastic, calcareous and organogenic sediments deposited from relatively slow and uniform sedimentation rates (Carrigy and Fairbridge 1954 in Baker *et al.* 2008 and Jones 1971 in Baker *et al.* 2008).

Sediments vary from sands and gravels on the shelf, to muds on the slope and abyssal plain/deep ocean floor (Baker *et al.* 2008). Calcium carbonate deposits are located on the inner shelf, middle shelf and outer shelf/ slope. The Exmouth Plateau is characterised by a thick Triassic sequence overlain by a Jurassic, Cretaceous and Cainozoic sediment sequence; and fine-grained carbonate ooze (Fugro 2010).

Sediment transport at WA-1-R on the outer shelf/ slope of the Exmouth Plateau is influenced by a combination of slope processes and large ocean currents.

The seafloor is generally flat and uniform with water depths ranging from 900 m to 970 m, with a gradual increase from the north/north-west to the south/ south-east of the area (*Figure 2.4*; Fugro 2010). To the south-west of WA-1-R, craters (up to 400 m across and depth of up to 10 m) and smaller pockmarks (metres to tens of metres across) have been identified through geophysical surveys (Fugro 2010). The seafloor exhibits gradients less than 1 degree (°) but extends to approximately 15 ° on the edge of craters (Fugro 2010). These crater and pockmark formations in WA-1-R may be associated with hydrocarbon seeps as well associated authigenic carbonate formations (Fugro 2010), and were a particular focus of the studies completed by ERM.

### 3.1.2 Benthic Communities

Studies completed within the region indicate that benthic composition in deepwater habitats is generally lower in abundance than shallow water habitats (DEWHA 2008, Brewer *et al.* 2007). Gage (1996) reported that the density of benthic fauna tends to be lower in deepwater sediments (>200 m) than in shallower coastal sediments, but the diversity of communities may be similar.

Information exists on the benthic communities of the Exmouth Plateau, although macrofaunal species diversity has been shown to be positively correlated to sediment diversity (Etter & Grassle, 1992). The mostly fine sediment environment of the Exmouth Plateau is expected to support scavengers, benthic filter feeders and epifauna, particularly at the intersection with the continental margin (Brewer *et al.* 2007). This soft bottom habitat is also likely to support patchy distributions of mobile epibenthos, such as sea cucumbers, ophiuroids, echinoderms, polychaetes and sea-pens (DEWHA 2008).

### 3.1.3 Hydrocarbon Seep-Associated Benthic Communities

Hydrocarbon seeps are the seeping of gaseous or liquid hydrocarbons (including oil and methane) to the surface of the seabed from fractures and fissures in the underlying rock, resulting in possible hydrocarbons and other chemicals in the water column (DEWHA 2008). It is possible that these formations may host thiotrophic (sulphur based metabolism) or methanotrophic (methane based metabolism) benthic communities and chemosymbiotic benthic fauna reliant on methane-oxidising bacteria, which usually aggregate in the form of mats over the seafloor (Barry *et al.* 1996).

These naturally occurring seeps are known to be present in the region, with an estimated 3,300 tonnes seepage of hydrocarbons annually (Fandry *et al.* 2006). Active hydrocarbon seeps have not been identified in WA-1-R. However, geophysical surveys conducted in 2010 identified crater and pockmark formations in WA-1-R, which may be associated with current or historic hydrocarbon seeps as well associated authigenic carbonate formations (Fugro 2010).

## 3.2 Survey Methods

The ERM marine investigation included sampling at 15 sampling sites as shown Figure 3-3 to:

- provide a broad characterisation of the habitats within WA-1-R;
- achieve spatial coverage across WA-1-R; and
- provide a representative selection of the various topographic features and corresponding benthic habitats (i.e. crater/pockmark versus non-crater areas).

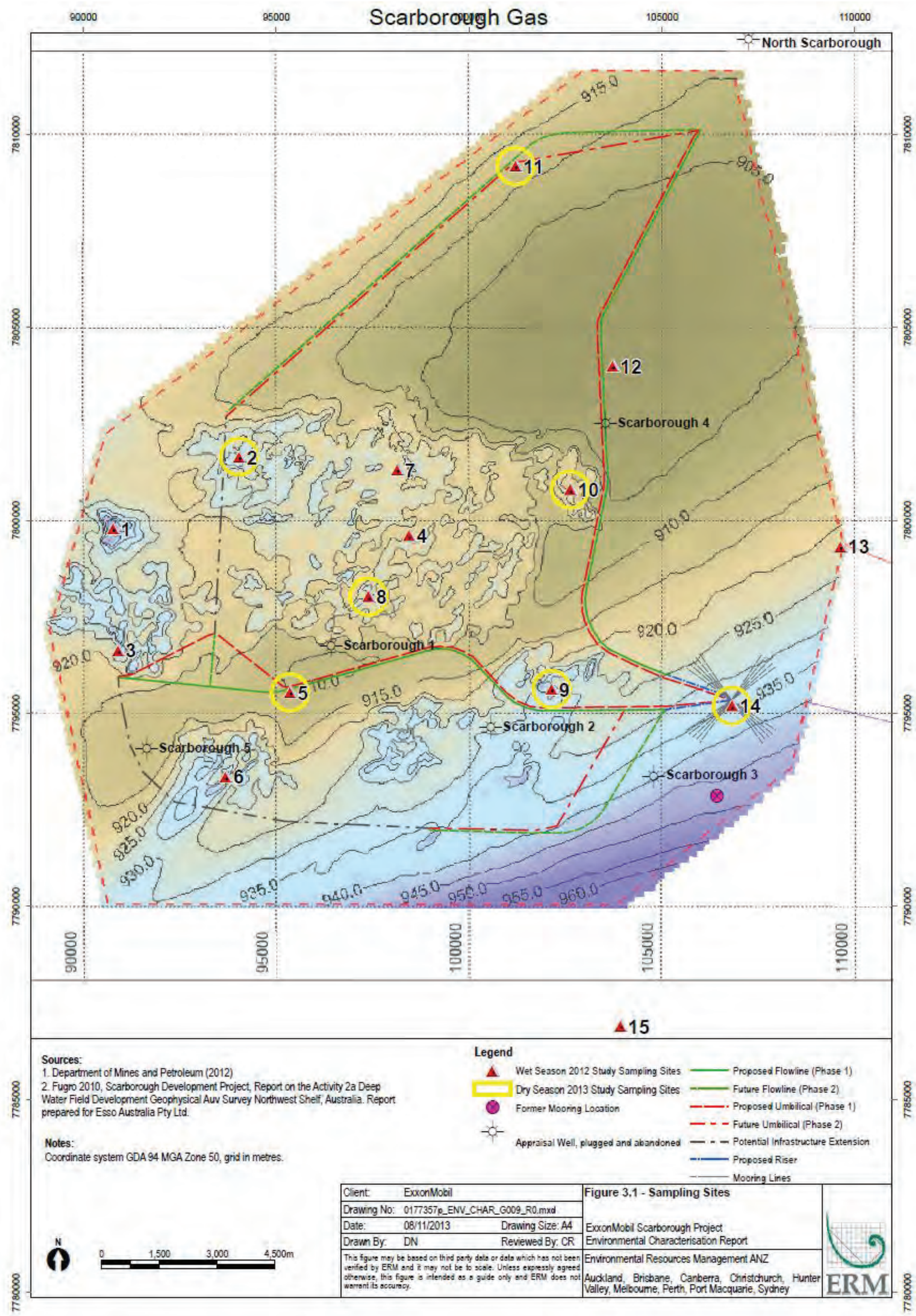


**Figure 3-3 Sampling Sites used in the ERM Environmental Characterisation Report (ERM 2013)**

### 3.2.1 Camera Study (Benthic Communities)

At each site, the camera was lowered to the seafloor of each sampling station. The vessel then drifted as slowly as possible across the station target area, capturing video footage. Video footage was collected for approximately 15 minutes at each of the three stations (45 minutes of footage per sampling site), with footage reviewed in real time. Video footage was acquired at all sites with the exception of Site 15 Stations 2 and 3 (due to bad weather).

Additionally, approximately 25 still images were captured opportunistically at each station sampled (75 images per sampling site). A total of 1,120 images were collected.

### 3.2.2 Infauna Study

Seafloor sediment was collected for physico-chemical analyses and identification of infauna. Sampling was undertaken using a box corer of the following dimensions: 0.49 x 0.52 x 0.55 m (length x width x height). The box corer was lowered to the seafloor for collection and recovered to the deck for inspection. The sample was split into quarters whereby one quarter was used for physicochemical subsamples and the other full quarters were sieved through a 0.5 mm mesh sieve.

## 3.3 Results

### 3.3.1 Benthic Communities

A total of 865 still images were quantitatively assessed by the South Australian Research and Development Institute (SARDI). A review of the benthic camera study recordings indicated a soft sediment seafloor across the area surveyed.

The quantitative assessment identified a total of 79 benthic taxa, consisting of the following phyla: echinoderms (28%), arthropods (24%), chordates (20%), cnidarians (19%), molluscs (4%) and poriferans (3%). In addition, there were 2% of taxa that appeared to be large protists (kingdom Chromista). Organisms were identified to the lowest recognisable taxonomic unit including species (5), genus (12), family (13), order (18), class (26), phylum (3) and kingdom (2).

The five species identified comprised a crab (*Eplumula* cf. *australiensis;),* sea urchin (*Phormosoma* cf. *placenta),* skate (*Insentiraja subtilispinosa)* and two fish species (*Bathypterois* cf *guentheri* and *Bathysaurus ferox*). Overall, a total of 605 individuals (including 54 unidentifiable organisms) were counted, dominated by arthropods (54.70%), followed by echinoderms (16.36**%**), cnidarians (10.41%), unidentified organisms (8.94%), chordates (7.44%), molluscs (0.99%), poriferans (0.83%) and the kingdom Chromista (0.33%).

The most abundant species were two shrimp species, of the genus *Nematocarcinus*. The next most abundant species were the gorgonian coral *Metallogorgia* sp. 1 (35 individuals) and the basket star *Gorgonocephalid* sp. 1 (29 individuals). Motile taxa such as shrimp, sea cucumbers and fish dominated the benthic fauna, comprising 75% of the species richness and 87% of the species.

Sessile taxa such as sea pens, corals, sponges, anemones and stalked crinoids made up the remainder of the contribution to overall species richness and abundance (25% and 13%, respectively).

The ERM (2013) study also noted bioturbation of the seabed in many of the images although most traces could not be confidently assigned to contributing taxa. Those that could be identified were considered potentially representative of echinoderms as well as biotic groups not identified in the still imagery such as foraminiferans, echiurans and annelids.

Bivalve shell debris was also recorded at several sites and was believed to be comprised of at least two species of the Vesicomyidae family. Aggregations of lithodid crabs were present in one occurrence of shell debris within one station. Small-scale bacterial mats that appear similar typical of *Beggiatoa* sp. were observed in a few of these bivalve shell debris occurrences. Shell debris and bacterial mats had mean percentage covers of 3.8% and 0.4%, respectively, across all the sites. For sites located in areas of coalescing seafloor craters, shell debris and bacterial mats had mean percentage covers of 6.3% and 0.7%, respectively.

### 3.3.2 Infauna

A total of 281 individuals and 43 different species were identified from the seven sediment samples collected from Sites 5, 8, and 14.

Of the 43-species identified, 33 were identified to family level, with the remainder identified to higher taxonomic levels. Crustaceans and polychaete worms were the dominant taxonomic groups, accounting for 89% and 86% of the individuals and species richness, respectively. The majority of crustaceans identified belonged to the Leptocheliidae and Apseudoidae families. The majority of polychaetes identified belonged to the Pilargidae family. Holothureans, molluscs, sponges, sipunculids and octocorals were recorded in relatively low abundances. The average density of infauna was estimated to be 214.1/m$^2$ (±43.3).

## 3.4 Discussion

No organisms identified to species level for the studies were listed as Threatened or Migratory under the EPBC Act according to the Species Profile and Threats (SPRAT) database (ERM 2013).

Benthic camera and sediment results indicated that the seafloor around the Scarborough Development is characterised by sparse marine life dominated by motile organisms. Such motile organisms included shrimp, sea cucumbers, demersal fish and small, burrowing worms and crustaceans (Figure 3-4, Figure 3-5 and Figure 3-6). Although these images were obtained from the original Pluto survey (Geoconsult 2005) and are closer to the Pluto slope, they are representative images of the deepwater habitat present at ~1,000m depth. The observed dominance by motile taxa is typical of deepwater soft substrates (DEWHA 2008), with sessile taxa more common on harder substrates (Ramirez-Llodra *et al.* 2010). Overall, observations made are representative of tropical deepwater soft sediment habitats reported in the region (BHP Billiton 2004; Woodside 2005; Woodside 2006; Brewer *et al.* 2007; RPS 2011; Apache 2013; Woodside 2013).

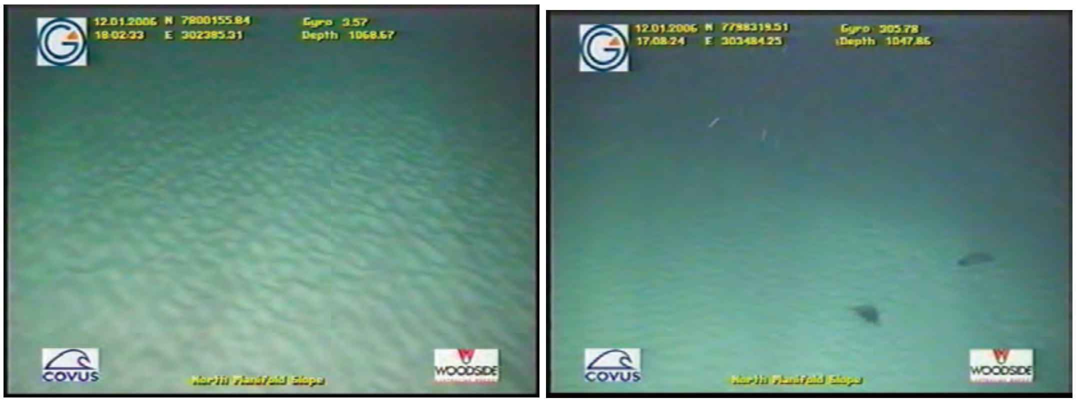

**Figure 3-4 Deepwater soft bottom habitat (depths 1047-1068m), Tape 07 (January 2006)**

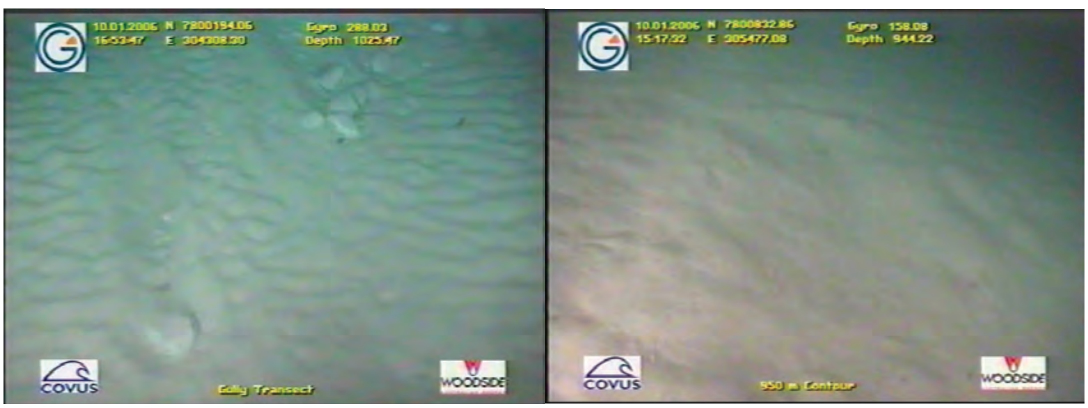

**Figure 3-5 Deepwater soft bottom habitat (depths 944-1025m), Tape 06 (January 2006)**

**Figure 3-6 Deepwater soft bottom habitat (depths 1029-1067m), Tape 07 (January 2006)**

The majority of the 15 taxa that were identified to species or genus level in the benthic camera study are distributed worldwide. It is thought that offshore deepwater habitats of the NWS tend to support widespread Indo-pacific species, retaining extensive genetic connections over large distances (Heyward *et al.* 2006).

Four taxa were classified as Indo-pacific species, namely the carrier crab *Eplumula* cf. *australiensis* (typically in waters off southern Australia, New Zealand and New Caledonia (Poore 2004)), the velvet skate *Insentiraja subtilispinosa* (only in waters off north-west Australia and the Western Central Pacific (Last and Stevens 2009, Froese and Pauly 2011)), the halosaur fish *Aldrovandia* sp. 1 (previously recorded in the North West Province (Sorokin and Brock 2013)) and the tribute spiderfish *Bathypterois* cf. *guentheri* (Indo- West Pacific to the north east Indian Ocean and southern Japan (Froese and Pauly 2011)).

The demersal fish observed potentially reflects the community near the Exmouth Plateau. The upper and middle parts of the continental slope in the North-west Province have a high number of demersal fish species with high endemism (DEWHA 2008). This is especially so in the area between the North West Cape and the Montebello Trough (along the south-east edge of the plateau, *Figure 2.1*), which supports over 508 fish species of which 76 are endemic. It is noted that the demersal fish species identified for the benthic camera study did not correlate with the ichthyoplankton species identified in the zooplankton samples. This is attributed to the large depths at WA-1-R and general lack of vertical mixing between the surface and deeper layers (Sundby 1996).

The dominant types of epifauna were arthropods and echinoderms (especially shrimp and sea cucumbers, respectively), while the dominant infauna groups were crustaceans and polychaetes.

Benthic community composition was generally similar across sampling sites. There was not a strong correlation between bathymetric features and sessile or motile organisms. However, bathymetric features may have played a role in the abundance of certain organisms. The majority of sites where soft coral was identified were found outside of the coalescing seafloor crater areas. More than double the number of sea fans was identified in noncrater areas as opposed to coalescing seafloor craters.

The ERM (2013) study also noted that potential indicators of historic or localised ephemeral hydrocarbon seep activity were the most noticeable exception to a uniform benthic composition across WA-1-R. These indicators were in the form of bivalve shell debris and bacterial mats and they were only identified across the sites in the seafloor crater areas, where hydrocarbon seeps were considered to be potentially present (Fugro 2010). The shell debris and bacterial mats had low mean percentage covers of 6.3 % and 0.7 %, respectively, across the seafloor crater sites. The shell debris is considered to comprise at least two species of the Vesicomyidae family, which are common components of communities of sulphide-rich reducing environments such as hydrocarbon seeps (Krylova and Sahling 2010).

## 3.5 Summary

The low energy, soft bottom seafloor around the Scarborough Offshore Project Area supports sparse marine fauna as reported for the Exmouth Plateau. Sediments are calcareous, fine-grained and low in nutrients. Benthic communities are dominated by motile organisms, including shrimp, sea cucumbers, demersal fish and small, burrowing worms and crustaceans. No threatened species/ecological communities or migratory species were identified in the studies (as defined under the EPBC Act).

# 4 Continental Slope

Much of the following section has been adapted from the offshore marine environmental survey for the Pluto LNG development (SKM 2006) and supporting investigations such as the Pluto AUV/ROV survey conducted by Geoconsult (2005) and most recently by the ROV survey completed by the Ocean Affinity (2018).

## 4.1 Background

The Pluto field is located on the continental slope of the NWS, where the slope is at its narrowest.

Assessment of geophysical and ROV data confirmed that the Pluto field is traversed by several canyon systems as shown in Figure 4-1. The work area was located more than 200 km NW of Dampier off the NW coast of Australia and covered approximately 311 $km^2$ in water depths ranging from approximately 160m to 1220m.

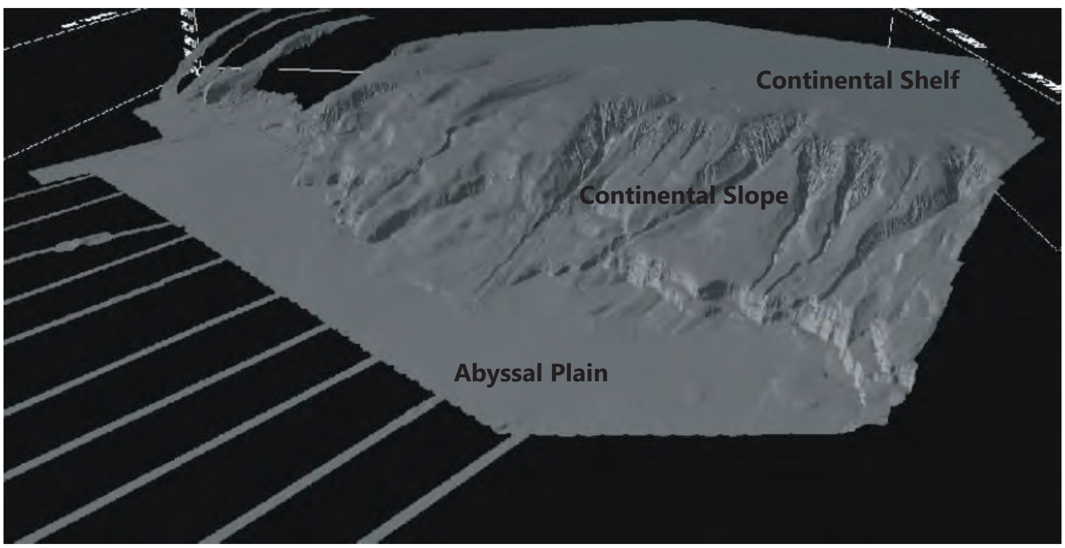


**Figure 4-1 Continental slope adjacent to the existing Pluto field development**

The Geoconsult (2005) report divides the Continental Slope into three sub-divisions, namely:

- Dendritic channel areas
- Channel areas
- Continental slope areas (between channels)

A total of six major and nine minor dendritic channel areas were recorded that are up to 200m deep and with gradients of 1:1. Major channels were well spaced through the site: in 300m to 750m water depth: between 500m to 1500m wide and up to 5km in length. The minor channels are prevalent in the southern half of the site: in 320m to 550m water depths: 500m to 900m wide and up to 2.4km in length. They are formed by the gradual erosion of the Continental Slope as numerous small, localised slumps, which trigger turbidity currents. It is suspected that dendritic channel areas act as a focus for seafloor currents. Sediments expected to comprise very soft sandy clay/silt.

Six major and nine minor complete channels were identified. Ten channels discharge sediment into the deeper water with the remaining minor channels discharging varying amounts of sediment on to the Continental Slope. Generally, they are between 15m and 300m wide, 5m to 150m deep with sidewall gradients of 1:1. The channels and their dendritic roots gradually erode the upper slope and transfer sediment to deeper water. Sediment is transported as local slumps and sediment flows and also as more extensive turbidity currents, which erode channel sidewalls and floors. Layered sediments in the base of channels document deposition following sediment flows. Plunge pools up to 230m wide and 20m deep have been observed. Channel sidewalls are susceptible to slumping and erosion.

The presence of sand in the channels has been confirmed by drop cores. Within the channel base current driven bedforms or erosive "back stepping" of bedding planes was observed. ROV stills show current driven bedforms and rounded cobble sized clasts and sediment clumps in the channel base. Channels are not only developed by seafloor currents but have in the past been conduits for large scale turbidity currents. Present day sedimentary processes are observed to be significant, with active seafloor currents.

The Continental Slope Area (between channels) undulates and deepens from the SE to the NW over a series of linear and steep scarps from water depths of ~250m to 1100m.

## 4.2 Survey Methods

### 4.2.1 SKM (2006) survey

The sampling programme was designed to collect representative biota across the outer shelf and slope habitats, to characterise species and habitat composition along a depth gradient down the slope (150 m, 200 m, 400 m, 600 m, 800 m and 1000 m). Sampling was conducted along two depth gradient transects, one transect orientate directly down a canyon system (referred to as canyon transect) and the second transect orientated down the continental slope outside of the canyon systems (referred to as slope transect).

The bathymetry of the canyon systems transecting the Pluto field include some very steep gradients, which suggests that the canyon systems could potentially contain some exposed hard substrate or cliff like structures. Surveys for the Vincent and Enfield fields, located near North West Cape, discovered rich and diverse epifaunal communities located on several rock outcroppings in 350–600 m water depth (Heyward and Rees 2001a and b; Heyward et al. 2001a and 2001b). In the absence of targeted geotechnical and geophysical data, the sampling strategy was focused on the seabed with the steepest gradients in the canyon systems. A total of twenty-eight sled tows were successfully completed by SKM (2006) across depths between 150 m and 800 m.

Over 40 hours of video of the seabed were collected by the ROV from depths ranging between 250 and 1050 m. While the majority of the seabed was composed of soft sediments, extensive video recording was collected of the steep cliffs located just below 1000 m and isolated pinnacles in the 300 m depth range.

### 4.2.2 Ocean Affinity (2018) survey

The purpose of this operation was to use a KD31 ROV to visually inspect points of interest (POI) along the base case route slope region that were identified during the geophysical survey and to revisit POI1 that was previously surveyed during the SKM (2006) ROV survey. The POI locations were identified following review of side scan sonar (SSS) and multi bean echo sounder (MBE) data collected during autonomous underwater vehicle (AUV) surveys as shown in Table 4-1.

**Table 4-1 Positioning Details for Points of Interest Survey, (Ocean Affinity 2018)**

| POI | Easting | Northing | Depth (m) |
|---|---|---|---|
| 1 | 310308 | 7798411 | 303 |
| 2 | 308721 | 7799862 | 454 |
| 3 | 309089 | 7800880 | 490 |
| 4 | 309498 | 7800578 | 422 |
| 5 | 309736 | 7800316 | 390 |
| 6 | 310145 | 7802325 | 450 |
| 7 | 311170.0 | 7796744 | 259 |

## 4.3 Results

### 4.3.1 Infauna

The infauna of the continental slope, (as based on data collected from the Pluto field) was very sparse with a maximum density of 167 individuals/m$^2$ from a sample collected in 400 m. Infauna was generally more abundant in sites located in shallow water, although this trend with depth was somewhat obscured because three samples contained no infauna, both samples from 800 m and one sample from 1000 m. A total of 47 individuals, representing 32 nominal species, were collected from the 12 samples. The fauna was dominated by polychaetes, which comprised 79% of the fauna by abundance and 75% of the fauna by species richness. Some crustaceans, sipunculids and nemerteans were also recorded but no molluscs or echinoderms were collected in any of the box core samples.

### 4.3.2 Epifauna

The sled catches varied between depths but were consistent across the two transects across the continental slope, inside and outside the canyon system.

Approximately 1200 specimens were collected from 25 sled shots. Cnidarians, mostly free-living deep water solitarily corals, were the most abundant phyla, followed by malacostracan crustaceans, mostly decapods, bony fish, and sponges. Together, these groups accounted for 70% of the fauna by abundance.

The fauna was most abundant along the 200 m contour but this was largely a result of the distribution of the free-living deep water, solitarily corals. Seventy percent of the corals collected occurred in samples collected from the 200 m sites. Crustaceans were most abundant at 400 m.

Commercial fishing for crustaceans (scampi, prawns) is concentrated between 200–400 m. Fish were most abundant in shallower water, particularly near the shelf break at 200 m depth. Sponges were most abundant in the deeper stations (600 m and 800 m). Ascidians were common in 150 m where one unidentified species was particularly abundant.

The Western Australian Museum (WAM) has identified the sponges, fish, molluscs, echinoderms, cnidarians and most of the crustaceans and made comparisons with existing deepwater collections. Five species of sponges, 45 species of fishes, 54 species of molluscs, 25 species of cnidarians, 34 species of echinoderms, and 50 species of crustaceans have been identified.

The WAM findings can be summarised as follows:

- Of the five species of sponges collected in the study, three belonged to the Class Demospongiae, which are shallow water sponges found at depths of 150 m or 200 m and two species belong to the Class Hexactinellida (glass sponges), which are deepwater species found at 600 m and 800 m. The glass sponges have a glass stalk holding the cup shaped sponge. The stalk is often covered in a cnidarian. No live sponges were collected from tows at 400 m.
- The fish species collected are typical of the area and depths with most of the taxa being deepwater representatives with tropical distribution.
- The echinoderm species belonged mainly to three classes, namely Asteroidea (seastars), Ophiuroidea (brittlestars) and Echinoidea (urchins), with only one species representing the class Holothuroidea (sea cucumbers). A number of animals could be identified to species level, with some of the identified species not previously recorded and many were not previously recorded in the area. Curiously, when compared to other recent sampling off the north west peninsula, several Asteriod genera found in similar water depths were absent in the Pluto samples. The Asteroid *Sidonaster waney* have not previously been recorded within Australian waters. Of the eleven Asteroid genera found, only 4 species could be identified to species level.
- The cnidarian species belonged mainly to the Family Nephtheidae and to a lesser extent the Family Alcyoniidae and Nephtheidae. Of the 41 cnidarian specimens, three specimens were black coral.
- The majority of the 50 crustacean species identified belonged to the Order Decapoda (48 decapods and two barnacles, Order Pedunculata). Most of the genera collected have been recorded previously from the deeper waters of Western Australia and all species were collected at depths typical for the species or genus. The material is mainly tropical with strong Indo-West Pacific affinities, particularly with the fauna of the Indo-Malayan sub-province, the area defined by the Indo-Malayan Archipelago, Australia and New Guinea to Japan. At the generic

level, the collection is comparable with material from similar depths in eastern Australian waters. The collection contains the first Australian records of *Raninoides hendersoni* Chopra, 1933 (Raninidae), *Mursia armata* de Haan, 1834 (Calappidae), *Polycheles coccifer* Galil, 2000 (Polychelidae), and *Eumunida (Eumunida) pacifica* Gordon, 1930 (Chyrostylidae). These species have known distributions in the Indo-Malayan sub-province of the Indo-west Pacific province. One species previously recorded in Australia from the east coast is recorded for the first time, *Conchoecetes artificiosus* (Dromiidae). A further two species, *Agonida* ? *eminens* and *A.* ? *incerta* (Galatheidae), are possible new records for WA but confirmation of their identifications is required. The specimens of the portunid crab *Charybdis (Charybdis) rufodactylus* represent the first record of the species outside of Queensland, Australia. The galitheid genus *Munidopsis* is also reported for first time from WA.

- Most of the 45 mollusc species had been previously recorded from western and northern Australian waters (WAM, January 2006), although some of the specimens in the collection belong to species that have been rarely collected for example, *Amoria diamantina*. Most molluscs occurred in depths of between 150 and 600 m. They represent 27 families, of which four are cephalopods, three are bivalves and the remaining 47 species are gastropods. The gastropods represented in this collection are mainly carnivores as would be expected from depths low in and below the photic zone. The broken shell of the sundial shell, *Discotectonica acutissima*, appears to be the first record for this species in Western Australian waters (WAM, January 2006). Of the cephalopods, those specimens identified as probably belonging to the genus *Mastigoteuthis* are the most noteworthy, being new to the collections of the Western Australian Museum. The actual depth at which the squids of the genera *Histioteuthis* and *Mastigoteuthis* were collected is doubtful as they swim in the water column, not on the substrate, and so must have been taken as the dredge was descending or ascending (Slack-Smith 2006).

### 4.3.3 ROV (SKM 2006)

The ROV recording was collected during December 2005 from five areas between 250 m and 1050 m depth (Figure 4-2). The soft sediments supported a very sparse coverage of epifauna overall but small areas supporting a higher density of epifaunal were also observed. The diversity of epifauna was far more limited overall than the diversity of fauna collected by the sled. Many tracks and marks were observed on the seabed through all depths but the fauna responsible for these tracks or living just below the sediment surface could not be identified. Only demersal species could be identified. The seafloor below about 800 m supported a similar fauna to that observed in shallow depths with mostly shrimps, batfish and holothurians observed. Glass sponges were noted to occur at high densities, particularly along the 750 m depth contour with an estimated density of 0.2 individuals/$m^2$.

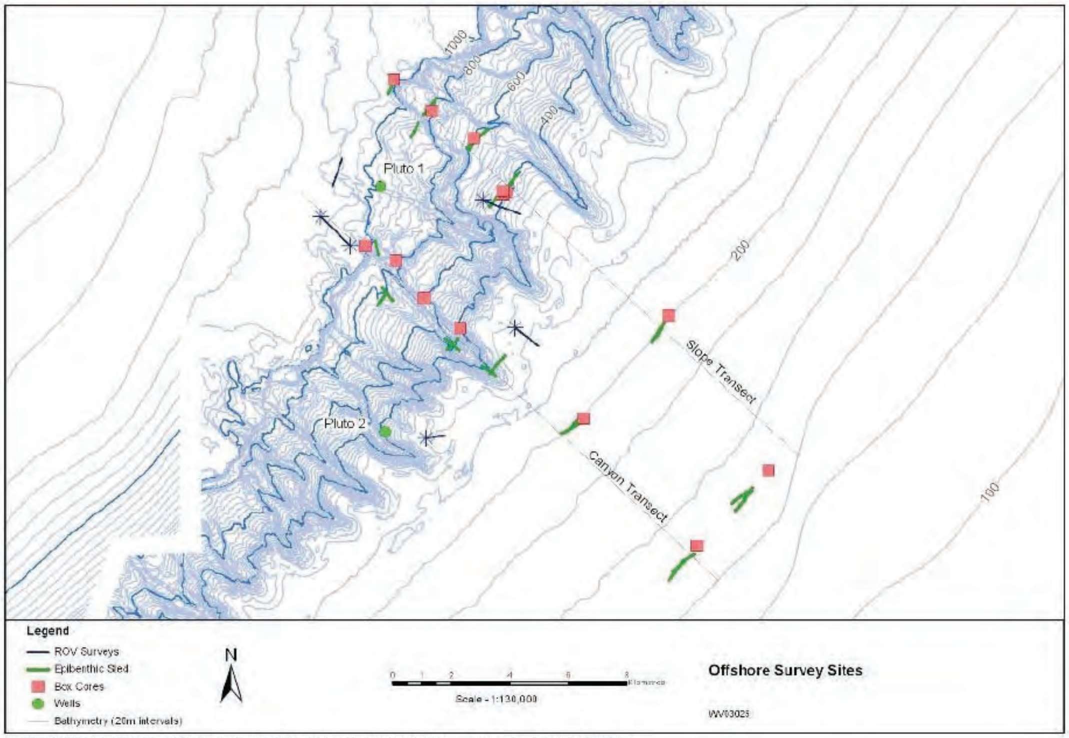


**Figure 4-2 Location of Pluto field, showing ROV survey transects (from SKM (2006)**

The majority of the substrate consisted of soft sediments, which were green, grey in colour below about 400 m and a light brown in shallower depths. Box core samples found the sediments to be silt below about 400 m and fine sand above this depth. Seabed gradients varied from flat to gradients in excess of 80°. Preliminary results from the geotechnical and geophysical survey of the Pluto field indicate that the seabed of the Pluto field is devoid of hard substrate except for two areas of seabed (M. Bowler [Woodside] 2006 *pers. comm*., January) which are particularly noteworthy.

### Sea Cliffs

Preliminary results of the geotechnical and geophysical studies (completed during the Geoconsult 2006 survey), which commenced at the same time as the offshore environmental survey, indicate that the continental slope at the Pluto field is largely devoid of hard substrate exposed above the sedimentary seafloor. The main area of exposed hard substrate occurs in about 1000 m depth where the continental slope meets the abyssal plain (Figure 4-3).

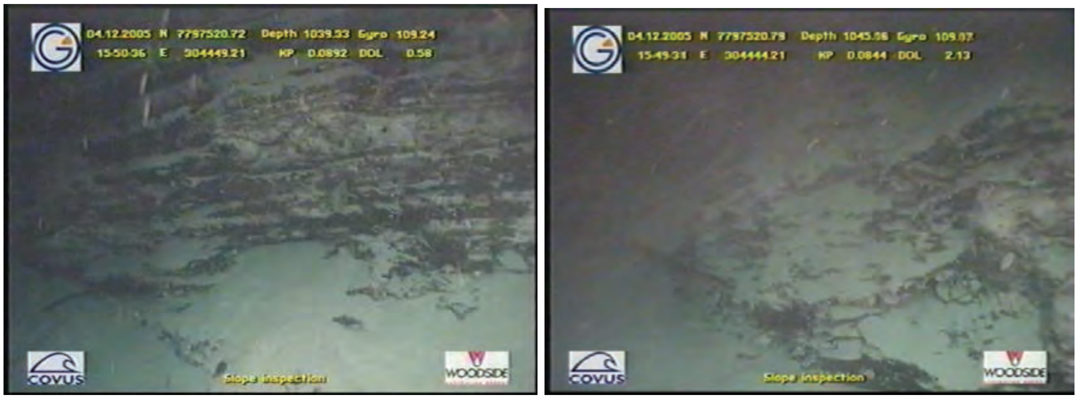


**Figure 4-3 Sea cliffs at the base of the continental slope where it meets the abyssal plain, (depth 1039-1045m)**

The bottom of the rocky cliffs is situated in about 1050 m water depths with an almost vertical wall extending 20 m up to about 1030 m at the surveyed location. The rock appears to be sedimentary with clear bands or layers occurring in the rock profile.  No epifauna was observed on the exposed rock. Where the seabed gradients are less steep, sediments accumulate and large anemones and batfish were observed. However, both the abundance and diversity of epifauna was limited in these rock areas, compared to the sedimentary seabed located above and below this area of rock cliffs. The size of the areas were not stated but were limited in size.

From about 1030 m to 880 m, rock and mud stone outcrops occur, interspersed with large areas of soft sediment which in places supported large numbers of glass sponges. Observations of the ROV’s manipulator arm indicated that the mudstone was very soft, disintegrating very easily. The mudstone was quite flat in areas with limited vertical relief and the sediment build up on the exposed rock and mudstone minimal, which suggests that sediment movement down the slope is very limited and/or strong currents sweep away exposed sediments.

**Rock Pinnacles**

The only other exposed hard substrate known to occur in the Pluto field is a series of rock pinnacles located about 300 m water depth (Figure 4-4). Results from the geotechnical studies indicate that there are a number of these pinnacles present in a confined area along the 300 m depth contour. They are also described as “coral heads” as they up to 2.5 m in height and 6 m in diameter which often occur in over 10m deep scour depressions (Geoconsult 2005).

The pinnacles contain a very low percentage cover of live soft coral with only a few live specimens of soft coral observed growing on top of the pinnacles.

**Figure 4-4 Rock Pinnacles, depth =297-299 m (Source: Geoconsult, 2006)**

### 4.3.4 ROV (Ocean Affinity 2018)

A total of seven POIs were surveyed using ROV in July 2018 by Ocean Affinity. POIs 3, 4 and 5 were mostly flat, sandy seabed, whereas PO1 encountered some of the pinnacles previously described.

The original SKM (2006) survey incorrectly identified the the rock pinnacle structures as biogenic in origin having been created by the deep-water coral *Lophelia* (SKM 2005). The subsequent ROV survey, completed by Ocean Affinity (July 2018), collected much higher resolution imagery of the rock pinnacle field which were sent to Professor Murray Roberts (University of Edinburgh) for expert assessment. It was confirmed that the yellow corals which were originally identified as *Lophelia* were "at first glance *Dendrophyllia cornigera* (well known in the Mediterranean Sea), but perhaps more likely a Leptosammia species (same family: Dendrophylliidae)". It was also confirmed that there was no evidence of *Lophelia* sp. in the imagery that was reviewed (M. Roberts, pers. comm).

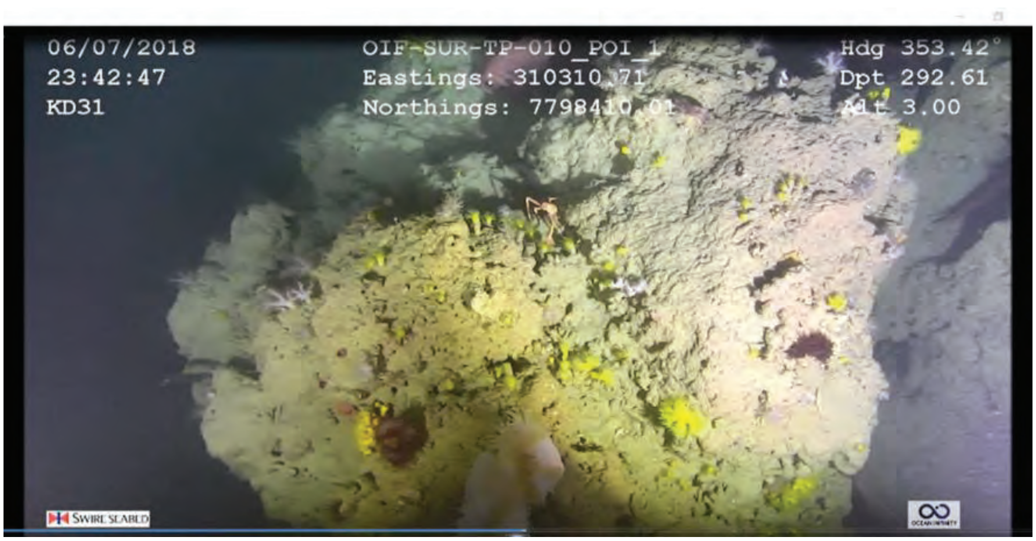

**Figure 4-5 Rock Pinnacles at POI1, depth=292m, (Source: Ocean Affinity, 2018)**

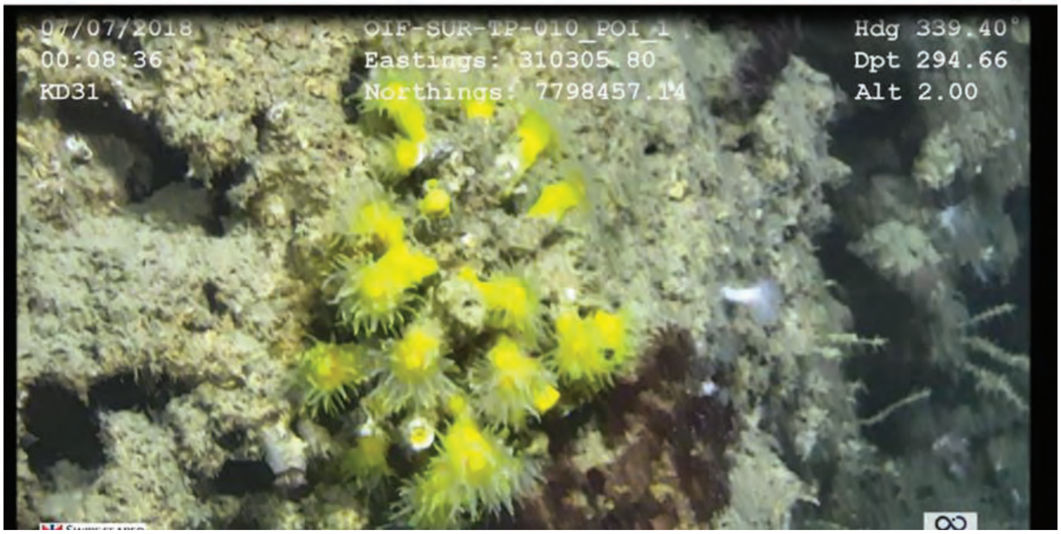


**Figure 4-6 Dendrophyllids on rock pinnacles (POI1), depth = 295m, (Source: Ocean Affinity, 2018)**

The pinnacles also provide structure for a diversity of fauna including fish and invertebrates. Many tens of fish were observed gathered around these pinnacles, most probably belonging to either the Glaucosomidae or Pricanthidae families.  Crinoids, hydroids and ophiuroids were also common. Other species visible on the mounds include anemones, soft corals, small crustacean like shrimp and some larger brachyurans, possibly *Cyrtomaia suhmii* (Figure 4-7).

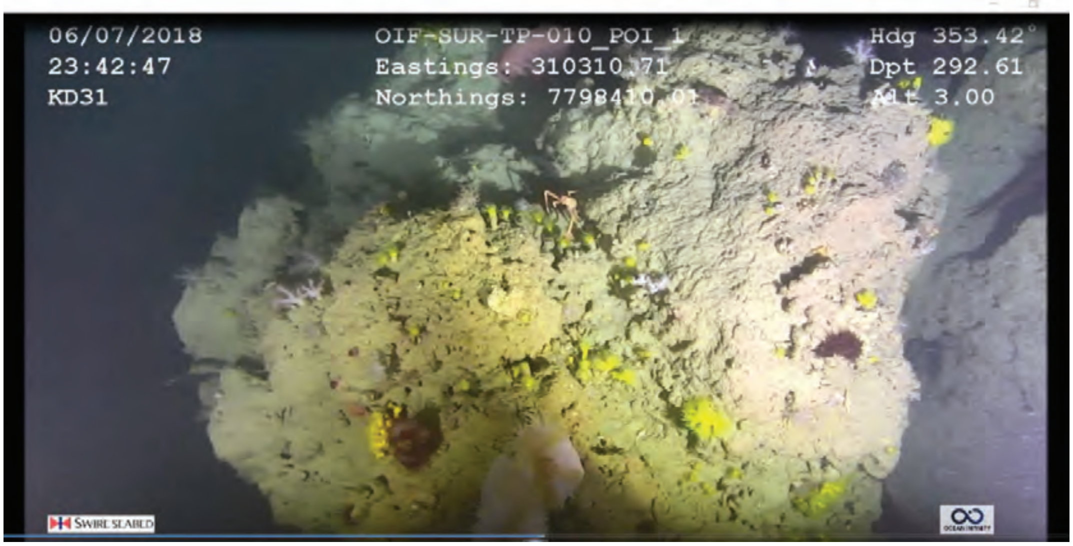


**Figure 4-7 Rock Pinnacle (POI1), depth =292m, (Source: Ocean Affinity, 2018)**

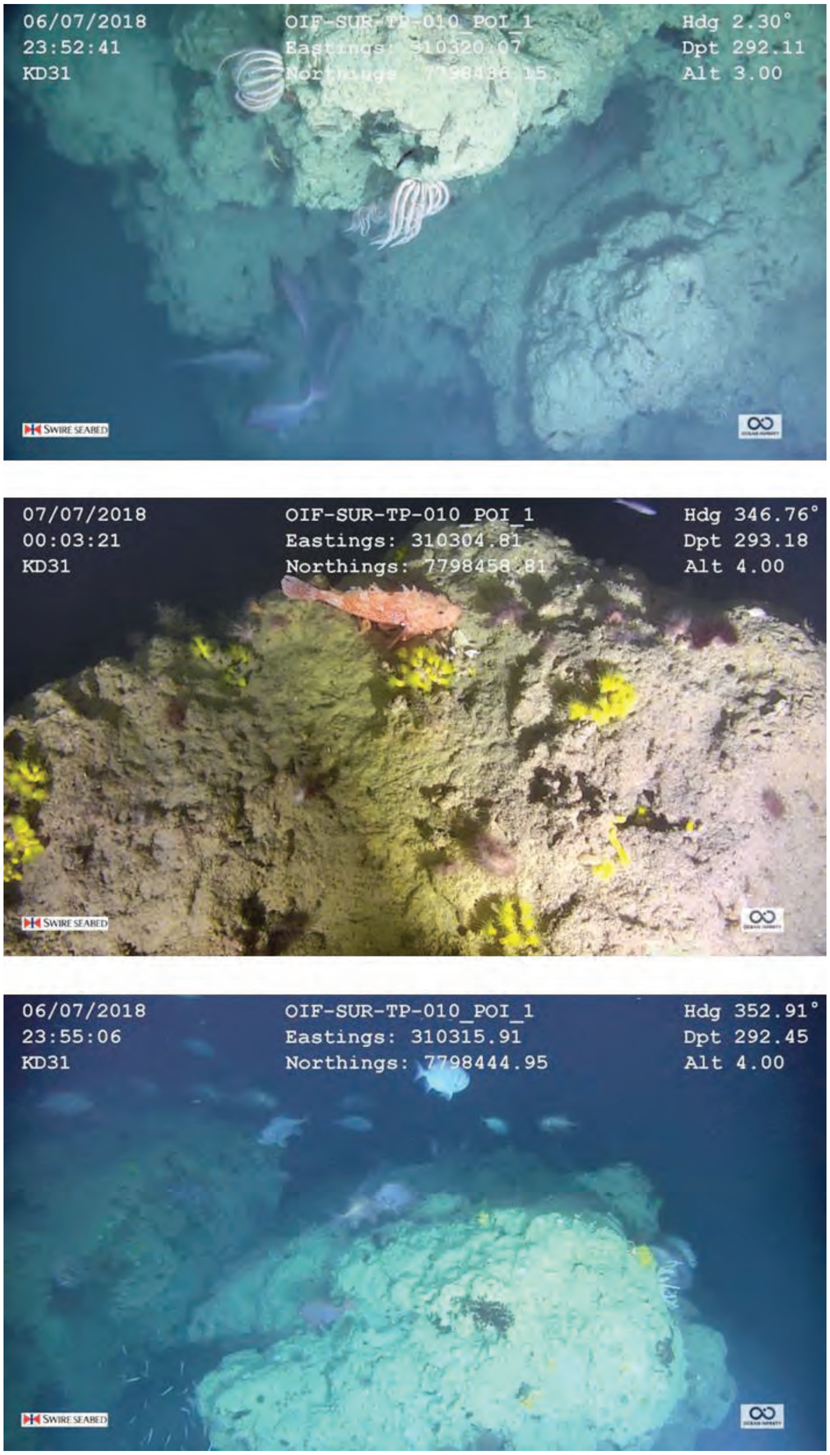


**Figure 4-8 Rock Pinnacles from POI 1, showing fish depth =292m, (Source: Ocean Affinity, 2018)**

Examples of the soft seabed from POI 3, 4 and 5 are shown in Figure 4-9.

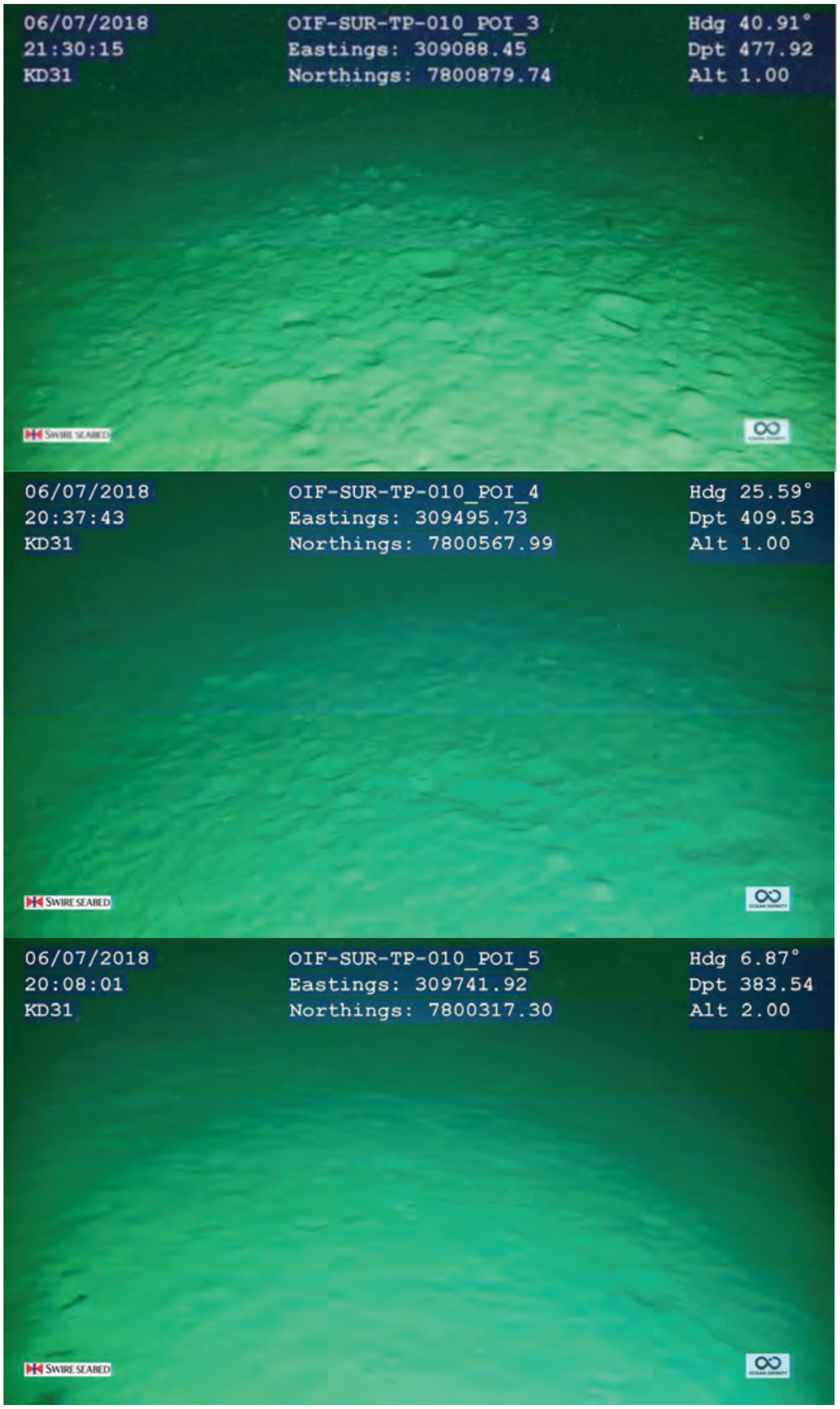


**Figure 4-9 Soft sediment substrate at POI 3,4 and 5, depth 383-477m**

The POI 2 was mostly soft sandy seabed, with one of the images capturing a solitary dory (Family Zeidae) close to the seabed (Figure 4-10). POI 6 was similar, with very little epifauna visible on the seabed. Species such as that shown in Figure 4-11 were uncommon.

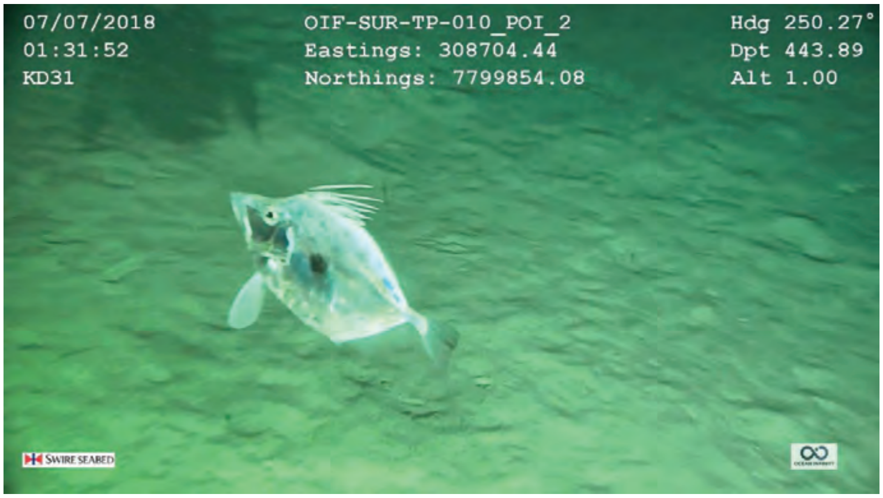


**Figure 4-10 Dory, (Family Zeidae), depth 443m, POI2**

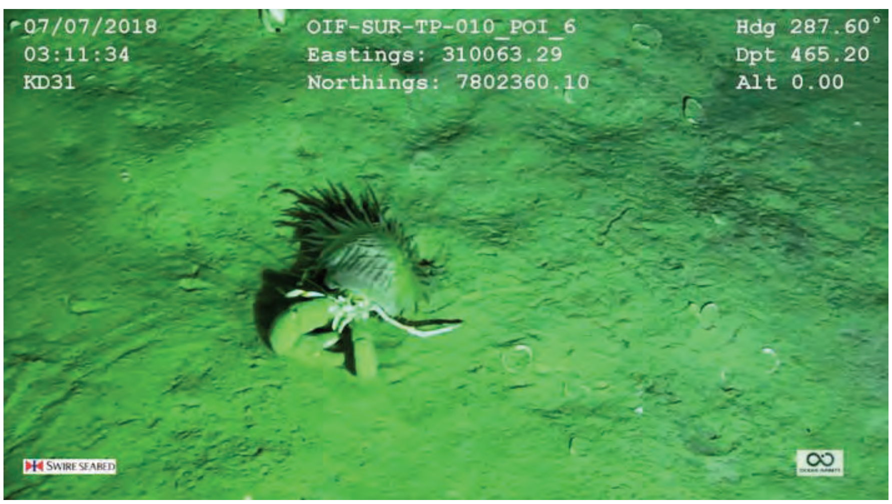


**Figure 4-11 ?Opisthobranchia, depth=465m, POI6**

All points of interest including the pinnacle field located at POI1 are shown in Figure 4-12. The ROV footage confirms that that the seabed along the trunkline alignment is entirely soft sediment benthos and that the pinnacles at their closest point are more than 350m away from the proposed trunkline alignment.

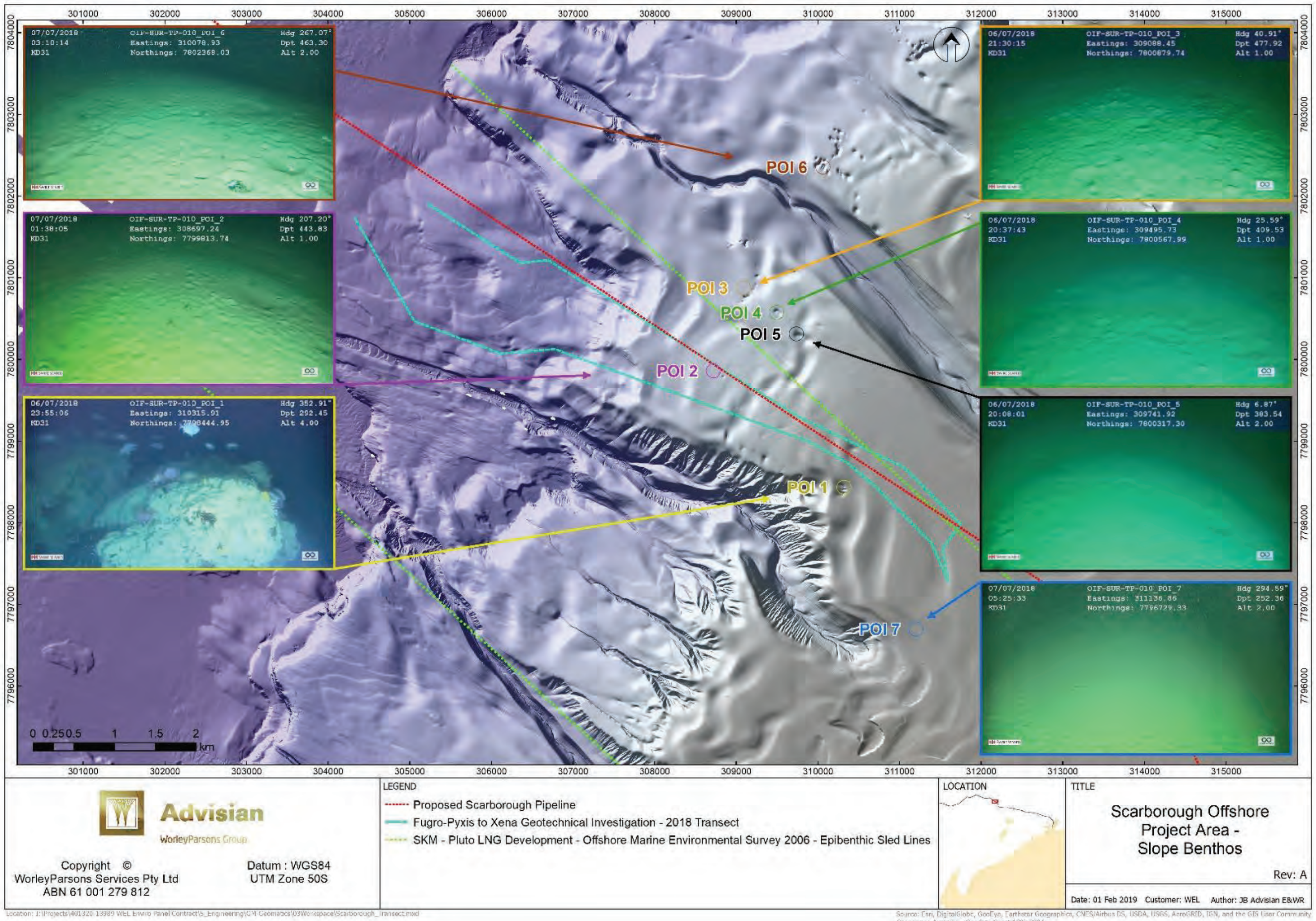


**Figure 4-12 Points of Interest surveyed relative to proposed Scarborough trunkline, Continental Slope**

## 4.4 Discussion

The greatest proportion of images analysed from around the Pluto field survey consist of soft sediments supporting a typically sparse deep-water fauna. The fauna was typical of the fauna expected on the North-West Shelf (NWS) and slope. A total of 231 epifaunal species and 32 infaunal species were identified during the SKM (2006) survey.

The infauna of the Pluto field was sparse but highly diverse (given the limited number of individuals collected). While a number of epifaunal species had not been recorded previously in Australia, Western Australia or the NWS region, this is attributed to the limited number of previous studies of the continental slope rather than the rarity of the fauna (SKM 2006).

Despite the limited distance between the Pluto and the Vincent and Enfield fields, the proportion of epibenthic species common to both fields was low. The distribution of fauna across the Pluto field differs to the patterns observed by AIMS during their recent studies around the Vincent and Enfield fields, where the fauna was patchily distributed and more strongly related to substrate type (rock outcrops *versus* soft sediments) than depth. The diversity of epifauna at Pluto was also lower than was observed in the AIMS studies off the North West Cape but this is largely attributable to the lack of rock outcrops in shallow water in the Pluto field.

While the majority of the Pluto field seabed was comprised of soft sediments, geotechnical data indicated the presence of a pinnacle field located in about 300 m depth. The pinnacle field covers an area  that is less than 3km$^2$ and consist of solitary outcrops rather than continuous reef. It remains unclear what the rock pinnacles are constructed from, however the structures provide habitat for a diverse suite of epifaunal and demersal species, including fish that are not usually found on the soft sediments.

## 4.5 Summary

The fauna observed was consistent with what would be expected to be found at the surveyed depths on the North West Shelf. The distribution of fauna across the Pluto field differs to the patterns observed by AIMS (Heyward and Rees 2001a and 2001b; Heyward et al. 2001 and 2001b) during historical studies around the Vincent and Enfield fields, off North West Cape. AIMS observed that the fauna was patchily distributed and more strongly related to substrate type (rock outcrops versus soft sediments) than depth. At Vincent and Enfield, the highest diversity of fauna was found on exposed rock outcrops. Preliminary geotechnical and geophysical data suggests that hard substrate is limited in the Pluto field. ROV recordings also indicate that the hard substrate located around 1000 m does not support a rich epifaunal community. The depth of water and sediment movement over the near vertical walls of the hard substrate may be the factors limiting the development of a rich epifaunal community (SKM 2006).

Despite the lack of similarities between the fauna in the collections made at Vincent-Enfield and the historical survey at the Pluto field, which are separated by less than 300 km, the Western Australian Museum researchers indicated that the species recorded from the Pluto field are representative of the area and collection depths with most species having been collected previously.

# 5 Continental Shelf

## 5.1 Background

The assessment of the offshore habitats that occur on the continental shelf (<300m water depth), have been based on ROV footage collected as part of subsea facility inspections around the Pluto field within Permit Area WA-34-L and WA-48-L. Whilst the Pluto platform itself is located within WA-48-L, in 83m water depth, much of the subsea infrastructure including pipelines and wellheads are in WA-34-L in ~190m water depth. The seabed composition through these areas has been previously described as being predominantly flat and featureless and comprises thick, unconsolidated fine grained sands. The sediments support soft sediment benthic communities dominated by infauna (including molluscs, crustaceans and worms) and isolated larger fauna (free swimming cnidarian, demersal fish and benthic crustaceans).

## 5.2 Survey Method

A total of 56 ROV video records from several subsea inspections were used as a basis for assessment. These included a review of footage from the following locations:

- Xeres-1A Well Head, (depth ~190m)
- Pluto Frond Mats (2015-2017), (depth ~170m)

## 5.3 Results

### 5.3.1 Xeres Well Head

The footage from the wellhead confirms that the seabed is comprised of soft unconsolidated sediments, possibly fine sand silts (Figure 5-1). The well head structure provides hard substrate for the colonisation by a range of invertebrates such as barnacles, hydroids and anemones. The structure in turn provides habitat for a range of fish species, as shown in Figure 5-1.


**Figure 5-1 Schools of fish, Xeres Well Head, Depth 188m**

### 5.3.2 Pluto Frond Mats

The footage from the annual surveys of the Pluto frond mats also confirms that the seabed surrounding the pipeline is comprised of soft unconsolidated sediments that is mainly fine sand (Figure 5-4, Figure 5-5, Figure 5-5).

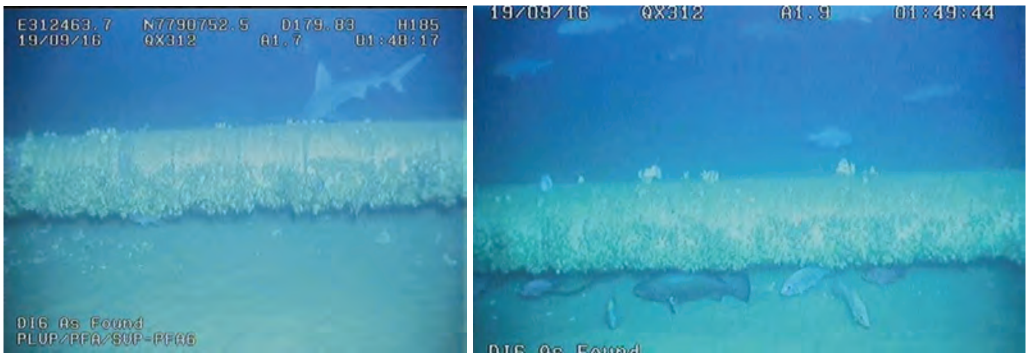


**Figure 5-2 Pipeline showing sandy substrate in the foreground, Pluto, depth =179m**

## 5.1 Discussion

Epifauna was observed to be most abundant on the continental shelf (150–200 m) and the abundance of the fauna appeared to be inversely associated with depth, with distinct differences in the fauna on the Shelf and slope (SKM 2006). However additional analysis of the proposed trunkline route shows the pipelines and wellheads offer significant areas of hard bottom habitat in a region that is characterised by soft unconsolidated sediments. Figure 5-3 provides a snapshot of images from the ROV locations surveyed relative to the trunkline alignment. Due to the uniform nature of the seabed across much of this area of shelf (as also confirmed by regional geomorphological mapping, refer to IMCRA 4.0), the ROV locations are considered representative of the larger project area and have been used to confirm that the trunkline route over the entire section of seabed is likely to be dominated by sand and other sediment types.

It is the pipeline itself that provides hard substrate for the establishment of a habitat that supports a diversity of species that includes invertebrates and fish. The images within Figure 5-4 and Figure 5-5 show how cover by species can also vary. The most common forms present include barnacles, sea whips (Octocorals), anemones, hydroids and to a lesser extent sponges and crinoids. The type and number of fish present is also highly variable and also depends on the relative position of the pipeline above the seabed. Partially buried pipelines do not appear to provide the same habitat complexity and opportunity that suspended or resting pipelines provide (McLean *et al*. 2017).

Fish assemblages and colonising invertebrate habitats on these artificial hard substrates also vary with depth and age. Generally speaking, the structures that are located in shallower water (<135m) had a greater diversity of fish compared to habitats at 350m depth where the number of fish species and abundance declined markedly (McLean *et al.* 2018). The study by Bond (*et al*. 2018) also confirmed that compared to adjacent natural seabed habitats, pipeline fish fauna were characterised by higher relative abundance and biomass of commercially important species.

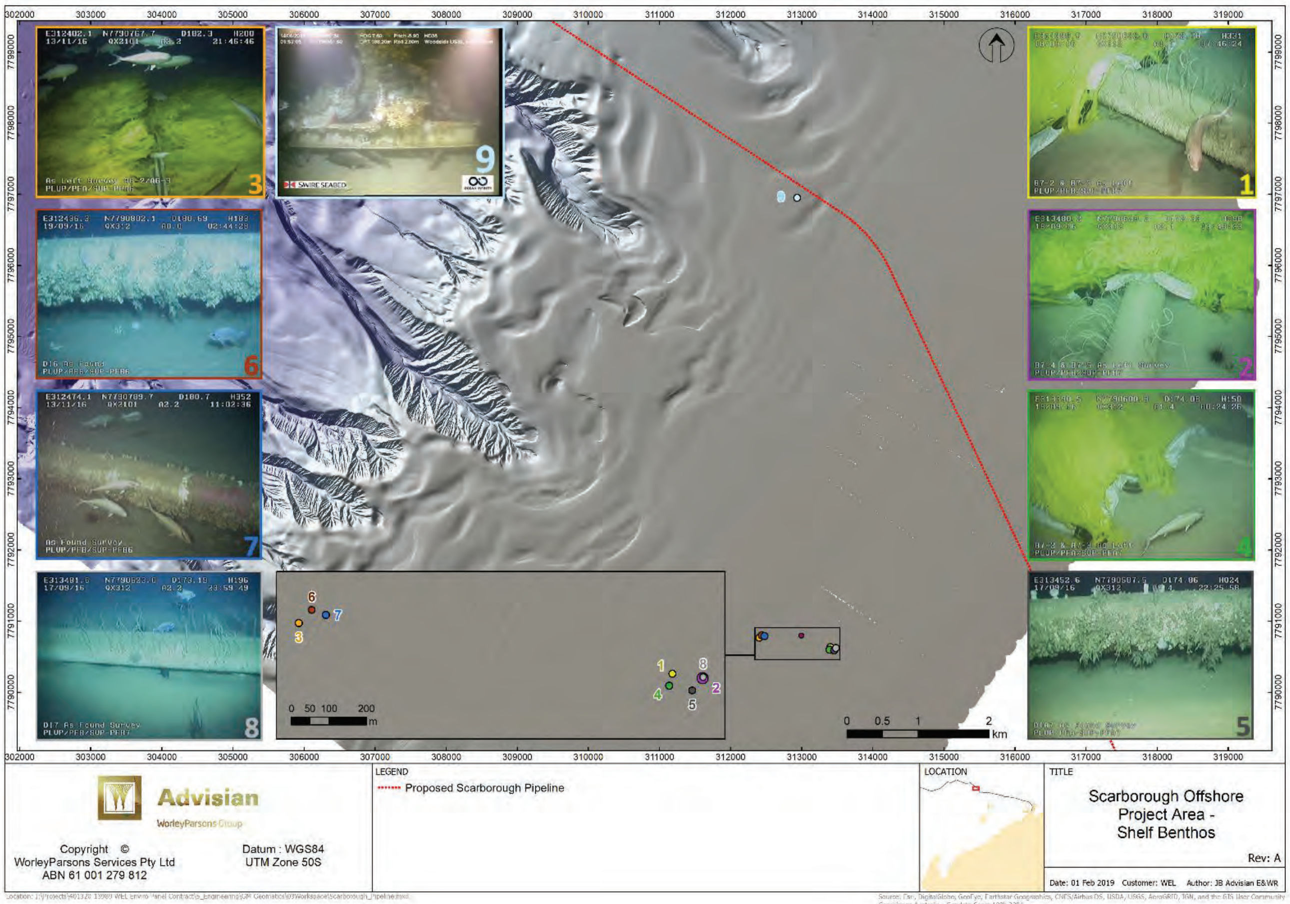


Figure 5-3 ROV survey locations, Continental Shelf

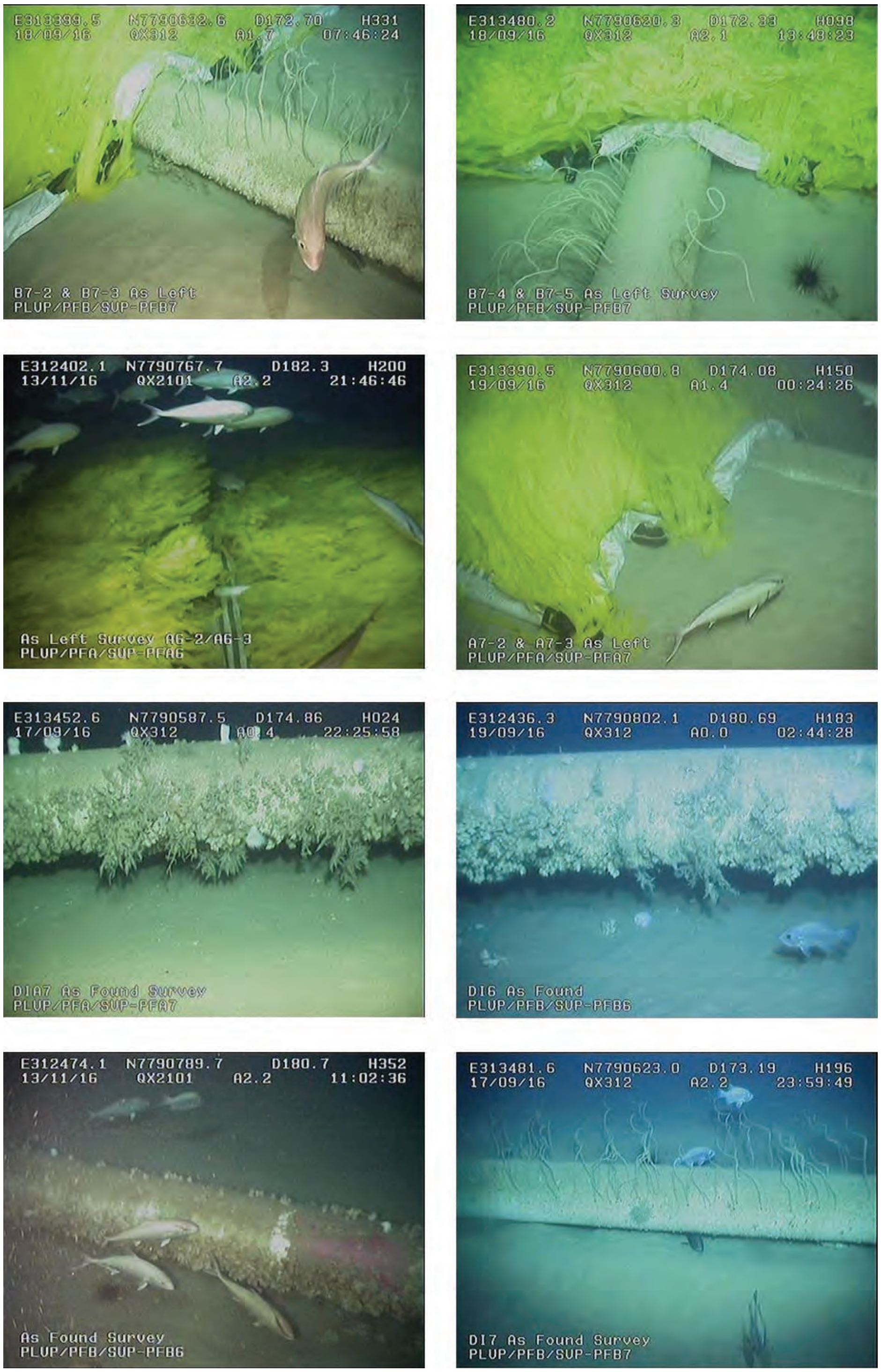


**Figure 5-4 Pluto Frond Mats, 2016 Survey, Depth ~170m**

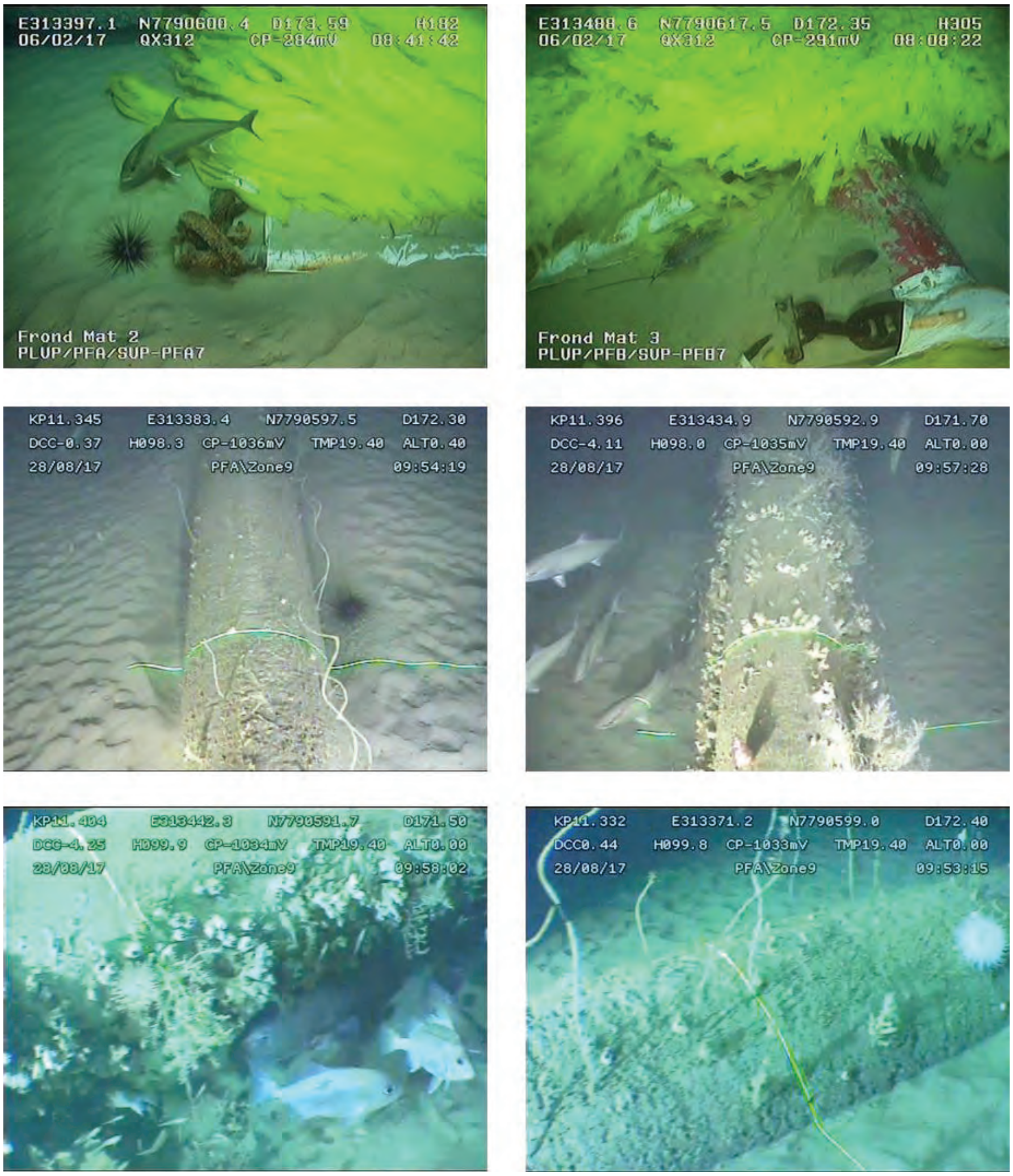


**Figure 5-5 Pluto Frond Mats, 2017 Survey, Depth ~170m**

# 6 Conclusions

Regional studies and the site specific studies reviewed indicate that seabed material along the proposed pipeline alignment (and around the gas field) is predominantly flat and featureless and comprises thick, unconsolidated fine grained sands. The sediments support soft sediment benthic communities dominated by infauna (including molluscs, crustaceans and worms) and isolated larger fauna (free swimming cnidarian, demersal fish and benthic crustaceans).

Sedimentary infauna associated with soft unconsolidated sediments of the general area is widespread and well represented along the continental shelf and upper slopes in the NWS region (Woodside 2004; SKM, 2007; Brewer *et al.,* 2007; RPS, 2011). Consequently, in the context of the contiguous extent of habitats across the region, benthic habitat along the proposed pipeline alignment consists primarily of soft unconsolidated sediments and is considered to be of relatively low environmental sensitivity.

Benthic communities of filter feeders generally live in areas that have strong currents and hard substratum (CALM, 2005) and are closely associated with substrate type, with areas of hard substrate typically supporting more diverse epibenthic communities (Heyward et al., 2001). The only natural habitat that is not classified as soft sediment is the pinnacle field that lies in about 300m water depth, on the continental slope. The pinnacle field covers an area less than 3km$^2$ but the pinnacles are isolated forms and do not constitute continuous reef. It remains unclear what the pinnacles are constructed from, however the structures provide habitat for a diverse suite of epifaunal and demersal species that commonly occur elsewhere in the NWS.

Recent research has also confirmed that habitats containing the greatest biodiversity in these offshore environments are the habitats formed by colonising invertebrates on oil and gas subsea infrastructure including the well heads and pipelines. These habitats and the species present on these structures in the NWS of Western Australia have been subject to detailed assessment by McLean *et al.* (2018), Bond *et al*. (2018) and McLean *et al*. (2017). These habitats not only have structural complexity but also create habitat for a large diversity of fish species that commonly occur elsewhere in the NWS but do not occur over soft unconsolidated sediments.

# 7 References

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# Appendix B

## Dampier Archipelago Commonwealth waters Marine Benthic Habitat Survey

# Dampier Archipelago

## Commonwealth Waters Marine Benthic Habitat Survey

18 January 2019

**Level 4, 600 Murray St**
**West Perth WA 6005**
**Australia**

401012-02612-EN-REP-0001

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## Project No: SPA-ENG-00-EN-REP-0001 – Dampier Archipelago: Commonwealth Waters Marine Benthic Habitat Survey

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| 1 | Updated with client comments and issued for use | A Lemmon | P Nichols | P Nichols | 13/02/2019 |
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# Executive Summary

The Scarborough gas resource is located approximately 375 km west-north-west off the Burrup Peninsula and is part of the Greater Scarborough gas fields which are estimated to hold 9.2 Tcf (2C, 100%) of dry gas. Woodside is proposing to develop the Scarborough gas resource through new offshore facilities connected by an approximately 430 km pipeline onshore. The proposal is to initially develop the Scarborough gas field with wells, tied back to a semi-submersible floating production unit (FPU) moored in 900 m of water close to the Scarborough field. This report has been developed in support of environmental approvals associated with the Scarborough Project.

As part of the trunkline installation, Woodside is assessing the feasibility of using backfill material from a potential borrow ground that has been identified in Commonwealth Waters. The potential borrow ground is located adjacent to the north-western extent of the habitat protection zone of the Dampier Marine Park. A benthic habitat survey of the potential borrow ground and surrounding areas within the Dampier Marine Park was commissioned (this study) to support the environmental impact assessment of the intended activities.

Surveys of marine benthic habitat of the potential borrow ground and nearby areas within the Dampier Marine Park were undertaken between 18th and 20th December 2018. This report presents the methodology and results from the survey.

Bare sandy substrate dominated most of the locations where towed/drop camera transects were conducted. Where biota was observed, it typically consisted of invertebrates such as anemones and crinoids at densities no greater than 10% and typically less than 5% cover. Of the 24 survey locations within the potential borrow ground, sparse invertebrate cover was observed at only two locations. Of the 51 survey locations within the habitat protection zone of the Dampier Marine Park, sparse invertebrate cover was observed at 12 locations.

# 1 Introduction

## 1.1 Project Background

Woodside is assessing the feasibility of using backfill material from a potential borrow ground in Commonwealth Waters. The potential borrow ground is adjacent to the north western extent of the Dampier Marine Park (DMP). The area of the DMP that is adjacent to the potential borrow ground is an International Union for Conservation of Nature (IUCN) Protected Area. It has been attributed Category IV status, which has the primary objective to maintain, conserve and restore species and habitats. An understanding of benthic communities at and surrounding the potential borrow ground is required to help inform the impact assessment for the intended activities associated with using the potential borrow ground.

This report presents the methodology and reports the findings of the benthic habitat survey that was undertaken in December 2018 at the potential borrow ground and adjacent areas within the DMP.

## 1.2 Scope of Work

The primary aim of the Commonwealth Waters survey was to gather information to support an environmental impact assessment of using the proposed borrow ground. The survey was completed to acquire qualitative data on species present, and to report on the presence of sensitive benthic biota or habitat near the proposed borrow ground and the adjacent DMP.

## 1.3 Survey Location

The potential borrow ground is located directly north of the western extent of the DMP, about 9 km north of the north-western extent of Legendre Island, outside the Dampier Archipelago (Figure 1-1).

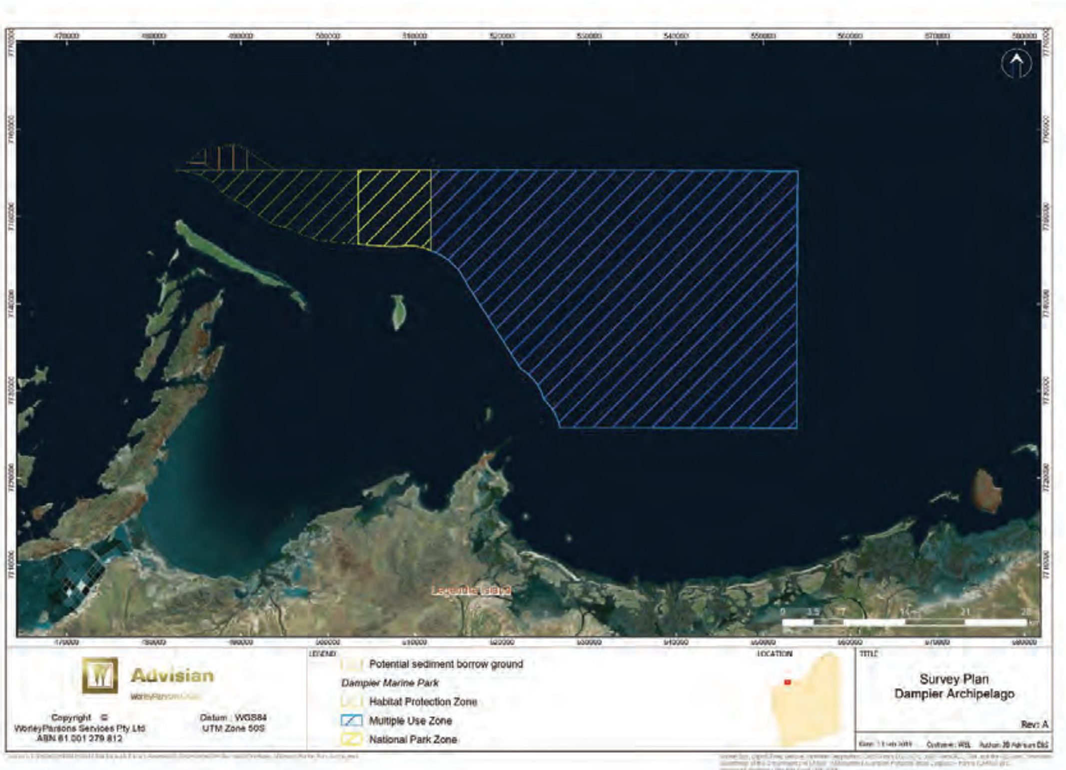


**Figure 1-1: Survey location showing potential borrow ground and adjacent section of Dampier Marine Park**

## 1.4 Previous Knowledge

The Marine Park was proclaimed in December 2013, though has been known as Dampier Marine Park since October 2017. DMP is significant because, as a whole, it provides protection for offshore shelf habitats adjacent to the Dampier Archipelago, the area between Dampier and Port Hedland and a seafloor rich with sponges (DNP, 2018). The habitat protection zone adjacent to the potential borrow ground is allocated Category IV Protection as it provides important habitat for benthic communities in the region. Previous knowledge of the benthic habitats and communities of the survey location includes a study by the CSIRO (Pitcher *et al* 2016), which covered an extensive area of the west Pilbara describing benthic habitats and categorizing the assemblages' present. The survey location appears to be on the outer fringes of the CSIRO study. Bathymetric information was limited to nautical charts of the region.

# 2 Methods

## 2.1 Survey Design

To optimise the field campaign, survey locations for video and still images were positioned to target the potential borrow ground and surrounding area (Figure 2-1). A 5km buffer was applied to the potential borrow ground to define the survey area in the Dampier Marine Park.

Existing historical data was not available to assist with directing survey effort. To maximise spatial coverage over this area in the available timeframe, a 1 km grid survey pattern was applied. Locations within the potential borrow ground and locations in the DMP closest to the potential borrow ground, were prioritised.

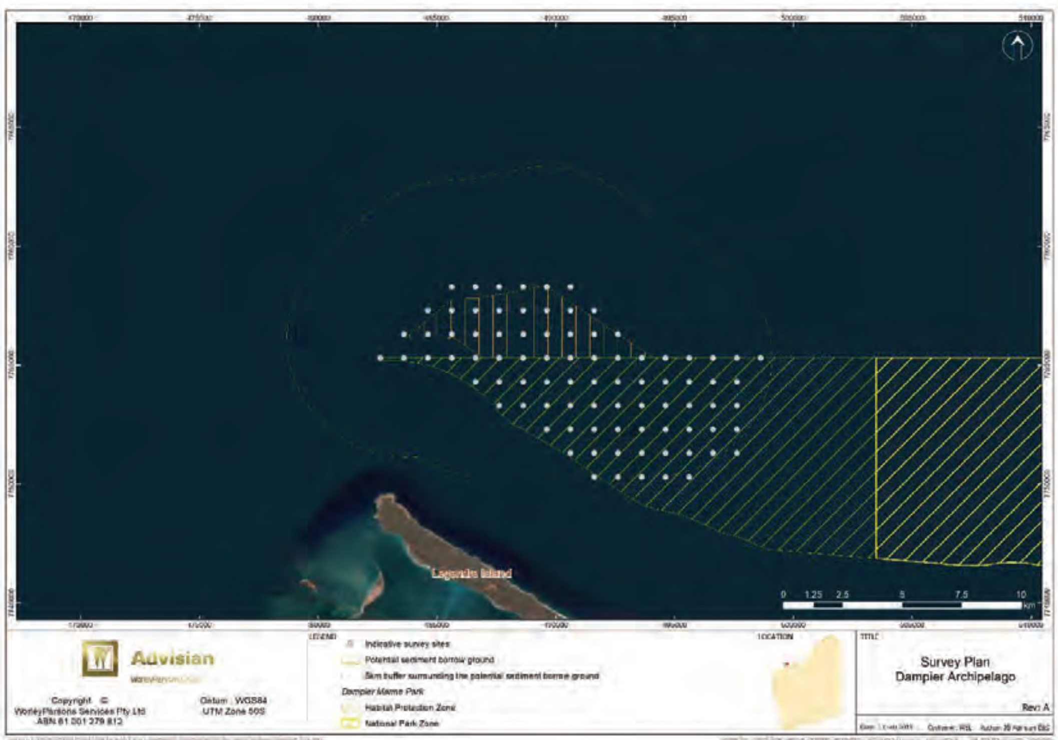


**Figure 2-1: Survey sites planned in Commonwealth Waters at the potential borrow ground and Dampier Marine Park**

## 2.2 Field Survey

The field survey was undertaken onboard the vessel *Kaelani*, operated by Bhagwan Marine, between 16th and 20th December 2018. A total of 24 transects were completed within the potential borrow ground and a further 51 transects were completed within the DMP during the survey. Transects varied in length from 30 m to about 230 m, though were typically around 100 m (Figure 2-2). The planned survey locations at the southern extent of the DMP were unable to be surveyed due to time constraints. Habitat data was obtained using a towed/drop camera array including digital recordings of high resolution still photographs and high definition video footage. When possible, real-time standard definition footage was observed by an attending marine scientist on the vessel. Preliminary qualitative habitat information was recorded into log sheets for subsequent review. Information recorded to the log sheet for each transect included:

- transect number (identifier)
- time of transect data collection (start/end) and observed changes of habitat
- dominant benthic habitat (substrate type and biota density)
- approximate depth (as measured by the vessel echo sounder)
- general comments relating to each transect.

Spatial positioning data was acquired using a Garmin GPSMap 62 and a Holux RCV-3000 located onboard the vessel. Two units were used for redundancy. The global positioning system (GPS) units recorded a tracklog for each day of operation and were time-synchronised with the laptops and cameras used to record habitat data.

At each survey location the camera array started recording on the deck of the vessel, where information about the transect and location was recorded before the array was deployed. Once the camera array reached the seabed, the vessel was allowed to drift for two to three minutes, depending on the rate of drift. When real-time viewing was available and more complex habitat was observed, or bathymetry was more variable, the transect/drift was allowed to proceed for a longer period but capped at around five minutes for operational efficacy. The typical drift speed was between 0.5 and 1.7 knots according to the vessel chart plotter.

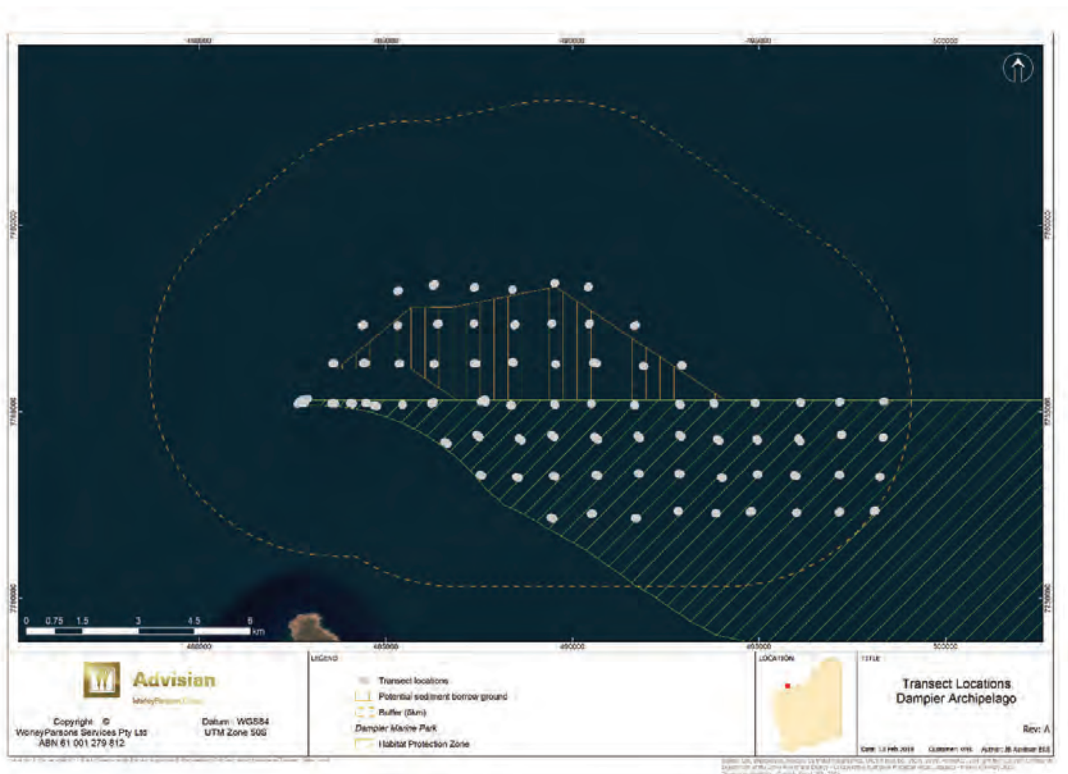


**Figure 2-2: Benthic habitat transects conducted in Commonwealth Waters at the potential borrow ground and Dampier Marine Park, December 2018**

## 2.3 Benthic Habitat Characterisation

High level habitat classes were derived from a benthic habitat map of the Dampier Archipelago by MScience (2018). These classes were refined based on habitats and biota observed during the survey (Table 2-1). The video footage and still imagery was reviewed after the field survey was complete, to confirm habitat classifications and to refine spatial data where necessary by improving time logs of habitat boundaries and transect start/end points. Where habitat boundaries or changes in epibenthic density were different to the initial logs, the elapsed time in the video was applied to determine the time and relative spatial position for the particular attribute and a new revision of the log was created.

Habitat information was georeferenced by relating the times recorded on the log sheets with the position logged by the GPS onboard the vessel. Position information was logged by the Holux GPS each second. For each spatial position received, the relative habitat information was attributed to create habitat point data of the areas surveyed.

Habitat point data was imported into ArcMap geographical information systems platform to create Esri shape files and to be displayed with other relevant spatial data for presentation in this report.

**Table 2-1: Habitat classification scheme utilised for the survey**

| Habitat Class | Definition |
|---|---|
| Coral | Hard coral communities dominate and were present in ≥10% cover. Some minor biota may be present (i.e. ascidians, bryozoans and sponges); however, they are secondary in density and ecological function. No coral was observed along any of the survey transects. |
| Algae | Macroalgae were the dominant biota (≥10% cover) over a consolidated hard substrate that may contain sparse (≤10%) secondary biota (i.e. solitary corals or seagrasses). No macroalgae or seagrass was observed along any of the survey transects. |
| Invertebrates | Sessile and mobile benthic invertebrate biota (including crinoids, ascidians, hydroids and sponges) were present (≥3%) on sandy substrate with little or no other biota. Both sessile and mobile invertebrates were observed along survey transects. Example images are supplied in Figure 2-3. |
| Bare Sediment | Substrate is predominantly bare sand. Biota is very sparse (≤10% cover of macroalgae or coral and ≤3% invertebrates) or entirely absent. Bare sediment was the dominant habitat class in the survey transects. Example images are supplied in Figure 2-4. |

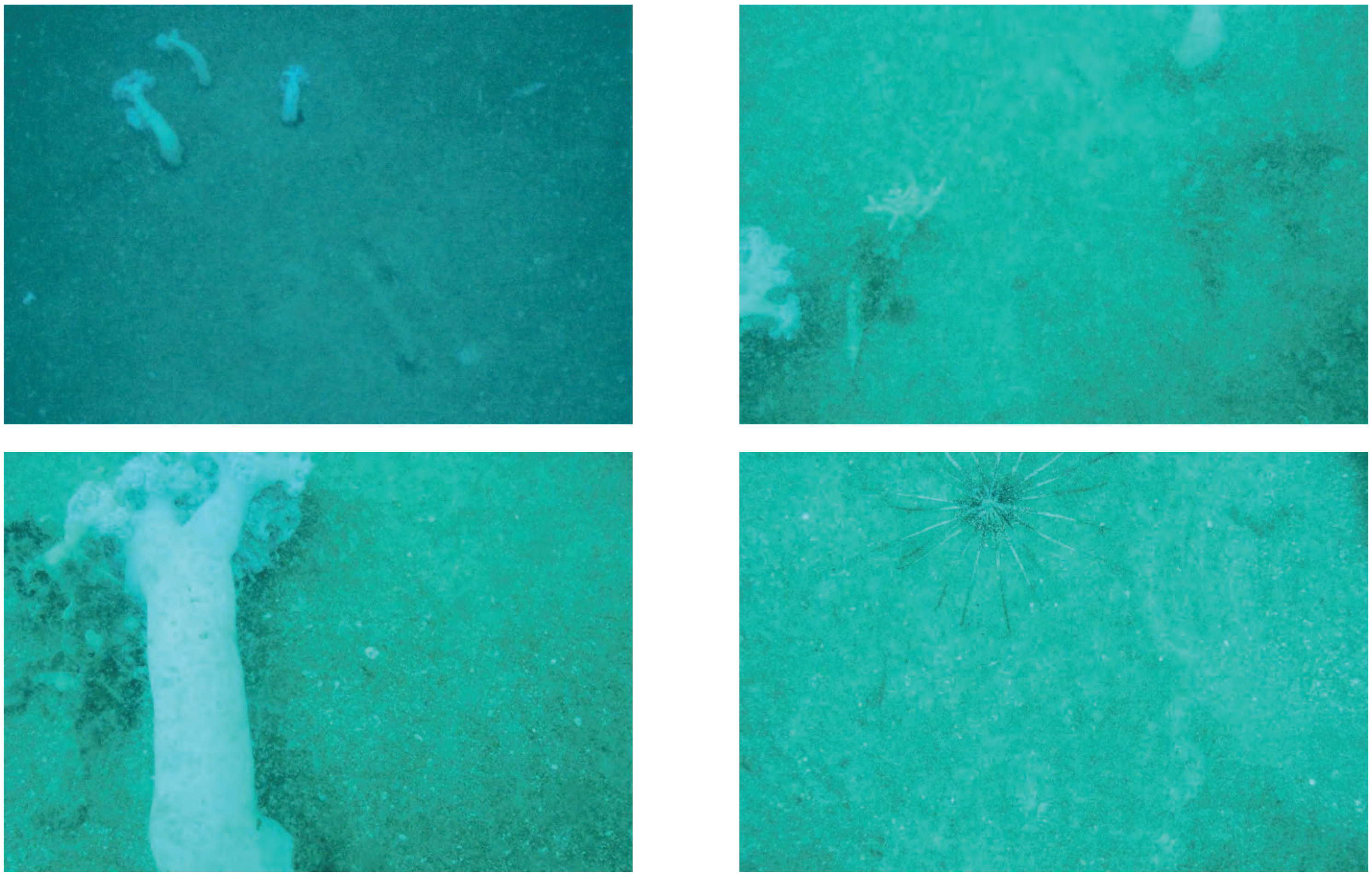

Figure 2-3: Examples of typical habitat classified as Invertebrates

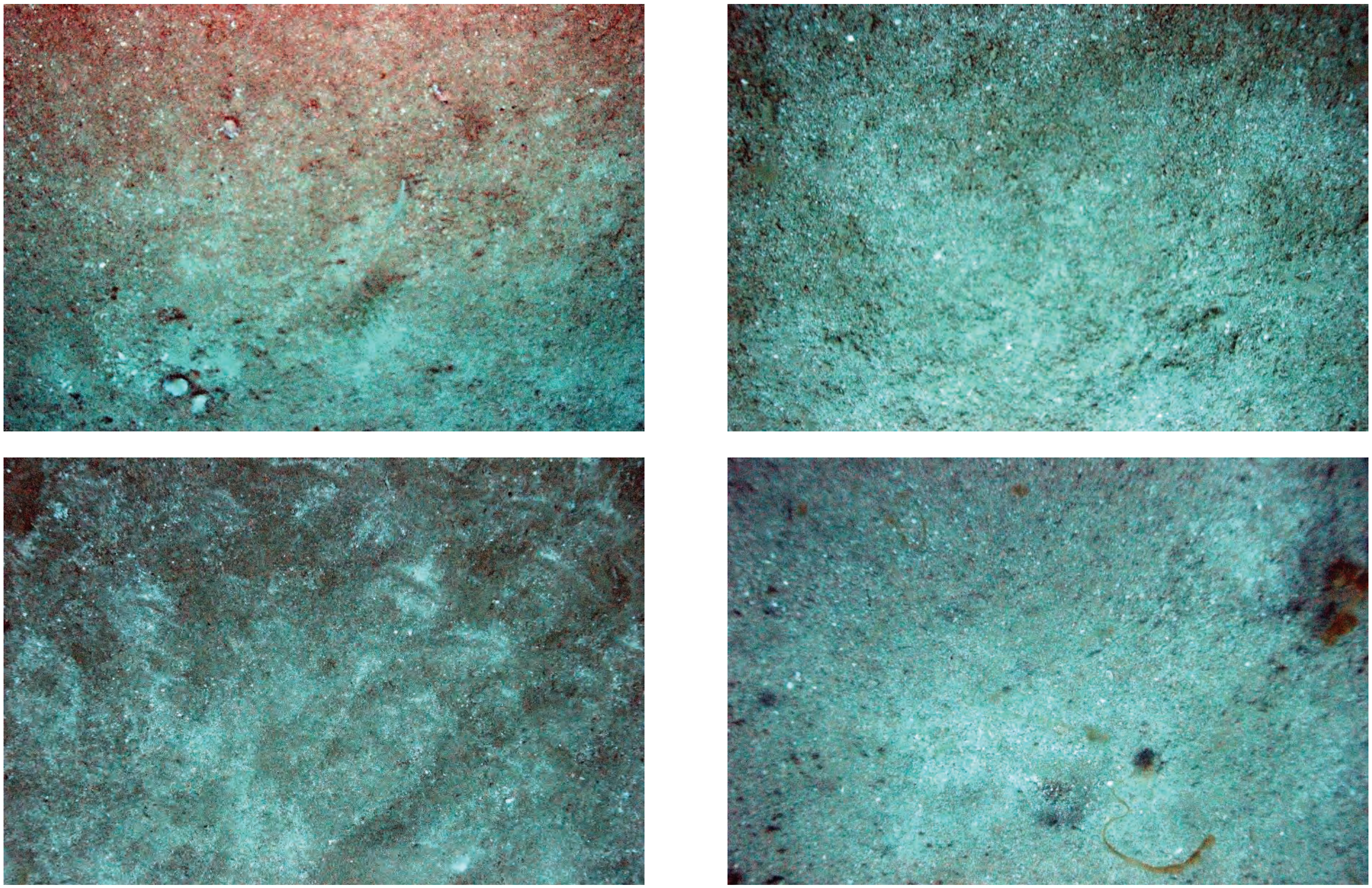

**Figure 2-4: Examples of typical habitat classified as Bare Sediment**

# 3 Results

## 3.1 Benthic Habitat

At the proposed borrow ground bare sandy substrate dominated areas where towed/drop camera transects were conducted. Where biota was observed, it typically consisted of invertebrates such as anemones and crinoids at densities no greater than 10%. Of the 24 survey locations, invertebrates were observed at only two (Figure 3-2 and Figure 3-3). Most transects were conducted in depths between 40 m and 42 m. Four transects were conducted in water depths between 37 and 40 m.

Like the potential borrow ground, bare sandy substrate dominated areas where towed/drop camera transects were conducted in the Dampier Marine Park. Where biota was observed, it typically consisted of invertebrates such as anemones and crinoids at densities no greater than 10%. Of the 51 survey locations, sparse invertebrate cover (3–10%) was observed at 12 of them (Figure 3-4, Figure 3-5 and Figure 3-6). Bathymetry was more variable within the marine park survey area, ranging from 31 m to 43 m. No particular association between habitat and depth is evident based on this data.

Figure 3-1 displays the general location of each the subsequent figures.


**Figure 3-1: Transects with superimposed boxes indicating where subsequent figures presented are located**

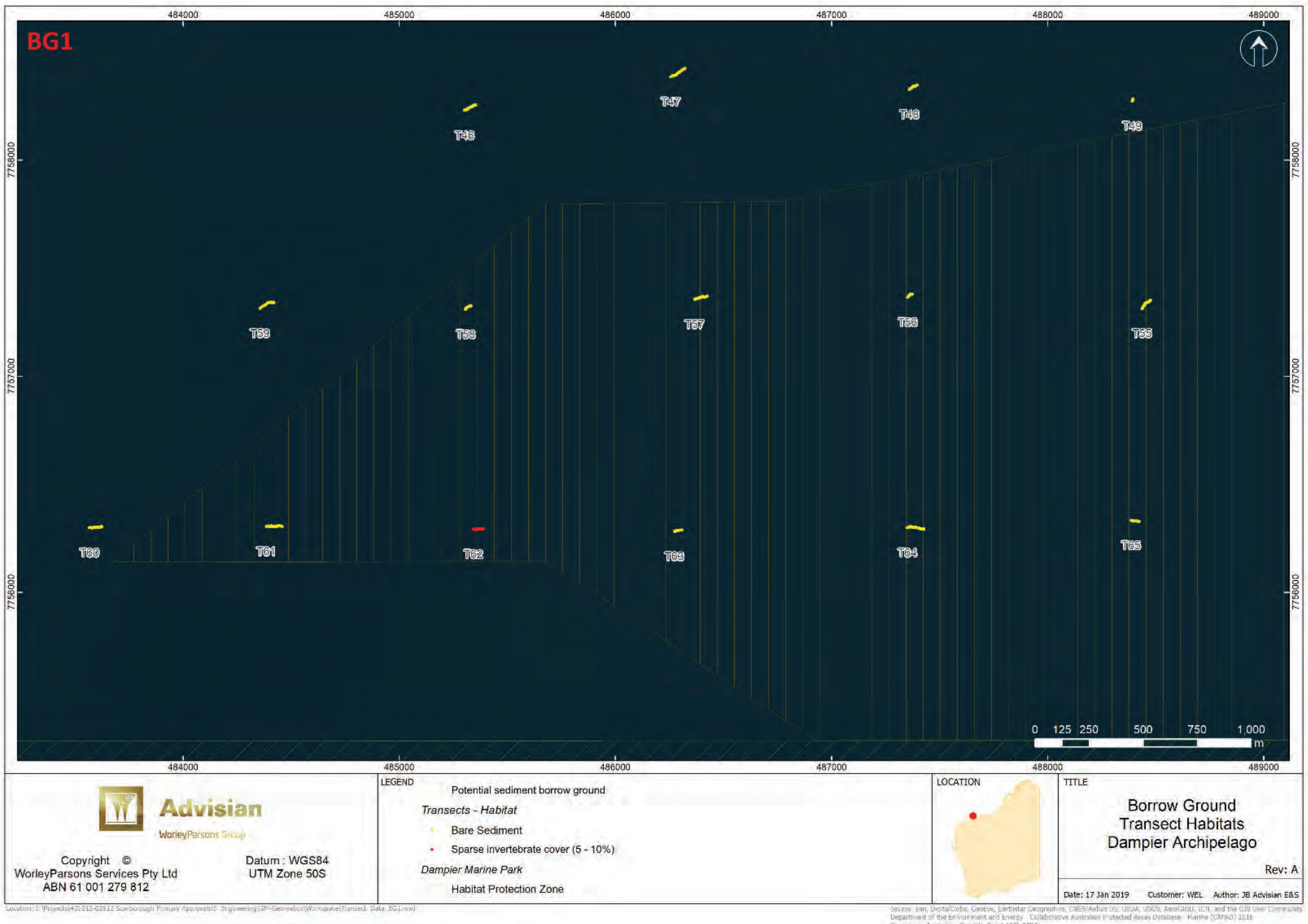


**Figure 3-2: Benthic habitat in the western portion of the potential borrow ground**

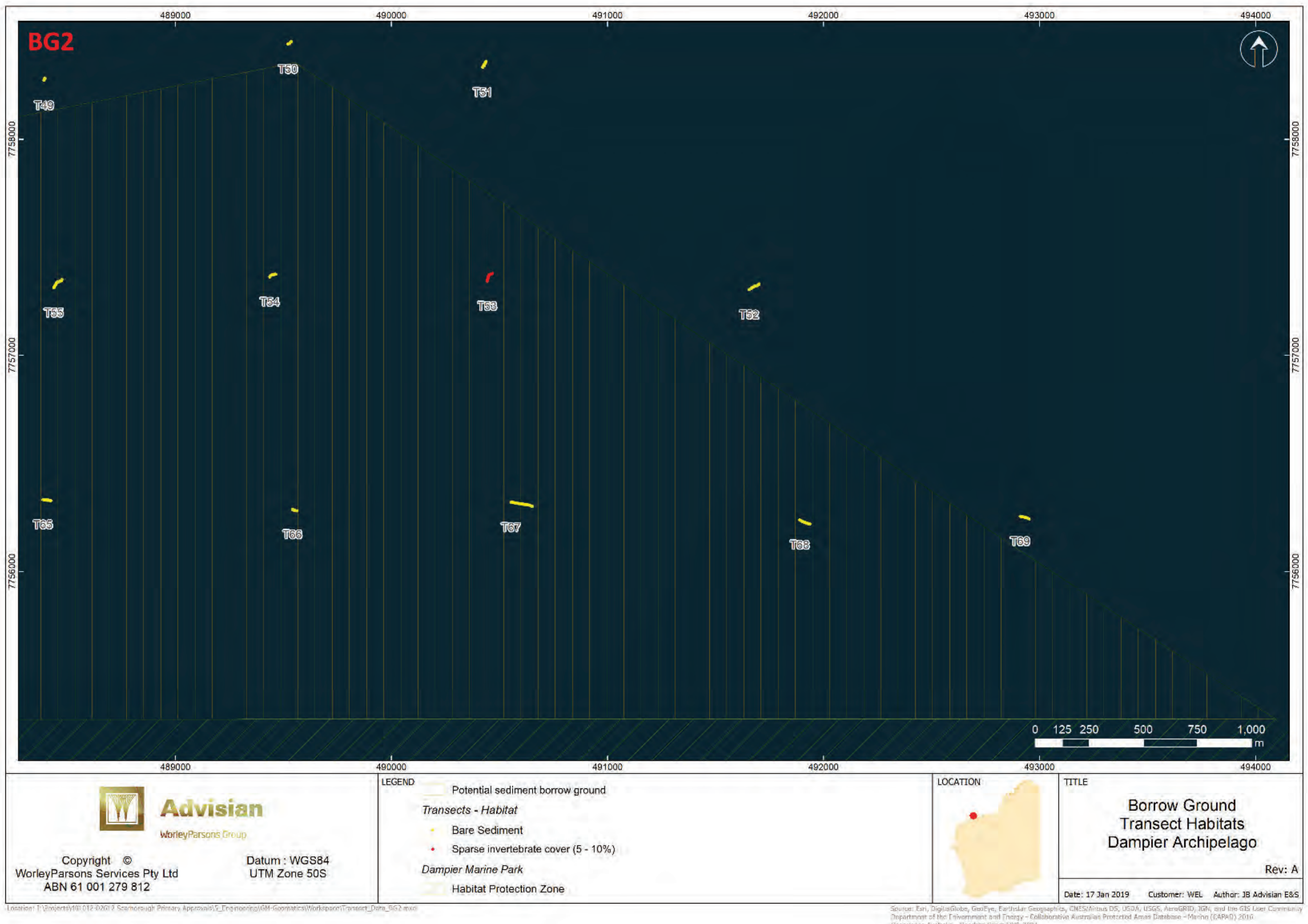


**Figure 3-3: Benthic habitat in the eastern portion of the potential borrow ground**

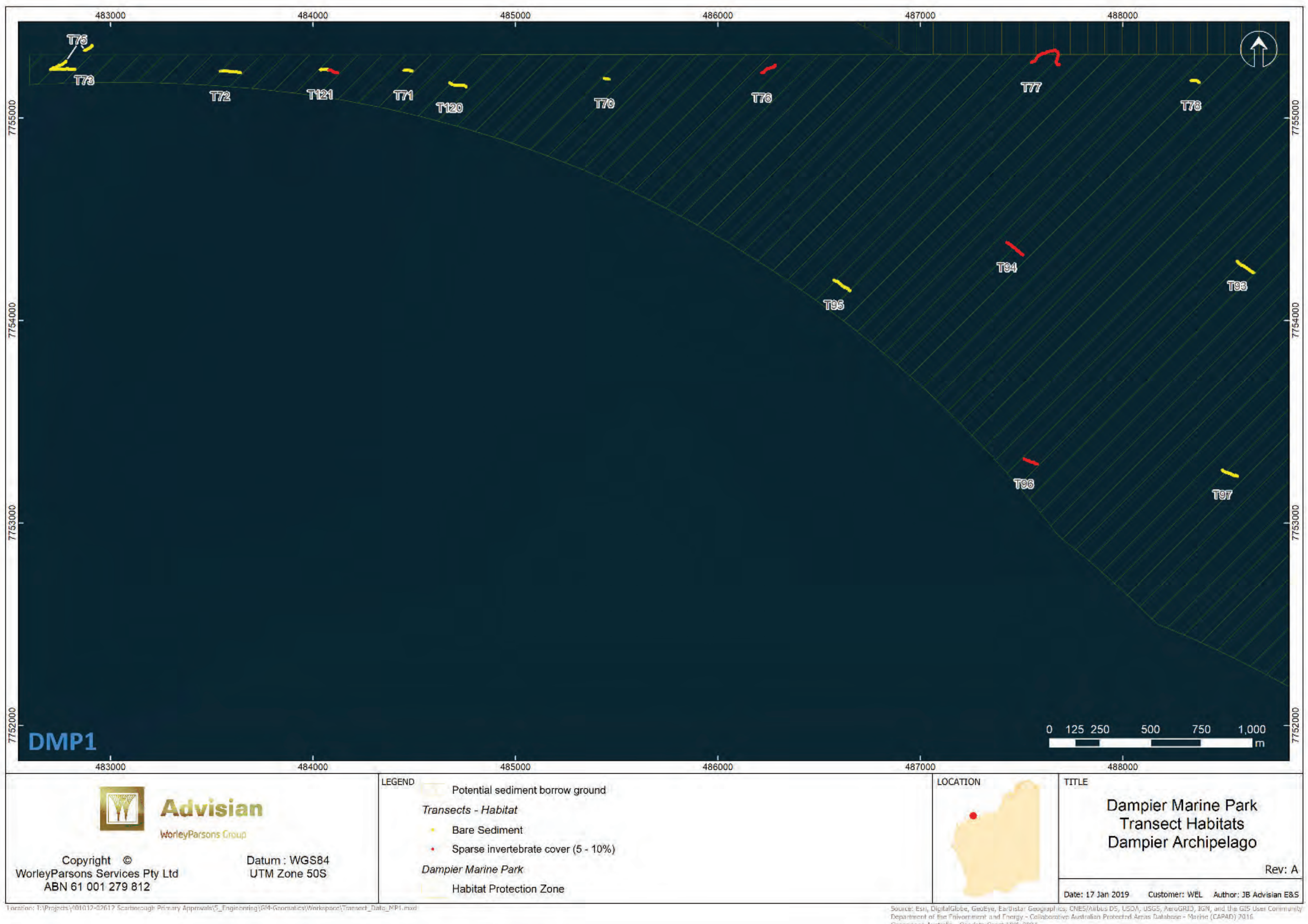


Figure 3-4: Benthic habitat in the western portion of the Dampier Marine Park

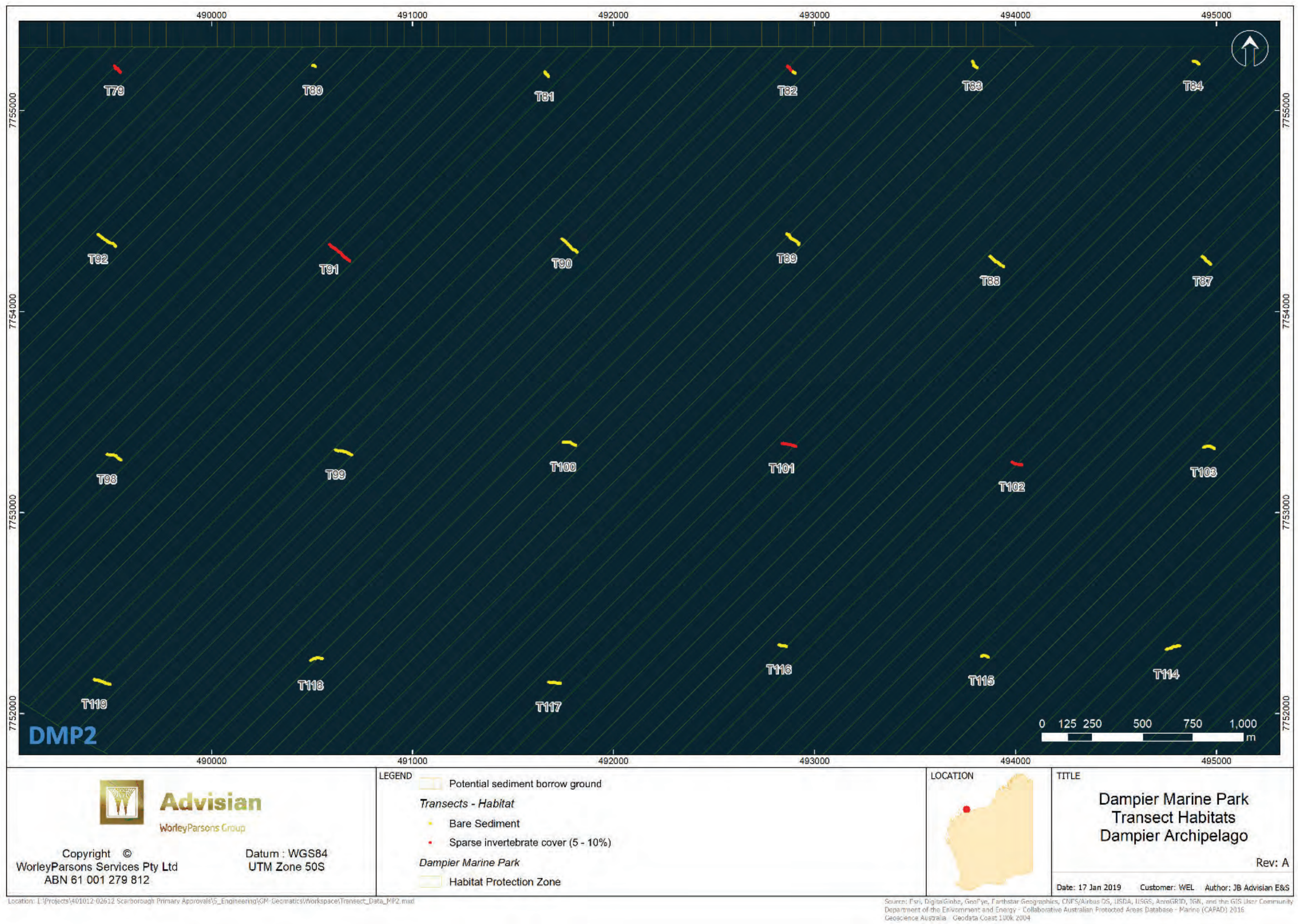


**Figure 3-5: Benthic habitat in the middle of the Dampier Marine Park**


Figure 3-6: Benthic habitat in the eastern portion of the Dampier Marine Park

# 4 Discussions and Conclusions

Towed video and drop camera survey of both the potential borrow ground and the DMP directly adjacent to the borrow ground confirm that the seabed and its benthic composition are relatively uniform in structure and composition. Both locations are dominated by bare substrate with large areas of seabed that are apparently largely devoid of any epibenthic species. Where epibenthos is present, the percentage cover of species is comparatively low (in the order of 5%), with no transects recording greater than 10% coverage in the species present.

Common species present were alcyonaceans (mainly solitary soft corals), pennatulaceans (sea pens), crinoids (feather stars), asteroids (sea stars), anemones and hydroids. No benthic primary producer habitat in the form of hard corals, macroalgae or seagrass was recorded or observed along any of the survey transects.

The benthic habitat observed during this survey appears to be consistent with a broad scale characterisation of the Pilbara seabed undertaken by UWA and CSIRO (Pitcher *et al* 2016), which categorises this area as "Assemblage 2" and describes it as "typically bare seabed interspersed with moderately high cover of whips (0– 95.6%), median gorgonians (0–12.4%) and median sponges (0–73.4%), some cover of algae (0 25%), and low cover of alcyonarians (0–2.2%), corals (0–6.8%), coral reef (0–5.4%), bioturbation (0– 13.4%) and halimeda (0–0.8%), and ~no cover of seagrass".

The similarity between benthic habitats observed within the potential borrow ground and habitat protection zone of the DMP during this survey, and those described above as Assemblage 2, indicates that the area surveyed is well represented in the regional context as opposed to more spatially discrete habitat features such as submerged coral reefs (Delambre Reef) and shoals (Tessa Shoals).

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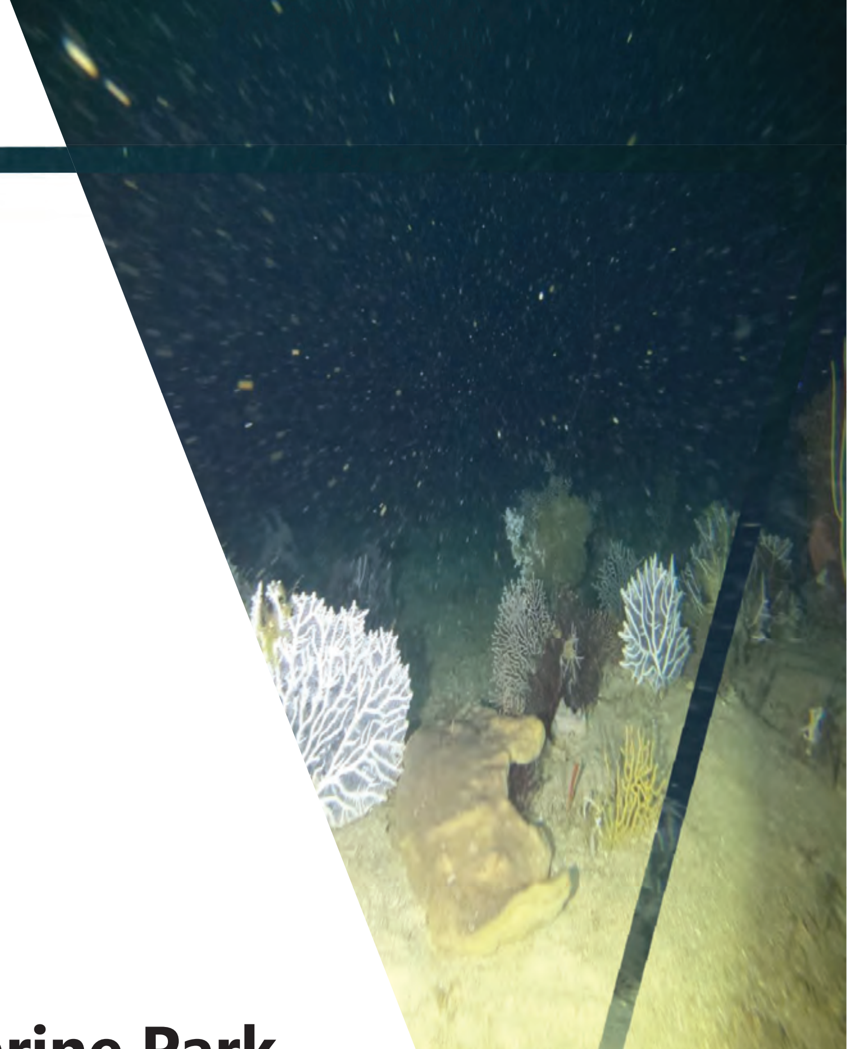
# Appendix C

## Montebello Marine Park Benthic Habitat Survey



# Montebello Marine Park Benthic Habitat Survey

ROV Analysis of the Scarborough Pipeline Route

18 April 2019

Level 4, 600 Murray St
West Perth WA 6005
Australia

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## Project No: 401012-02698- – Montebello Marine Park Benthic Habitat Survey: ROV Analysis of the Scarborough Pipeline Route

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| Rev2 | Draft 2 submitted for client review | K Newton / R Tate | Woodside | NA | AppDate4 |
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# Executive Summary

The Scarborough gas resource is located approximately 375 km west-north-west off the Burrup Peninsula and is part of the Greater Scarborough gas fields. Woodside is proposing to develop the Scarborough gas resource through new offshore facilities connected by an approximately 430 km pipeline onshore. The proposal is to initially develop the Scarborough gas field with wells, tied back to a semi-submersible floating production unit (FPU) moored in 900 m of water close to the Scarborough field. This report has been developed in support of environmental approvals associated with the Scarborough Project.

This report provides the results of ROV surveys which were undertaken for the Scarborough project to characterise benthic habitat along the proposed trunkline route within the Montebello Australian Marine Park (AMP).

The objectives of this study were to:

- Confirm the environmental characteristics (physical and biological attributes) of the seabed along the pipeline route, including identification and qualitative descriptions of seabed habitat types and their general distribution;
- Provide spatial and habitat representation of the area of the Montebello AMP that the trunkline traverses; and
- Provide benthic habitat data at Key Ecological Features (KEFs) including the ancient coastline at the 125m depth contour KEF and potential turtle foraging habitat on hard substrate in the AMP where the trunkline overlaps.

Five areas within the Montebello AMP were surveyed, with three Remote Operated Vehicle (ROV) video transects undertaken within each area, except for Area 5 where only one transect was completed. The benthic habitat and epibenthic organisms within each area of the Montebello AMP were characterised through the assessment of the high definition (HD) video collected. Benthic habitat was described and classified in accordance with the CATAMI Classification Scheme for Scoring Marine Biota and Substrata in Underwater Imagery. Area 1, which was by far the deepest location, and which had one transect within the KEF, was most different with a much lower cover of benthic organisms than Areas 2 to 5. Areas 2 to 5 were quite similar in depth and in nature, with some small differences in the density and occurrence of benthic organisms and also in substrate type (e.g. variants of soft sediment bedforms and cover of biogenic gavel). A summary of findings for each area is provided below along with a discussion of the ROV results in relation to the published values for the Montebello AMP and 125m Depth Contour KEF.

**Area 1 Summary**

Area 1 was selected to assess the benthic habitat in the vicinity of the ancient coastline 125 m depth contour KEF and to provide spatial coverage of the AMP. One transect in Area 1 was located within the KEF (Transect 1A) and was 0.8 km from the eastern edge and 1.36 km from the north-western edge of the KEF. The most northern tip of this transect was located 0.45 km from the northern edge of the Montebello AMP and the south-western tip was 1.238 km from the western edge of the Montebello AMP. The depth at the midpoint of the transects surveyed in this area ranged from 103.2 m to 126.4 m. Benthic habitat was typically bare sand with various bedforms. Some areas of seafloor were covered in a light bacterial mat and others were seen to have a cover of biologenic gravel. No moderate or high relief features or areas of consolidated hard substrate were present. Benthic organisms (sponges and soft corals) typically occurred as single or in very low density aggregations. Mobile organisms including fish and echinoderms were also present on occasion.

The environmental values of the KEF refer to potential areas of hard substrate or rocky escarpments which may provide enhanced biodiversity or biologically important habitat in areas otherwise dominated by soft sediments. However, no potential features of the KEF described above were observed in any of the transects surveyed in Area 1.

**Area 2 to 5**

Areas 2 to 5 were selected to provide spatial coverage of the AMP, investigate areas of potentially high rugosity, areas that may include ancient coastline and areas of potential turtle foraging habitat. The depths in areas 2 to 5 were very similar with the midpoints depth of transects ranging from approximately 70 m to 78 m. The benthic habitats present along all transects in Areas 2 to 5 were very similar to each other. The seafloor in each area was relatively flat and sandy with a light to high cover of unconsolidated biologenic gravel and/or organic material. Small undulations of the seafloor were seen at times, as was scouring which typically occurred around large benthic organisms or aggregations of organisms. No significant high relief habitat features, or obvious areas of consolidated hard substrate, were observed in Areas 2 to 5. Benthic epifauna was present over the length of each transect, occurring in patches which varied from low (~5%) to high (~80%) density. Area 5 tended to have lower cover of organisms than areas 2 to 4. Benthic fauna in all of these areas comprised a diverse array of sponges and soft corals with varying forms, sizes and colours. Hydroids were also apparent. Mobile fauna including echinoderms (sea stars, feather stars) and Holothurians (sea cucumbers) and fish were common along most of the transects. Fish were especially abundant amongst the patches of sponges and corals. Bioturbation of the seafloor was common over the entire transect length and usually occurred in the form of thin trails, small mounds or craters.

For many transects a higher cover of benthic organisms was often seen in areas with higher amounts of biologenic gravel, however, benthic organisms were in no way limited to these areas, also being common in areas with fine sediment with little or no biologenic gravel. While at times the occurrence of benthic organisms could be loosely related to areas of high rugosity seen on detailed bathymetric mapping, this was not always apparent.

The high biodiversity of sessile and mobile organisms seen at depths of around 70 m – 78 m in Areas 2 to 5 of the Montebello AMO was in accordance with the natural values of the Montebello AMP in that the area surveyed 'includes diverse benthic and pelagic fish communities'. These areas are all likely to provide foraging habitat for mobile (and potentially threatened) fauna such as marine turtles and other fish fauna that feed on soft bodied benthic organisms such as sponges and soft corals.

The benthic habitat descriptions in the current study are generally in alignment with the findings of previous (recent and historical) benthic habitat surveys undertaken in the Montebello AMP. These studies have also reported the typical benthic habitat in the AMP as low relief sandy seafloor (with various bedforms such as ripples and ridges) with occasional areas of rubble (often increasing at more inshore sites). Dominant benthic organisms recorded for the AMP (noted to vary in diversity and density between sites) typically include a wide variety of sponges, soft corals and crinoids.

# 1 Introduction

## 1.1 Project Background

The Scarborough gas resource is located approximately 375 km west-north-west off the Burrup Peninsula and is part of the Greater Scarborough gas fields which are estimated to hold 9.2 Tcf (2C, 100%) of dry gas. Woodside is proposing to develop the Scarborough gas resource through new offshore facilities connected by an approximately 430 km pipeline onshore. The proposal is to initially develop the Scarborough gas field with wells, tied back to a semi-submersible floating production unit (FPU) moored in 900 m of water close to the Scarborough field. This report has been developed in support of environmental approvals associated with the Scarborough Project.

Activities undertaken as a part of the Scarborough Project will include seabed preparation and trunkline installation activities, which will result in localised seabed disturbance and ongoing physical presence of the trunkline for the life of the project. The proposed pipeline is approximately 32 inch in diameter and the disturbance corridor is estimated at less than 30 m. The Scarborough trunkline is proposed to traverse through the northern section of the Montebello Australian Marine Park (AMP) as shown in Figure 1-1. This report provides the results of ROV surveys which were undertaken for the Scarborough Project to characterise benthic habitat along the proposed trunkline route within the Montebello AMP.

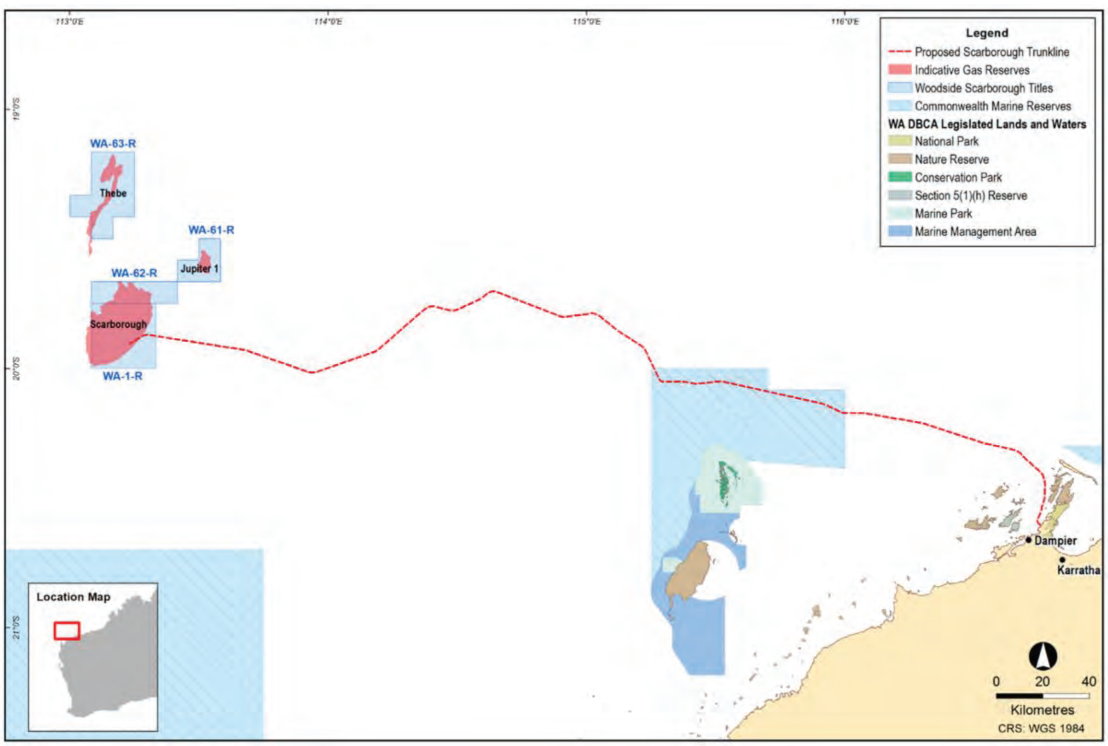


*Figure 1-1 Location of the Scarborough Project and proposed trunkline (Image Source: Woodside 2019).*

## 1.2 Environmental Setting of the Proposed Trunkline Route

The Scarborough Project occurs in Commonwealth waters off the northwest coast of Western Australia (WA) within the North-west Marine Region (NWMR) (Integrated Marine and Coastal Regionalisation of Australia (IMCRA) 4.0). The target fields occur within the Northern Carnarvon Basin on the Exmouth Plateau, and are about 380 km offshore from Dampier, in water depths of approximately 900 - 970 m, with the proposed trunkline ultimately crossing into State waters along the same alignment as the Pluto Gas Export Pipeline (Figure 1-2).

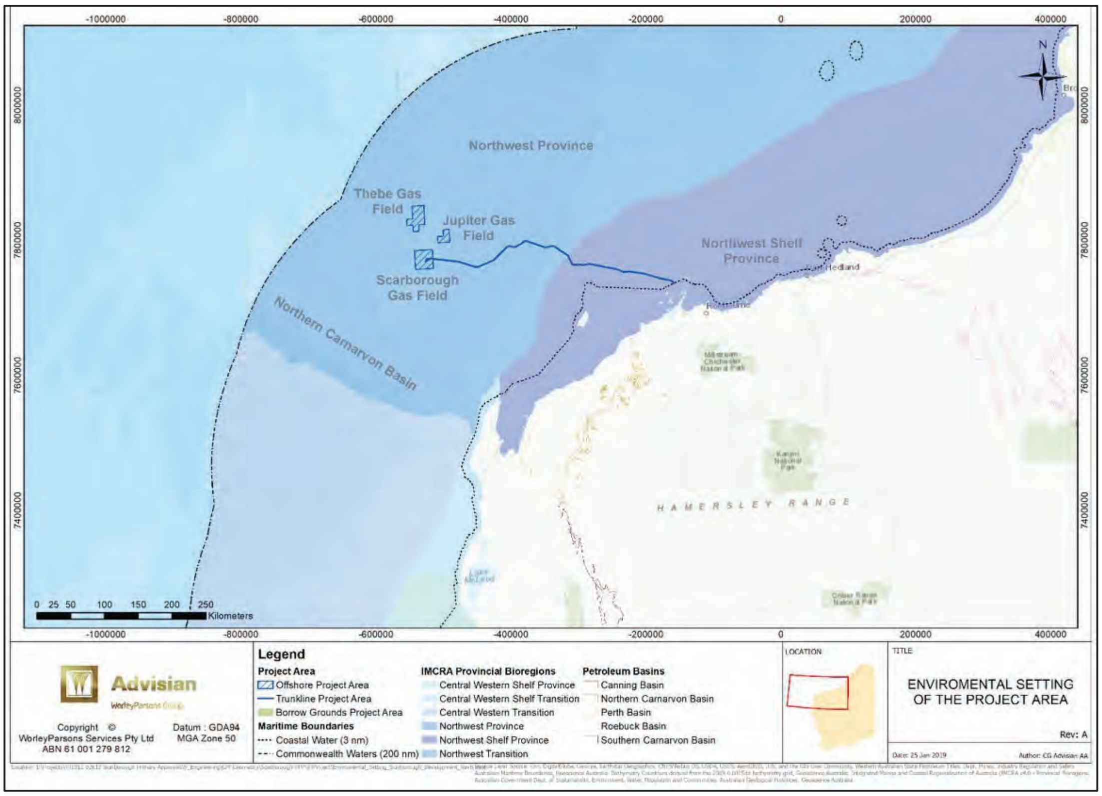


*Figure 1-2 Environmental setting of the project area.*

A number of studies and reviews of the Exmouth Plateau and North West Shelf have been compiled and/or undertaken to provide an understanding of the physical, biological and socio-economic environmental conditions within the Project Area. The majority of these have been made available in the public domain. The environmental values of the Montebello AMP and the ancient coastline KEF have been described in Sections 1.2.1 and 1.2.2 of this report.

The Trunkline Project Area extends from the State-Commonwealth boundary on the inner continental shelf, onto the continental slope where it traverses the continental slope westwards to the Offshore Project Area on the Exmouth Plateau. The eastern half of the Trunkline Project Area is adjacent to the existing Pluto trunkline. The inner continental shelf is the area from the coast to about 30 m water depth, and the middle continental shelf is the area between 30 m and 120 m water depth. At about 120 m depth, a terrace (start of the outer shelf) of gradients of between 5° and 20° represents a paleo-shoreline and marks an important divide between the continental shelf and continental slope (SKM, 2006). Sediments along the Trunkline Project Area are expected to be dominated by sand as is typical of the continental slope in the Northwest Transition bioregion (DEWHA, 2008a).

### 1.2.1 Natural Values of the Montebello AMP

**Location**

The Montebello Marine Park is located offshore of Barrow Island and 80 km west of Dampier extending from the Western Australian state water boundary and is adjacent to the Western Australian Barrow Island and Montebello Islands Marine Parks. The Marine Park covers an area of 3413 km$^2$ and water depths from less than 15 m to 150 m. The Marine Park was proclaimed under the EPBC Act on 14 December 2013 and renamed Montebello Marine Park on 9 October 2017 (Director of National Parks, 2018).

**Statement of Significance**

The Montebello AMP is significant because it contains habitats, species and ecological communities associated with the Northwest Shelf Province. It includes one KEF: the ancient coastline at the 125-m depth contour (valued as a unique seafloor feature with ecological properties of regional significance) (environmental values of the KEF are provided in Section 1.2.2). The Marine Park provides connectivity between deeper waters of the shelf and slope, and the adjacent Barrow Island and Montebello Islands Marine Parks. A prominent seafloor feature in the Marine Park is Trial Rocks consisting of two close coral reefs. The reefs are emergent at low tide (Director of National Parks, 2018).

**Natural Values**

The values of the Montebello AMP are outlined in the North-west Marine Parks Network Management Plan 2018 (Director of National Parks, 2018). The Marine Park includes examples of ecosystems representative of the Northwest Shelf Province, which is a dynamic environment influenced by strong tides, cyclonic storms, long-period swells and internal tides. The bioregion includes diverse benthic and pelagic fish communities, and ancient coastline thought to be an important seafloor feature and migratory pathway for humpback whales. A KEF of the Marine Park is the ancient coastline at the 125-m depth contour where rocky escarpments are thought to provide biologically important habitat in areas otherwise dominated by soft sediments (Director of National Parks, 2018).

The Marine Park supports a range of species including species listed as threatened, migratory, marine or cetacean under the EPBC Act 1999. Biologically important areas within the Marine Park include breeding habitat for seabirds, internesting, foraging, mating, and nesting habitat for marine turtles, a migratory pathway for humpback whales and foraging habitat for whale sharks (Director of National Parks, 2018).

### 1.2.2 Environmental Values of the Ancient Coastline at 125 m Depth Contour (KEF)

The shelf of the North-west Marine Region contains several terraces and steps which reflect changes in sea level that occurred over the last 100 000 years. The most prominent of these features occurs as an escarpment along the North West Shelf and Sahul Shelf at a depth of 125 m. The ancient coastline at 125 m depth contour is defined as a KEF as it is a unique seafloor feature with ecological properties of regional significance. The spatial boundary of this KEF, as defined in the Conservation Values Atlas, is defined by depth range 115-135 m in the Northwest Shelf Province and Northwest Shelf Transition provincial bioregions as defined in the Integrated Marine and Coastal Regionalisation of Australia (IMCRA v 4.0) (DSEWPaC, 2012). The boundary of the KEF in the study area is shown in Figure 2-1.

**Environmental Values**

The 'environmental values' of the 'ancient coastline at 125 m depth contour' KEF are described in the Marine Bioregional Plan for the North-west Marine Region (DSEWPaC, 2012). The ancient submerged coastline provides areas of hard substrate and therefore may provide sites for higher diversity and enhanced species richness relative to surrounding areas of predominantly soft sediment. Little is known about the fauna associated with the hard substrate of the escarpment, likely to include sponges, corals, crinoids, molluscs, echinoderms and other benthic invertebrates representative of hard substrate fauna in the North West Shelf bioregion (DSEWPaC, 2012).

The escarpment may also facilitate increased availability of nutrients off the Pilbara by interacting with internal waves and enhancing vertical mixing of water layers. Enhanced productivity associated with the sessile communities and increased nutrient availability may attract larger marine life such as whale sharks and large pelagic fish (DEWHA, 2008).

## 1.3 Objectives

The objectives of the current study were to:

- Characterise benthic habitat along the proposed trunkline route in the Montebello AMP;
- Confirm the environmental characteristics (physical and biological attributes) of the seabed along the pipeline route, including identification and qualitative descriptions of seabed habitat types and their general distribution;
- Provide spatial and habitat representation of the area of the Montebello AMP that the trunkline traverses; and
- Provide benthic habitat data at environmental sensitive locations including the ancient coastline at the 125m depth contour Key Ecological Feature (KEF) and potential turtle foraging habitat on hard substrate in the AMP where the trunkline overlaps.

# 2 Methods

Habitat characterisation was undertaken using a remotely operated underwater vehicle (ROV) to capture seabed imagery (video/stills) along pre-defined survey locations. Imagery was then used to describe the physical habitats and the presence/absence of benthic communities within the vicinity of the trunkline route in the section that traverses the Montebello AMP.

The survey was focused along the proposed trunkline route where it deviates from the existing Pluto pipeline route (located in the eastern area of the multi-use zone of the park). Survey sites reflected the potential variation in habitat, as determined by the geophysical data (e.g. bathymetry and interpreted seabed substrates) and general representativeness of the main seabed characteristics of the multi-use zone of the park, that the proposed trunkline route will traverse.

## 2.1 Survey Areas

Seafloor imagery was collected by Neptune, within five survey areas, which were sized approximately 4 km x 250 m, inside the Montebello AMP. The survey areas selected provide spatial coverage and representative habitat of the Montebello AMP. The locations of survey areas and transects, along with transect depths are provided in Table 2-1 and Figure 2-1. Figure 2-1 also provides the location of the ancient coastline 125 m depth contour KEF.

The five survey areas were selected for the following reasons:

- **Survey areas 1**: Was selected to assess benthic habitat in the vicinity of the ancient coastline 125 m depth contour KEF and to provide spatial coverage of the AMP (Figure 2-1 and Figure 2-2).

- **Survey areas 2 to 5**: Were selected to provide spatial coverage of the AMP, identify any outcropping / subcropping in rugose areas of seafloor (as seen on bathymetry) and assess the benthic habitat in areas which could provide potential turtle foraging habitat (Figure 2-1, Figure 2-3, Figure 2-4, Figure 2-5 and Figure 2-6).

The approximate distance between all adjacent transects from each other is shown in Table 2-2.

Within each survey area, there were three proposed sampling locations (Figure 2-1). At each location an ~500 m transect of trunkline was attempted to be surveyed. Transects were to provide a snake like path deviating from the proposed pipeline route by approximately 100 m each side of the pipeline and were to follow the pipeline route in a parallel direction (rather than running perpendicular). A kilometre buffer was allowed around each survey location, for flexibility given weather conditions etc. A minimum distance of 200 m between transects was to be maintained. Due to strong currents and the ROV tether management it was not possible to run the transect across the proposed pipeline route in Area 5 and the transect locations 5B and 5C were unable to be surveyed. Table 2-1 provides details for all transects.

*Table 2-1 Location of the five survey areas and transect details.*

| Survey Area | Sampling Location | Position GDA94 Zone 50 (Midpoint) | | Potential Seafloor Features | Actual Midpoint Depth (m) |
|---|---|---|---|---|---|
| | | Latitude | Longitude | | |
| Survey Area 1 | 1A | 318462.69 | 7787004.58 | 125m contour KEF | -126.4 |
| | 1B | 319281.801 | 7785309.82 | 125m contour KEF | -110.2 |
| | 1C | 320006.8476 | 7783542.972 | 125m contour KEF | -103.2 |
| Survey Area 2 | 2A | 328859.16 | 7781967.15 | Outcrop/subcrop | -70.6 |
| | 2B | 330692.8515 | 7781974.137 | Outcrop/sand | -74.4 |
| | 2C | 332650.32 | 7781636.45 | Outcrop/sand | -74 |
| Survey Area 3 | 3A | 336633.23 | 7781316.65 | Outcrop/subcrop | -73.8 |
| | 3B | 338590.04 | 7781516.29 | Sand | -72.5 |
| | 3C | 341540.88 | 7781917.17 | Outcrop/subcrop | -71.6 |
| Survey Area 4 | 4A | 342526.27 | 7782010.53 | Sand | -75.3 |
| | 4B | 344543.13 | 7782286.02 | Sand/subcrop | -74.5 |
| | 4C | 346553.46 | 7782136.72 | Subcrop/outcrop | -78.2 |
| Survey Area 5 | 5A | 361146.91 | 7778773.61 | Sand | -74.6 |
| | 5B | Not surveyed | | Sand | NA |
| | 5C | Not surveyed | | Sand | NA |

*Table 2-2 Distances between adjacent transects (based on the approx. centre of each transect).*

| Transects | Distance |
|---|---|
| 1A TO 1B | 1.85 km |
| 1B TO 1C | 1.88 km |
| 1C TO 2A | 1.88 km |
| 2A TO 2B | 1.88 km |
| 2B TO 2C | 1.88 km |
| 2C TO 3A | 3.98 km |
| 3A TO 3B | 1.88 km |
| 3B TO 3C | 2.89 km |
| 3C TO 4A | 0.98 km |
| 4A TO 4B | 2.06 km |
| 4B TO 4C | 1.96 km |
| 4C TO 5A | 15 km |

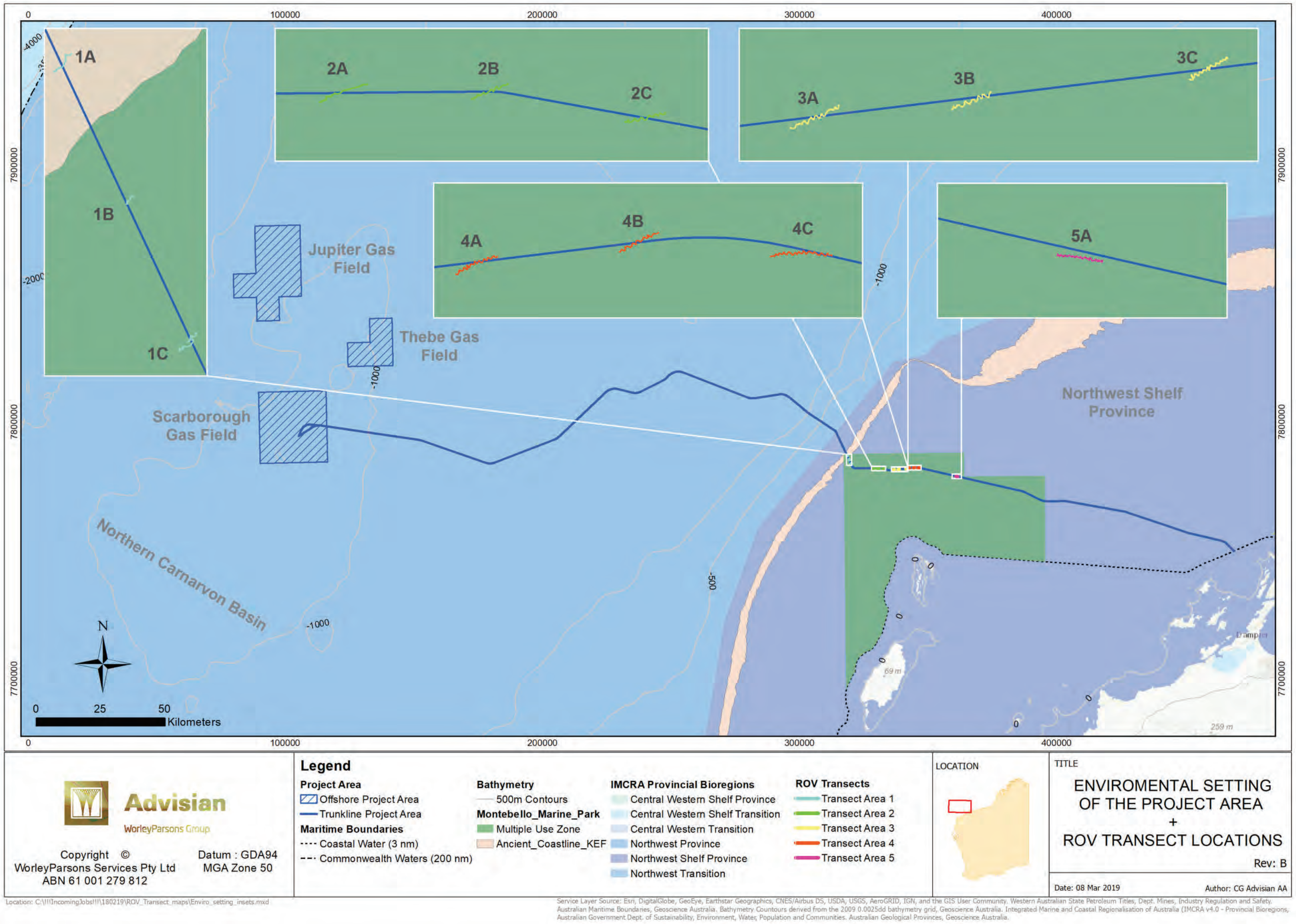


Figure 2-1 Location of the five survey areas and ROV transects.

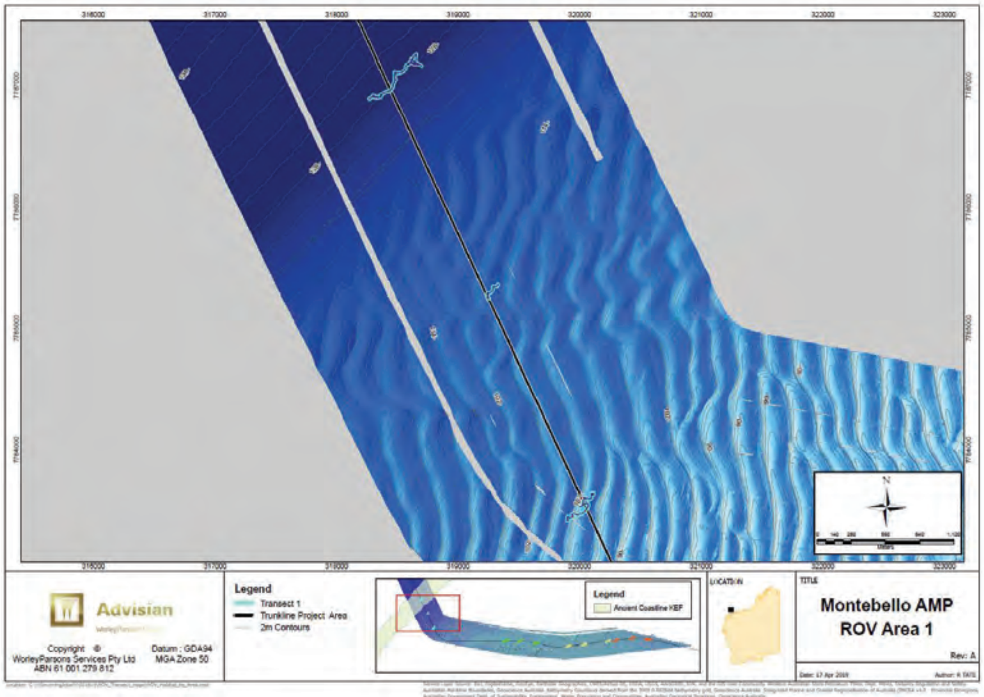


*Figure 2-2 Transects 1A, 1B and 1C.*

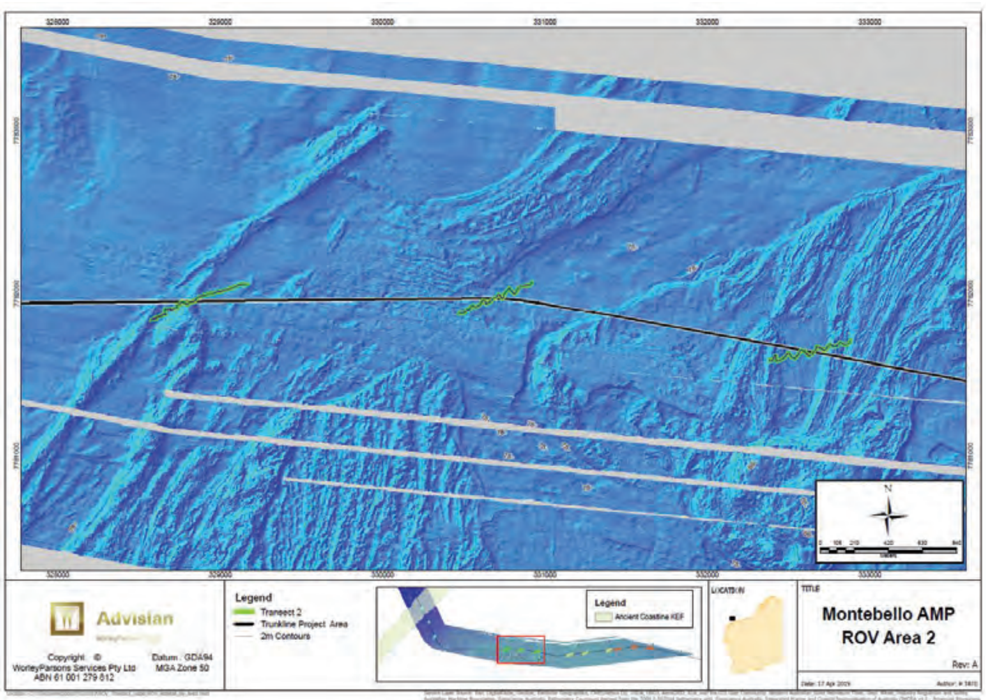


*Figure 2-3 Transects 2A, 2B and 2C.*

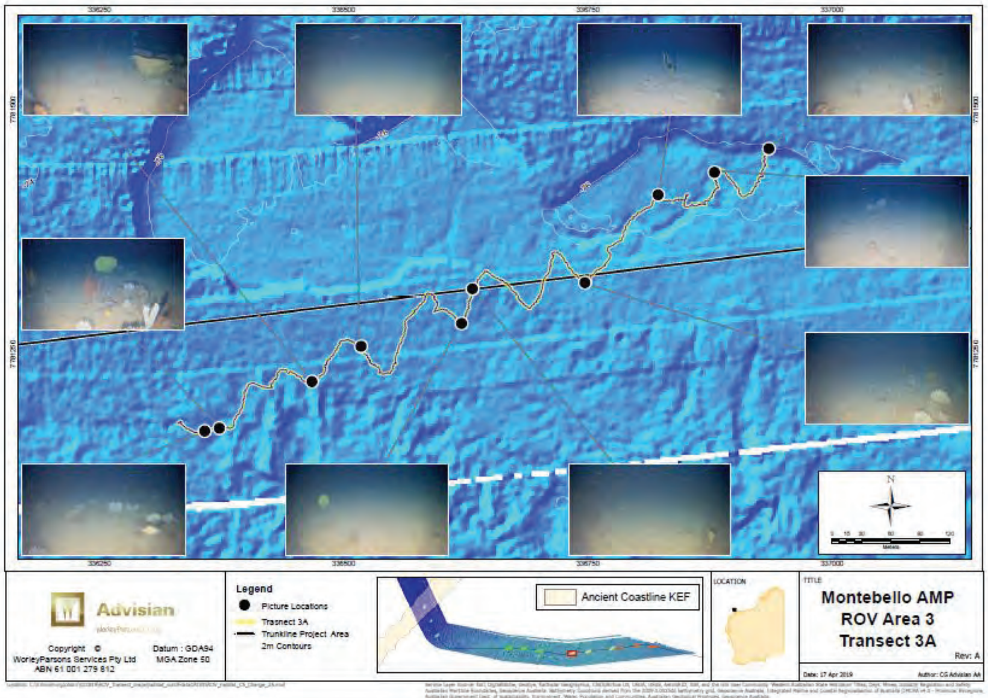


*Figure 2-4 Transects 3A, 3B and 3C.*

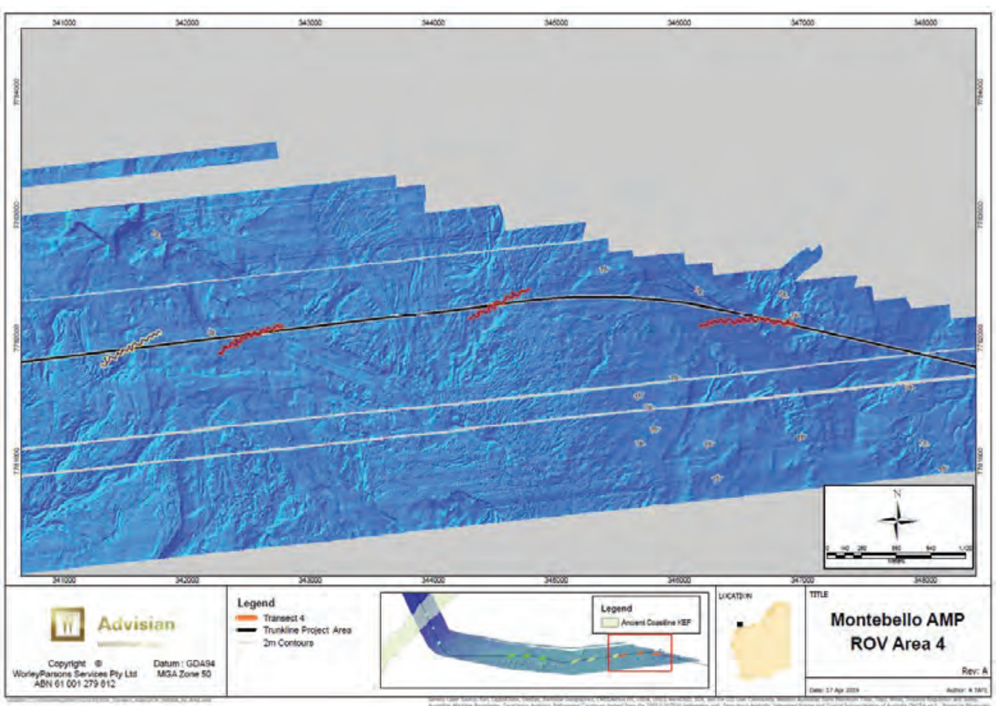


*Figure 2-5 Transects 4A, 4B and 4C.*

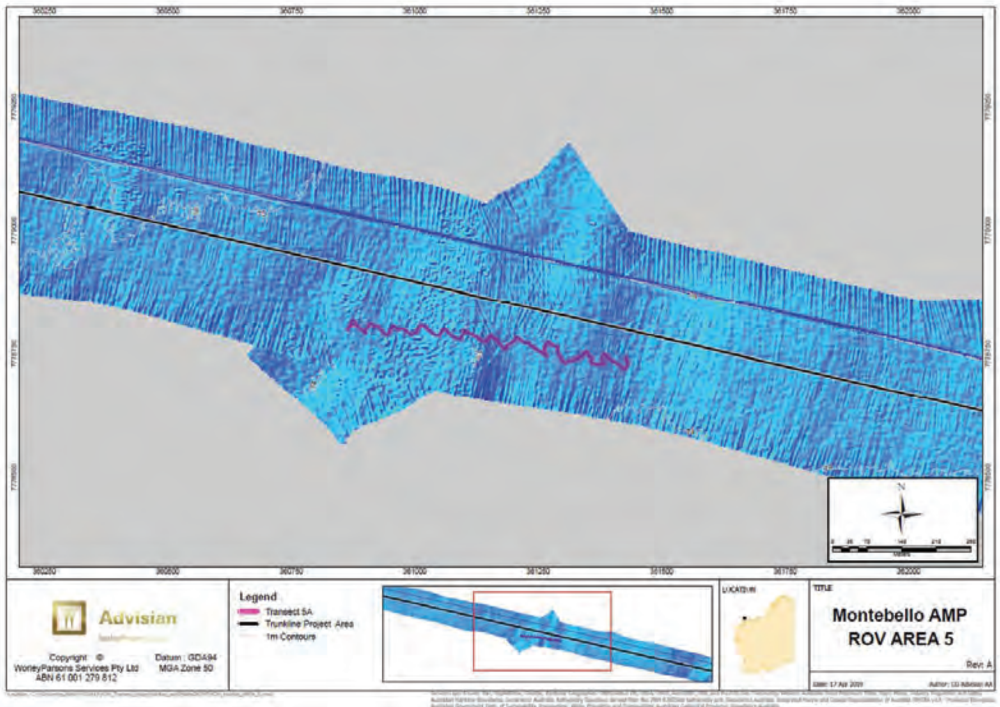


*Figure 2-6 Transect 5A.*

## 2.2 Remotely Operated Vehicle (ROV) Surveys

ROV surveys were undertaken by Neptune at each of the survey locations provided in Table 2-1 and shown in Figure 2-1. HD video was collected from a standardised height of approximately 1 m to 2 m. The camera was angled where possible to capture both the seabed and forward facing perspective of the general seascape. Depth and geospatial data of the ROV location was recorded at all sites. The depth and location of the midpoint of each transect is provided in Table 2-1.

## 2.3 Video Analysis

### 2.3.1 Technical Memos (Neptune)

Following the collection of the ROV video data, Neptune prepared a short technical memo for each transect which included the survey date, time, area of operations, location, brief seabed description, conclusions and recommendations and any issues encountered. All technical memos were reviewed and are provided in **Appendix A**.

### 2.3.2 Benthic Habitat Analysis

Prior to assessment of the benthic habitat, potential differences in seafloor bathymetry / rugosity were identified along each of the transect routes and five points of interest were selected for each. On video analysis, still images from each of these locations were captured.

High definition (HD) video data was viewed using VLC Media Player and the benthic habitat and sessile organisms present were classified in accordance with the CATAMI Classification Scheme for Scoring Marine Biota and Substrata in Underwater Imagery (http://CATAMI.github.io/) (Althaus et al. 2014). Data specifically collected and reported for each transect included:

- Substrate Type
- Bedform
- Relief
- Bioturbation
- Bacterial mats
- Flora
- Fauna

HD video assessment showed that the seafloor along all transects was low profile and no moderate or high profile features were present within any transect. For all transects surveyed, the seafloor habitat was found to be very similar along the entire transect length, or consisted of a mosaic of benthic habitat types / variations in habitat type which changed continually at small scales (typically a couple of m's) but represented the transect as a whole (e.g. area of bare sandy substrate, to area of sponges/corals on sandy substrate, back to bare substrate, or continually changing percentage cover of sponges and corals). For these reasons, and the qualitative nature of the assessment, an overall habitat classification was applied to each transect.

Still images of the various states of benthic habitat and the sessile benthic organisms seen along each transect were also taken from the HD video. Some of these were georeferenced and are overlaid on the transect maps. The report Appendices also include a greater number of images from each transect which are provided to demonstrate the small scale variability within a single general habitat type.

## 2.4 Transect and Habitat Mapping

Transects were created as line shapefiles from ROV derived X, Y point data. High resolution (2 m) bathymetry data was then used to generate the underlying raster surface as well as 2 m contour line data. All data was projected in GDA MGA Zone 50 coordinate system and processed in ArcMAP 10.4.

As the benthic habitat along each individual transect was generally the same and consisted of often very small scale (every few meters) and continual changes in substrate (e.g. sand ripple type) or the cover of benthic organisms (i.e. changes in density of benthic organisms), georeferenced 'habitat types' were not defined along the length of each transect. Each transect was mapped with detailed seafloor bathymetry and these transect maps were overlaid with georeferenced images of the benthic habitat along the transect.

# 3 Results

## 3.1 Area 1

Three transects (of varying length) were surveyed in Area 1 and are described in more detail below. The depth at the midpoint of these transects ranged from 103.2 m to 126.4 m. One transect in Area 1 (Transect 1a) was located within the KEF; located 0.8 km from the eastern edge and 1.36 km from the north-western edge of the KEF. The most northern tip of this transect was located 0.45 km from the northern edge of the Montebello AMP and the south-western tip was 1.238 km from the western edge of the Montebello AMP. While some representative images of each transect are provided in the Sections below, **Appendix B** provides additional images of the benthic habitat and organisms seen along each transect in Area 1.

### 3.1.1 Area 1a

Notes provided by Neptune for Area 1a included:

- The ROV transect crossed the pipeline route at E318445, N7786967 (time stamp 13:49:11).
- The ROV was on bottom at 13:49 and off bottom at 14:03.
- The seabed comprised a flat fine sandy seabed, with small isolated sand waves. There was a sparse benthic sand-dwelling habitat. Ripples had an organic/algae covering, particularly in the troughs. Isolated corals also occurred on the sand.
- No significant high relief habitat features were observed.
- Due to strong currents and the ROV tether management it was not possible to run the transect more along the proposed pipeline route.

Analysis of video data by Advisian was undertaken and the following additional notes regarding benthic habitat in Area 1a are provided:

- The entire seafloor along the transect in Area 1a consisted of a low relief, flat and fine sandy seabed with bedforms alternating between small 2D and 3D ripples (< 10 cm) and some areas which had no ripples.
- No significant, or other, moderate or high relief features, or areas of hard substrate, were present. The transect ran almost entirely along the 126 m depth contour (Figure 3-2).
- Transect 1a was entirely located within the boundary of the ancient coastline KEF (refer to Figure 2-1 and Figure 3-2). However, no potential features of the KEF (i.e. areas of hard substrate with high biodiversity) were noted here, and the transect was comprised fully of soft sediment habitat.

- The seabed was generally bare sand (with very occasional benthic epifauna) and much of the transect area was noted to have a light covering of organic matter. This is very likely to be a bacterial mat considering the water depth and lack of light penetration in this location (refer to Figure 3-2 and **Appendix B** for images).
- No benthic flora (i.e. macroalgae or seagrass) was present in Area 1a.
- Benthic epifauna were present, although were quite uncommon. They generally occurred as single individuals (i.e. not in aggregations / clusters). Benthic epifauna included echinoderms (e.g. brittle stars and feather stars), sponges (erect simple, erect laminar, erect branching and cup like forms) and cnidarians (whip corals and quill corals (seapens) (refer to Table 3-1 for additional detail and CATAMI classification codes).
- The percentage cover of benthic organisms (within the entire video frame) in Area 1a ranged from 0% to ~5% (excluding any cover of biologenic gravel) over the entire transect length. No obvious bathymetric features could be seen on the transect maps or corresponded with the occurrence of different substrate types (e.g. sand ripples / flat sand / steps) or scattered benthic organisms. The benthic organisms recorded occurred on all different substrate types/bedforms.
- Occasional bioturbation of the seabed in the form of light trails, small mounds and craters was seen over the entire transect indicating the presence of various mobile fauna living on top of and within the seabed.
- Mobile fauna were seen on occasion but were also uncommon. They included small bony fishes (often quickly moving out of the field of view of the ROV) and jellies. Both types of fauna were unidentified.
- Due to currents affecting the stability of the ROV, along with a high level of suspended material in the water at times, visibility of the seabed was compromised in places. However, these less visible areas are very likely to be similar to the seafloor which could be seen based on the overall transect assessment.

A summary of the general benthic habitat characteristics, flora and fauna seen along the transect in Area 1a is provided in Table 3-1. This table also provides the CATAMI Species Codes for each seafloor feature and taxa that were identified.

The benthic habitat in the location where the transect crossed the pipeline route (as per the time stamp provided by Neptune) is shown in Figure 3-1 and consists of rippled bare sand.

A map showing the location of the transect in Area 1a in relation to seafloor bathymetry and the KEF, along with some georeferenced representative images of benthic habitat in this area, is provided in Figure 3-2. No correlation between the seafloor bathymetry / rugosity as evident on the transect map and the occurrence of benthic organisms was apparent for Transect 1a.

Additional seafloor images and images of some of the isolated benthic fauna recorded in Area 1a are provided in **Appendix B**.


*Figure 3-1 Benthic habitat in the location of the pipeline crossing in Area 1a.*

*Table 3-1 Summary of habitat features in Area 1a.*

| Habitat Features | Description | CATAMI Species Code(s) | Occurrence |
|---|---|---|---|
| Substrate Type | Unconsolidated (soft): Sand/mud (<2mm) | 82001005 | Entire Transect |
| Bedform | 2D ripples (<10 cm height)<br>3D ripples (<10 cm height) | 82002003<br>82002007 | Alternating 2D and 3D ripples over transect |
| Relief | Flat | 82003001 | Entire Transect |
| Bioturbation | Bioturbation: Crawling traces: Thin trail<br>Bioturbation: Dwelling traces: Small mound<br>Bioturbation: Dwelling traces: Crater cone | 81005001<br>81001003<br>81001012 | Occasional sightings over entire transect |
| Bacterial mats | Bacterial mat | 80000000 | Around ½ transect |
| Flora | Nil | NA | NA |
| Fauna | Echinoderms: Ophiuroids: Brittle / snake stars<br>Echinoderms: Feather stars<br>Sponges: Erect simple<br>Sponges: Erect laminar<br>Sponges: Erect branching<br>Sponges: Cup like<br>Corals: Black & Octocorals: Whip<br>Corals: Black & Octocorals: Quill (seapen)<br>Jellies<br>Fishes: Bony fishes | 25160901<br>25000000<br>10000916<br>10000913<br>10000915<br>10000909<br>11168917<br>11168918<br>80600903<br>37990083 | Occasional sightings over the entire transect length – most organisms occurred in isolation |

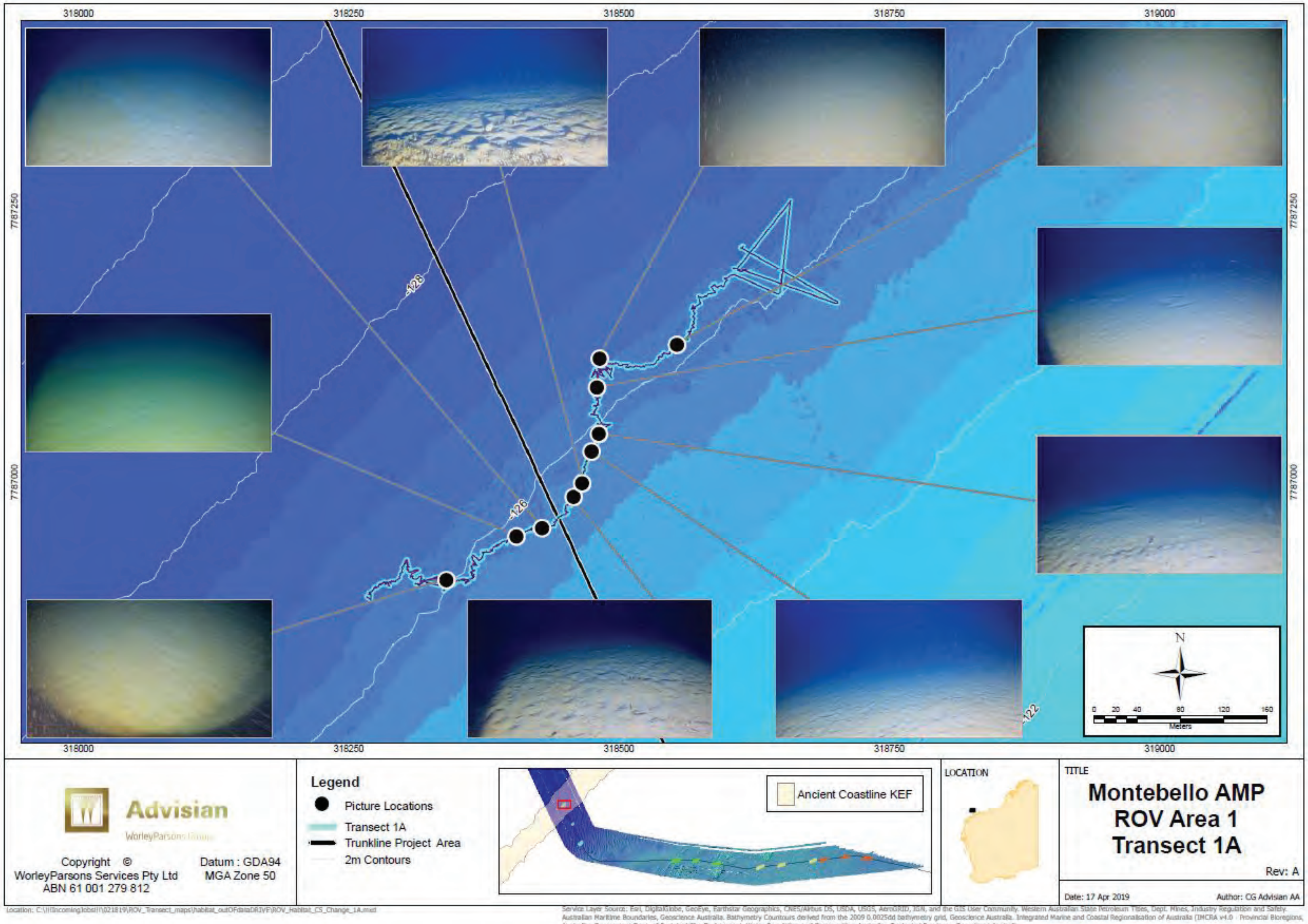


*Figure 3-2 Typical benthic habitat and bathymetry in Area 1a.*

### 3.1.2 Area 1b

Notes provided by Neptune for Area 1b included:

- The ROV crossed the proposed pipeline route at E 319248, N 7785254 at approximately 17:44:15.
- The ROV was on bottom at 17:43 and off bottom at 17:48.
- The seabed comprised a typically flat fine sandy seabed with ripples and larger sand waves. There was sparse benthic sand-dwelling habitat. Sand ripples had an organic/algae covering particularly in the troughs. The small sand wave crests (probably less than 0.5 m high) were cleaner and could be seen to prograde over the sediments burying isolated benthic fauna which typically occurred as soft corals and sponges.
- No significant high relief habitat features were observed.
- Due to strong currents and the ROV tether management it was not possible to run the transect more along the proposed pipeline route.

Analysis of video data by Advisian was undertaken and the following additional notes regarding benthic habitat in Area 1b are provided:

- The seafloor along the transect in Area 1b was similar to that observed in Area 1a and was also similar along the entire transect length.
- Where the transect crossed the proposed pipeline route (as per the time stamp provided by Neptune), a flat sandy seafloor with 3D ripples was present (see image in Figure 3-3).
- Benthic habitat typically consisted of a low relief sandy seabed, with bedforms alternating between small 2D and 3D ripples and areas of flat sand. A series of small 'steps' / rises in the sand occurred over the entire length of the transect and these were generally <50 cm high. These 'steps' were identified as 'sand wave crests' by Neptune. Towards the end of the transect the small 2D and 3D sand ripples became slightly less common and the seafloor had a slightly flatter form. This area of flatter sand is not considered to be a separate habitat type, nor can it been identified on the transect map showing detailed bathymetry. Images of the variable types of sandy seafloor along Transect 1b are provided in Figure 3-4 and **Appendix B**.
- No significant, or other, moderate or high relief features, or areas of consolidated hard substrate, were present in Area 1b. However, some small areas of scattered biologenic rubble (perhaps shell, coral or small gravel) were noted along the transects length (see Figure 3-4 and **Appendix B)**. These areas cannot be seen on the transect maps with detailed bathymetry.
- Area 1b was located near to, but not within, the area mapped as the KEF (ancient coastline 125 m depth contour). The transect traversed an area of seabed which had a depth of

around 108 m to 113 m (refer to Figure 3-4). No potential features of the KEF (i.e. hard substrate with high biodiversity) were seen here.

- Some areas of sand were bare while others were covered in a light bacterial mat. This covering occurred over the entire transect however was more prevalent in the troughs of ripples and the base of each of the sand 'steps'. It was also common towards the end of the transect where sand ripples were less common.
- No benthic flora (i.e. macroalgae or seagrass) was present in Area 1b.
- Benthic epifauna were present, although were relatively uncommon and most often occurred as single organisms. Fauna included echinoderms (e.g. feather stars and sea cucumbers), cnidaria (e.g. seapens), soft corals and sponges (various erect forms). Some organisms were partially buried under the sand and could not be identified (refer to Table 3-2 for additional detail and CATAMI classification codes).
- The percentage cover of benthic organisms (within the entire video frame) in Area 1b ranged from 0% to ~10% (excluding cover of biologenic gravel) over the entire transect length. As for Transect 1a, no obvious bathymetric features were seen on the transect maps or corresponded with the occurrence of different substrate types (e.g. sand ripples / flat sand / steps) or these scattered benthic organisms. These organisms occurred on all different substrate 'types'.
- Small bony fishes were seen on occasion, usually quickly moving out of the field of view of the ROV but were not identified for this assessment.
- Bioturbation of the seafloor in the form of small mounds, craters and thin trails was seen along the entire length of the transect indicating the presence of mobile organisms living on and within the seabed.

A summary of the habitat characteristics, flora and fauna recorded in Area 1b is provided in Table 3-2. This table also provides the CATAMI Species Codes for each seafloor feature and taxa identified.

The benthic habitat in the location where the transect crossed the pipeline route (as per the time stamp provided by Neptune) is shown in Figure 3-3 and consists of 3D rippled sand with a small amount of biologenic gravel.

A map showing the location of the transect in Area 1b in relation to bathymetry and the KEF, along with some georeferenced representative images of benthic habitat, is provided in Figure 3-4. No correlation between the seafloor bathymetry / rugosity and occurrence of benthic organisms could be seen for Transect 1b. Less sand ripples were apparent in the north-eastern deeper portion of the transect but this could not be seen on the mapping.

Additional images of benthic habitat and organisms present are provided in **Appendix B**.

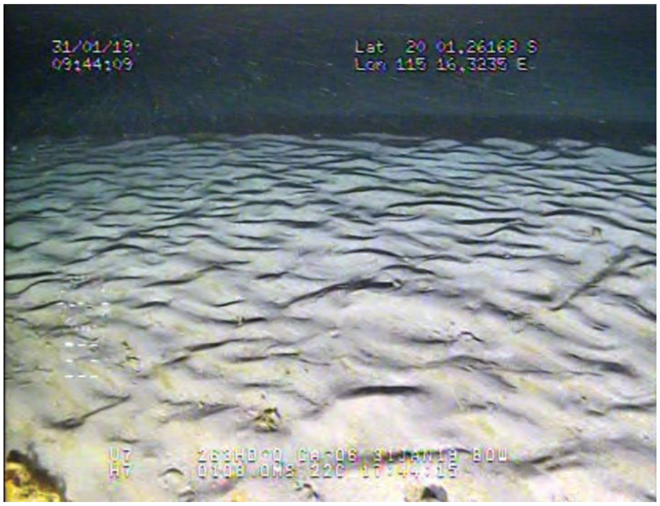


*Figure 3-3 Benthic habitat in the location of the pipeline crossing in Area 1b.*

*Table 3-2 Summary of habitat features in Area 1b.*

| Habitat Features | Description | CATAMI Species Code | Occurrence |
|---|---|---|---|
| Substrate Type | Unconsolidated (soft): Sand/mud (<2mm) | 82001005 | Entire Transect |
| Bedform | 2D ripples (<10 cm height)<br>3D ripples (<10 cm height) | 82002003<br>82002007 | Alternating 2D and 3D ripples over transect |
| Relief | Flat (with some small sand steps <50 cm) | 82003001 | Entire Transect |
| Bioturbation | Bioturbation: Crawling traces: Thin trail<br>Bioturbation: Dwelling traces: Small mound<br>Bioturbation: Dwelling traces: Crater cone | 81005001<br>81001003<br>81001012 | Occasional over entire transect |
| Bacterial mats | Bacterial mat | 80000000 | Around ½ transect |
| Flora | Nil | NA | NA |
| Fauna | Echinoderms: Feather stars<br>Echinoderms: Sea cucumbers<br>Sponges: Erect simple<br>Sponges: Erect laminar<br>Sponges: Erect branching<br>Sponges: Cup like<br>Corals: Black & Octocorals: Quill (seapen)<br>Corals (unidentified soft corals)<br>Fishes: Bony fishes | 25000000<br>25400901<br>10000916<br>10000913<br>10000915<br>10000909<br>11168918<br>11168000<br>37990083 | Occasional sightings over the entire transect length – most organisms occurred in isolation |

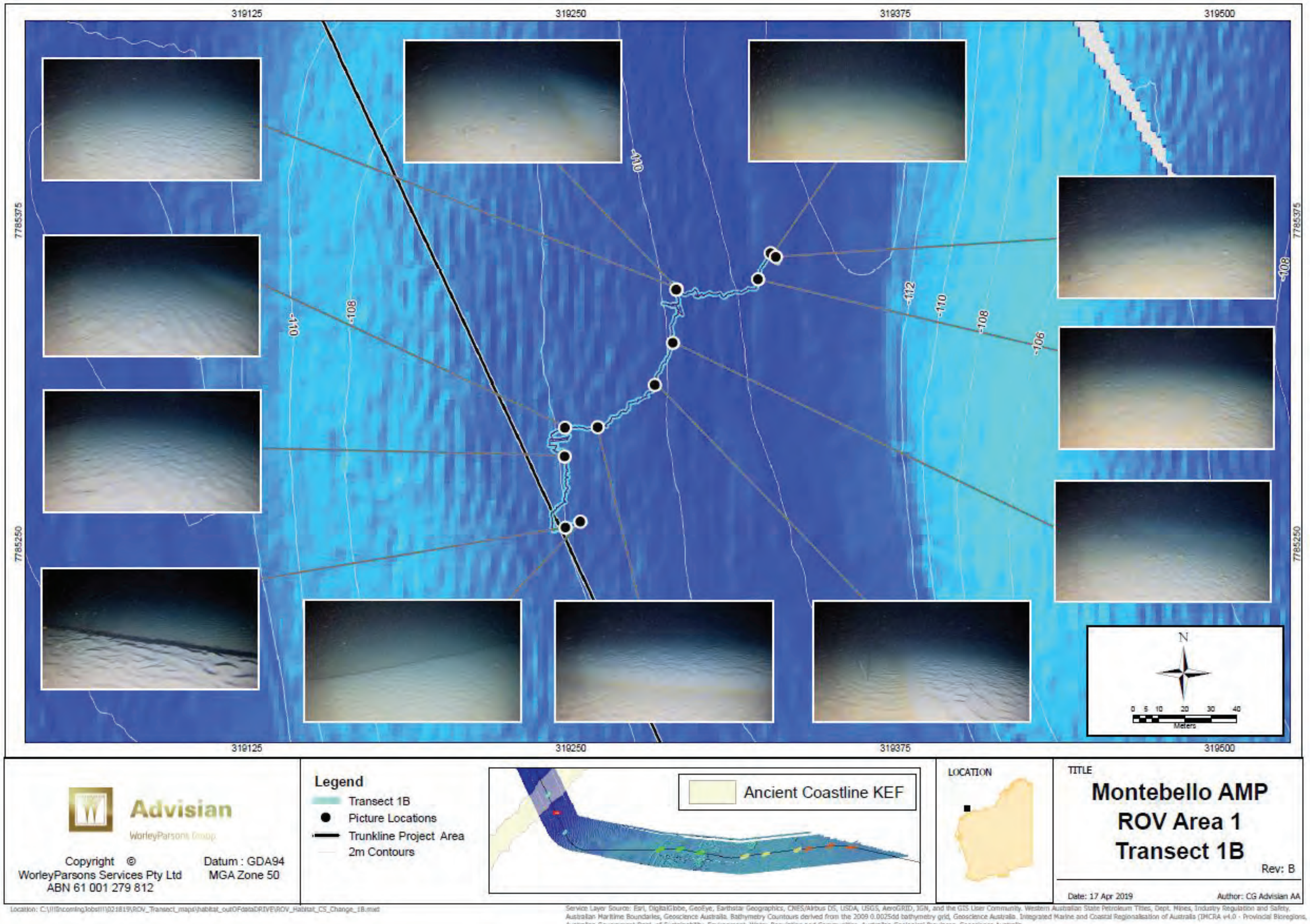


*Figure 3-4 Typical benthic habitat and bathymetry in Area 1b.*

### 3.1.3 Area 1c

Notes provided by Neptune for Area 1c included:

- The ROV crossed the proposed pipeline route at E320057, N7783523 at approximately 18:41:46.
- The ROV was on bottom at 18:34 and off bottom at 18:49.
- The south western margin of the track showed the seabed was flat comprising sand and larger gravel to small boulder sized carbonate debris which may be a localised hardpan formed from biological activity or sub-outcropping calcarenite.
- In the vicinity of the pipeline route the seabed was typically flat and had ripples associated with it. These typically had an organic/algae covering particularly in the troughs. Isolated soft corals also occurred.
- The seabed comprised a flat sandy seabed which had a sparse benthic habitat.
- No significant habitat features were observed.
- Due to strong currents and the ROV tether management it was not possible to run the transect more along the proposed pipeline route.

Analysis of video data by Advisian was undertaken and the following additional notes regarding benthic habitat in this location are provided:

- The entire seafloor along the transect in Area 1c was flat and the bedforms alternated continually between flat bare sand to flat sand with small ripples (of both 2D and 3D forms) as for Area 1a and 1b. Some areas of seafloor had a higher cover of biologenic rubble (of unidentified origin) while others were bare (see Figure 3-6 and **Appendix 2**).
- In the vicinity of the pipeline route (as identified by the timestamp provided by Neptune), the seafloor was sandy with small ripples and occasional epifauna (see Figure 3-5).
- No moderate or high relief features or areas of consolidated hard substrate were present along the transect in Area 1c. However, some areas of biologenic rubble (perhaps shell, coral or small gravel but unidentifiable) were noted on the seafloor. However, the location of these areas could not be determined on the transect map with detailed bathymetry.
- Area 1c was located near to, but not within, the area mapped as the KEF (ancient coastline 125 m depth contour). The transect traversed an area of seabed which had a depth of around 95 to 100 m depth (see Figure 3-6). No potential features of the KEF (i.e. hard substrate with high biodiversity) were seen in Area 1c.

- Some areas of sand were bare while others were covered in a light bacterial mat. The bacterial mat was more prevalent in the troughs of ripples. This occurred over the length of the transect.
- Benthic epifauna were present on occasion and included echinoderms (e.g. feather stars and sea stars), cnidaria (e.g. seapens), soft corals (various forms) and sponges (various forms). Some organisms were buried under the sand and could not be identified (further detail and CATAMI classifications are provided in Table 3-3).
- The percentage cover of benthic organisms (within the entire video frame) in Area 1c ranged from 0% to ~ 15% and was typically greater in areas that had a higher cover of biologenic gravel. However, no obvious bathymetric features seen on the transect map corresponded with the occurrence of different substrate types (e.g. sand ripples / flat sand), areas with higher cover biologenic gravel or these scattered benthic organisms.
- Bioturbation of the seafloor in the form of small mounds, craters and thin trails was seen over the transect length, evidence of mobile organisms living within and on the seafloor.
- Sightings of mobile fauna were uncommon but included echinoderms (sea stars and sea cucumbers) and various small bony fishes (unidentified and usually quickly moving out of the field of view of the ROV).

A summary of the habitat characteristics, flora and fauna seen in Area 1c is provided in Table 3-3. This table also provides the CATAMI Species Codes for each seafloor feature and taxa identified.

The benthic habitat in the location of the pipeline crossing in Area 1c (as per the time stamp provided by Neptune) is shown in Figure 3-5 and includes a rippled sandy seabed with a low (<5%) cover of benthic organisms and some biologenic gravel.

A map showing the location of the transect in Area 1c in relation to bathymetry and the KEF, along with georeferenced representative images of benthic habitat is provided in Figure 3-6. No obvious correlation between the seafloor bathymetry / rugosity and occurrence of different habitat types or cover of benthic organisms could be seen for Transect 1c when looking at the transect map. However, video analysis noted that benthic cover was typically greater in areas which had a higher cover of biologenic gravel.

Additional images of the seafloor and benthic organisms in Area 1c are provided in **Appendix B**.


*Figure 3-5 Benthic habitat in the location of the pipeline crossing in Area 1c.*

*Table 3-3 Summary of habitat features in Area 1c.*

| Habitat Features | Description | CATAMI Species Code | Occurrence |
|---|---|---|---|
| Substrate Type | Unconsolidated (soft): Sand/mud (<2mm) | 82001005 | Entire Transect |
| Bedform | 2D ripples (<10 cm height)<br>3D ripples (<10 cm height) | 82002003<br>82002007 | Alternating between flat, 2D and 3D ripples over transect |
| Relief | Flat | 82003001 | Entire Transect |
| Bioturbation | Bioturbation: Crawling traces: Thin trail<br>Bioturbation: Dwelling traces: Small mound<br>Bioturbation: Dwelling traces: Crater cone | 81005001<br>81001003<br>81001012 | Occasional over entire transect |
| Bacterial mats | Bacterial mat | 80000000 | Around ½ transect |
| Flora | Nil | NA | NA |
| Fauna | Echinoderms: Feather stars<br>Echinoderms: Feather stars - Unstalked crinoids<br>Echinoderms: Sea stars<br>Echinoderms: Sea cucumbers<br>Sponges: Erect simple<br>Sponges: Erect laminar<br>Sponges: Erect branching<br>Sponges: Cup like | 25000000<br>25001902<br>25102000<br>25400901<br>10000916<br>10000913<br>10000915<br>10000909 | Occasional sightings over the entire transect length – most organisms occurred in isolation |

| Habitat Features | Description | CATAMI Species Code | Occurrence |
|---|---|---|---|
| | Sponges: Crusts: Creeping / ramose | 10000917 | |
| | Sponges: Massive forms – simple | 10000904 | |
| | Corals: Black & Octocorals: Quill (seapen) | 11168918 | |
| | Corals (unidentified soft corals) | 11168000 | |
| | Corals: Fleshy: Arborescent | 11168911 | |
| | Corals: Non-fleshy: Bushy | 11168908 | |
| | Fishes: Bony fishes | 37990083 | |

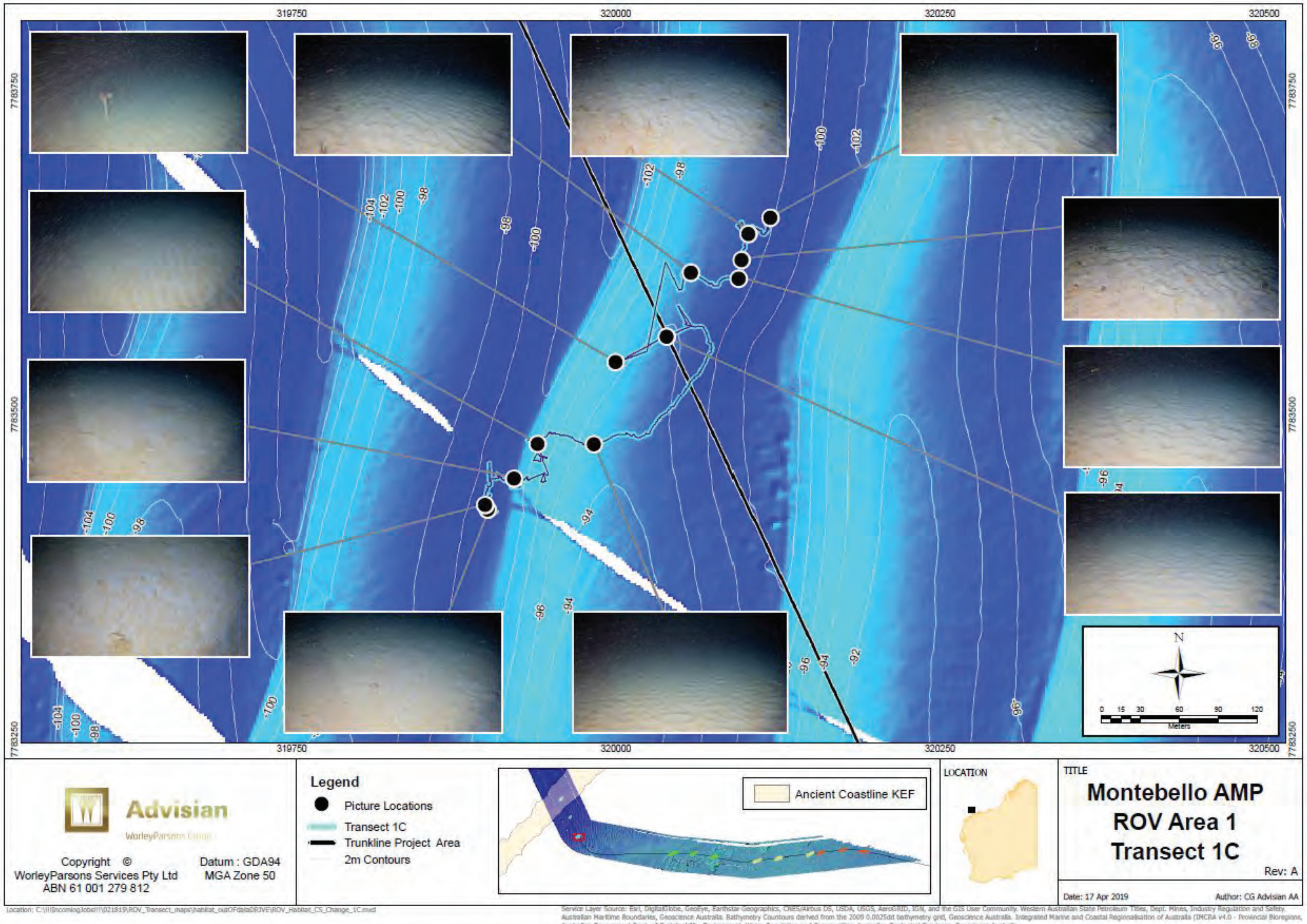


*Figure 3-6 Typical benthic habitat and bathymetry in Area 1c.*

## 3.2 Area 2

Three transects (of varying length) were surveyed in Area 2 and are described in more detail below. The depth at the midpoint of each of these transects ranged from 70.6 m to 74.4 m. While some representative images of each transect are provided in the Sections below, **Appendix C** provides additional images of benthic habitat and organisms seen along each transect in Area 2.

### 3.2.1 Area 2a

Notes provided by Neptune for Area 2a included:

- The ROV crossed the proposed pipeline route at E328839, N7781947 at approximately 06:48:04.
- The ROV was on bottom at 06:34 and off bottom at 06:59.
- The seabed was flat and comprised sand with subordinate bioclastic gravel. Benthic fauna included prolific soft corals, including large gorgonians and sponges.
- The seabed comprised a flat and predominantly sandy seabed which had considerable benthic habitat in the form of soft corals and sponges.
- No significant high relief habitat features were observed.

Analysis of video data by Advisian was undertaken and the following additional notes regarding benthic habitat in this location are provided:

- The seafloor along Transect 2a was relatively flat and sandy with a light to high cover of biologenic gravel and/or organic material over its entire length. Some areas were relatively bare while others had a low (~5%) to high (~75%) density of benthic organisms. This benthic cover changed continually (within meters) over the transects length. Small undulations of the seabed were seen at times but no other bedforms such as sand ripples or sand waves were apparent (images are provided in Figure 3-8 and in **Appendix C**).
- The seafloor in the vicinity of the pipeline crossing (as per the timestamp provided by Neptune) was flat and sandy with a cover of ~30% of sponges and corals. This habitat types was similar to the rest of the transect (Figure 3-7).
- Bioturbation of the seafloor in the form of small cones, craters, burrows, small and large trails was apparent, evidence of mobile organisms living within and on the seabed.
- No significant high relief habitat features, or areas of consolidated hard substrate, were observed. The entire transect occurred in water depths ranging from around 72 m to 74 m (refer to Figure 3-8).

- Benthic epifauna were present along almost the entire transect, occurring in patches which varied from low (~5%) to high (~75%) density, and which changed continuously. High density aggregations were often found in areas which had a high cover of biologenic gravel, but were not limited to these areas, also being found where the sediment appeared to be quite fine and where no biologenic gravel was obvious. This benthic fauna comprised a diverse array of sponges and soft corals with varying forms, sizes and colours (refer to Figure 3-8 and **Appendix C**). Hydroids were also apparent on occasion along the transect length. Further details of taxa present and CATAMI codes are provided in Table 3-4.
- Fish fauna diversity was quite high, and varying sizes of fish were seen amongst the aggregations of corals and sponges and over bare sandy seafloor. Identification of fish fauna was not undertaken as part of this assessment.

A summary of the habitat characteristics, flora and fauna seen along the transect in Area 2a is provided in Table 3-4. This table also provides the CATAMI Species Codes for each seafloor feature and taxa that could be identified.

The benthic habitat in the location of the pipeline crossing in Area 2a (as per timestamp provided by Neptune) is shown in Figure 3-7. This area was flat and sandy with many sponges and corals present (~30% cover).

A map showing the location of the transect in Area 2a in relation to depth contours and detailed bathymetry, along with georeferenced representative images of benthic habitat is provided in Figure 3-8. There were no obvious differences in the cover of benthic organisms related to seafloor bathymetry / rugosity on the map which could be clearly differentiated by looking at the transect map, with a higher cover of organisms occurring in areas which appeared to be highly rugose and also in areas not as rugose. Similarly, areas with low cover of organisms occurred in more rugose and less rugose areas. Video analysis showed that sponges and corals occurred in low to high density along most of the transect length and occurred in varying density in areas of bare soft sediment and also those areas with higher levels of biologenic gravel.

Benthic habitat in the location of the pipeline crossing in Area 2a (as per the time stamp provided by Neptune) is shown in Figure 3-7. Additional images of the benthic habitat and fauna in Area 2a are provided in **Appendix C**.


*Figure 3-7 Benthic habitat in the location of the pipeline crossing in Area 2a.*

*Table 3-4 Summary of habitat features in Area 2a.*

| Habitat Features | Description | CATAMI Species Code | Occurrence |
|---|---|---|---|
| Substrate Type | Unconsolidated (soft): Sand/mud (<2mm)<br>Unconsolidated (soft): Pebble / gravel: Biologenic | 82001005<br>82001007 | Entire Transect<br>Entire Transect |
| Bedform | Bioturbated | 82002005 | Entire transect |
| Relief | Flat | 82003001 | Entire Transect |
| Bioturbation | Bioturbation: Crawling traces: Thin trail<br>Bioturbation: Dwelling traces: Small mound<br>Bioturbation: Dwelling traces: Crater cone<br>Bioturbation: Dwelling traces: Single burrow | 81005001<br>81001003<br>81001012<br>81001006 | Occasional over entire transect |
| Bacterial mats | Nil | NA | NA |
| Flora | Nil | NA | NA |
| Fauna | Echinoderms: Feather stars<br>Echinoderms: Sea stars<br>Echinoderms: Sea cucumbers<br>Sponges: Erect simple<br>Sponges: Erect laminar<br>Sponges: Erect branching<br>Sponges: Cup like<br>Sponges: Cup-likes: Cups<br>Sponges: Cups: Cup / goblet | 25000000<br>25102000<br>25400901<br>10000916<br>10000913<br>10000915<br>10000909<br>10000910<br>10000919 | Sponges and corals of high diversity were common and scattered over most of the seafloor in transect Area 2a. Patches of benthic epifauna changed |

| Habitat Features | Description | CATAMI Species Code | Occurrence |
|---|---|---|---|
| | Sponges: Cup-likes: Tubes and chimneys | 10000911 | continuously from low to high density. |
| | Sponges: Crusts: Creeping / ramose | 10000917 | |
| | Sponges: Massive forms – simple | 10000904 | |
| | Sponges: Massive forms: Cryptic | 10000908 | |
| | Corals: Black & Octocorals: Quill (seapen) | 11168918 | |
| | Corals (unidentified soft corals) | 11168000 | |
| | Corals: Fleshy: Arborescent | 11168911 | |
| | Corals: Non-fleshy: Bushy | 11168908 | |
| | Corals: Fern-frond: Complex | 11168915 | |
| | Corals: Black & Octocorals: Fan (2D) | 11168912 | |
| | Corals: Black & Octocorals: Whip | 11168917 | |
| | Cnidaria: Hydroids | 11001000 | |
| | Fishes: Bony fishes | 37990083 | |

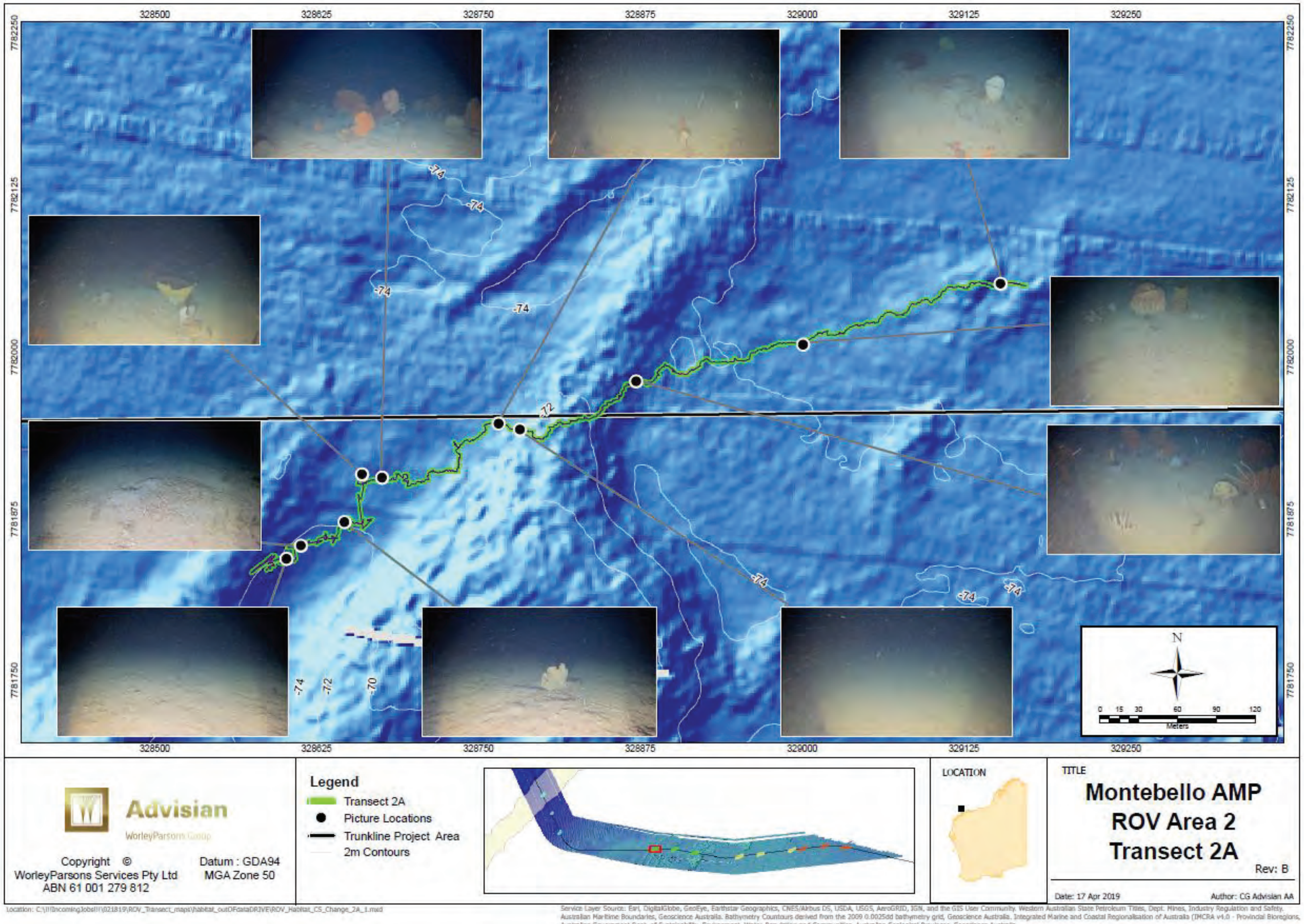


*Figure 3-8 Typical benthic habitat and bathymetry in Area 2a.*

### 3.2.2 Area 2b

Notes provided by Neptune for Area 2b included:

- The ROV crossed the proposed pipeline route in the vicinity of E330686, N7781970 at approximately 07:38:39.
- The ROV was on bottom at 07:29 and off bottom at 07:47.
- The seabed was flat and comprised sand with subordinate bioclastic gravel. Benthic fauna included soft corals, including large gorgonians and sponges.
- The seabed comprised a flat predominantly sandy seabed with considerable benthic habitat in the form of soft corals and sponges.
- No significant high relief habitat features were observed.

Analysis of video data by Advisian was undertaken and the following additional notes regarding benthic habitat in this location are provided:

- The seafloor along Transect 2b was very similar to 2a. The seafloor was relatively flat and sandy with a light to high cover of biologenic gravel and/or organic material over its entire length. Some areas were relatively bare while others had a low (~5%) to high (~75%) density cover of benthic organisms. The cover of benthic organisms changed continually over the transect length. Small undulations of the seabed and some more pronounced scouring around larger sponges / soft corals was seen at times but no other formal bedforms such as sand ripples or sand waves were apparent. Images are provided in Figure 3-10 and **Appendix C**.
- The seafloor in the vicinity of the pipeline crossing was flat and sandy with many sponges and soft corals present (~50% cover). This habitat was similar to the rest of the transect (see Figure 3-9).
- Bioturbation of the seafloor in the form of small cones, craters, burrows, small and large trails was apparent providing evidence of mobile organisms within and on the seafloor.
- No significant moderate or high relief habitat features, or areas of consolidated hard substrate, were observed. Biologenic gravel was present and quite common. The transect occurred in water depths ranging from around 74 m to 76 m (refer to Figure 3-10)
- Benthic epifauna were present along almost the entire transect, occurring in aggregations which varied continually from low (~5%) to high (~75%) density. As for Transect 2a, high density aggregations were often found in areas which had a high cover of biologenic gravel, but were in no way limited to these areas, with dense aggregations also found in areas with less or no biologenic gravel and soft sediment.

- This benthic epifauna comprised a diverse array of sponges and corals with varying forms, sizes and colours. Hydroids were also apparent on occasion along the transect length. More detail on taxa and CATAMI codes are provided in

- Table 3-5.

- Fish fauna diversity was quite high, and varying sizes of fish were seen amongst the aggregations of corals and sponges and over bare sandy seafloor. Although, IDs of fish fauna were not undertaken for this assessment.

- A summary of the habitat characteristics, flora and fauna seen along the transect in Area 2b is provided in

- Table 3-5. This table also provides the CATAMI Species Codes for each seafloor feature and taxa that could be identified.

The benthic habitat in the location of the pipeline crossing in Area 2b (as per timestamp provided by Neptune) is shown in Figure 3-9. This area was flat and sandy with many sponges and corals present (around 50% cover).

A map showing the location of the transect in Area 2b in relation to depth contours, detailed bathymetry and with georeferenced representative images of benthic habitat is provided in Figure 3-10. Rugosity along the length of transect was quite similar and while some georeferenced images suggest that areas with slightly higher rugosity had a higher cover of organisms, other images show that some areas of higher rugosity also had a lower cover of benthic organisms. Similarly, high cover of organisms was also seen in relatively less rugose areas. However, the 'generally' rugose nature of the seabed as indicated by the transect image may provide some explanation for the generally common occurrence of benthic organisms in this location. Additional images of habitat and fauna are provided in **Appendix C**.

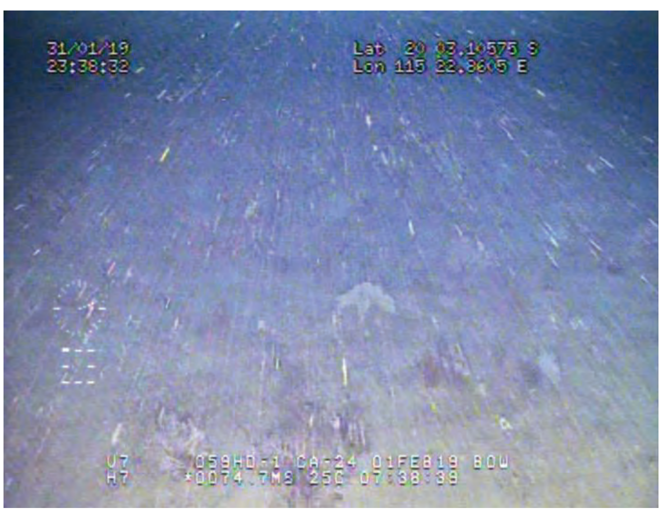

*Figure 3-9 Benthic habitat in the location of the pipeline crossing in Area 2b.*

*Table 3-5 Summary of habitat features in Area 2b.*

| Habitat Features | Description | CATAMI Species Code | Occurrence |
|---|---|---|---|
| Substrate Type | Unconsolidated (soft): Sand/mud (<2mm)<br>Unconsolidated (soft): Pebble / gravel: Biologenic | 82001005<br>82001007 | Entire Transect<br>Entire Transect |
| Bedform | Bioturbated | 82002005 | Entire transect |
| Relief | Flat | 82003001 | Entire Transect |
| Bioturbation | Bioturbation: Crawling traces: Thin trail<br>Bioturbation: Dwelling traces: Small mound<br>Bioturbation: Dwelling traces: Crater cone<br>Bioturbation: Dwelling traces: Single burrow | 81005001<br>81001003<br>81001012<br>81001006 | Occasional over entire transect |
| Bacterial mats | Nil | NA | NA |
| Flora | Nil | NA | NA |
| Fauna | Echinoderms: Feather stars<br>Echinoderms: Sea stars<br>Echinoderms: Sea cucumbers<br>Sponges: Erect simple<br>Sponges: Erect laminar<br>Sponges: Erect branching<br>Sponges: Cup like<br>Sponges: Cup-likes: Cups<br>Sponges: Cups: Cup / goblet<br>Sponges: Cup-likes: Tubes and chimneys<br>Sponges: Crusts: Creeping / ramose<br>Sponges: Massive forms – simple<br>Sponges: Massive forms: Cryptic<br>Corals: Black & Octocorals: Quill (seapen)<br>Corals (unidentified soft corals)<br>Corals: Fleshy: Arborescent<br>Corals: Non-fleshy: Bushy<br>Corals: Fern-frond: Complex<br>Corals: Black & Octocorals: Fan (2D)<br>Corals: Black & Octocorals: Whip<br>Cnidaria: Hydroids<br>Fishes: Bony fishes | 25000000<br>25102000<br>25400901<br>10000916<br>10000913<br>10000915<br>10000909<br>10000910<br>10000919<br>10000911<br>10000917<br>10000904<br>10000908<br>11168918<br>11168000<br>11168911<br>11168908<br>11168915<br>11168912<br>11168917<br>11001000<br>37990083 | Sponges and corals of high diversity were common and scattered over most of the seafloor in transect Area 2b. Patches of benthic epifauna changed continuously from low to high density. |

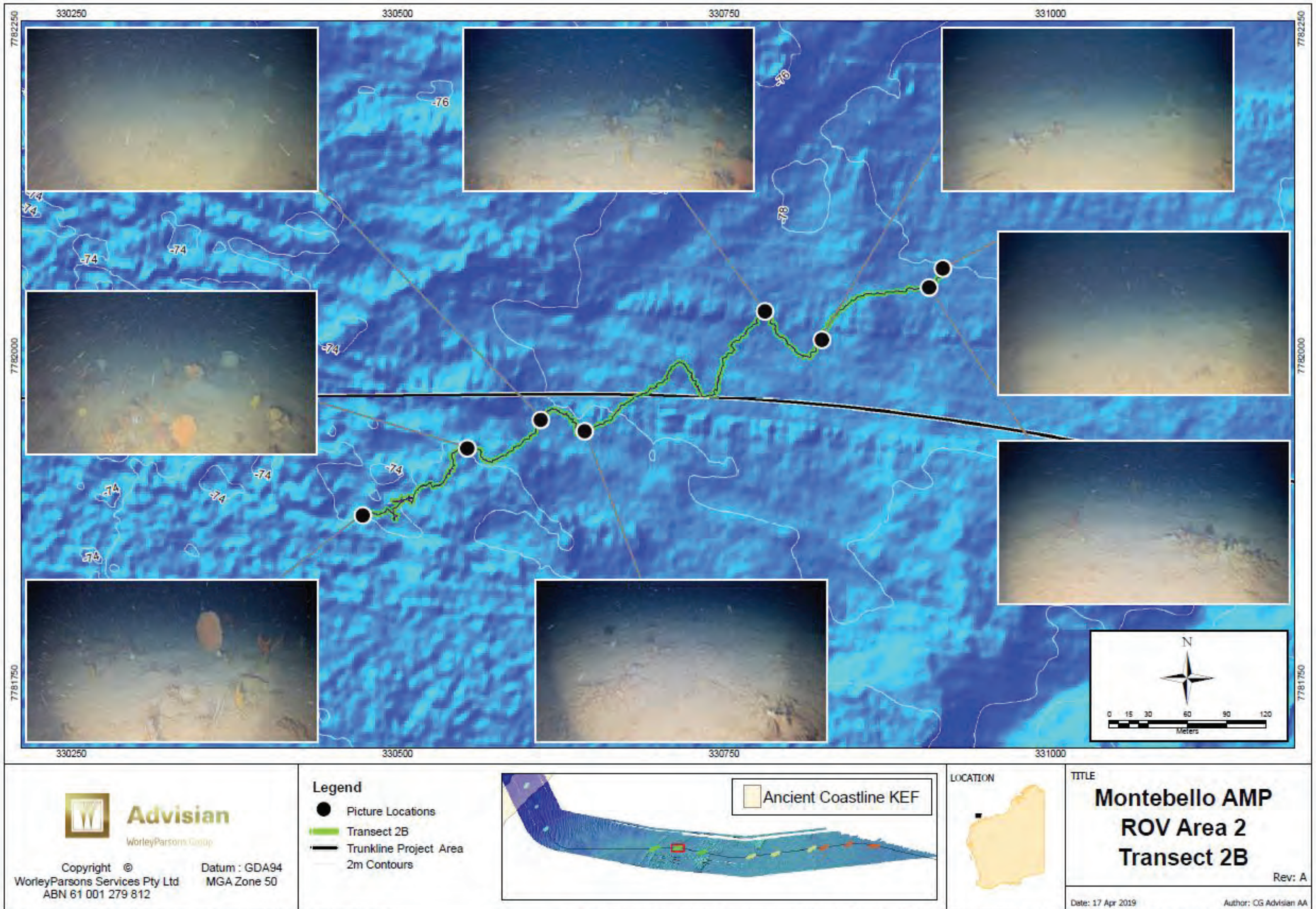


Figure 3-10 Typical benthic habitat and bathymetry in Area 2b.

### 3.2.3 Area 2c

Notes provided by Neptune for Area 2c included:

- The ROV crossed the proposed pipeline route in the vicinity of E332653, N7781637 at approximately 08:26:10.
- The ROV was on bottom at 08:16 and off bottom at 08:34.
- The seabed was flat and comprised sand with subordinate bioclastic gravel. Benthic fauna included areas of soft corals, including large gorgonians and sponges.
- The seabed comprised a flat predominantly sandy seabed with benthic habitat in the form of areas of soft corals and sponges.
- No significant high relief habitat features were observed.

Analysis of video data by Advisian was undertaken and the following additional notes regarding benthic habitat in this location are provided:

- The seafloor along Transect 2c was again very similar to that in Area 2a and 2b. The seafloor was relatively flat and sandy (fine sand) with a light to high cover of biologenic gravel and/or organic material over most of its length. Some areas were relatively bare while others had a low (~5%) to high (~80%) density of benthic organisms. The benthic cover changed continually (and within meters) over the transects length. Small undulations of the seabed and some scouring around larger sponges / soft corals was seen, but no other formal bedforms such as sand ripples or sand waves were apparent. Images are provided in Figure 3-12 and **Appendix C**.
- The seafloor in the vicinity of the pipeline crossing (as per timestamp provided by Neptune) was flat and sandy with sponges and soft corals present (~20%) and the habitat was similar to the rest of the transect (see Figure 3-11).
- Bioturbation of the seafloor in the form of small cones, craters, burrows, small and large trails was apparent providing evidence of mobile organisms living on and within the seabed.
- No significant moderate or high relief habitat features, or areas of consolidated hard substrate, were observed on the video. Some areas of unconsolidated biologenic rubble of unknown origin were seen. The depth of the seafloor in Area 2c ranged from around 72 m to 74 m (refer to Figure 3-12). Figure 3-12 shows that the seafloor was slightly more rugose at the start and end of the transect with a flatter expanse in the middle.
- Benthic epifauna were present along almost the entire transect, occurring in patches which varied continually from low (~5%) to high (~80%) density. This benthic fauna comprised a diverse array of sponges and corals with varying forms, sizes and colours. Hydroids were also apparent on occasion along the transect length. Additional details and CATAMI

classifications are provided in Table 3-6. Video analysis (and georeferenced images to some degree) showed that benthic organisms were more common (and their cover was denser) at the start and end of the transect. This may be related to the reduced rugosity of the seafloor in the middle expanse seen in Figure 3-12. However, benthic organisms were in no way excluded from this less rugose area, they just tended to occur in lower densities when they did occur.

- Fish fauna diversity was quite high, and varying sizes of fish were seen amongst the aggregations of corals and sponges and over bare sandy seafloor. Although, IDs of fish fauna were not undertaken.

A summary of the habitat characteristics, flora and fauna seen along the transect in Area 2c is provided in Table 3-6. This table also provides the CATAMI Species Codes for each seafloor feature and taxa that could be identified.

The benthic habitat in the location of the pipeline crossing (as per timestamp provided by Neptune) is shown in Figure 3-11. This area was flat and sandy sponges and soft corals present, representing about 20% cover.

A map showing the location of the transect in Area 2c in relation to depth contours, along with representative images of benthic habitat, is provided in Figure 3-12. Area 2c showed some increased rugosity at either end of the transect with an expansive flatter area in the middle. The occurrence (and density) of benthic organisms was also generally greater at both ends of the transect and these bottom features may be related in this case. Notwithstanding this, benthic organisms were not excluded from the flatter mid section of Transect 2c.

Additional images of benthic habitat and fauna are provided in **Appendix C**.


*Figure 3-11 Benthic habitat in the location of the pipeline crossing in Area 2c.*

*Table 3-6 Summary of habitat features in Area 2c.*

| Habitat Features | Description | CATAMI Species Code | Occurrence |
|---|---|---|---|
| Substrate Type | Unconsolidated (soft): Sand/mud (<2mm)<br>Unconsolidated (soft): Pebble / gravel: Biologenic | 82001005<br>82001007 | Entire Transect<br>Entire Transect |
| Bedform | Bioturbated | 82002005 | Entire transect |
| Relief | Flat | 82003001 | Entire Transect |
| Bioturbation | Bioturbation: Crawling traces: Thin trail<br>Bioturbation: Dwelling traces: Small mound<br>Bioturbation: Dwelling traces: Crater cone<br>Bioturbation: Dwelling traces: Single burrow | 81005001<br>81001003<br>81001012<br>81001006 | Occasional over entire transect |
| Bacterial mats | Nil | NA | NA |
| Flora | Nil | NA | NA |
| Fauna | Echinoderms: Feather stars<br>Echinoderms: Sea stars<br>Echinoderms: Sea cucumbers<br>Sponges: Erect simple<br>Sponges: Erect laminar<br>Sponges: Erect branching<br>Sponges: Cup like<br>Sponges: Cup-likes: Cups<br>Sponges: Cups: Cup / goblet<br>Sponges: Cup-likes: Tubes and chimneys<br>Sponges: Crusts: Creeping / ramose<br>Sponges: Massive forms – simple<br>Sponges: Massive forms: Cryptic<br>Corals: Black & Octocorals: Quill (seapen)<br>Corals (unidentified soft corals)<br>Corals: Fleshy: Arborescent<br>Corals: Non-fleshy: Bushy<br>Corals: Fern-frond: Complex<br>Corals: Black & Octocorals: Fan (2D)<br>Corals: Black & Octocorals: Whip<br>Cnidaria: Hydroids<br>Fishes: Bony fishes | 25000000<br>25102000<br>25400901<br>10000916<br>10000913<br>10000915<br>10000909<br>10000910<br>10000919<br>10000911<br>10000917<br>10000904<br>10000908<br>11168918<br>11168000<br>11168911<br>11168908<br>11168915<br>11168912<br>11168917<br>11001000<br>37990083 | Sponges and corals of high diversity were common and scattered over most of the seafloor in transect Area 2c. Patches of benthic epifauna changed continuously from low to high density. |

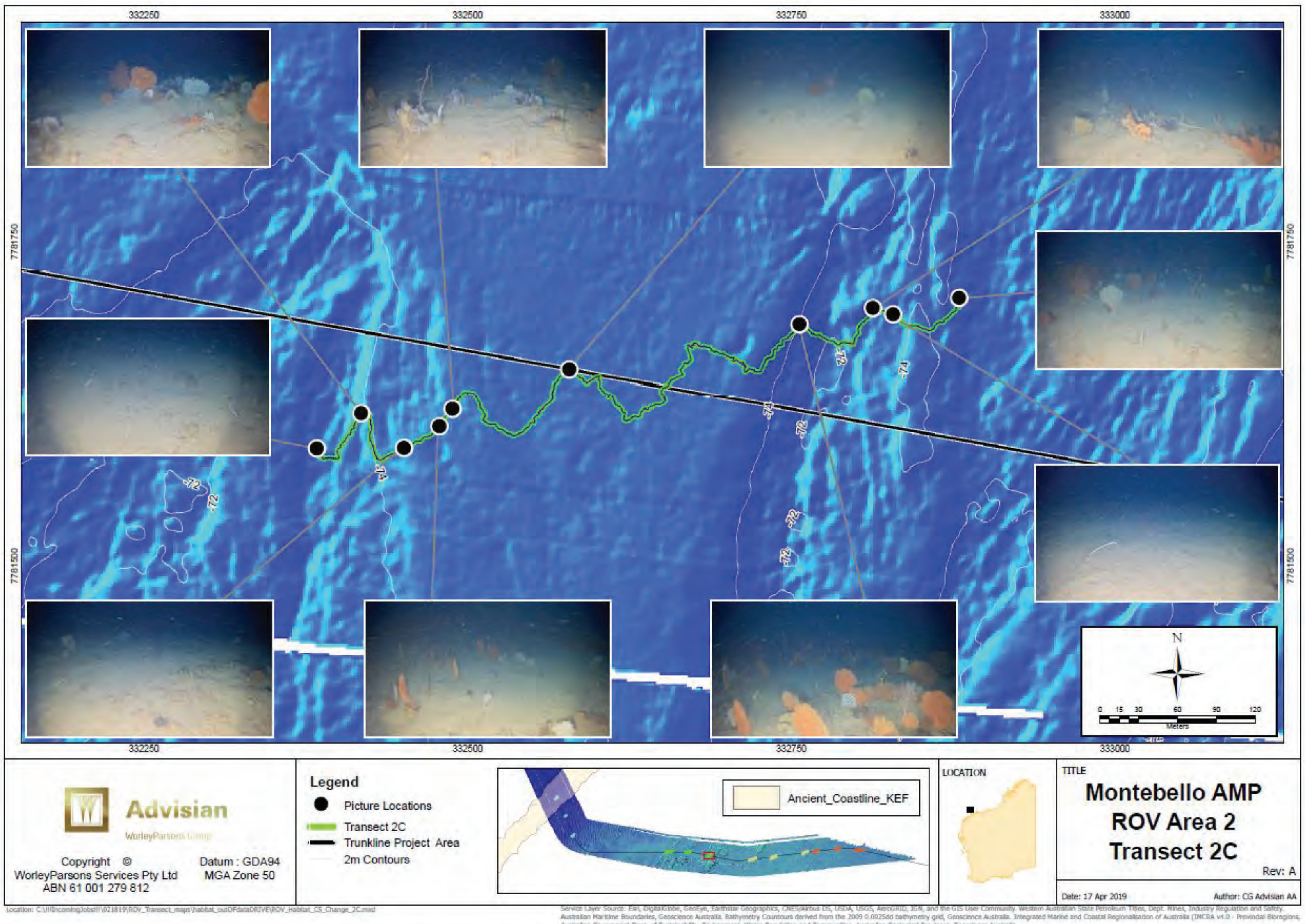


*Figure 3-12 Typical benthic habitat and bathymetry in Area 2c.*

## 3.3 Area 3

Three transects were completed in Area 3 and are described in more detail in the Sections below. The depth at the midpoint of these transects ranged from 71.6 m to 73.8 m. While some representative images of each transect are provided in the Sections below, **Appendix D** provides additional images of the benthic habitat and organisms seen along each transect in Area 3.

### 3.3.1 Area 3a

Notes provided by Neptune for Area 3a included:

- The ROV crossed the proposed pipeline route in the vicinity of E336608, N7781312 at approximately 09:35.
- The ROV was on bottom at 09:25 and off bottom at 09:51.
- The seabed was typically flat and comprised sand with subordinate bioclastic gravel. Benthic fauna included areas of soft corals, including large gorgonians and sponges as well as black 'whip' corals.
- The seabed comprised a flat predominantly sandy seabed with benthic habitat in the form of areas of soft corals and sponges.
- No significant high relief habitat features were observed.

Analysis of video data by Advisian was undertaken and the following additional notes regarding benthic habitat in this location are provided:

- The seafloor along Transect 3a was relatively flat and sandy with a light to high cover of biologenic gravel and/or organic material over its entire length (continually changing). The seabed was a mosaic of bare substrate and low (~5%) to high (~75%) density cover of benthic organisms (e.g. sponges / soft corals), changing every few meters. This was very similar to Area 2. Small undulations of the seabed and some small sand waves were present on occasion, but no other regular bedforms such as sand ripples or sand waves were apparent. Images are provided in Figure 3-14 and **Appendix D**.
- The seafloor in the vicinity of the pipeline crossing (as identified by the time stamp provided by Neptune) was flat and sandy with a low-medium density cover (~20%) of sponges and soft corals and this habitat was typical of the rest of the transect (see Figure 3-13).
- Bioturbation of the seafloor in the form of small cones, craters, burrows and small and large trails was apparent. This occurred over the entire transect length and indicates the presence of mobile organisms living within and on top of the seabed.

- No significant moderate or high relief habitat features or areas which could clearly be defined as consolidated hard substrate were observed. Some potential very low profile outcropping was seen, although this was hard to clearly define with the often high cover of biologenic gravel and benthic organisms. The depth of the seafloor was between 75 m to 76 m along the entire transect (refer to Figure 3-14).

- Benthic epifauna were present along the entire transect and occurred in patches which changed continuously from low (~5%) to high (~75%) density. This benthic fauna comprised a diverse array of sponges and soft corals with varying forms, sizes and colours. Hydroids were also apparent on occasion along the transect length. Additional details and CATAMI classifications are provided in Table 3-7. High density benthic cover was seen in areas where biologenic gravel was high but also in areas of fine sediment. In addition, there were areas with a high cover of biologenic gravel which lacked any benthic organisms. The detailed bathymetry shown in Figure 3-14 did not differ significantly over the transect length. While there is some evidence of higher benthic cover in more rugose areas and less benthic cover in less rugose areas, this was not always the case as seen on the video.

- Fish fauna diversity was quite high, and varying sizes of fish were seen amongst the aggregations of corals and sponges and also over bare sandy seafloor. Identifications of fish were not undertaken as part of this assessment. Seastars and feather stars were both present.

A summary of the habitat characteristics, flora and fauna seen in Area 3a is provided in Table 3-7. This table also provides the CATAMI Species Codes for each seafloor feature and taxa that could be identified.

The benthic habitat in the location of the pipeline crossing (as per the timestamp provided by Neptune) is shown in Figure 3-13. The seafloor in this area was flat and sandy with a low-medium density cover (~20%) of sponges and soft corals. This habitat type was typical of the transect.

A map showing the location of the transect in Area 3a in relation to detailed bathymetry, along with georeferenced representative images of benthic habitat, is provided in Figure 3-14. While this mapping shows some evidence for higher benthic cover in areas of slightly higher rugosity, this was not always the case. In addition, the video analysis found that high benthic cover was not limited to particular substrate types (e.g. bare sand/soft sediment or areas with higher biologenic gravel).

Additional images of the seafloor habitat and epifauna in Area 3a are provided in **Appendix D**.

*Figure 3-13 Benthic habitat in the location of the pipeline crossing in Area 3a.*

*Table 3-7 Summary of habitat features in Area 3a.*

| Habitat Features | Description | CATAMI Species Code | Occurrence |
|---|---|---|---|
| Substrate Type | Unconsolidated (soft): Sand/mud (<2mm)<br>Unconsolidated (soft): Pebble / gravel: Biologenic | 82001005<br>82001007 | Entire Transect<br>Entire Transect |
| Bedform | Bioturbated | 82002005 | Entire transect |
| Relief | Flat | 82003001 | Entire Transect |
| Bioturbation | Bioturbation: Crawling traces: Thin trail<br>Bioturbation: Dwelling traces: Small mound<br>Bioturbation: Dwelling traces: Crater cone<br>Bioturbation: Dwelling traces: Single burrow | 81005001<br>81001003<br>81001012<br>81001006 | Occasional over entire transect |
| Bacterial mats | Nil | NA | NA |
| Flora | Nil | NA | NA |
| Fauna | Echinoderms: Feather stars<br>Echinoderms: Sea stars<br>Echinoderms: Sea cucumbers<br>Sponges: Erect simple<br>Sponges: Erect laminar<br>Sponges: Erect branching<br>Sponges: Cup like<br>Sponges: Cup-likes: Cups<br>Sponges: Cups: Cup / goblet | 25000000<br>25102000<br>25400901<br>10000916<br>10000913<br>10000915<br>10000909<br>10000910<br>10000919 | Sponges and corals of high diversity were common and scattered over |

| Habitat Features | Description | CATAMI Species Code | Occurrence |
|---|---|---|---|
| | Sponges: Cup-likes: Tubes and chimneys | 10000911 | most of the seafloor in transect Area 3a. Patches of benthic epifauna changed continuously from low to high density. |
| | Sponges: Crusts: Creeping / ramose | 10000917 | |
| | Sponges: Massive forms – simple | 10000904 | |
| | Sponges: Massive forms: Cryptic | 10000908 | |
| | Corals: Black & Octocorals: Quill (seapen) | 11168918 | |
| | Corals (unidentified soft corals) | 11168000 | |
| | Corals: Fleshy: Arborescent | 11168911 | |
| | Corals: Non-fleshy: Bushy | 11168908 | |
| | Corals:  Fern-frond: Complex | 11168915 | |
| | Corals: Black & Octocorals: Fan (2D) | 11168912 | |
| | Corals: Black & Octocorals: Whip | 11168917 | |
| | Cnidaria: Hydroids | 11001000 | |
| | Fishes: Bony fishes | 37990083 | |

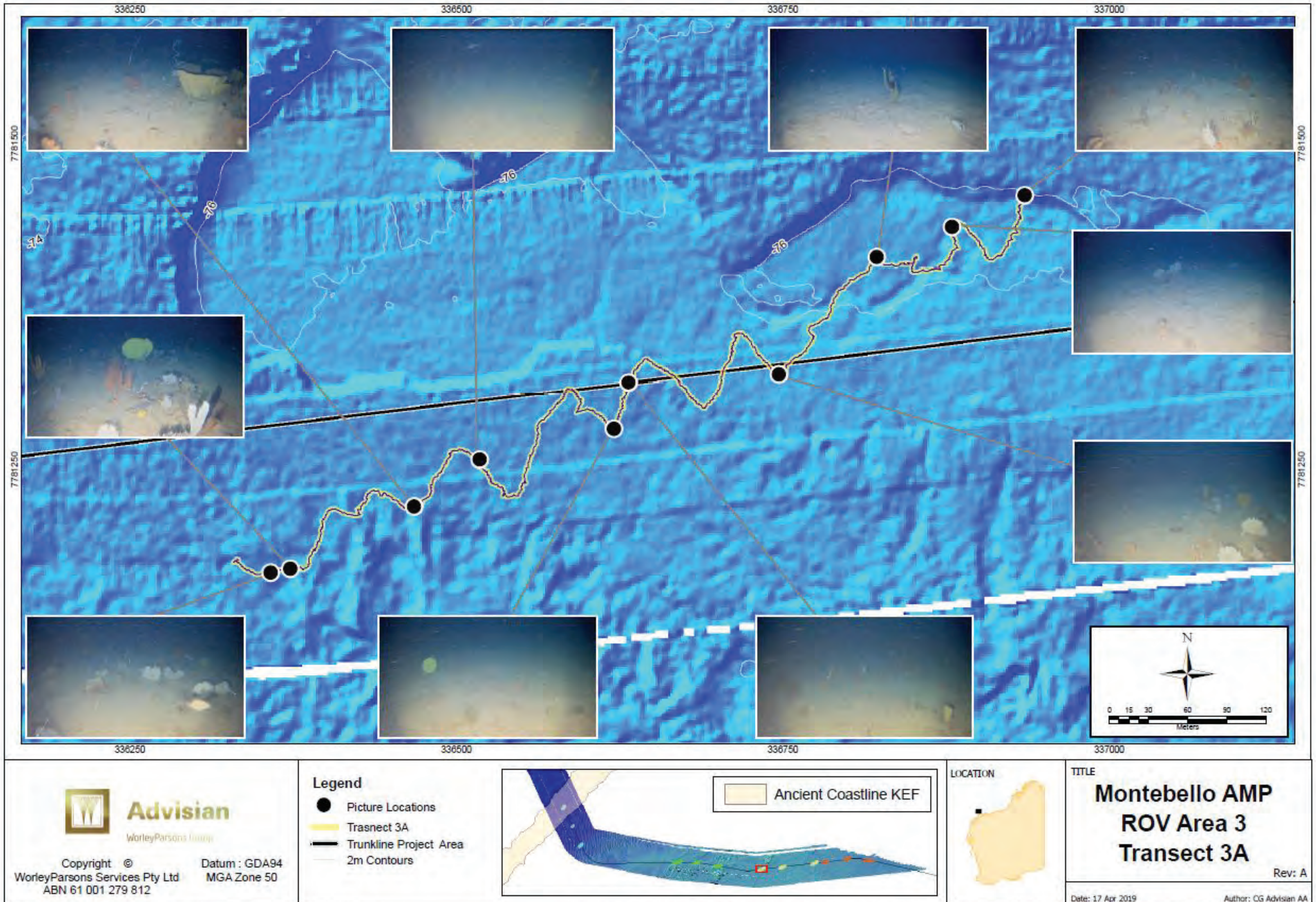


*Figure 3-14 Typical benthic habitat and bathymetry in Area 3a.*

### 3.3.2 Area 3b

Notes provided by Neptune for Area 3b included:

- The ROV crossed the proposed pipeline route in the vicinity of E338667, N7781567 at approximately 10:41.
- The ROV was on bottom at 10:25 and off bottom at 10:49.
- The seabed was typically flat and comprised sand with subordinate bioclastic gravel. Benthic fauna included areas of soft corals, including large gorgonians and sponges.
- The seabed comprised a flat and predominantly sandy seabed with benthic habitat in the form of areas of soft corals and sponges.
- No significant high relief habitat features were observed.

Analysis of video data by Advisian was undertaken and the following additional notes regarding benthic habitat in this location are provided:

- The seafloor along Transect 3b was very similar to 3a. The seafloor was relatively flat and sandy with a light to high cover of biologenic gravel and/or organic material over its entire length (continually changing). Small undulations of the seabed and some small sand waves and scour pits (typically around larger organisms or aggregations of organisms) were present on occasion, but no other regular bedforms such as sand ripples or sand waves were apparent. The seabed was a mosaic of bare substrate and low (~5%) to medium (~50%) density cover of benthic organisms (e.g. sponges / soft corals), changing every few meters. Images are provided in Figure 3-16 and **Appendix D**.
- The seafloor in the vicinity of the pipeline crossing (as identified by the time stamp provided by Neptune) was flat and sandy with a low-medium density cover (~30%) of sponges and soft corals (see Figure 3-15).
- Bioturbation of the seafloor in the form of small cones, craters, burrows and small and large trails was apparent. This occurred over the entire transect length and provides evidence for mobile organisms living within and on the seafloor.
- No significant moderate or high relief habitat features, or significant areas of consolidated hard substrate, were present. Some potential small areas of outcropping were seen although this was hard to clearly define with the high cover of biologenic gravel and benthic organisms. The entire transect occurred in water depths of about 73 m to 74 m (refer to Figure 3-16). Rugosity was quite consistent over the transect length.
- Benthic epifauna were present along the entire transect and occurred in patches which changed continuously from low (~5%) to medium (~50%) density. Benthic fauna comprised a diverse array of sponges and soft corals with varying forms, sizes and colours. Hydroids were also apparent on occasion along the transect length. Additional

classification details and CATAMI codes are provided in Table 3-8. The transect map for Area 3b (Figure 3-16), overlaid with georeferenced images, shows that benthic organisms occurred along the entire transect length and were often of a medium density (~30-40% cover). Bare substrate was less common in Area 3b.

- Fish fauna diversity was quite high, as seen for transect 3a, and varying sizes of fish were seen amongst the aggregations of soft corals and sponges and over bare sandy seafloor. Identifications of fish were not undertaken as part of this assessment. Seastars and feather stars were both present.

A summary of the habitat characteristics, flora and fauna seen in Area 3b is provided in Table 3-8. This table also provides the CATAMI Species Codes for each seafloor feature and taxa that could be identified.

The benthic habitat in the location of the pipeline crossing in Area 3b is shown in Figure 3-15. This area was flat and sandy with a low-medium density cover (~30%) of sponges and soft corals.

A map showing the location of the transect in Area 3b in relation to bathymetry, along with representative images of benthic habitat, is provided in Figure 3-16. Benthic organisms were common along the entire length of the transect, which was quite similar in its rugosity.

Additional images of the seafloor habitat and epifauna in Area 3b are provided in **Appendix D**.

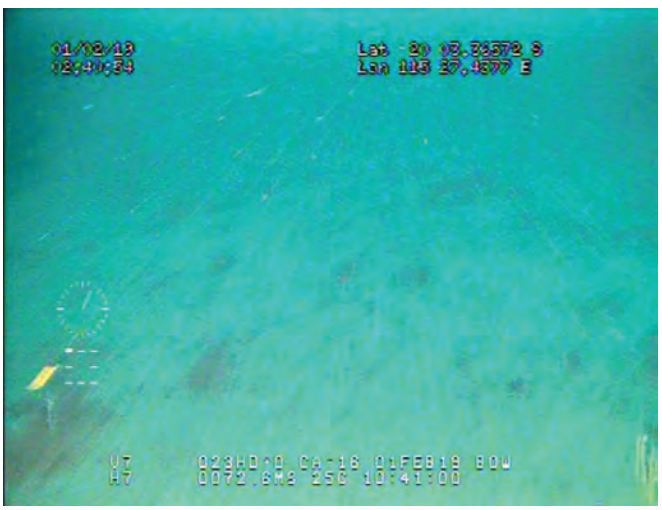

*Figure 3-15 Benthic habitat in the location of the pipeline crossing in Area 3b.*

*Table 3-8 Summary of habitat features in Area 3b.*

| Habitat Features | Description | CATAMI Species Code | Occurrence |
|---|---|---|---|
| Substrate Type | Unconsolidated (soft): Sand/mud (<2mm)<br>Unconsolidated (soft): Pebble / gravel: Biologenic | 82001005<br>82001007 | Entire Transect<br>Entire Transect |
| Bedform | Bioturbated | 82002005 | Entire transect |
| Relief | Flat | 82003001 | Entire Transect |
| Bioturbation | Bioturbation: Crawling traces: Thin trail<br>Bioturbation: Dwelling traces: Small mound<br>Bioturbation: Dwelling traces: Crater cone<br>Bioturbation: Dwelling traces: Single burrow | 81005001<br>81001003<br>81001012<br>81001006 | Occasional over entire transect |
| Bacterial mats | Nil | NA | NA |
| Flora | Nil | NA | NA |
| Fauna | Echinoderms: Feather stars<br>Echinoderms: Sea stars<br>Echinoderms: Sea cucumbers<br>Sponges: Erect simple<br>Sponges: Erect laminar<br>Sponges: Erect branching<br>Sponges: Cup like<br>Sponges: Cup-likes: Cups<br>Sponges: Cups: Cup / goblet<br>Sponges: Cup-likes: Tubes and chimneys<br>Sponges: Crusts: Creeping / ramose<br>Sponges: Massive forms – simple<br>Sponges: Massive forms: Cryptic<br>Corals: Black & Octocorals: Quill (seapen)<br>Corals (unidentified soft corals)<br>Corals: Fleshy: Arborescent<br>Corals: Non-fleshy: Bushy<br>Corals: Fern-frond: Complex<br>Corals: Black & Octocorals: Fan (2D)<br>Corals: Black & Octocorals: Whip<br>Cnidaria: Hydroids<br>Fishes: Bony fishes | 25000000<br>25102000<br>25400901<br>10000916<br>10000913<br>10000915<br>10000909<br>10000910<br>10000919<br>10000911<br>10000917<br>10000904<br>10000908<br>11168918<br>11168000<br>11168911<br>11168908<br>11168915<br>11168912<br>11168917<br>11001000<br>37990083 | Sponges and corals of high diversity were common and scattered over most of the seafloor in transect Area 3b. Patches of benthic epifauna changed continuously from low to high density. |

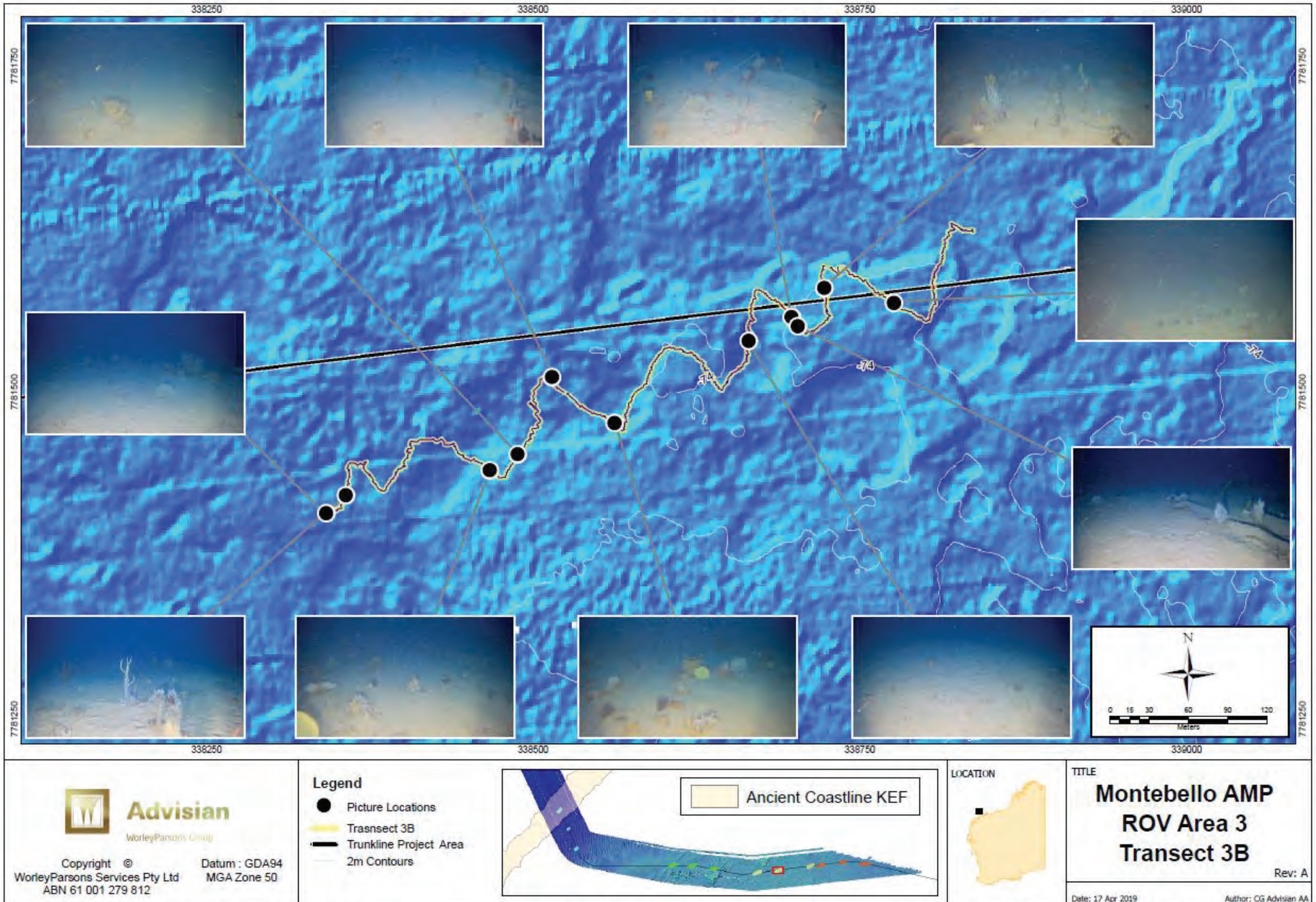


*Figure 3-16 Typical benthic habitat and bathymetry in Area 3b.*

### 3.3.3 Area 3c

Notes provided by Neptune for Area 3c included:

- The ROV crossed the proposed pipeline route in the vicinity of E341572, N7781919 at approximately 11:40.
- The ROV was on bottom at 11:28 and off bottom at 11:54.
- The seabed was typically flat to undulating and comprised sand with subordinate bioclastic gravel. Benthic fauna included sporadic areas of soft corals, including large gorgonians and sponges as well as black 'whip' corals. Current scour moats were noted around some of the sponges.
- The seabed comprised a flat predominantly sandy seabed with benthic habitat in the form of isolated areas of soft corals and sponges.
- No significant high relief habitat features were observed.

Analysis of video data by Advisian was undertaken and the following additional notes regarding benthic habitat in this location are provided:

- The seafloor along Transect 3c was very similar to 3a and 3b. The seafloor was relatively flat and sandy with a light to high cover of biologenic gravel and/or organic material over its entire length (continually changing). Small undulations of the seabed and some small sand waves and scour pits were present on occasion, but no other regular bedforms such as sand ripples or sand waves were apparent. The seabed was a mosaic of bare substrate and low to high density cover of benthic organisms (e.g. sponges / soft corals), changing every few meters. Images are provided in Figure 3-18 and **Appendix D**.
- The seafloor in the vicinity of the pipeline crossing (as identified by the time stamp provided by Neptune) was flat and sandy with a low-medium density cover (~30%) of sponges and soft corals (see Figure 3-17).
- Bioturbation of the seafloor in the form of small cones, craters, burrows and small and large trails was apparent. This occurred over the entire transect length and provides evidence for mobile organisms living within and on the soft sediment.
- No significant moderate or high relief habitat features, or significant areas of consolidated hard substrate, were present. Some potential small areas of outcropping were seen on the video although this was hard to clearly define with the high cover of biologenic gravel and benthic organisms. The entire transect occurred in water depths between around 75 m and 76 m (refer to Figure 3-18). Rugosity was generally consistent over the transect length but was slightly higher in the south-western end of the transect.
- Benthic epifauna were present along the entire transect and occurred in patches which changed continuously from low (~5%) to medium (~50%) density, very similar to the other

transects in Area 3. Benthic fauna comprised a diverse array of sponges and soft corals with varying forms, sizes and colours. Hydroids were also apparent on occasion along the transect length. Additional classification details and CATAMI codes are provided in Table 3-9. While video analysis showed that benthic cover was often higher in areas which had a higher cover of biologenic gravel, and also occurred in higher densities in more rugose areas as shown in Figure 3-18, this was not always the case, with moderate benthic cover also seen in areas with little or no biologenic gravel and areas of the transect map which appear to be less rugose.

- Fish fauna diversity was again quite high with fish were seen amongst the aggregations of corals and sponges and also over areas of sandy seafloor. Identifications of fish were not undertaken as part of this assessment. Seastars and feather stars were both present.

A summary of the habitat characteristics, flora and fauna seen in Area 3c is provided in Table 3-9. This table also provides the CATAMI Species Codes for each seafloor feature and taxa that could be identified.

The seafloor in the area of the pipeline crossing is shown in Figure 3-17. This area was flat and sandy with a low-medium density cover of sponges and soft corals.

A map showing the location of the transect in Area 3c in relation to bathymetry, along with representative images of benthic habitat, is provided in Figure 3-18. While higher benthic cover could be related to a higher cover of biologenic gravel and/or rugosity on some occasions, this was not always the case. the detailed bathymetry / rugosity shown on the transect map cannot be used as an accurate predictor of the occurrence, or lack of, benthic organisms.

Additional images of the seafloor habitat and epifauna in Area 3c are provided in **Appendix D**.


*Figure 3-17 Benthic habitat in the location of the pipeline crossing in Area 3c.*

*Table 3-9 Summary of habitat features in Area 3c.*

| Habitat Features | Description | CATAMI Species Code | Occurrence |
|---|---|---|---|
| Substrate Type | Unconsolidated (soft): Sand/mud (<2mm)<br>Unconsolidated (soft): Pebble / gravel: Biologenic | 82001005<br>82001007 | Entire Transect<br>Entire Transect |
| Bedform | Bioturbated | 82002005 | Entire transect |
| Relief | Flat | 82003001 | Entire Transect |
| Bioturbation | Bioturbation: Crawling traces: Thin trail<br>Bioturbation: Dwelling traces: Small mound<br>Bioturbation: Dwelling traces: Crater cone<br>Bioturbation: Dwelling traces: Single burrow | 81005001<br>81001003<br>81001012<br>81001006 | Occasional over entire transect |
| Bacterial mats | Nil | NA | NA |
| Flora | Nil | NA | NA |
| Fauna | Echinoderms: Feather stars<br>Echinoderms: Sea stars<br>Echinoderms: Sea cucumbers<br>Sponges: Erect simple<br>Sponges: Erect laminar<br>Sponges: Erect branching<br>Sponges: Cup like<br>Sponges: Cup-likes: Cups<br>Sponges: Cups: Cup / goblet<br>Sponges: Cup-likes: Tubes and chimneys<br>Sponges: Crusts: Creeping / ramose<br>Sponges: Massive forms – simple<br>Sponges: Massive forms: Cryptic<br>Corals: Black & Octocorals: Quill (seapen)<br>Corals (unidentified soft corals)<br>Corals: Fleshy: Arborescent<br>Corals: Non-fleshy: Bushy<br>Corals: Fern-frond: Complex<br>Corals: Black & Octocorals: Fan (2D)<br>Corals: Black & Octocorals: Whip<br>Cnidaria: Hydroids<br>Fishes: Bony fishes | 25000000<br>25102000<br>25400901<br>10000916<br>10000913<br>10000915<br>10000909<br>10000910<br>10000919<br>10000911<br>10000917<br>10000904<br>10000908<br>11168918<br>11168000<br>11168911<br>11168908<br>11168915<br>11168912<br>11168917<br>11001000<br>37990083 | Sponges and corals of high diversity were common and scattered over most of the seafloor in transect Area 3c. Patches of benthic epifauna changed continuously from low to high density. |

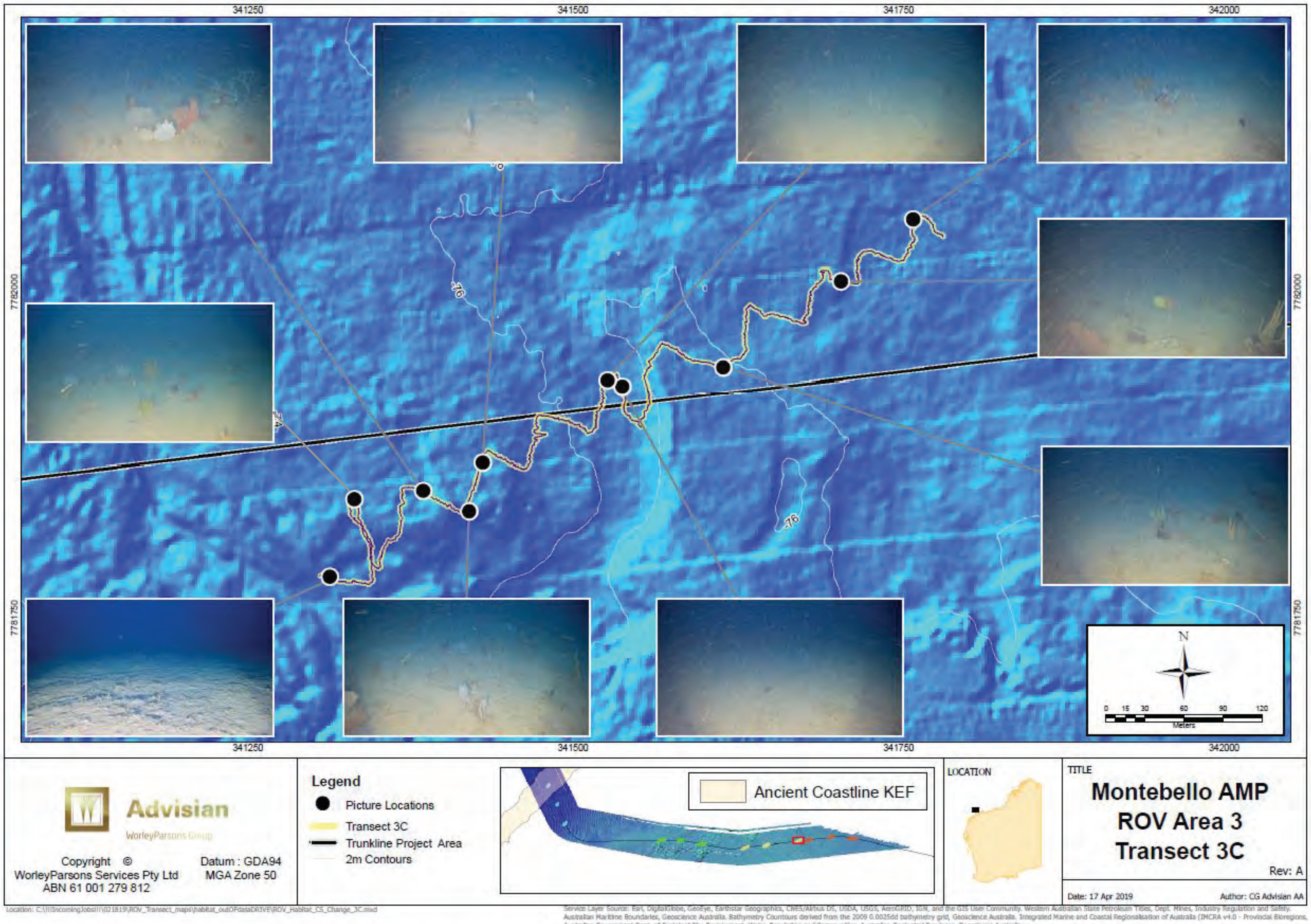


*Figure 3-18 Typical benthic habitat and bathymetry in Area 3c.*

## 3.4 Area 4

Three transects were completed in Area 4 and are described in more detail in the Sections below. The depth at the midpoint of these transects ranged from 74.5 m to 78.2 m (slightly deeper but similar to the depth in Area 2 and 3). **Appendix E** provides additional images of the benthic habitat and organisms seen along each transect in Area 4.

### 3.4.1 Area 4a

Notes provided by Neptune for Area 4a included:

- The ROV crossed the proposed pipeline route around E342566, N7782035 at approximately 13:15.
- The ROV was on bottom at 13:01 and off bottom at 13:29.
- The seabed was typically flat to undulating and comprised sand with subordinate bioclastic gravel. 'Starved' ripples occurred and typically had coarser gravel in their troughs. Benthic fauna includes sporadic areas of soft corals, including large gorgonians and sponges as well as black 'whip' corals. Current scour moats are noted around some of the sponges.
- The seabed comprised a flat predominantly sandy seabed which had a benthic habitat in the form of isolated areas of soft corals and sponges.
- No significant high relief habitat features were observed.

Analysis of video data by Advisian was undertaken and the following additional notes regarding benthic habitat in Area 4a are provided:

- The seafloor within Area 4a was typically flat sand with a high level of biologenic gravel of unknown origin. Small mounds, waves and undulations all < 50 cm in height were seen on occasion and mainly occurred around aggregations of benthic epifauna (i.e. sponges and soft corals). Images are provided in Figure 3-20 and **Appendix E**.
- In the vicinity of the pipeline route (as identified by the time stamp provided by Neptune), the seafloor was typical of the area being flat and sandy with biologenic rubble and a medium density cover (~30%) of scattered sponges and soft corals (Figure 3-19).
- The vast majority of the seafloor along the transect in Area 4a was scattered with sponges and soft corals of varying forms and sizes. Some occurred as individuals and more dense clusters (up to ~50% cover) of these organisms were also common. Large areas of bare substrate were quite uncommon in Area 4a.
- No significant moderate or high relief features, or significant areas of consolidated hard substrate, were present along the transect in Area 4a (i.e. they were not seen on the video nor can be seen on the transect map). However, like in Area 2 and Area 3, much of the

seafloor was covered in a biologic gravel of unknown origin and this was quite dense at times. The depth along the Area 4a transect was around 76 m to 78 m (refer to Figure 3-20). This transect was in close proximity to the transect in Area 3c (which occurred in waters from 75 – 76 m).

- Benthic epifauna were common throughout the entire Area 4a, scattered in low to medium density clusters (5% - 30%) for the most part but also commonly occurring in larger more dense clusters (up to ~50% density). Soft corals (including gorgonians and seapens) and sponges were abundant and diverse in their form and size. Other benthic epifauna included echinoderms (e.g. feather stars which were often attached to sponges/corals). Additional details and CATAMI classifications are provided in Table 3-10. Like in other areas, the occurrence of benthic organisms could not be clearly predicted from any rugosity or other features shown on the detailed bathymetric map (Figure 3-20) nor were they always associated with a certain substrate type (e.g. high biologenic gravel).
- Mobile fauna (mainly small bony fishes) were most common around the larger clusters of sponges and soft corals. Fish were not identified as part of this assessment.
- Bioturbation of the seafloor in the form of small mounds and craters was evident along the entire transect length and provides evidence for the occurrence of mobile fauna (typically invertebrates) living within and on the soft sediment seafloor.

A summary of the habitat characteristics, flora and fauna seen along the transect in Area 4a is provided in Table 3-10. This table also provides the CATAMI Species Codes for each seafloor feature and taxa that could be identified.

The seafloor in the vicinity of the pipeline crossing in Area 4a (as identified by the timestamp provided by Neptune) is shown in Figure 3-19. This area was flat and sandy with biologenic rubble and a medium density cover (~30%) of sponges and soft corals.

A map showing the location of the transect in Area 4a in relation to bathymetry, along with representative images of benthic habitat, is provided in Figure 3-20. There were no clear or consistent relationships that could be seen between bathymetric features or rugosity in Area 4a with the occurrence or cover of benthic organisms.

Additional images of the seafloor habitat and epifauna in Area 4a are provided in **Appendix E**.

*Figure 3-19 Benthic habitat in the location of the pipeline crossing in Area 4a.*

*Table 3-10 Summary of habitat features in Area 4a.*

| Habitat Features | Description | CATAMI Species Code | Occurrence |
|---|---|---|---|
| Substrate Type | Unconsolidated (soft): Sand/mud (<2mm)<br>Unconsolidated (soft): Pebble / gravel: Biologenic | 82001005<br>82001007 | Entire Transect<br>Entire Transect |
| Bedform | Bioturbated | 82002005 | Entire transect |
| Relief | Flat | 82003001 | Entire Transect |
| Bioturbation | Bioturbation: Dwelling traces: Small mound<br>Bioturbation: Dwelling traces: Crater cone | 81001003<br>81001012 | Occasional over entire transect |
| Bacterial mats | Bacterial mat | 80000000 | Occasional |
| Flora | Nil | NA | NA |
| Fauna | Echinoderms: Feather stars<br>Echinoderms: Sea stars<br>Echinoderms: Sea cucumbers<br>Sponges: Erect simple<br>Sponges: Erect laminar<br>Sponges: Erect branching<br>Sponges: Cup like<br>Sponges: Cup-likes: Cups<br>Sponges: Cups: Cup / goblet<br>Sponges: Cup-likes: Tubes and chimneys<br>Sponges: Crusts: Creeping / ramose | 25000000<br>25102000<br>25400901<br>10000916<br>10000913<br>10000915<br>10000909<br>10000910<br>10000919<br>10000911<br>10000917 | Sponges and corals of high diversity were common and scattered over most of the seafloor in transect Area 4a. Larger 'clumps' of sponges and corals were also seen on occasion along the entire transect. |

| Habitat Features | Description | CATAMI Species Code | Occurrence |
|---|---|---|---|
| | Sponges: Massive forms – simple | 10000904 | |
| | Sponges: Massive forms: Cryptic | 10000908 | |
| | Corals: Black & Octocorals: Quill (seapen) | 11168918 | |
| | Corals (unidentified soft corals) | 11168000 | |
| | Corals: Fleshy: Arborescent | 11168911 | |
| | Corals: Non-fleshy: Bushy | 11168908 | |
| | Corals: Fern-frond: Complex | 11168915 | |
| | Corals: Black & Octocorals: Fan (2D) | 11168912 | |
| | Corals: Black & Octocorals: Whip | 11168917 | |
| | Cnidaria: Hydroids | 11001000 | |
| | Fishes: Bony fishes | 37990083 | |

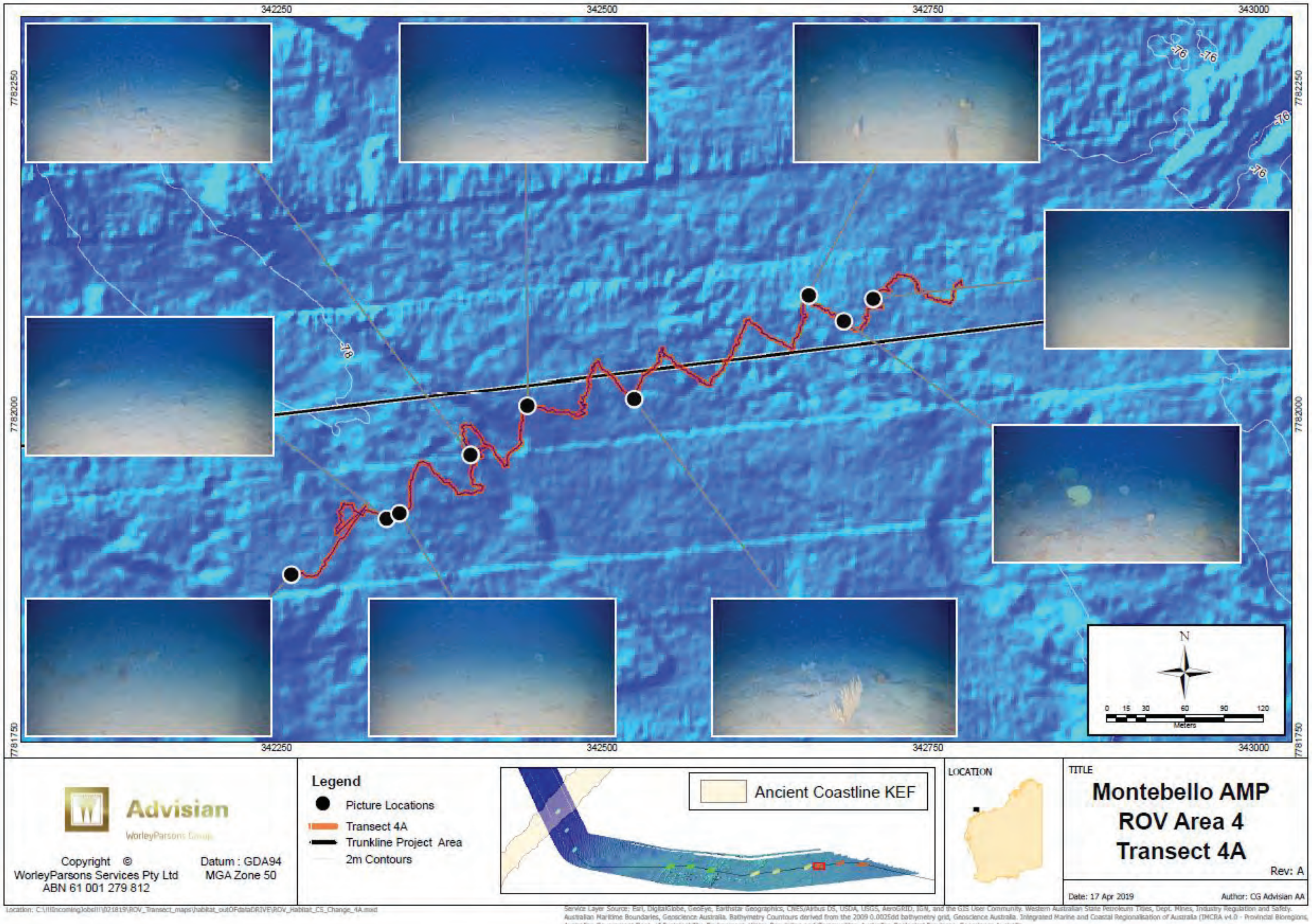


*Figure 3-20 Typical benthic habitat and bathymetry in Area 4a.*

### 3.4.2 Area 4b

Notes provided by Neptune for Area 4b included:

- The ROV crossed the proposed pipeline route around E344502, N7782269 at approximately 14:23.
- The ROV was on bottom at 14:15 and off bottom at 14:38.
- The seabed was typically flat to undulating and comprised sand with subordinate bioclastic gravel. 'Starved' ripples occurred and typically had coarser gravel in their troughs. Benthic fauna included sporadic areas of soft corals, including gorgonians and sponges as well as black 'whip' corals. Current scour moats were noted around some of the sponges.
- The seabed comprised a flat and predominantly sandy seabed which had a benthic habitat in the form of isolated areas of soft corals and sponges.
- No significant high relief habitat features were observed.

Analysis of video data by Advisian was undertaken and the following additional notes regarding benthic habitat in Area 4b are provided:

- The seafloor within Area 4b was very similar to 4a, consisting of a typically flat and sandy seabed with a high level of biogenic gravel of unknown origin. Small mounds, waves and undulations all < 50 cm in height were seen on occasion and these mainly occurred around aggregations of benthic epifauna (i.e. sponges and soft corals). Images are provided in Figure 3-22 and **Appendix E**.
- The vast majority of the seafloor along the transect was scattered with a low to medium density cover (~5-30%) of sponges and soft corals of varying forms and sizes, although bare patches of sand were slightly more common than was seen in Area 4a. Medium density clusters of these organisms (up to ~40-50% cover) also occurred along the transects length. Images are provided in Figure 3-22 and **Appendix E**.
- In the vicinity of the pipeline route (as identified with the time stamp provided by Neptune), the seafloor was flat and sandy with biologenic rubble and a medium density cover of scattered sponges and soft corals (~30% cover). This habitat was consistent with the rest of the habitat in Area 4b (refer to Figure 3-21).
- No significant moderate or high relief features, or significant areas of consolidated hard substrate, were present along the transect in Area 4b (as seen on the video and on the detailed bathymetric mapping; Figure 3-22). However, much of the seafloor in this area was covered in a biologic gravel of unknown origin (with variable cover). The depth of the seafloor in Area 4b was around 74 m over the entire transect length. Rugosity along the transects length was relatively consistent and given the consistent depth, any small bathymetric features seen on the map would be of a very small scale (Figure 3-22).

- Benthic epifauna were common throughout the entire Area 4b, scattered for the most part in low density (ranging from ~5-20% cover), but also occurring in larger and more dense clusters of up to ~40-50% cover. Soft corals (including gorgonians and seapens) and sponges were abundant and diverse in their form and size. Other benthic epifauna included echinoderms (e.g. feather stars). Images are provided in Figure 3-22 and **Appendix E**. These shown that benthic organisms were common over most of the transect length regardless of small scale bathymetry / rugosity or substrate type (e.g. bare soft sediment or biologenic gravel).

- Mobile fauna (i.e. bony fishes) were most common around the larger clusters of sponges and soft corals in Area 4c. A high diversity of fish fauna was observed on the video however; these species were not identified as part of this assessment.

- Bioturbation of the seafloor in the form of small mounds and craters was evident along the entire transect length providing evidence for mobile fauna (typically invertebrates) living within and on the soft sediment seafloor.

A summary of the habitat characteristics, flora and fauna seen along the transect in Area 4b is provided in Table 3-11. This table also provides the CATAMI Species Codes for each seafloor feature and taxa that could be identified. The seafloor in the vicinity of the pipeline crossing in Area 4b (as per the timestamp provided by Neptune) is shown in Figure 3-21. This area was flat and sandy with biologenic rubble and scattered sponges and soft corals of about 30% cover.

The location of the transect in Area 4b in relation to detailed bathymetry, with georeferenced representative images of benthic habitat, is provided in Figure 3-22. There were no consistent patterns seen in the occurrence of benthic organisms or substrate type in relation to rugosity, nor were there significant changes in depth or rugosity. Additional images of seafloor habitat and epifauna in Area 4b are provided in **Appendix E**.

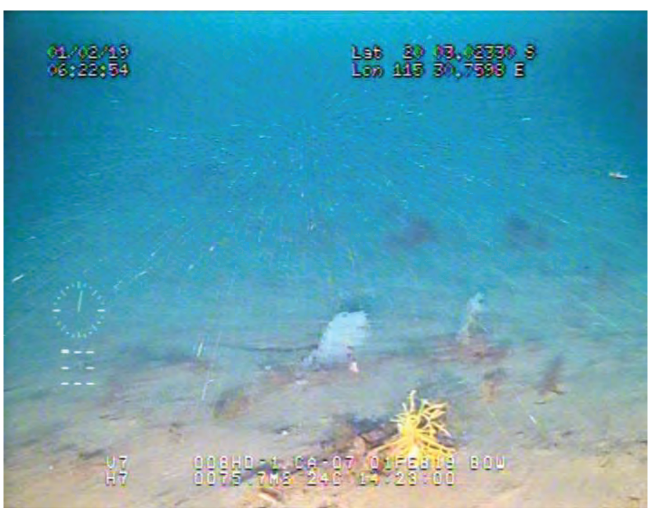

*Figure 3-21 Benthic habitat in the location of the pipeline crossing in Area 4b.*

*Table 3-11 Summary of habitat features in Area 4b.*

| Habitat Features | Description | CATAMI Species Code | Occurrence |
|---|---|---|---|
| Substrate Type | Unconsolidated (soft): Sand/mud (<2mm)<br>Unconsolidated (soft): Pebble / gravel: Biologenic | 82001005<br>82001007 | Entire Transect<br>Entire Transect |
| Bedform | Bioturbated | 82002005 | Entire transect |
| Relief | Flat | 82003001 | Entire Transect |
| Bioturbation | Bioturbation: Dwelling traces: Small mound<br>Bioturbation: Dwelling traces: Crater cone | 81001003<br>81001012 | Occasional over entire transect |
| Bacterial mats | Bacterial mat | 80000000 | Occasional |
| Flora | Nil | NA | NA |
| Fauna | Echinoderms: Feather stars<br>Echinoderms: Sea stars<br>Echinoderms: Sea cucumbers<br>Sponges: Erect simple<br>Sponges: Erect laminar<br>Sponges: Erect branching<br>Sponges: Cup like<br>Sponges: Cup-likes: Cups<br>Sponges: Cups: Cup / goblet<br>Sponges: Cup-likes: Tubes and chimneys<br>Sponges: Crusts: Creeping / ramose<br>Sponges: Massive forms – simple<br>Sponges: Massive forms: Cryptic<br>Corals: Black & Octocorals: Quill (seapen)<br>Corals (unidentified soft corals)<br>Corals: Fleshy: Arborescent<br>Corals: Non-fleshy: Bushy<br>Corals: Fern-frond: Complex<br>Corals: Black & Octocorals: Fan (2D)<br>Corals: Black & Octocorals: Whip<br>Cnidaria: Hydroids<br>Fishes: Bony fishes | 25000000<br>25102000<br>25400901<br>10000916<br>10000913<br>10000915<br>10000909<br>10000910<br>10000919<br>10000911<br>10000917<br>10000904<br>10000908<br>11168918<br>11168000<br>11168911<br>11168908<br>11168915<br>11168912<br>11168917<br>11001000<br>37990083 | Sponges and corals of high diversity were common and scattered over most of the seafloor in transect Area 4b. Larger 'clumps' of sponges and corals were also seen on occasion along the entire transect. |

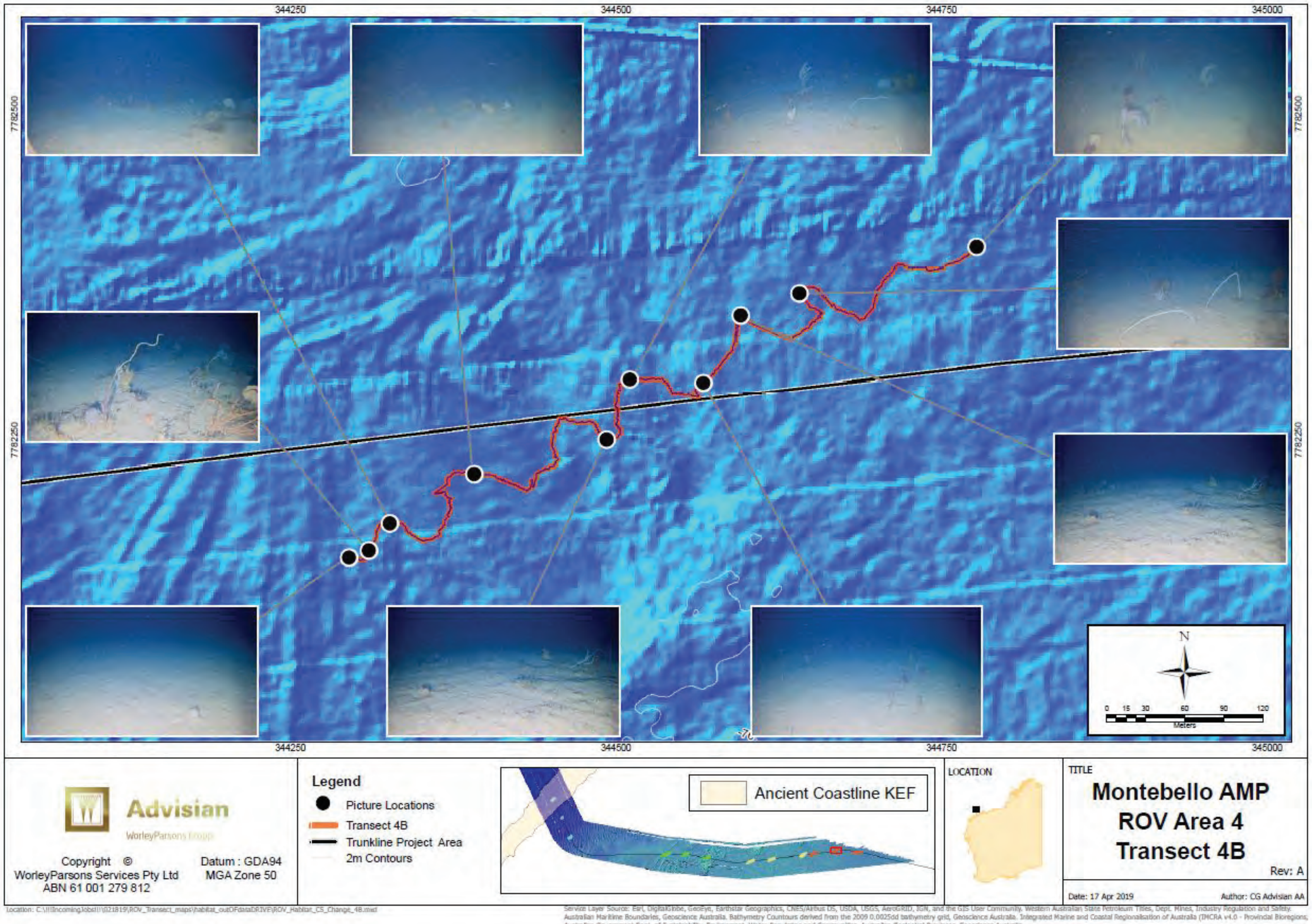


*Figure 3-22 Typical benthic habitat and bathymetry in Area 4b.*

### 3.4.3 Area 4c

Notes provided by Neptune for Area 4c included:

- The ROV crossed the proposed pipeline route at about E346650, N7782160 at approximately 15:34.
- The ROV was on bottom at 15:13 and off bottom at 15:47.
- The seabed was typically flat to undulating and comprised sand with subordinate bioclastic gravel. 'Starved' ripples occurred and typically had coarser gravel in their troughs. Benthic fauna included sporadic areas of soft corals, including gorgonians and sponges. Current scour moats were noted around some of the sponges.
- The seabed comprised a flat and predominantly sandy seabed which had a benthic habitat in the form of isolated areas of soft corals and sponges.
- No significant high relief habitat features were observed.

Analysis of video data by Advisian was undertaken and the following additional notes regarding benthic habitat in Area 4c are provided:

- The seafloor within Area 4c was very similar to 4a and 4b, consisting of typically flat fine sand with a generally high cover of biologenic gravel of unknown origin. Small mounds, waves and undulations all < 50 cm in height were seen on occasion, mainly around aggregations of benthic epifauna (sponges and soft corals). Images are provided in Figure 3-24 and **Appendix E**.
- The vast majority of the seafloor along the transect 4c was bare soft sediment, however, some areas were scattered with sponges and soft corals of varying forms and sizes. The majority of these were smaller in their form, however, larger forms tended to increase in occurrence towards the end of the transect. The density of benthic organisms in Area 4c was generally low (~5-15%) but some more dense clusters of these organisms also occurred towards the end of the transect (up to ~30% cover). The occurrence of sponges and corals in transect 4c was generally less than in Areas 4a and 4b. Bare sand was also more common in Area 4c than it was in 4b and 4a (while Area 4b also had more bare sand than Area 4a). Images are provided in Figure 3-24 and **Appendix E**.
- In the vicinity of the pipeline route (as identified by the time stamp provided by Neptune), the seafloor was flat and sandy with biologenic rubble and a low density of scattered sponges and soft corals (~5%). This is shown in in Figure 3-23.
- No significant moderate or high relief features or significant areas of consolidated hard substrate were present along the transect in Area 4c (as indicated on the video and the transect map with detailed bathymetry Figure 3-24). However, some of the seafloor was covered in a biologic gravel of unknown origin. The depth of the seafloor in Area 4c ranged between around 76 m to 78 m (refer to Figure 3-24). The eastern end of the

transect had a couple of smaller features relative to the rest of the transect which typically had low rugosity, however, these were only small scale (i.e. ~1 m).

- Benthic epifauna were diverse in Area 4c, as seen in Areas 4a and 4b, and were scattered throughout the entire Area 4c. Some larger clusters of epibenthic organisms occurred on occasion and these were mainly towards the eastern end of the transect. These areas of denser benthic fauna may be related to the small features which can be seen on the eastern half of the transect map. Soft corals (which included but were not limited to gorgonians and seapens) and sponges in this area were abundant and very diverse in their form and size. Other benthic epifauna included echinoderms (e.g. feather stars). Additional details and CATAMI classifications are shown in Table 3-12.

- Mobile fauna including bony fishes, sea stars and feather stars were most common around the larger clusters of sponges and corals. Sea cucumbers were also seen on occasion on the bare sand.

- Bioturbation of the seafloor in the form of small mounds, craters and large / small trails was evident over the entire transect length, again providing evidence for mobile fauna (typically invertebrates) living within and on the soft sediment seafloor.

A summary of the habitat characteristics, flora and fauna seen along the transect in Area 4c is provided in Table 3-12. This table also provides the CATAMI Species Codes for each seafloor feature and taxa that could be identified.

The benthic habitat in the vicinity of the pipeline crossing in Area 4c is shown in Figure 3-23. The seafloor was sandy and quite bare in this location which was consistent with much of the rest of this transect. There was ~5% cover of benthic organisms in this location.

A map showing the location of the transect in Area 4c in relation to bathymetry, along with georeferenced representative images of benthic habitat, is provided in Figure 3-24. The video analysis and transect map for Area 4c both provide some indication of a higher density of benthic organisms occurring in the eastern half of the transect, the location of a couple of bathymetric features on a relatively low rugosity seafloor. However, benthic organisms were not limited to this location and bare substrate was also seen in these locations.

Additional images of the seafloor habitat and epifauna in Area 4c are provided in **Appendix E**.


*Figure 3-23 Benthic habitat in the location of the pipeline crossing in Area 4c.*

*Table 3-12 Summary of habitat features in Area 4c.*

| Habitat Features | Description | CATAMI Species Code | Occurrence |
|---|---|---|---|
| Substrate Type | Unconsolidated (soft): Sand/mud (<2mm)<br>Unconsolidated (soft): Pebble / gravel: Biologenic | 82001005<br>82001007 | Entire Transect<br>Entire Transect |
| Bedform | Bioturbated | 82002005 | Entire transect |
| Relief | Flat | 82003001 | Entire Transect |
| Bioturbation | Bioturbation: Crawling traces: Thin trail<br>Bioturbation: Dwelling traces: Small mound<br>Bioturbation: Dwelling traces: Crater cone | 81005001<br>81001003<br>81001012 | Occasional over entire transect |
| Bacterial mats | Bacterial mat | 80000000 | Occasional |
| Flora | Nil | NA | NA |
| Fauna | Echinoderms: Feather stars<br>Echinoderms: Sea stars<br>Echinoderms: Sea cucumbers<br>Sponges: Erect simple<br>Sponges: Erect laminar<br>Sponges: Erect branching<br>Sponges: Cup like<br>Sponges: Cup-likes: Cups<br>Sponges: Cups: Cup / goblet<br>Sponges: Cup-likes: Tubes and chimneys | 25000000<br>25102000<br>25400901<br>10000916<br>10000913<br>10000915<br>10000909<br>10000910<br>10000919<br>10000911 | Sponges and corals of high diversity were scattered over the seafloor in transect Area 4c. Larger 'clumps' of sponges and corals were also seen on occasion along the entire transect, mainly in the |

| Habitat Features | Description | CATAMI Species Code | Occurrence |
|---|---|---|---|
| | Sponges: Crusts: Creeping / ramose | 10000917 | second half of the transect. |
| | Sponges: Massive forms – simple | 10000904 | |
| | Sponges: Massive forms: Cryptic | 10000908 | |
| | Corals: Black & Octocorals: Quill (seapen) | 11168918 | |
| | Corals (unidentified soft corals) | 11168000 | |
| | Corals: Fleshy: Arborescent | 11168911 | |
| | Corals: Non-fleshy: Bushy | 11168908 | |
| | Corals:  Fern-frond: Complex | 11168915 | |
| | Corals: Black & Octocorals: Fan (2D) | 11168912 | |
| | Corals: Black & Octocorals: Whip | 11168917 | |
| | Cnidaria: Hydroids | 11001000 | |
| | Fishes: Bony fishes | 37990083 | |

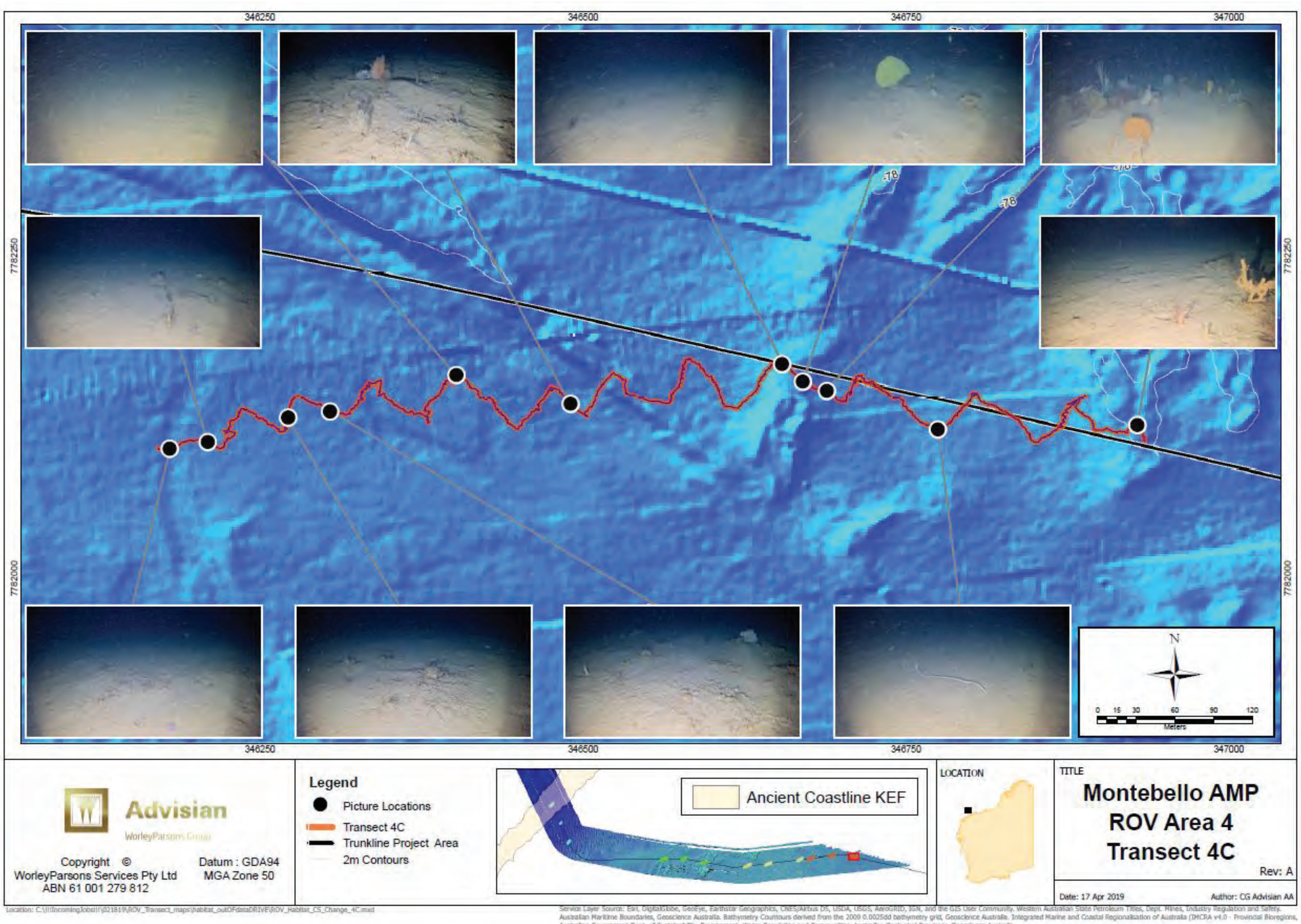


*Figure 3-24 Typical benthic habitat and bathymetry in Area 4c.*

## 3.5 Area 5

Only one transect was completed in Area 5. The depth at the midpoint of this transect was 74.6 m. This transect did not cross the pipeline route. **Appendix F** provides additional images of the benthic habitat and organisms seen in Area 5.

### 3.5.1 Area 5a

Notes provided by Neptune for Area 5a included:

- The ROV surveyed south of the proposed pipeline route round E361160, N7778778.
- The ROV was on bottom at 18:31 and off bottom at 19:00.
- The seabed was typically flat to undulating and comprised sand with subordinate bioclastic gravel. Where flat, the seabed had an algae cover. Where undulating, the seabed was characterised by starved ripples and scour moats, typically around sponges. Benthic fauna included sporadic areas of soft corals, including gorgonians and sponges.
- The seabed comprised a flat predominantly sandy seabed which had a benthic habitat in the form of isolated areas of soft corals and sponges.
- No significant high relief habitat features were observed.
- Due to strong currents and the ROV tether management it was not possible to run the transect across the proposed pipeline route. No image of the pipeline crossing area is shown for this reason.

Further analysis of video data by Advisian resulted in the following notes regarding benthic habitat in this location:

- The seafloor in Area 5a consisted of flat sand, often with an organic cover (likely bacterial or algae) or biologenic gravel component. The seafloor showed some slight undulation in places and scour marks commonly occurred around small 'clusters' of benthic epifauna (i.e. sponges and soft corals). No regular bedforms such as sand ripples or sand waves were present in this location. Images are provided in Figure 3-25 and **Appendix F**.
- No significant moderate or high relief features were present along the transect in Area 5a as identified during the video analysis or on the detailed bathymetric map (Figure 3-25). No areas of consolidated hard substrate were present. However, some small and more expansive areas of unconsolidated biologenic gravel resulted in the appearance of a partially-hard substrate. This gravel component was more common in the second half of the transect however cannot be identified on the transect map. The transect was located in water depths which ranged from around 74 m to 76 m (Figure 3-25). Rugosity was generally consistent over the entire transect length.

- While much of the seafloor was bare, benthic epifauna occurred sporadically along the entire transect length and sometimes occurred as small and diverse 'clusters' of sponges and soft corals. These organisms were often quite large and were very diverse in form. Isolated organisms also occurred and were more common in the second half of the transect where the seafloor tended to have a higher biologenic gravel component. Additional classification details and CATAMI codes are provided in Table 3-13. The percentage cover of benthic organisms (within the entire video frame) ranged from around 5% to 40% (excluding any cover of biologenic gravel). The location of georeferenced images with higher benthic cover on the transect map do correspond somewhat to areas with slightly increased rugosity, however, video analysis found they were not restricted to these areas. In addition, higher densities were found in areas with higher biologenic gravel cover and also areas without gravel and fine soft sediment.

- Mobile fauna was present and more common around these clumps of sponges and soft corals. They included echinoderms (e.g.  sea stars, feather stars and sea cucumbers) and small bony fishes (unidentified and usually quickly moving out of the field of view of the ROV).

- Bioturbation of the seafloor was common over the entire transect length and usually occurred in the form of thin trails, small mounds or craters. These indicate that mobile fauna (typically invertebrates) live within and on the soft sediment seafloor.

- Due to strong currents and the ROV tether management it was not possible to run the transect across the proposed pipeline route. In addition, Area 5a was the only area which was surveyed within Area 5.

A summary of the habitat characteristics, flora and fauna seen in Area 5a is provided in Table 3-13. This table also provides the CATAMI Species Codes for each seafloor feature and taxa identified.

A map showing the location of the transect in Area 5a in relation to bathymetry, along with representative images of benthic habitat is provided in Figure 3-25. While some images with benthic cover do tend to occur in locations with slightly higher rugosity this variation in seafloor bathymetry is actually very small. No strong or consistent relationship between bathymetry / rugosity and the occurrence or density of benthic organisms could be inferred from the combined video and mapping analysis, with organisms occurring along the length of the transect and in areas with higher biologenic gravel and also areas with fine soft sediment and no gravel.

Additional images of benthic habitat and sessile organism in Area 5a are provided in **Appendix F**.

*Table 3-13 Summary of habitat features in Area 5a.*

| Habitat Features | Description | CATAMI Species Code | Occurrence |
|---|---|---|---|
| Substrate Type | Unconsolidated (soft): Sand/mud (<2mm)<br>Unconsolidated (soft): Pebble / gravel: Biologenic | 82001005<br>82001007 | Entire Transect<br>Entire Transect |
| Bedform | Bioturbated | 82002005 | Entire transect |
| Relief | Flat | 82003001 | Entire Transect |
| Bioturbation | Bioturbation: Crawling traces: Thin trail<br>Bioturbation: Dwelling traces: Small mound<br>Bioturbation: Dwelling traces: Crater cone | 81005001<br>81001003<br>81001012 | Occasional bioturbation over entire transect |
| Bacterial mats | Bacterial mat | 80000000 | Around ½ transect |
| Flora | Nil | NA | NA |
| Fauna | Echinoderms: Feather stars<br>Echinoderms: Sea stars<br>Echinoderms: Sea cucumbers<br>Sponges: Erect simple<br>Sponges: Erect laminar<br>Sponges: Erect branching<br>Sponges: Cup like<br>Sponges: Cup-likes: Cups<br>Sponges: Cups: Cup / goblet<br>Sponges: Cup-likes: Tubes and chimneys<br>Sponges: Crusts: Creeping / ramose<br>Sponges: Massive forms – simple<br>Sponges: Massive forms: Cryptic -<br>Corals: Black & Octocorals: Quill (seapen)<br>Corals (unidentified soft corals)<br>Corals: Fleshy: Arborescent<br>Corals: Non-fleshy: Bushy<br>Corals: Fern-frond: Complex<br>Corals: Black & Octocorals: Fan (2D)<br>Corals: Black & Octocorals: Whip<br>Cnidaria: Hydroids<br>Fishes: Bony fishes | 25000000<br>25102000<br>25400901<br>10000916<br>10000913<br>10000915<br>10000909<br>10000910<br>10000919<br>10000911<br>10000917<br>10000904<br>10000908<br>11168918<br>11168000<br>11168911<br>11168908<br>11168915<br>11168912<br>11168917<br>11001000<br>37990083 | Diverse 'clumps' of sponges and corals were seen on occasion along the entire transect in Area 5 |

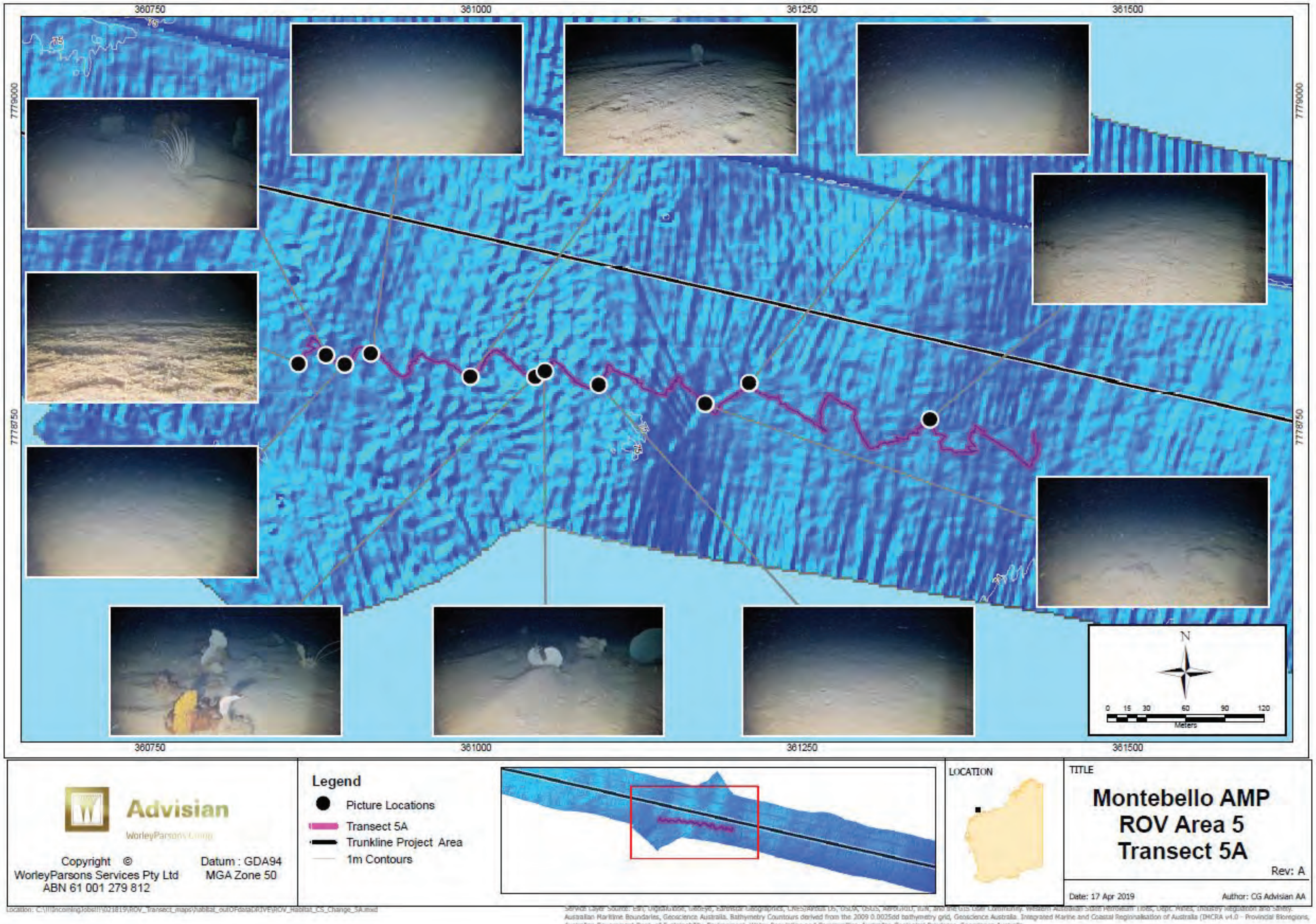


*Figure 3-25 Typical benthic habitat in Area 5a.*

# 4 Summary and Discussion

The benthic habitat within five areas of the Montebello AMP was characterised through assessment of video collected by ROV. This habitat has been described and classified in accordance with the CATAMI Classification System. Area 1 which was the deepest location and was located in the vicinity of the KEF was most different, with a much lower cover of benthic organisms than Areas 2 to 5. Areas 2 to 5 were quite similar in depth and in nature, with some small differences in the density and occurrence of benthic organisms and in substrate type (e.g. variants of soft sediment bedforms and cover of biologenic gavel). A summary of findings for each area surveyed is provided below along with a discussion of the results in relation to the published values for the Montebello AMP and 125m Depth Contour KEF.

## 4.1 Area 1

Area 1 was selected to assess the benthic habitat at the ancient coastline 125 m depth contour KEF and to provide spatial coverage of the AMP. Area 1a was located within the KEF, however Area 1b and 1c were not. No potential features of the KEF (i.e. areas of hard substrate with high biodiversity) were seen along any of the transects surveyed. The actual depth at the midpoint of the transects in Area 1 ranged from 103.2 m to 126.4 m. Benthic habitat along all transects surveyed in Area 1 were typically bare sand with various bedforms including flat bare sand, small ripples (of 2D and 3D forms) and small 'steps' (<50 cm). Some areas of seafloor were bare, while others were covered in a light bacterial mat and others were seen to have a cover of biologenic gravel (of unidentified origin). The cover of biologenic gravel changed continuously over the course of the transects. No moderate or high relief features or areas of consolidated hard substrate were present within any transect.

Benthic organisms (including sponges and soft corals) were present on occasion and generally occurred as single or low density aggregations of individuals. The cover of benthic organisms in Area 1 ranged from 0% to ~15% (being highest in Transect 1c). Slightly higher occurrences of benthic organisms were noted in areas with a higher cover of biologenic gravel (although were in no way limited to these areas and this feature could not be identified by looking at the transect maps). Furthermore, this relationship was not quantified. No relationship between bathymetry and different habitat 'types' or the cover of benthic organisms was seen along individual transects. The occurrence and cover of benthic organisms and the location of different substrate types could not be predicted from any obvious features on the bathymetric maps. Bioturbation of the seafloor was evident in all three transects in Area 1 indicating the presence of mobile organisms living on and within the seabed. Mobile organisms including fish, echinoderms and jellies, were also noted on the video.

The environmental values of the KEF refer to potential areas of hard substrate or rocky escarpments which may provide enhanced biodiversity or biologically important habitat in areas otherwise dominated by soft sediments. However, no hard substrate or rocky escarpments were recorded in Area 1 in the current study. Nonetheless, the soft sediment habitat did support a number of epibenthic and mobile fauna in the form of corals, sponges, echinoderms and fish.

## 4.2 Area 2

Area 2 was selected to provide spatial coverage of the AMP in an area which may include ancient coastline. The actual depth at the midpoint of each of the transects in Area 2 ranged from 70.6 m to 74.4 m. The benthic habitats present along all transects in Area 2 were very similar to each other. The seafloor in Area 2 was relatively flat and sandy with a light to high cover of unconsolidated biologenic gravel and/or organic material. Small undulations of the seabed were seen but no other regular bedforms such as sand ripples or sand waves were apparent. No significant high relief habitat features, or areas of consolidated hard substrate, were observed in any transect. Some areas of seafloor were relatively bare while others included a low (~5%) to high (~80%) density cover of benthic organisms. This was true for all three transects. This benthic cover changed continually and often (within m's) over each transect. Bioturbation of the seafloor in the form of small cones, craters, burrows, small and large trails was also apparent. Mobile organisms including fish, echinoderms and jellies, were also noted on the videos for Area 2.

Benthic epifauna was present over the length of each transect, occurring in patches which varied from low (~5%) to high (~80%) density, and which changed continuously. All three transects were quite similar. Benthic fauna comprised a diverse array of sponges and corals with varying forms, sizes and colours. Hydroids and cnidarians were also apparent on occasion along the transect length. Fish fauna were also common amongst the patches of sponges and corals. Higher cover of benthic organisms were often seen in areas which had higher amounts of visible biologenic gravel, however this was also seen in areas which seemed to comprise more fine sediment with less or no biologenic gravel. The generally common occurrence of benthic organisms in Area 2 may be related to the generally high rugosity which can be seen in all three transect maps. A decrease in benthic cover on some occasions could be related to more expansive areas of lower rugosity (e.g. in Transect 2c) however this was not always the case.

The high biodiversity of sessile and mobile organisms seen at depths of around 70 m – 76 m in Area 2 was in accordance with the natural values of the Montebello AMP in that the area surveyed 'includes diverse benthic and pelagic fish communities'. Area 2 may provide foraging habitat for mobile threatened fauna such as marine turtles and other fish fauna that feed on soft bodied benthic organisms such as sponges and soft corals.

## 4.3 Area 3

Area 3 was selected because it was identified as a point of interest in the AMP and along the trunkline corridor where there are likely to be outcropping / subcropping calcarenite with shallow sediment cover and sediment ponds, along with sections of sandy bottom (KP165-170). The actual depth at the midpoint of the transects in Area 3 ranged from 71.6 m to 73.8 m. The seafloor in Area 3 was relatively flat and sandy with a light to high cover of biologenic gravel and/or organic material over its entire length (continually changing). The seabed was a mosaic of bare substrate and low (~5%) to high (~75% - in Area 3a) density cover of benthic organisms (e.g. sponges / corals). Small undulations of the seabed and some small sand waves were present on occasion, but no other regular bedforms such as sand ripples or sand waves were apparent. No significant moderate or high relief habitat features were observed on the video or can be seen on the transect maps with detailed bathymetry. Any features seen are in the order of ~1 m and occur over relatively large scales. Some potential outcropping was seen, although this was hard to clearly define with the often high cover of unconsolidated biologenic gravel and cover of benthic organisms. Bioturbation of the seafloor in the form of small cones, craters, burrows and small and large trails was apparent. Mobile organisms including fish, echinoderms and jellies, were also noted on the videos for Area 3. Fish fauna diversity was quite high, and varying sizes of fish were seen amongst the aggregations of corals and sponges and also over bare sandy seafloor.

Benthic epifauna were present along the entire transect and occurred in patches which changed continuously from low (~5%) to high (~75%) density. Area 3a contained high density (~75%) aggregations on occasion, however, Area 3b and 3c only reached a medium density (~50%). Benthic fauna comprised a diverse array of sponges and corals with varying forms, sizes and colours. Hydroids and cnidarians were also apparent on occasion along the transect length. While some indication for higher benthic cover in areas containing a higher cover of biologenic gravel and/or areas which appeared slightly more rugose on the transect maps was seen, this relationship was not consistent and there were many occasions where a higher density of organisms was seen on soft sediment with little gravel cover and also on areas of the transect maps which appeared to be quite flat in relation to the rest of the transect.

The high biodiversity of sessile and mobile organisms seen at depths of around 73 m – 76 m in Area 3 was in accordance with the natural values of the Montebello AMP in that the area surveyed 'includes diverse benthic and pelagic fish communities'. Although no clear outcropping / subcropping of calcarenite was seen, areas of biologenic gravel with a medium cover of benthic organisms were common. Area 3, like Area 2, may provide foraging habitat for mobile threatened fauna such as marine turtles and other fish fauna that feed on soft bodied benthic organisms such as sponges and soft corals.

## 4.4 Area 4

Area 4 was included to provide data to assess the benthic habitat adjacent to the Pluto pipeline, in an area that could potentially provide turtle foraging on hard substrate / subcrops (KP160-164). The actual depth at the midpoint of the transects in Area 4 ranged from 74.5 m to 78.2 m. The seafloor within Area 4 was typically flat sand with a high level of biologenic gravel of unknown origin. Small mounds, waves and undulations all < 50 cm in height were seen on occasion and mainly occurred around aggregations of benthic epifauna (i.e. sponges and corals). The seafloor in Area 4 was scattered with sponges and corals of varying forms and sizes. Some occurred as individuals with a low density cover (~5%) and more dense clusters (up to about 50% cover) of organisms were also seen and were more common in some transects (namely 4a and 4b). Areas of bare sand were present amongst the patches of epifauna and were more common in Area 4c than 4b and again than in Area 4a. The switch between bare sand to benthic cover changed constantly and quickly however. Corals and sponges were abundant and diverse in their form and size. Other benthic epifauna included echinoderms (e.g. feather stars which were often attached to sponges/corals) and cnidaria (e.g. seapens). Mobile fauna (mainly small bony fishes) were most common around the larger clusters of sponges and corals. Bioturbation of the seafloor in the form of small mounds and craters was evident along the entire transect length.

No significant moderate or high relief features, or significant areas of consolidated hard substrate, were present in Area 4 as could be seen on the video or transect maps. However, much of the seafloor was covered in a biologic gravel of unknown origin and this was quite dense at times. While at times the bathymetric maps provided some indication of increased cover of benthic organisms in areas with higher rugosity, this was not always the case. In general, Area 4a and 4b were more rugose than 4c, and these two areas did appear to have a more consistent cover of benthic organisms. However, within individual transects, a medium - high density of benthic organisms could be seen in areas that were not necessarily highly rugose (as indicated on the bathymetric maps), and in some cases, density was high in areas with expansive biologenic gravel and at other times was high on areas of bare soft sediment.

The high biodiversity of sessile and mobile organisms seen at depths of around 74 m – 78 m in Area 4 was in accordance with the natural values of the Montebello AMP in that the area surveyed 'includes diverse benthic and pelagic fish communities'. Although no areas of consolidated hard substrate or subcrops were seen, the high epibenthic diversity, which included soft corals and sponges, could very well provide a foraging habitat for threatened marine turtles, along with other mobile fauna which are able to live at or travel to these depths.

## 4.5 Area 5

Area 5 was included for completeness to compare benthic habitat adjacent to the existing Pluto pipeline at the eastern end of the AMP. The actual depth at the midpoint of the only transect surveyed in Area 5 was 74.6 m. The seafloor in Area 5 consisted of flat sand, often with an organic cover (likely bacterial or algae) or a biologenic gravel component. The seafloor showed some slight undulation in places and scour marks commonly occurred around small 'clusters' of benthic epifauna (i.e. sponges and corals). No regular bedforms such as sand ripples or sand waves were present in this location. No significant moderate or high relief features were present along the transect in Area 5. No significant areas of consolidated hard substrate were seen. However, the biologenic gravel resulted in a partially-hard looking substrate.

Benthic epifauna occurred sporadically along the entire transect length and generally occurred as diverse 'clusters' of sponges and corals. These organisms were often large and were very diverse in form. The percentage cover of benthic organisms (within the entire video frame) ranged from 5% to ~40% (excluding any cover of biologenic gravel). No strong or consistent relationship between bathymetry / rugosity and the occurrence or density of benthic organisms could be inferred from the combined video and mapping analysis, with organisms occurring along the length of the transect and in areas with higher biologenic gravel and also areas with fine soft sediment and no gravel.

Mobile fauna were common around these clumps of sponges and corals. They included echinoderms (e.g. sea stars, feather stars and sea cucumbers) and small bony fishes. Bioturbation of the seafloor was common over the entire transect length and usually occurred in the form of thin trails, small mounds or craters.

The high biodiversity of sessile and mobile organisms seen at depths of around 74 m in Area 5 was in accordance with the natural values of the Montebello AMP in that the area surveyed 'includes diverse benthic and pelagic fish communities'. This area may provide foraging habitat for mobile threatened fauna such as marine turtles and other fish fauna that feed on soft bodied benthic organisms such as sponges and soft corals.

## 4.6 Previous Benthic Surveys

Benthic habitat data from the North-West Shelf including the Montebello AMP has been collected in several previous surveys including the 2017 RV Investigator voyage (Keesing, 2019), the 2013 Pilbara Marine Conservation Partnership (PMCP) surveys (Pitcher et al., 2016) and the 1982–1997 CSIRO North West Shelf (NWS) Effects of Trawling project (Sainsbury, 1988; 1991). General findings of these studies are provided below.

Data used to describe benthic substrates and biota from the 2017 RV Investigator voyage were principally derived from still camera images. This study showed that substrate and topography in the Montebello AMP was predominantly fine sand or a mix of fine and coarse sand. While deeper sites were often all coarse sand, some rubbly areas were observed at the shallowest sites. The general topography was predominantly flat bottom with occasional bioturbated areas. Apart from the most inshore site, most sites surveyed in the eastern section of the Montebello AMP had low numbers of sponges, whips and gorgonians. Complex benthic filter feeder communities were largely absent. The dominant filter feeders were hydroids, seapens and crinoids. The most commonly recorded crinoid was *Comatula rotalaria* which is free living on sand rather than associated with other filter feeders like gorgonians. One site surveyed was notable for the large numbers of seapens present and most sites had large areas characterised by soft sediment dwelling crinoids or hydroids and seapens rather than the complex sponge and soft coral communities observed in the Dampier MP.

The CSIRO Effects of Trawling Project conducted between 1982 and 1997 included 21 transects in the Montebello AMP. Substrate type was very similar across the whole of the AMP and similar to the 2017 surveys, being predominantly fine sand or a mix or fine and coarse sand, with some sites having rubbly areas. Topography was mostly fine sand or fine sand with ripples. Three sites had large proportions of ridges or large ripples or very large ripples. All of these sites were located at the far western side of the MP, two of these in the very south-western section of the MP. The biota recorded in the CSIRO studies varied notably from that during the 2017 RV Investigator surveys. In particular, the large proportion of sponges and small proportion of crinoids seen on the historical voyages. However, two historical sites located in the eastern part of the MP where the 2017 samples were taken also had a large proportion of images with no biota.

The Pilbara Marine Conservation Partnership (PMCP) project (Babcock et al. 2017) included habitat and biodiversity mapping in the region between North West Cape and Barrow Island and the Montebello Islands. One of the study components assessed benthic habitats and biodiversity in this region (Pitcher et al. 2016) and included sites in what is now the Montebello AMP. Substrate type recorded by video at the 2013 survey sites was either fine or coarse sand at four sites and rippled at two sites located in the south-western section of the AMP. The towed video sites surveyed in the south-western part of the AMP had large proportions of video transects where no biota was evident. Dense sponges occurred at shallower sites on the central southern and south-western section of the MP, west of the islands and a site also in the south-western section had a large proportion of gorgonian habitat.

The results of previous benthic studies in the Montebello AMP are largely in alignment with the findings of the current study in terms of the benthic habitat recorded (typically low relief sandy seafloor (with various bedforms) with occasional rubbly areas increasing at sites more inshore) as well as the dominant benthic organisms identified (which varied in diversity and density within and between survey areas, but typically included a wide variety of sponges and soft corals including whips and gorgonians, hydroids, seapens and crinoids).

# 5 References

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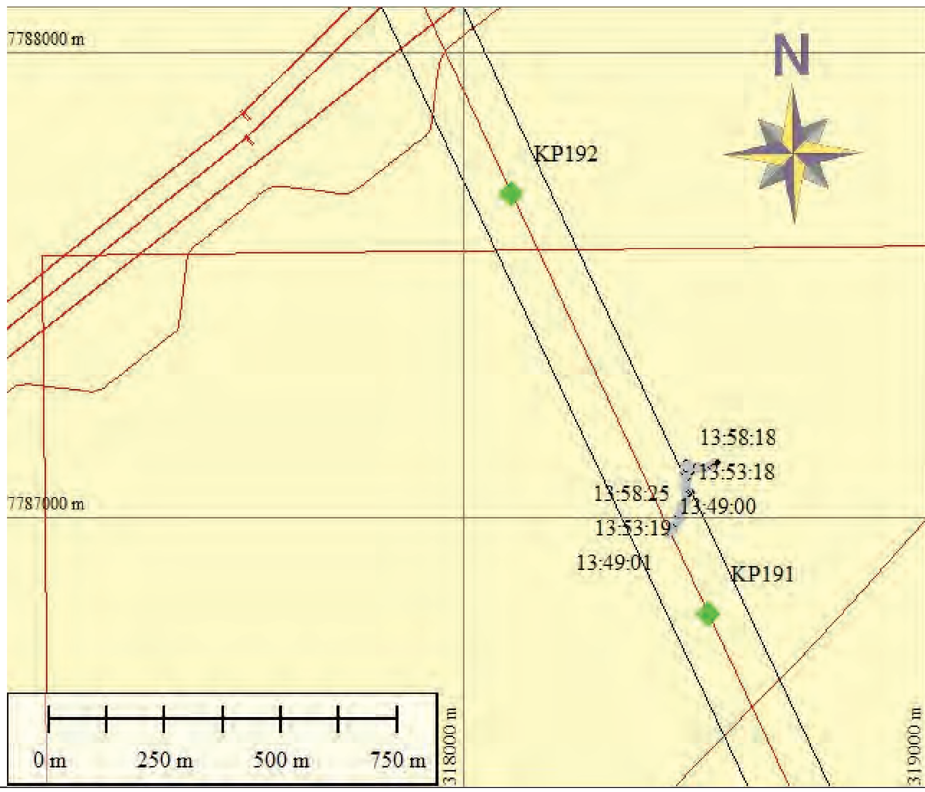
Sainsbury, K. J. (1988). The ecological basis of multispecies fisheries, and management of a demersal fishery in tropical Australia. In: Fish population dynamics. 2nd ed. ed. Editor J. A. Gulland, Chapter 14, pp 349–382, John Wiley & Sons Ltd.

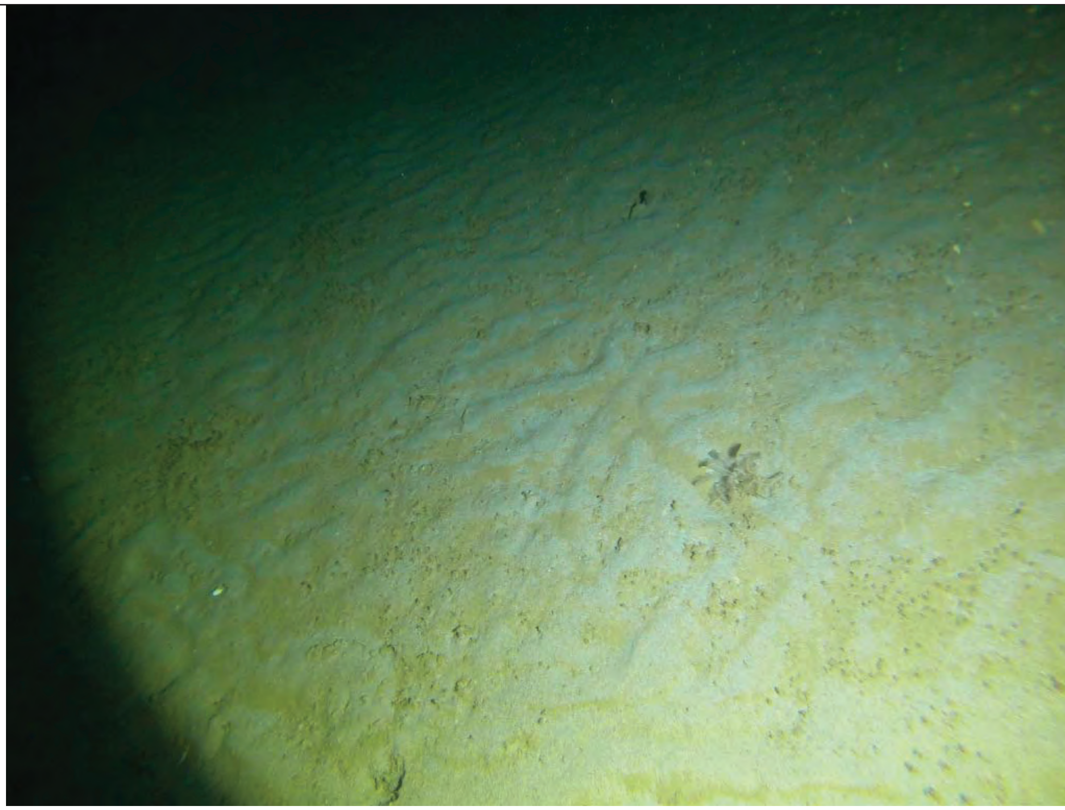
Sainsbury, K. J. (1991). Application of an experimental approach to management of a tropical multispecies fishery with highly uncertain dynamics. ICES Marine Science Symposia, 193, 301–320.

# Appendix A: Transect Memos (Neptune)

<table>
<tr><td colspan="5">SCARBOROUGH DEVELOPMENT - SHALLOW WATER GEOPHYSICAL & GEOTECHNICAL SURVEY 2018</td></tr>
<tr><td>Technical Memo:<br>No. 01</td><td>Date:<br>31/01/2019</td><td>Phase:<br>Environmental</td><td>Area of Ops: Area 1A<br>(KP191.5)</td><td>Rev.1</td></tr>
<tr><td colspan="5">Title: ENVIRONMENTAL OBSERVATIONS FROM AREA 1A</td></tr>
<tr><td colspan="5">Scope: Undertake a ROV transect obliquely across the planned PL route to identify benthic habitat.<br><br>Aim: Report preliminary findings of ROV transect to office</td></tr>
<tr><td colspan="5">Location: Proposed pipeline route in the vicinity of KP191.195, in the area of the AMP. The ROV transect crosses the PL route at E318445, N7786967 (time stamp 13:49:11). ROV on bottom at 13:49, off bottom at 14:03.



</td></tr>
<tr><td colspan="5">Description:<br>A flat rippled fine sandy seabed with small isolated sandwaves. Ripples have an organic/algae? covering particularly in the troughs. Isolated soft corals also occur on the sand.</td></tr>
</table>



**Conclusions and recommendations:**
Seabed comprise a flat sandy seabed which has a sparse benthic sand-dwelling habitat. No significant high relief habitat features were observed.

Due to strong currents and the ROV tether management it was not possible to run the transect more along the proposed pipeline route.

| | |
|---|---|
| Author: Ian Wright | Client Approval: Mike Varsanyi |

**SCARBOROUGH DEVELOPMENT - SHALLOW WATER GEOPHYSICAL & GEOTECHNICAL SURVEY 2018**

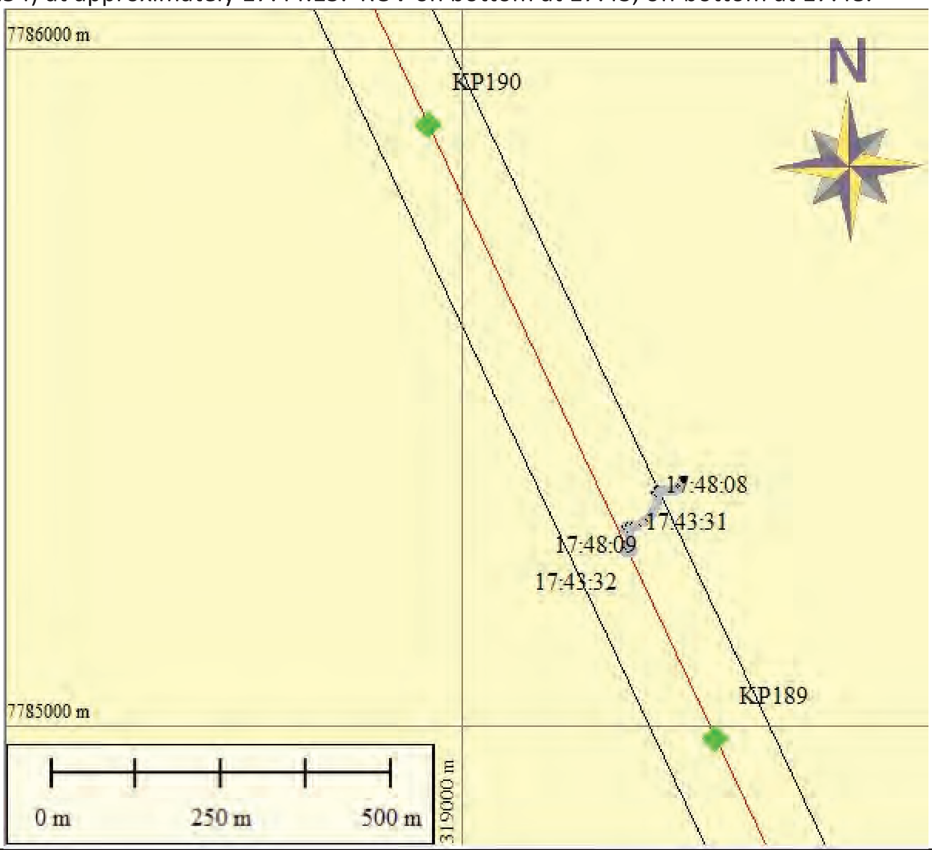
| Technical Memo: No. 02 | Date: 31/01/2019 | Phase: Environmental | Area of Ops: Area 1B (KP189.5) | Rev.1 |
|---|---|---|---|---|

**Title:** ENVIRONMENTAL OBSERVATIONS FROM AREA 1B

**Scope:** Undertake a ROV transect obliquely across the planned PL route to identify benthic habitat.

**Aim:** Report preliminary findings of ROV transect to office

**Location:** ROV crosses the proposed pipeline route in the vicinity of KP189.308 (E 319248, N7785254) at approximately 17:44:15. ROV on bottom at 17:43, off bottom at 17:48.

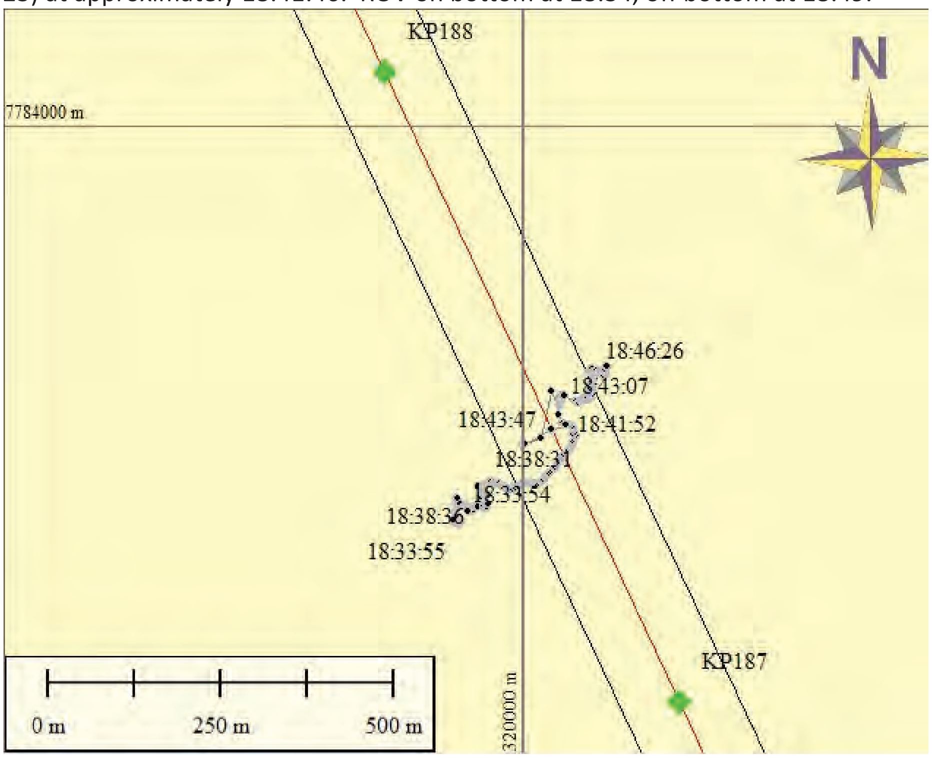


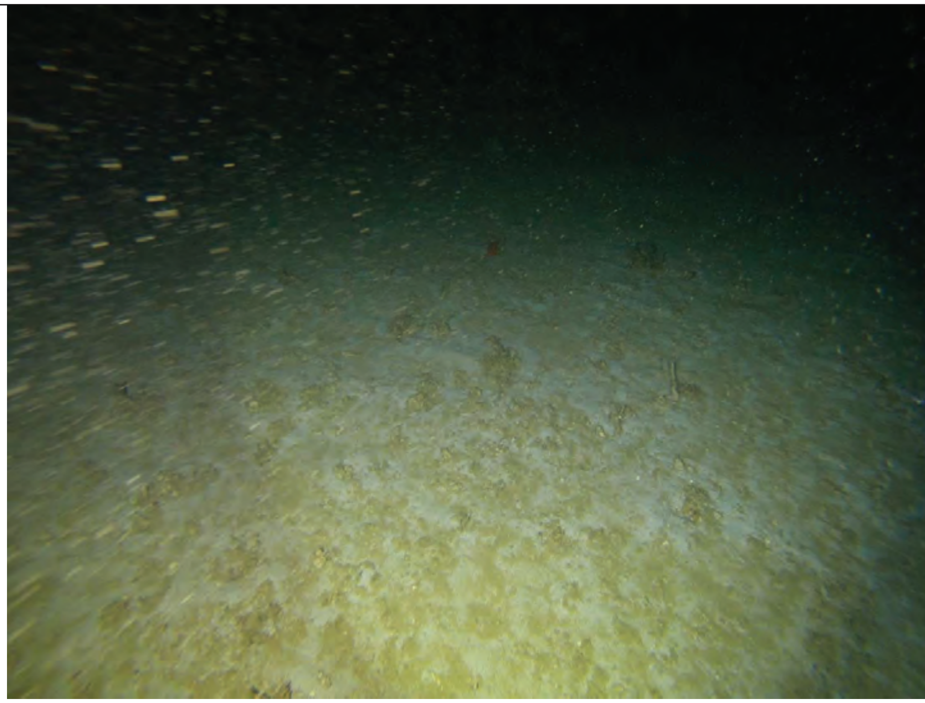

**Description:**
A typically flat fine sandy seabed which has ripples and larger sandwaves associated with it. Ripples have an organic/algae? covering particularly in the troughs. The small sandwave crests (probably less than 0.5m high) are cleaner and can be seen to prograde over the sediments burying isolated benthic fauna which typically occurs as soft corals and sponges

**Conclusions and recommendations:**
Seabed comprise a flat sandy seabed which has a sparse benthic sand-dwelling habitat. No significant high relief habitat features were observed.

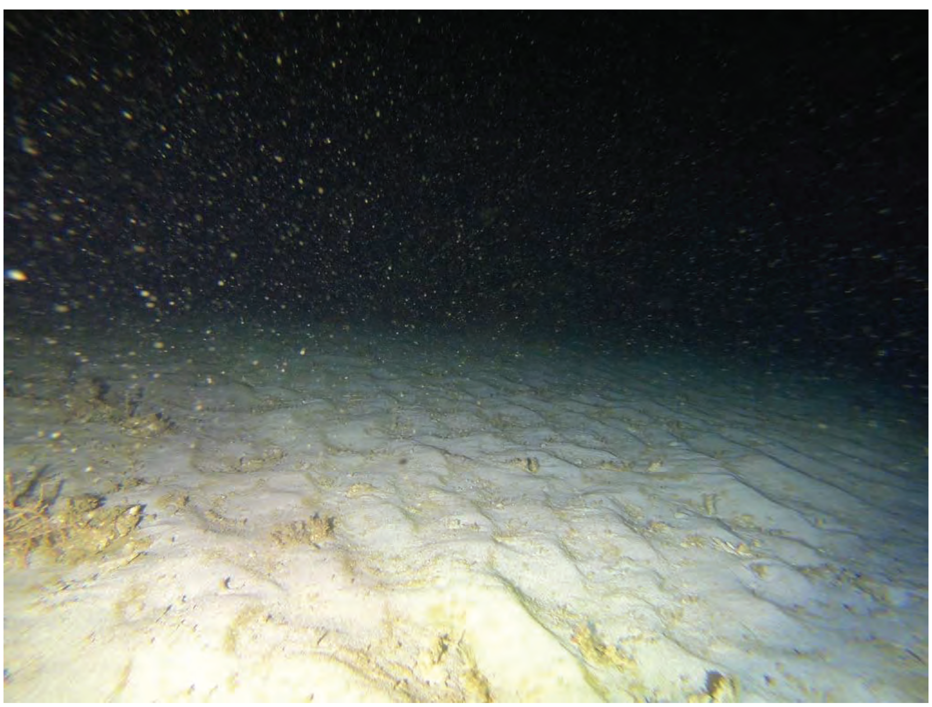
Due to strong currents and the ROV tether management it was not possible to run the transect more along the proposed pipeline route.

| | |
|---|---|
| Author: Ian Wright | Client Approval: Mike Varsanyi |

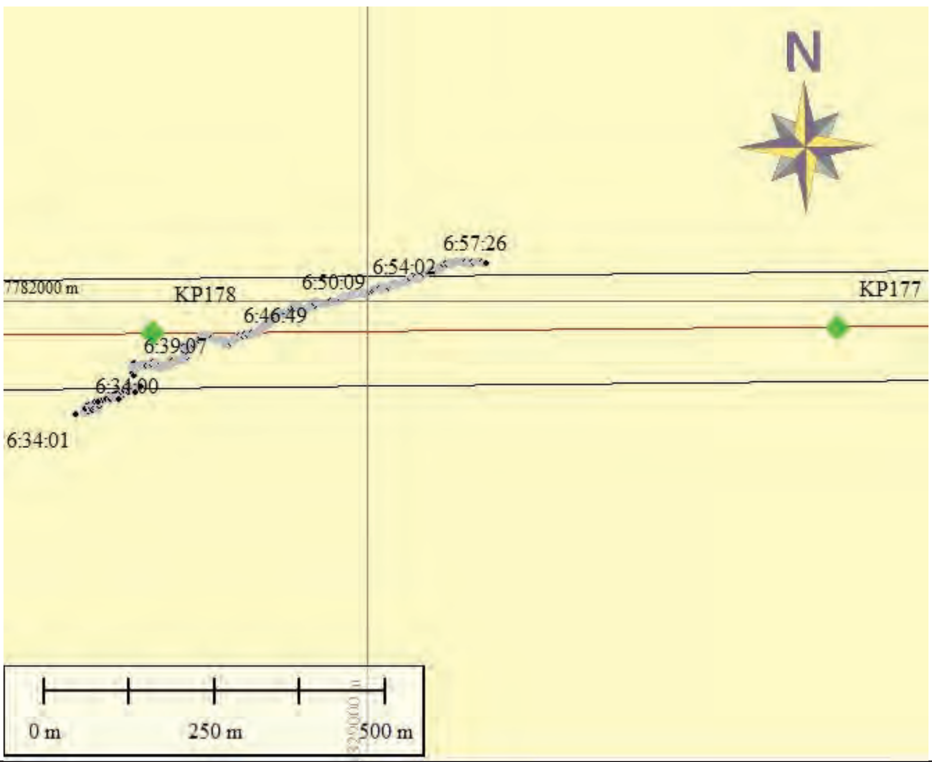
| SCARBOROUGH DEVELOPMENT - SHALLOW WATER GEOPHYSICAL & GEOTECHNICAL SURVEY 2018 | | | | |
|---|---|---|---|---|
| Technical Memo: No. 03 | Date: 31/01/2019 | Phase: Environmental | Area of Ops: Area 1C (KP187.5) | Rev.1 |
| **Title:** ENVIRONMENTAL OBSERVATIONS FROM AREA 1C | | | | |
| **Scope:** Undertake a ROV transect obliquely across the planned PL route to identify benthic habitat.<br><br>**Aim:** Report preliminary findings of ROV transect to office | | | | |
| **Location:** ROV crosses the proposed pipeline route in the vicinity of KP187.392 (E320057, N7783523) at approximately 18:41:46. ROV on bottom at 18:34, off bottom at 18:49. | | | | |
|   | | | | |
| **Description:** The south western margin of the track shows the seabed is flat comprising sand and larger gravel to small boulder sized carbonate debris which may be a localised hardpan formed from biological activity or sub-outcropping calcarenite. | | | | |

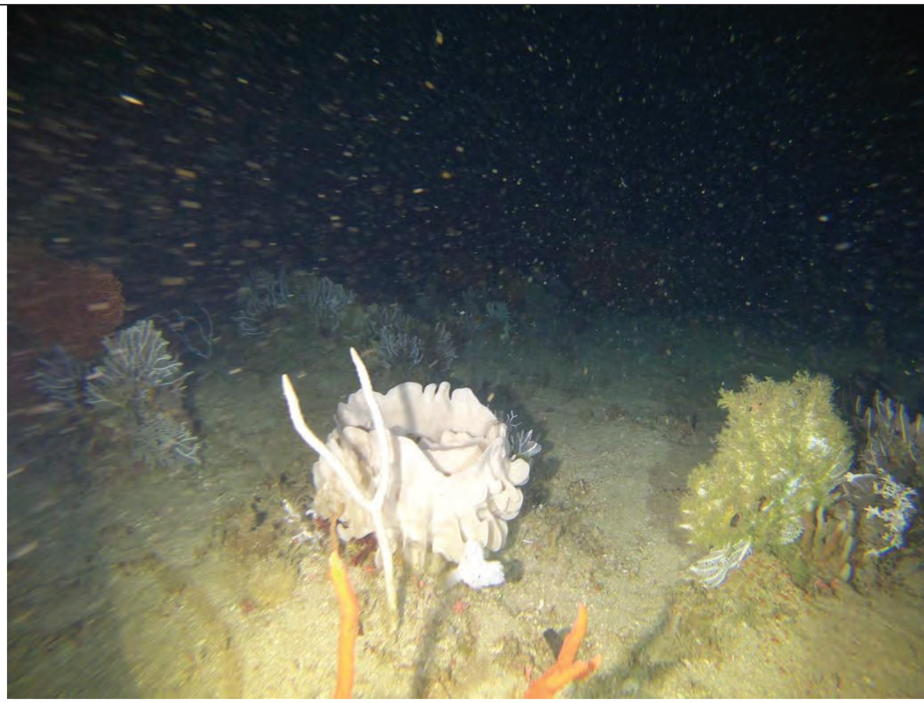


In the vicinity of the PL route (KP187.392, E320057, N7783520) the seabed is typically flat and has ripples associated with it. These typically have an organic/algae? covering particularly in the troughs. Isolated soft corals also occur.



| **Conclusions and recommendations:**<br>Seabed comprise a flat sandy seabed which has a sparse benthic habitat. No significant habitat features were observed.<br><br>Due to strong currents and the ROV tether management it was not possible to run the transect more along the proposed pipeline route. | |
|---|---|
| Author: Ian Wright | Client Approval: Mike Varsanyi |

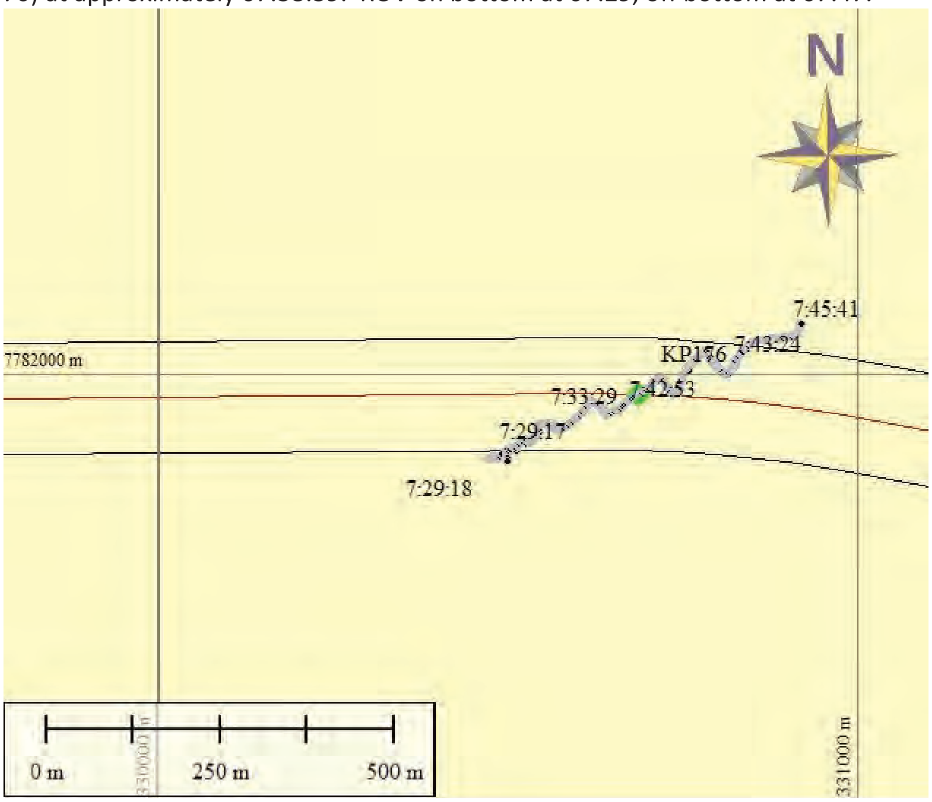
| **SCARBOROUGH DEVELOPMENT - SHALLOW WATER GEOPHYSICAL & GEOTECHNICAL SURVEY 2018** | | | | |
|---|---|---|---|---|
| Technical Memo: No. 04 | Date: 01/02/2019 | Phase: Environmental | Area of Ops: Area 2A (KP178) | Rev.0 |
| **Title:** ENVIRONMENTAL OBSERVATIONS FROM AREA 2A | | | | |
| **Scope:** Undertake a ROV transect obliquely across the planned PL route to identify benthic habitat.<br><br>**Aim:** Report preliminary findings of ROV transect to office | | | | |
| **Location:** ROV crosses the proposed pipeline route in the vicinity of KP177.8 (E328839, N7781947) at approximately 06:48:04. ROV on bottom at 06:34, off bottom at 06:59.  | | | | |
| **Description:** The seabed is flat and comprises sand with subordinate bioclastic gravel. Benthic fauna includes prolific soft corals, including large gorgonians and sponges | | | | |



**Conclusions and recommendations:**
Seabed comprise a flat predominantly sandy seabed which has a considerable benthic habitat in the form of soft corals and sponges. No significant high relief habitat features were observed.

| Author: Ian Wright | Client Approval: Mike Varsanyi |
| --- | --- |

<table>
<tr><td colspan="5">SCARBOROUGH DEVELOPMENT - SHALLOW WATER GEOPHYSICAL & GEOTECHNICAL SURVEY 2018</td></tr>
<tr><td>Technical Memo:<br>No. 05</td><td>Date:<br>01/02/2019</td><td>Phase:<br>Environmental</td><td>Area of Ops: Area 2B<br>(KP176)</td><td>Rev.0</td></tr>
<tr><td colspan="5">Title: ENVIRONMENTAL OBSERVATIONS FROM AREA 2B</td></tr>
<tr><td colspan="5">Scope: Undertake a ROV transect obliquely across the planned PL route to identify benthic habitat.<br><br>Aim: Report preliminary findings of ROV transect to office</td></tr>
<tr><td colspan="5">Location: ROV crosses the proposed pipeline route in the vicinity of KP175.95 (E330686, N7781970) at approximately 07:38:39. ROV on bottom at 07:29, off bottom at 07:47.<br>



</td></tr>
<tr><td colspan="5">Description: The seabed is flat and comprises sand with subordinate bioclastic gravel. Benthic fauna includes soft corals, including large gorgonians and sponges</td></tr>
</table>

**Conclusions and recommendations:**
Seabed comprise a flat predominantly sandy seabed which has a benthic habitat in the form of soft corals and sponges.  No significant high relief habitat features were observed.

| | |
|---|---|
| Author: Ian Wright | Client Approval: Mike Varsanyi |

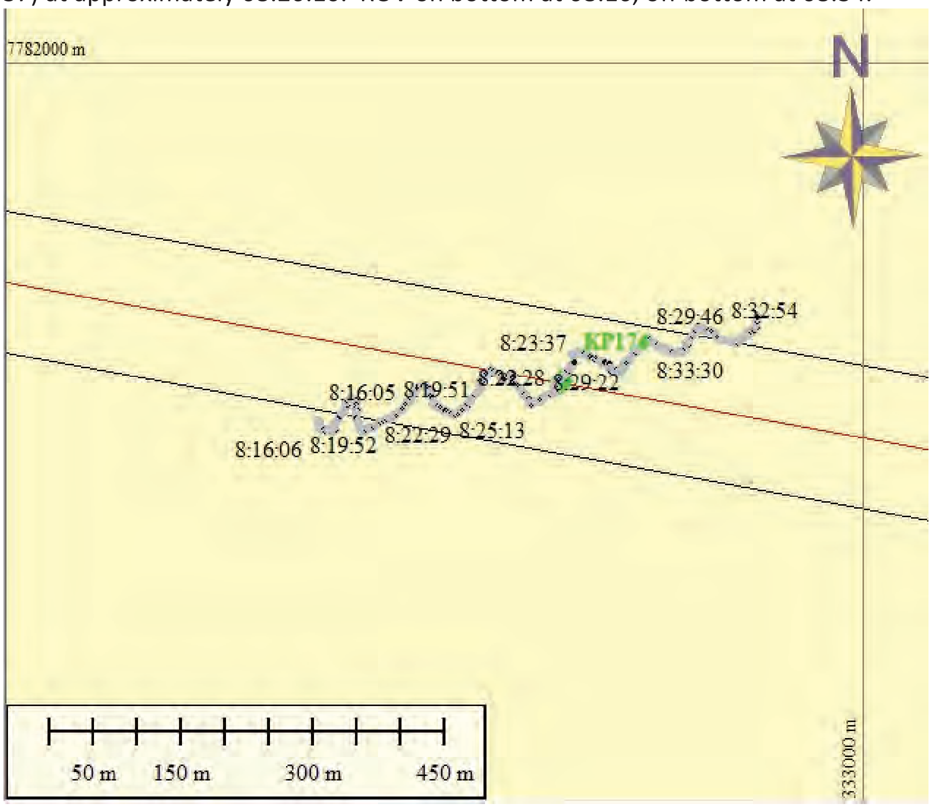
| SCARBOROUGH DEVELOPMENT - SHALLOW WATER GEOPHYSICAL & GEOTECHNICAL SURVEY 2018 | | | | |
|---|---|---|---|---|
| Technical Memo: No. 06 | Date: 01/02/2019 | Phase: Environmental | Area of Ops: Area 2C (KP174) | Rev.0 |

**Title:** ENVIRONMENTAL OBSERVATIONS FROM AREA 2C

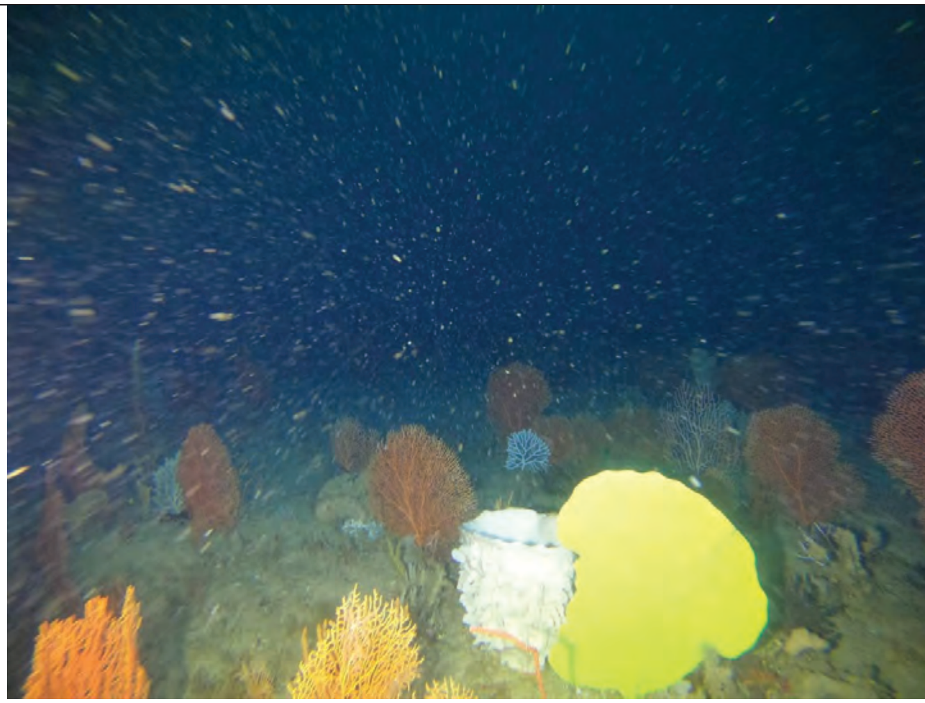
**Scope:** Undertake a ROV transect obliquely across the planned PL route to identify benthic habitat.

**Aim:** Report preliminary findings of ROV transect to office

**Location:** ROV crosses the proposed pipeline route in the vicinity of KP173.95 (E332653, N7781637) at approximately 08:26:10. ROV on bottom at 08:16, off bottom at 08:34.




**Description:** The seabed is flat and comprises sand with subordinate bioclastic gravel. Benthic fauna includes areas of soft corals, including large gorgonians and sponges.



**Conclusions and recommendations:**
Seabed comprise a flat predominantly sandy seabed which has a benthic habitat in the form of areas of soft corals and sponges.  No significant high relief habitat features were observed.

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|---|---|
| Author: Ian Wright | Client Approval: Mike Varsanyi |

**SCARBOROUGH DEVELOPMENT - SHALLOW WATER GEOPHYSICAL & GEOTECHNICAL SURVEY 2018**

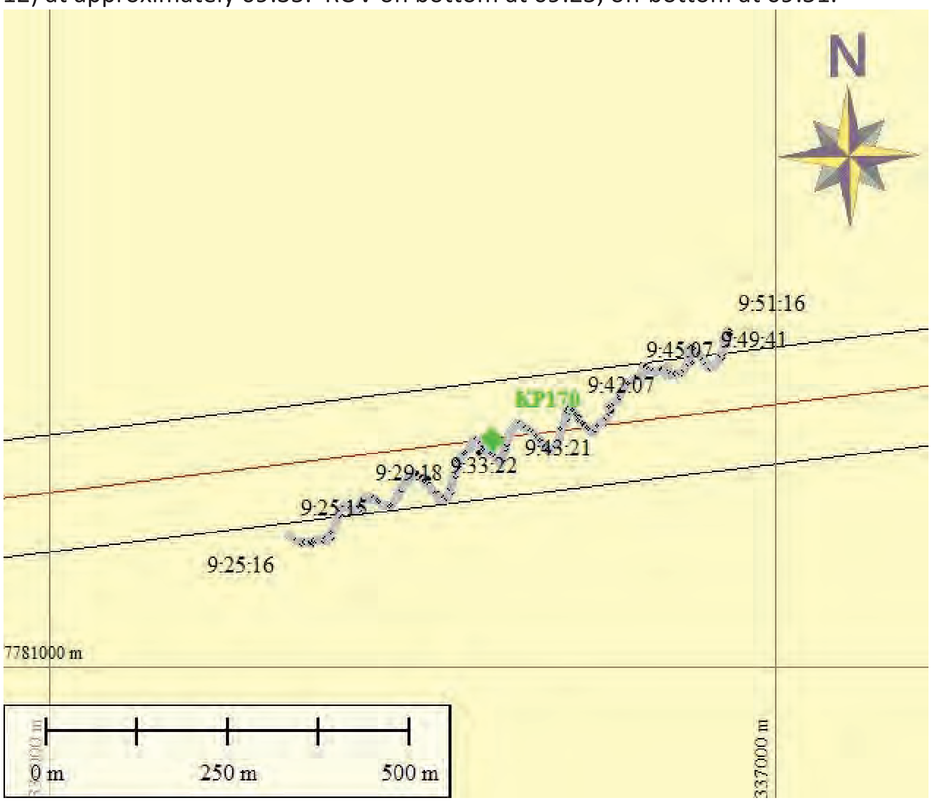
| Technical Memo: No. 07 | Date: 01/02/2019 | Phase: Environmental | Area of Ops: Area 3A (KP170) | Rev.0 |
|---|---|---|---|---|

**Title:** ENVIRONMENTAL OBSERVATIONS FROM AREA 3A

**Scope:** Undertake a ROV transect obliquely across the planned PL route to identify benthic habitat.

**Aim:** Report preliminary findings of ROV transect to office

**Location:** ROV crosses the proposed pipeline route in the vicinity of KP169.05 (E336608, N7781312) at approximately 09:35. ROV on bottom at 09:25, off bottom at 09:51.




**Description:** The seabed is typically flat and comprises sand with subordinate bioclastic gravel. Benthic fauna includes areas of soft corals, including large gorgonians and sponges as well as black 'whip' corals.

**Conclusions and recommendations:**
Seabed comprise a flat predominantly sandy seabed which has a benthic habitat in the form of areas of soft corals and sponges. No significant high relief habitat features were observed.

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| Author: Ian Wright | Client Approval: Mike Varsanyi |

**SCARBOROUGH DEVELOPMENT - SHALLOW WATER GEOPHYSICAL & GEOTECHNICAL SURVEY 2018**

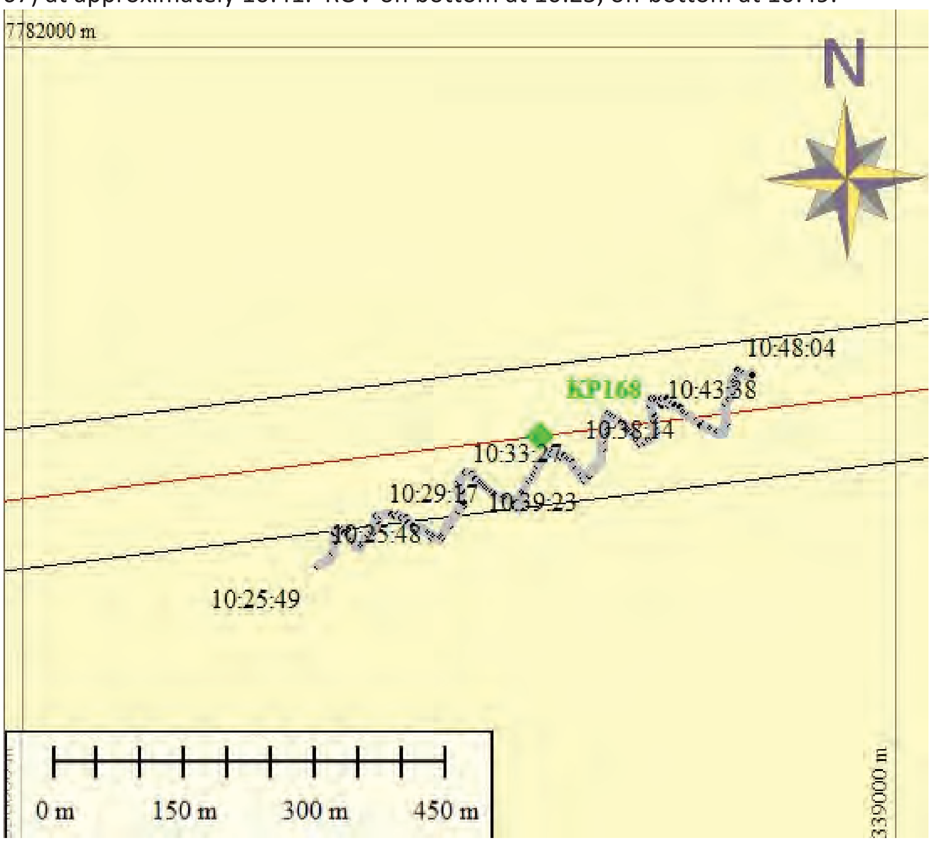
| Technical Memo: No. 08 | Date: 01/02/2019 | Phase: Environmental | Area of Ops: Area 3B (KP168) | Rev.0 |
|---|---|---|---|---|

**Title:** ENVIRONMENTAL OBSERVATIONS FROM AREA 3B

**Scope:** Undertake a ROV transect obliquely across the planned PL route to identify benthic habitat.

**Aim:** Report preliminary findings of ROV transect to office

**Location:** ROV crosses the proposed pipeline route in the vicinity of KP167.88 (E338667, N7781567) at approximately 10:41. ROV on bottom at 10:25, off bottom at 10:49.




**Description:** The seabed is typically flat and comprises sand with subordinate bioclastic gravel. Benthic fauna includes areas of soft corals, including large gorgonians and sponges.

| | |
|---|---|
| **Conclusions and recommendations:**<br>Seabed comprise a flat predominantly sandy seabed which has a benthic habitat in the form of areas of soft corals and sponges.  No significant high relief habitat features were observed. | |
| Author: Ian Wright | Client Approval: Mike Varsanyi |

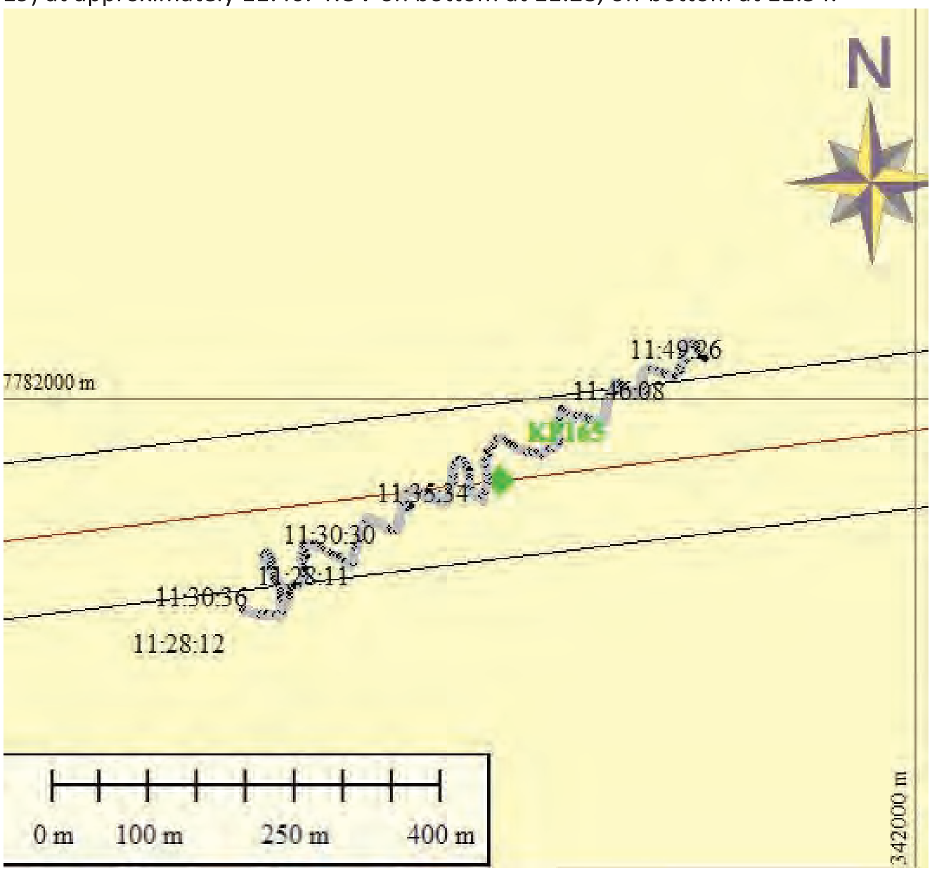
| SCARBOROUGH DEVELOPMENT - SHALLOW WATER GEOPHYSICAL & GEOTECHNICAL SURVEY 2018 | | | | |
|---|---|---|---|---|
| Technical Memo: No. 09 | Date: 01/02/2019 | Phase: Environmental | Area of Ops: Area 3C (KP165) | Rev.0 |

**Title:** ENVIRONMENTAL OBSERVATIONS FROM AREA 3C

**Scope:** Undertake a ROV transect obliquely across the planned PL route to identify benthic habitat.

**Aim:** Report preliminary findings of ROV transect to office

**Location:** ROV crosses the proposed pipeline route in the vicinity of KP164.95 (E341572, N7781919) at approximately 11:40. ROV on bottom at 11:28, off bottom at 11:54.




**Description:** The seabed is typically flat to undulating and comprises sand with subordinate bioclastic gravel. Benthic fauna includes sporadic areas of soft corals, including large gorgonians and sponges as well as black ‘whip’ corals. Current scour moats are noted around some of the sponges.

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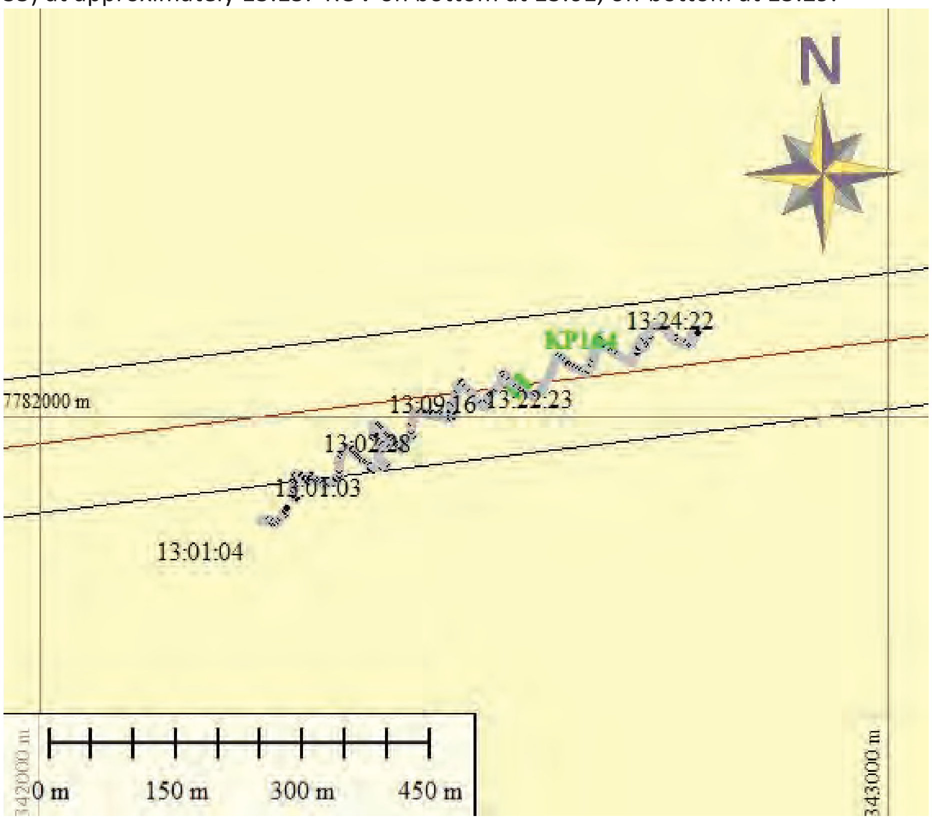
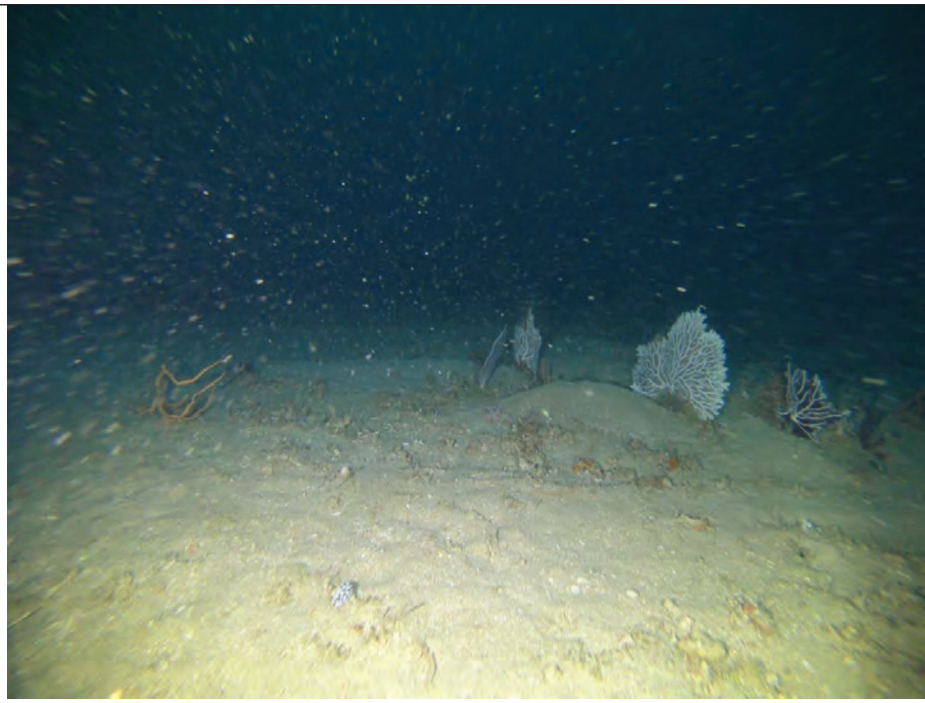
|---|---|
| **Conclusions and recommendations:**<br>Seabed comprise a flat predominantly sandy seabed which has a benthic habitat in the form of isolated areas of soft corals and sponges. No significant high relief habitat features were observed. | |
| Author: Ian Wright | Client Approval: Mike Varsanyi |

<table>
<tr><td colspan="5">SCARBOROUGH DEVELOPMENT - SHALLOW WATER GEOPHYSICAL & GEOTECHNICAL SURVEY 2018</td></tr>
<tr><td>Technical Memo:<br>No. 10</td><td>Date:<br>01/02/2019</td><td>Phase:<br>Environmental</td><td>Area of Ops: Area 4A<br>(KP164)</td><td>Rev.0</td></tr>
<tr><td colspan="5">Title: ENVIRONMENTAL OBSERVATIONS FROM AREA 4A</td></tr>
<tr><td colspan="5">Scope: Undertake a ROV transect obliquely across the planned PL route to identify benthic habitat.<br><br>Aim: Report preliminary findings of ROV transect to office</td></tr>
<tr><td colspan="5">Location: ROV crosses the proposed pipeline route in the vicinity of KP163.95 (E342566, N7782035) at approximately 13:15. ROV on bottom at 13:01, off bottom at 13:29.<br></td></tr>
<tr><td colspan="5">Description: The seabed is typically flat to undulating and comprises sand with subordinate bioclastic gravel. ‘Starved’ ripples occur and typically have coarser gravel in their troughs. Benthic fauna includes sporadic areas of soft corals, including large gorgonians and sponges as well as black ‘whip’ corals. Current scour moats are noted around some of the sponges.</td></tr>
</table>



| | |
|---|---|
| **Conclusions and recommendations:**<br>Seabed comprise a flat predominantly sandy seabed which has a benthic habitat in the form of isolated areas of soft corals and sponges. No significant high relief habitat features were observed. | |
| Author: Ian Wright | Client Approval: Mike Varsanyi |

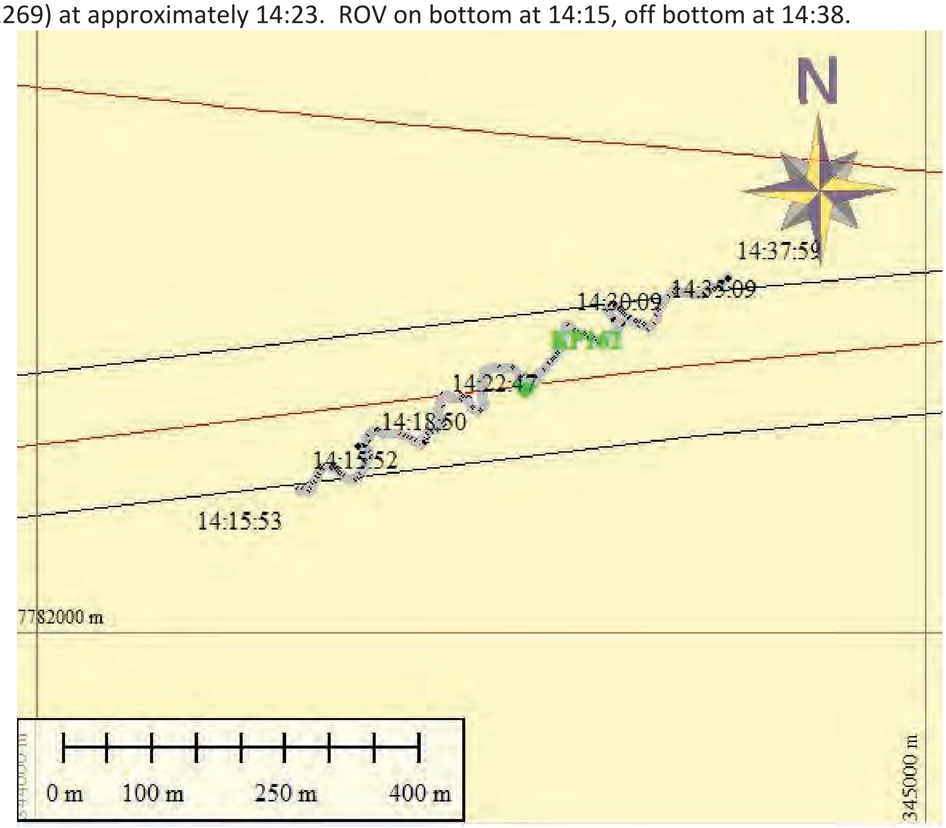
| **SCARBOROUGH DEVELOPMENT - SHALLOW WATER GEOPHYSICAL & GEOTECHNICAL SURVEY 2018** | | | | |
|---|---|---|---|---|
| Technical Memo: No. 11 | Date: 01/02/2019 | Phase: Environmental | Area of Ops: Area 4B (KP162) | Rev.0 |

**Title:** ENVIRONMENTAL OBSERVATIONS FROM AREA 4B

**Scope:** Undertake a ROV transect obliquely across the planned PL route to identify benthic habitat.

**Aim:** Report preliminary findings of ROV transect to office

**Location:** ROV crosses the proposed pipeline route in the vicinity of KP162.00 (E344502, N7782269) at approximately 14:23. ROV on bottom at 14:15, off bottom at 14:38.




**Description:** The seabed is typically flat to undulating and comprises sand with subordinate bioclastic gravel. 'Starved' ripples occur and typically have coarser gravel in their troughs. Benthic fauna includes sporadic areas of soft corals, including gorgonians and sponges as well as black 'whip' corals. Current scour moats are noted around some of the sponges.

**Conclusions and recommendations:**
Seabed comprise a flat predominantly sandy seabed which has a benthic habitat in the form of isolated areas of soft corals and sponges.  No significant high relief habitat features were observed.

| | |
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| Author: Ian Wright | Client Approval: Mike Varsanyi |

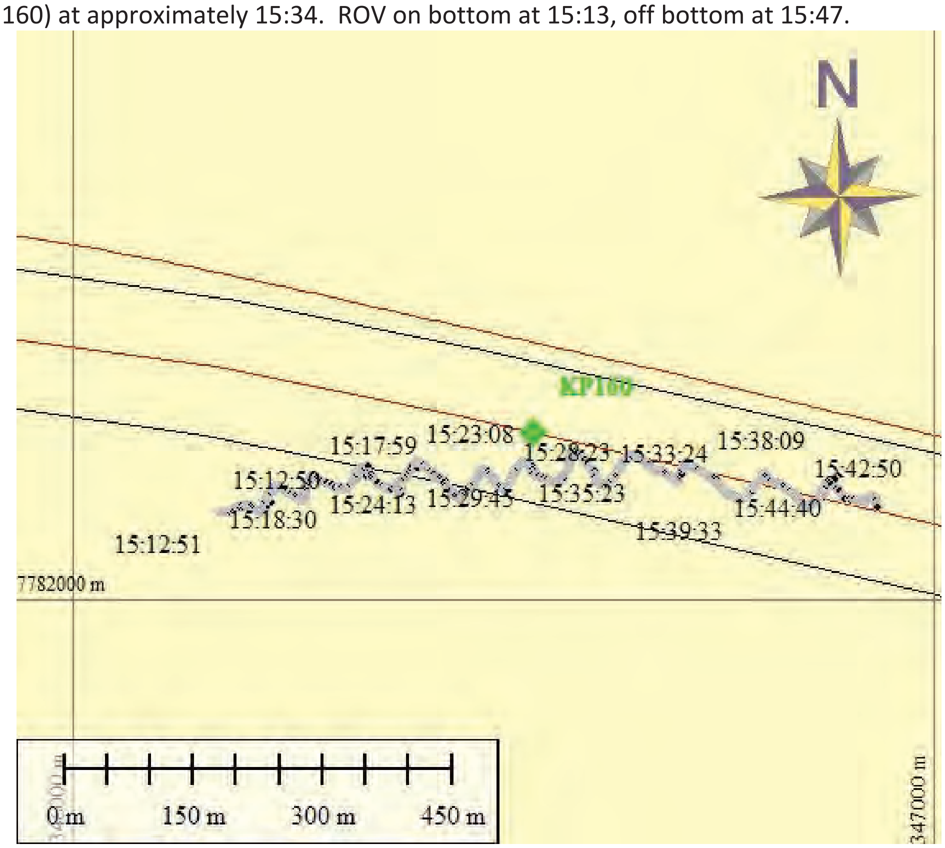
| SCARBOROUGH DEVELOPMENT - SHALLOW WATER GEOPHYSICAL & GEOTECHNICAL SURVEY 2018 | | | | |
|---|---|---|---|---|
| Technical Memo: No. 12 | Date: 01/02/2019 | Phase: Environmental | Area of Ops: Area 4C (KP160) | Rev.0 |

**Title:** ENVIRONMENTAL OBSERVATIONS FROM AREA 4C

**Scope:** Undertake a ROV transect obliquely across the planned PL route to identify benthic habitat.

**Aim:** Report preliminary findings of ROV transect to office

**Location:** ROV crosses the proposed pipeline route in the vicinity of KP159.83 (E346650, N7782160) at approximately 15:34. ROV on bottom at 15:13, off bottom at 15:47.




**Description:** The seabed is typically flat to undulating and comprises sand with subordinate bioclastic gravel. 'Starved' ripples occur and typically have coarser gravel in their troughs. Benthic fauna includes sporadic areas of soft corals, including gorgonians and sponges. Current scour moats are noted around some of the sponges.

| | |
|---|---|
| **Conclusions and recommendations:**<br>Seabed comprise a flat predominantly sandy seabed which has a benthic habitat in the form of isolated areas of soft corals and sponges.  No significant high relief habitat features were observed. | |
| Author: Ian Wright | Client Approval: Mike Varsanyi |

**SCARBOROUGH DEVELOPMENT - SHALLOW WATER GEOPHYSICAL & GEOTECHNICAL SURVEY 2018**

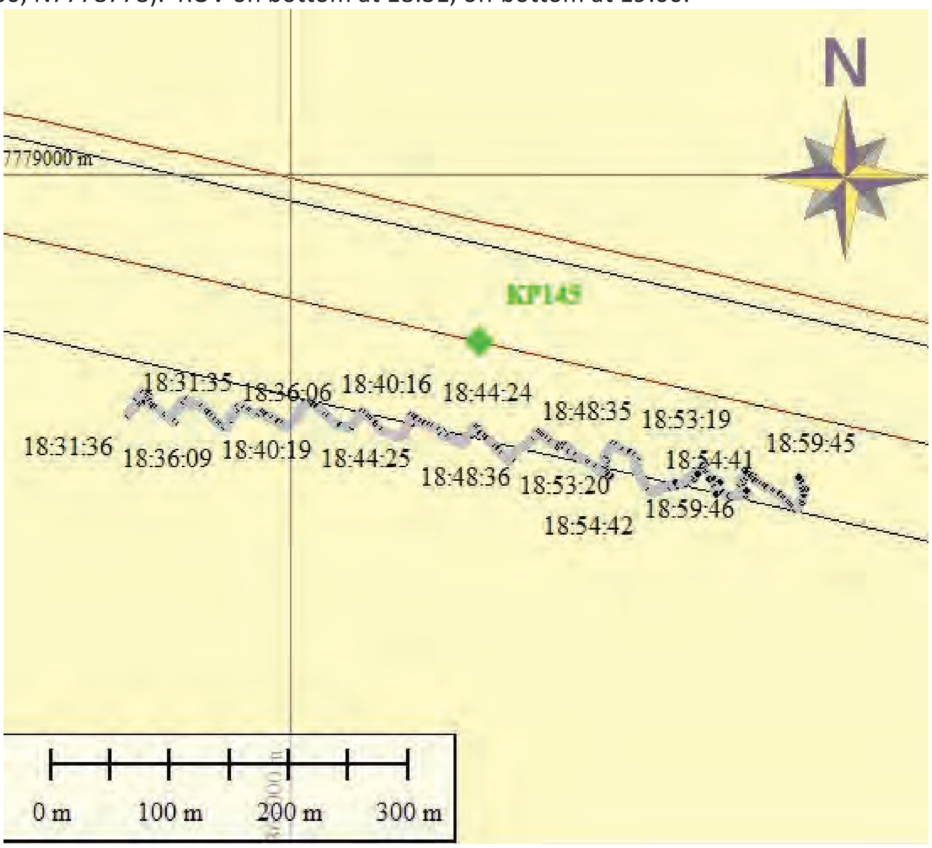
| Technical Memo: No. 13 | Date: 01/02/2019 | Phase: Environmental | Area of Ops: Area 5A (KP145) | Rev.0 |
|---|---|---|---|---|

**Title:** ENVIRONMENTAL OBSERVATIONS FROM AREA 5A (NO 5B or C)

**Scope:** Undertake a ROV transect obliquely across the planned PL route to identify benthic habitat.

**Aim:** Report preliminary findings of ROV transect to office

**Location:** ROV surveyed south of the proposed pipeline route in the vicinity of KP144.93 (E361160, N7778778). ROV on bottom at 18:31, off bottom at 19:00.




**Description:** The seabed is typically flat to undulating and comprises sand with subordinate bioclastic gravel. Where flat, the seabed has an algae cover. Where undulating, the seabed is characterised by starved ripples and scour moats, typically around sponges. Benthic fauna includes sporadic areas of soft corals, including gorgonians and sponges.

**Conclusions and recommendations:**

Seabed comprise a flat predominantly sandy seabed which has a benthic habitat in the form of isolated areas of soft corals and sponges. No significant high relief habitat features were observed.

Due to strong currents and the ROV tether management it was not possible to run the transect across the proposed pipeline route.

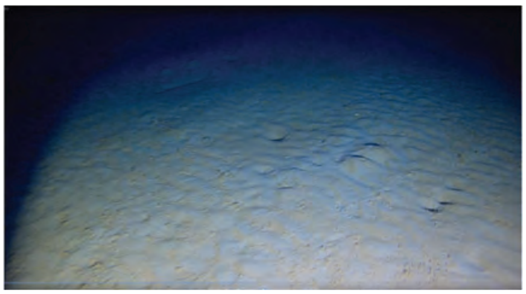
| | |
|---|---|
| Author: Ian Wright | Client Approval: Mike Varsanyi |

# Appendix B: Additional Images Area 1

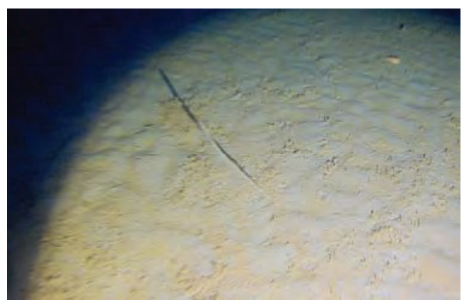
# Transect Images – Area 1

## Area 1 – Transect 1a





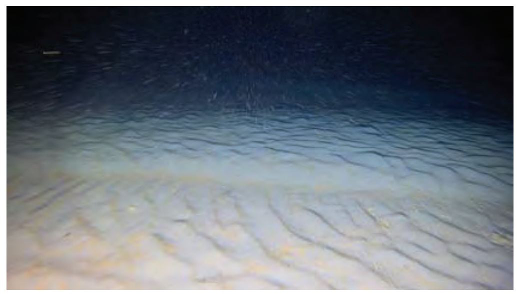

## Benthic Organisms – Transect 1a

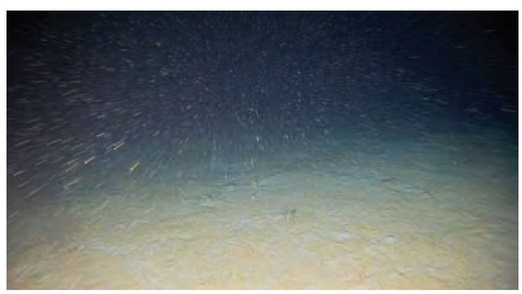


## Area 1 – Transect 1b

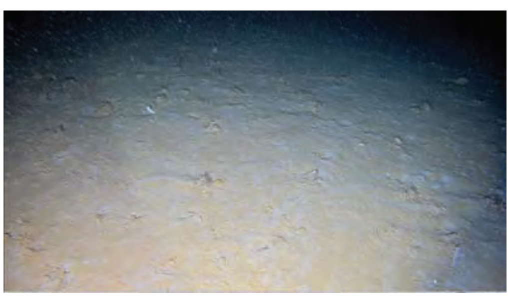
## Benthic Organisms – Transect 1b

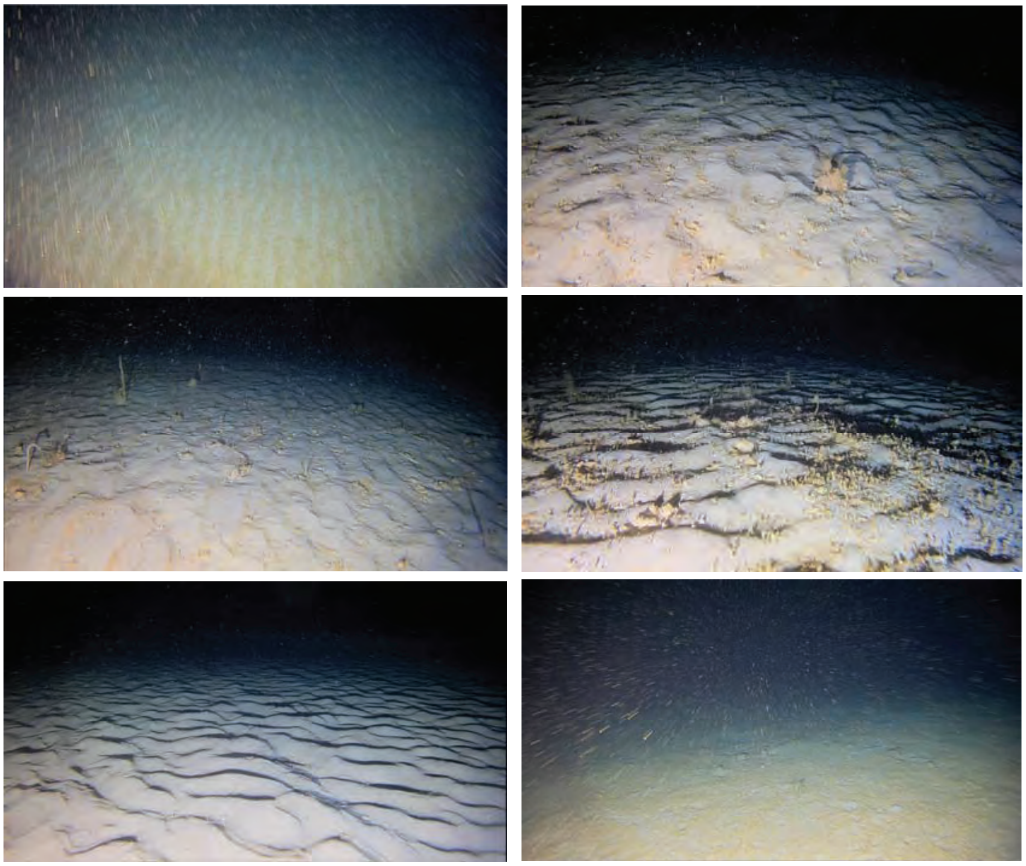
  






## Area 1 – Transect 1c



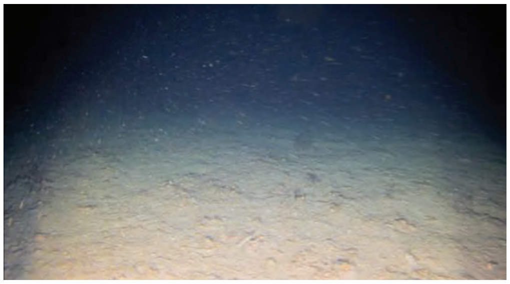
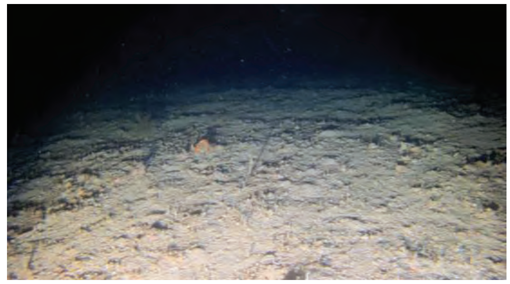
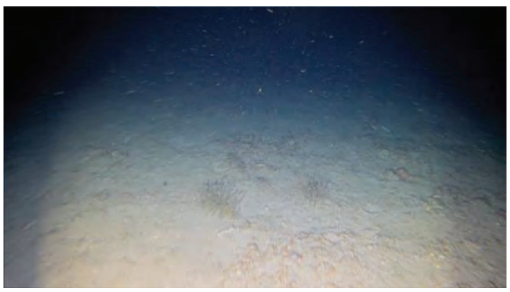
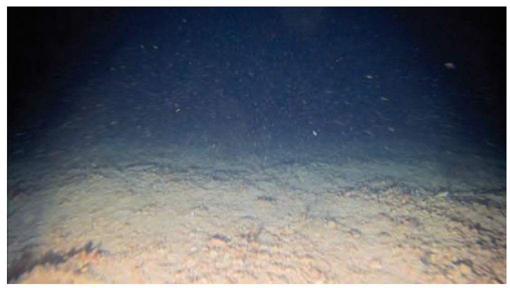



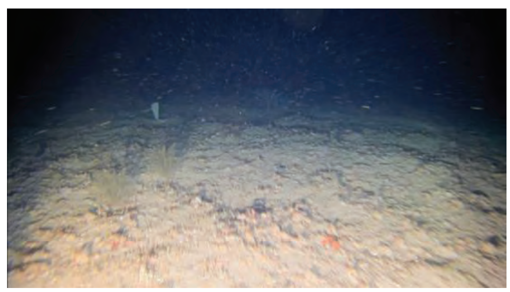
## Benthic Organisms – Transect 1c

# Appendix C: Additional Images Area 2

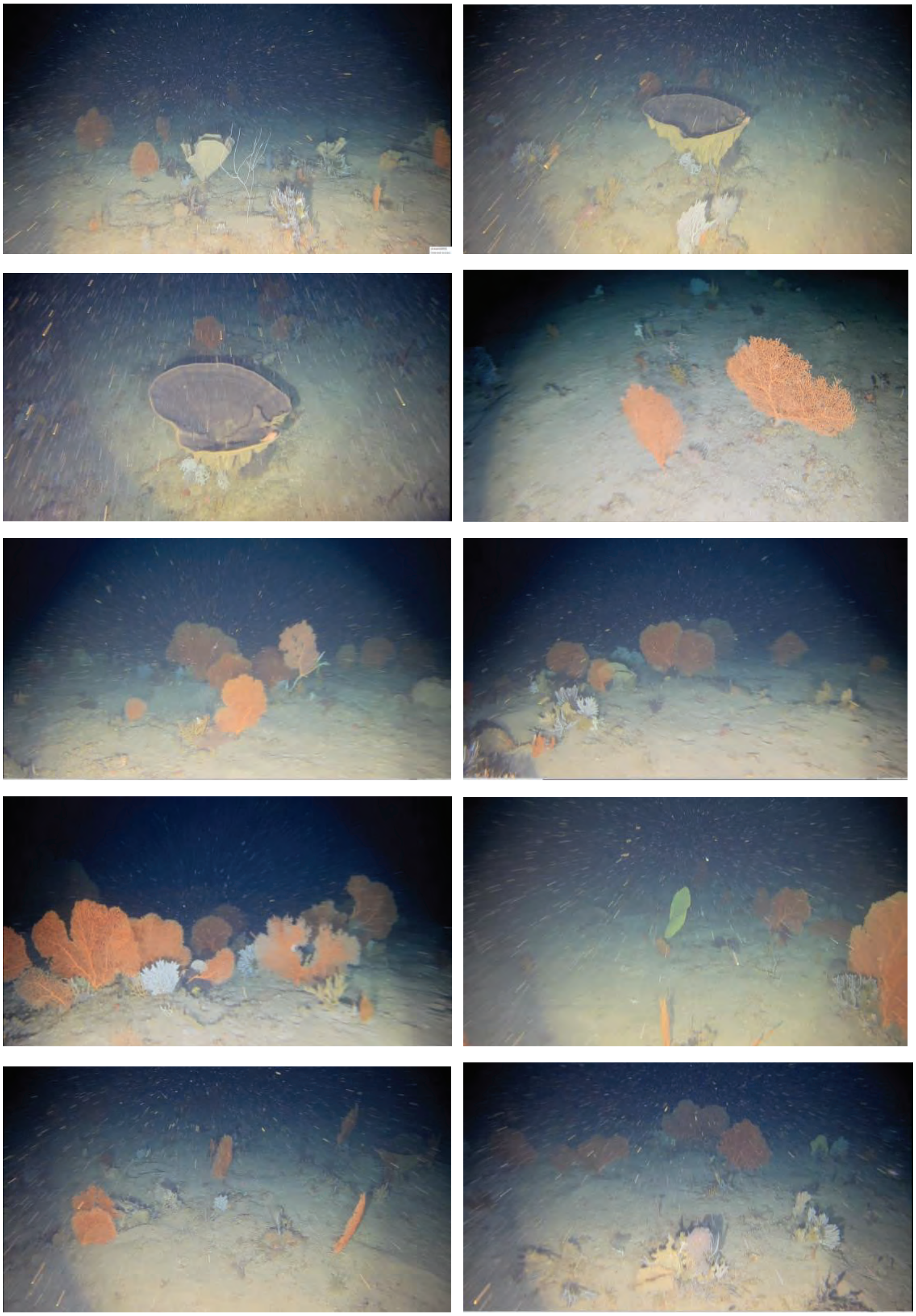
# Transect Images – Area 2

## Area 2 – Transect 2a

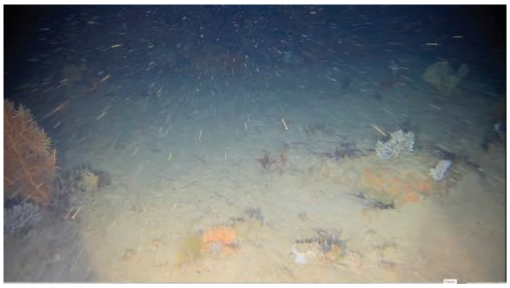





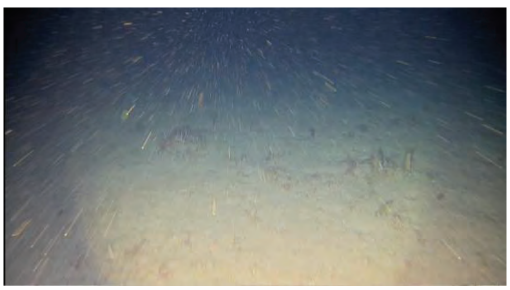






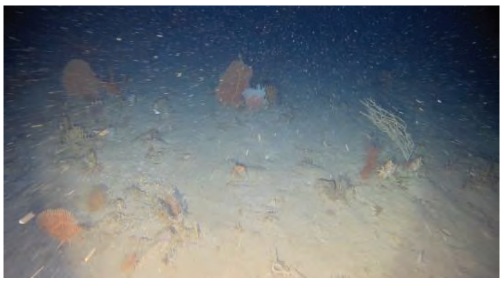


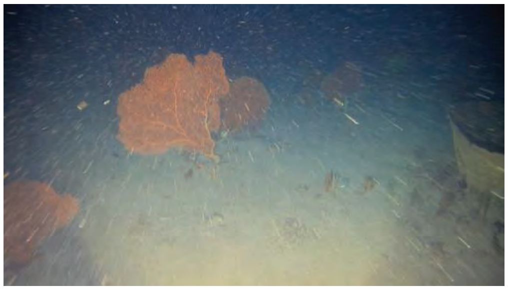







## Area 2 – Transect 2b

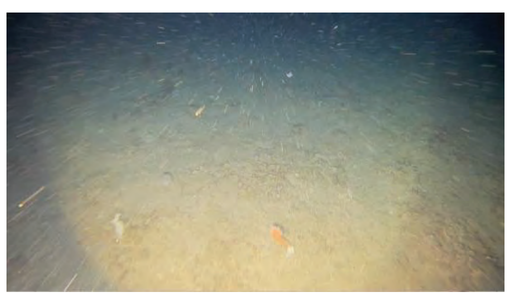




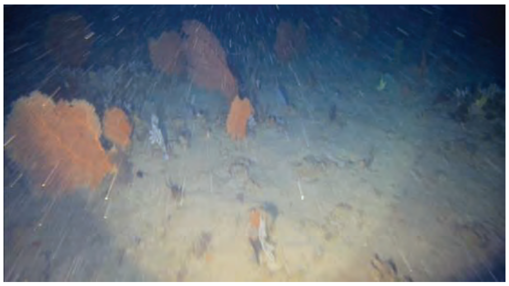






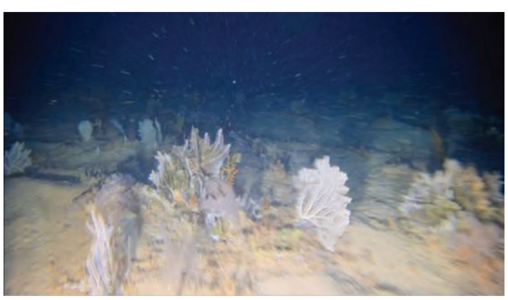





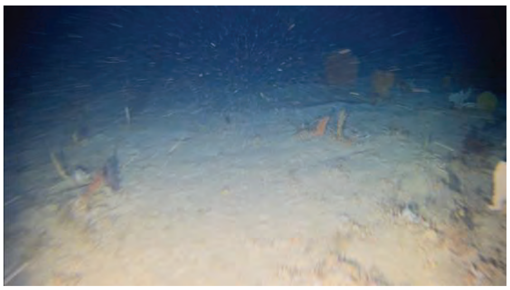
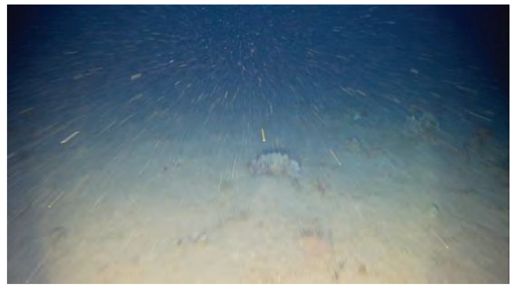






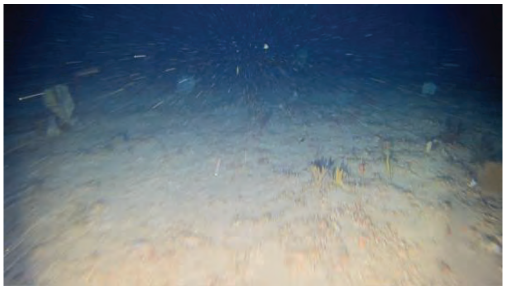


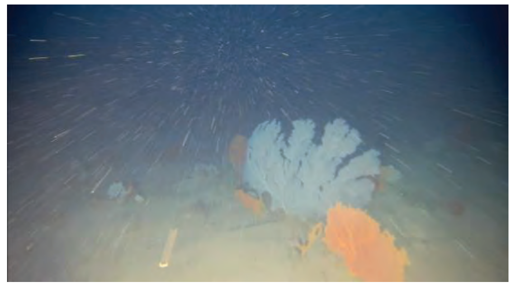


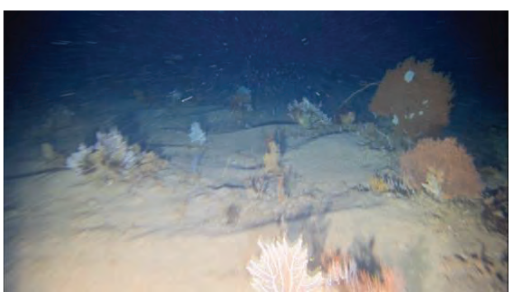




## Area 2 – Transect 2c



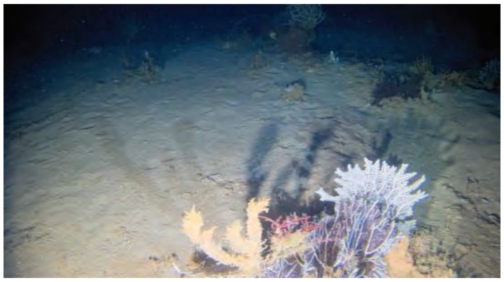



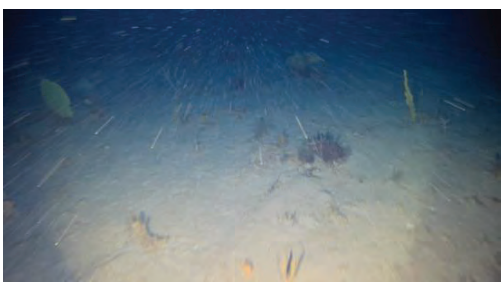

# Appendix D: Additional Images Area 3

# Transect Images – Area 3

## Area 3 – Transect 3a









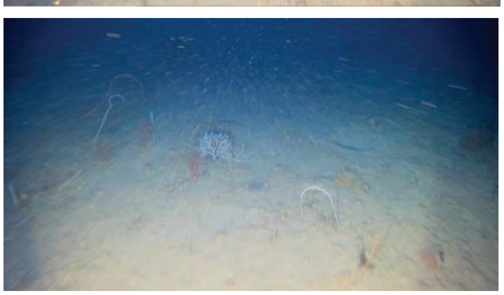


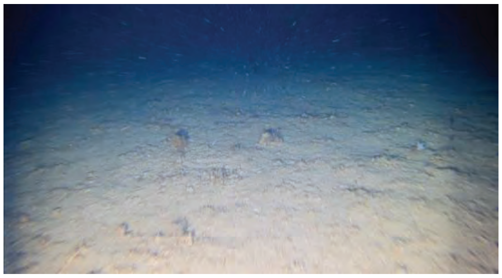


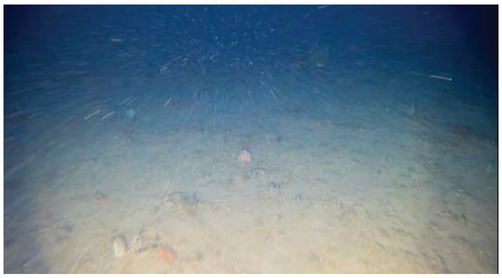
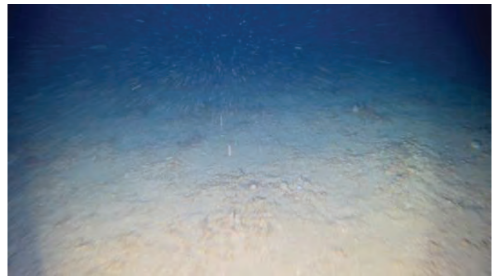


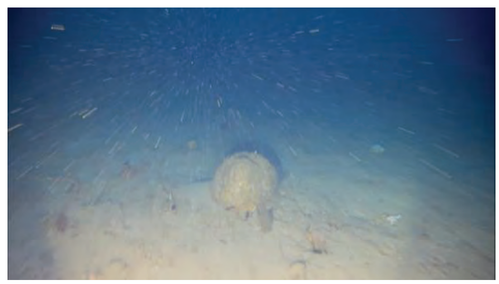
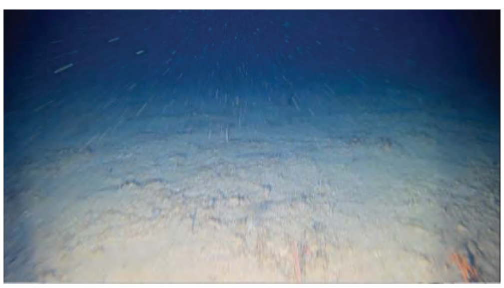
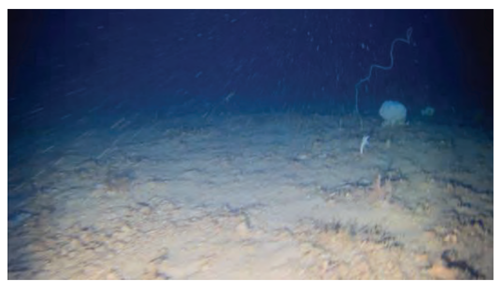
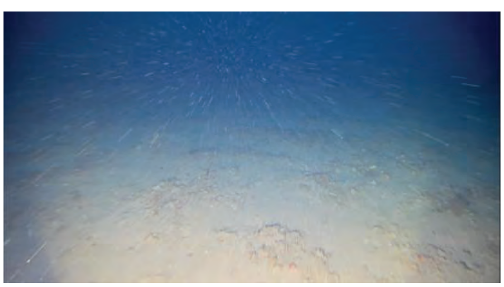




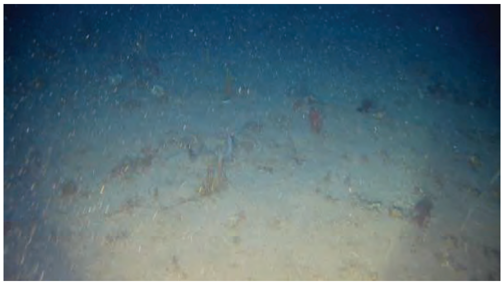
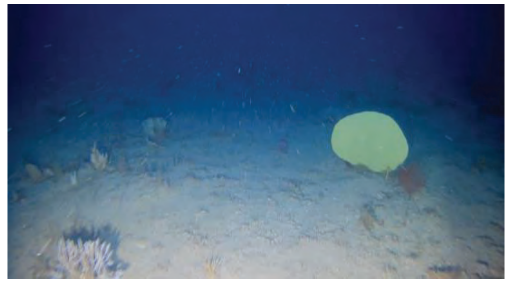



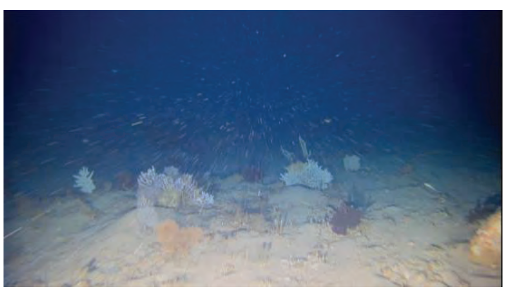



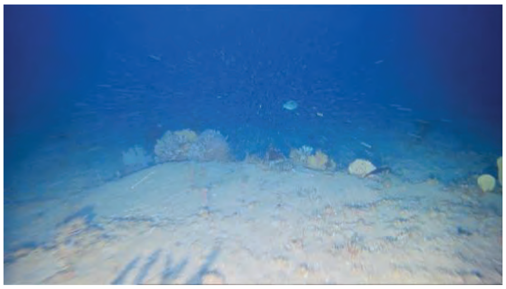

## Area 3 – Transect 3b

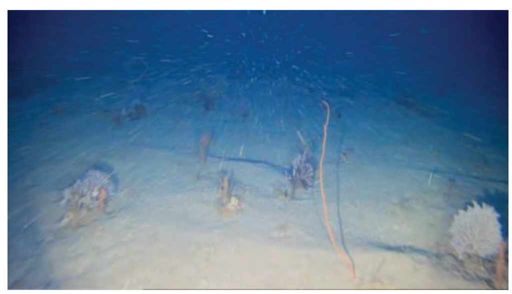


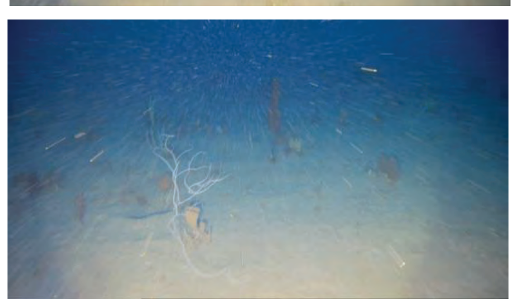


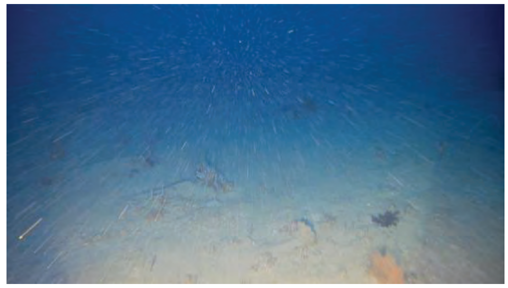
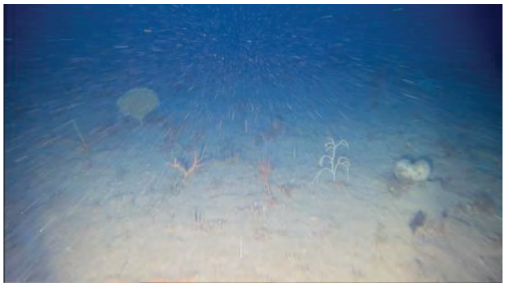



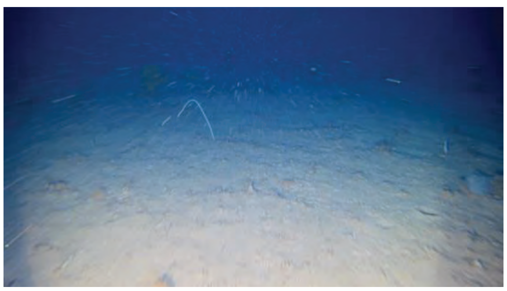


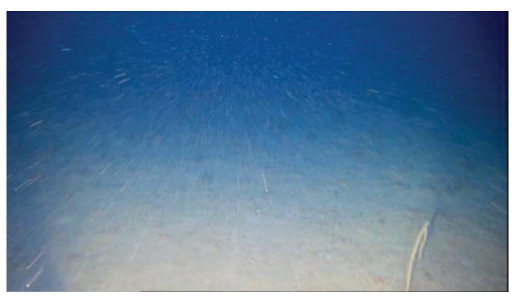
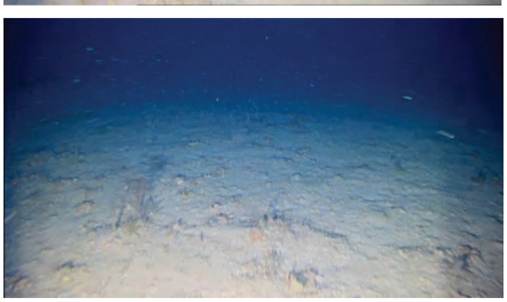




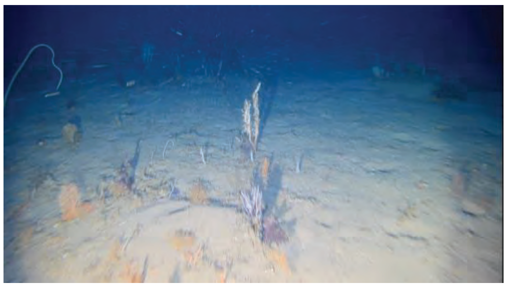








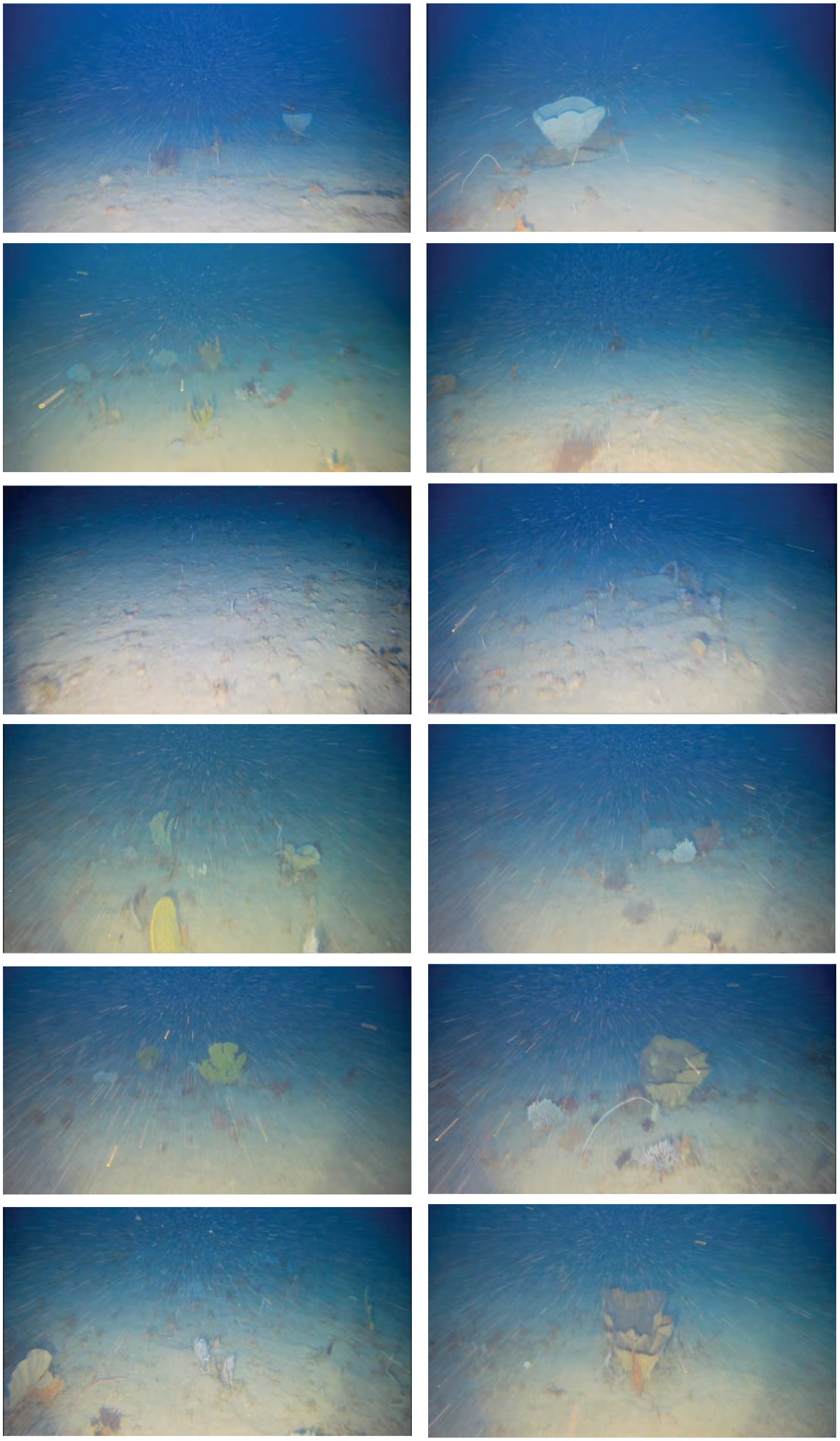


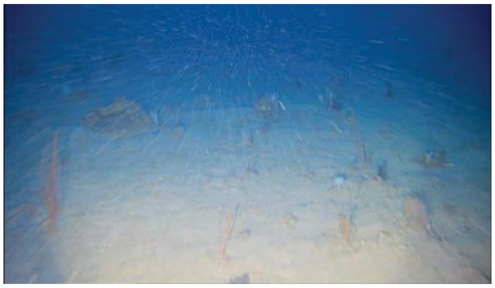



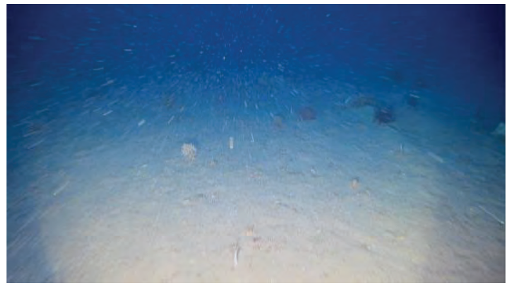

## Area 3 – Transect 3c







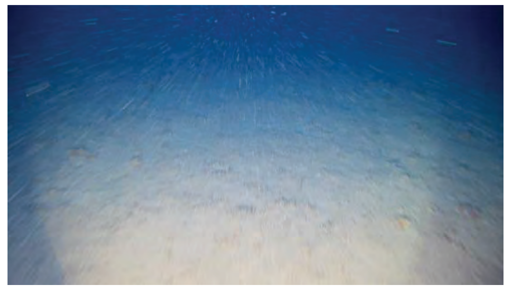



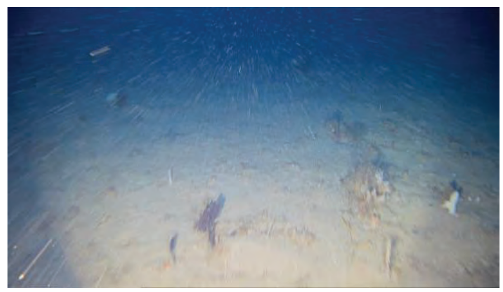


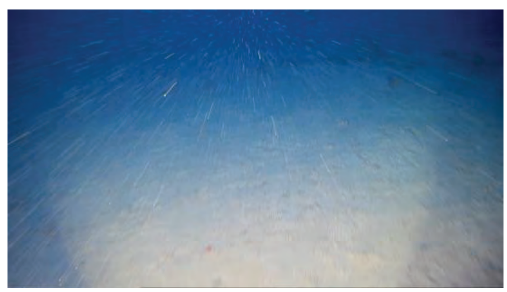




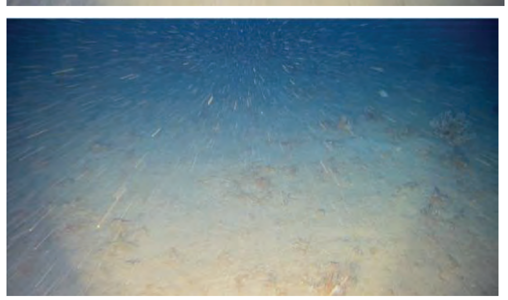


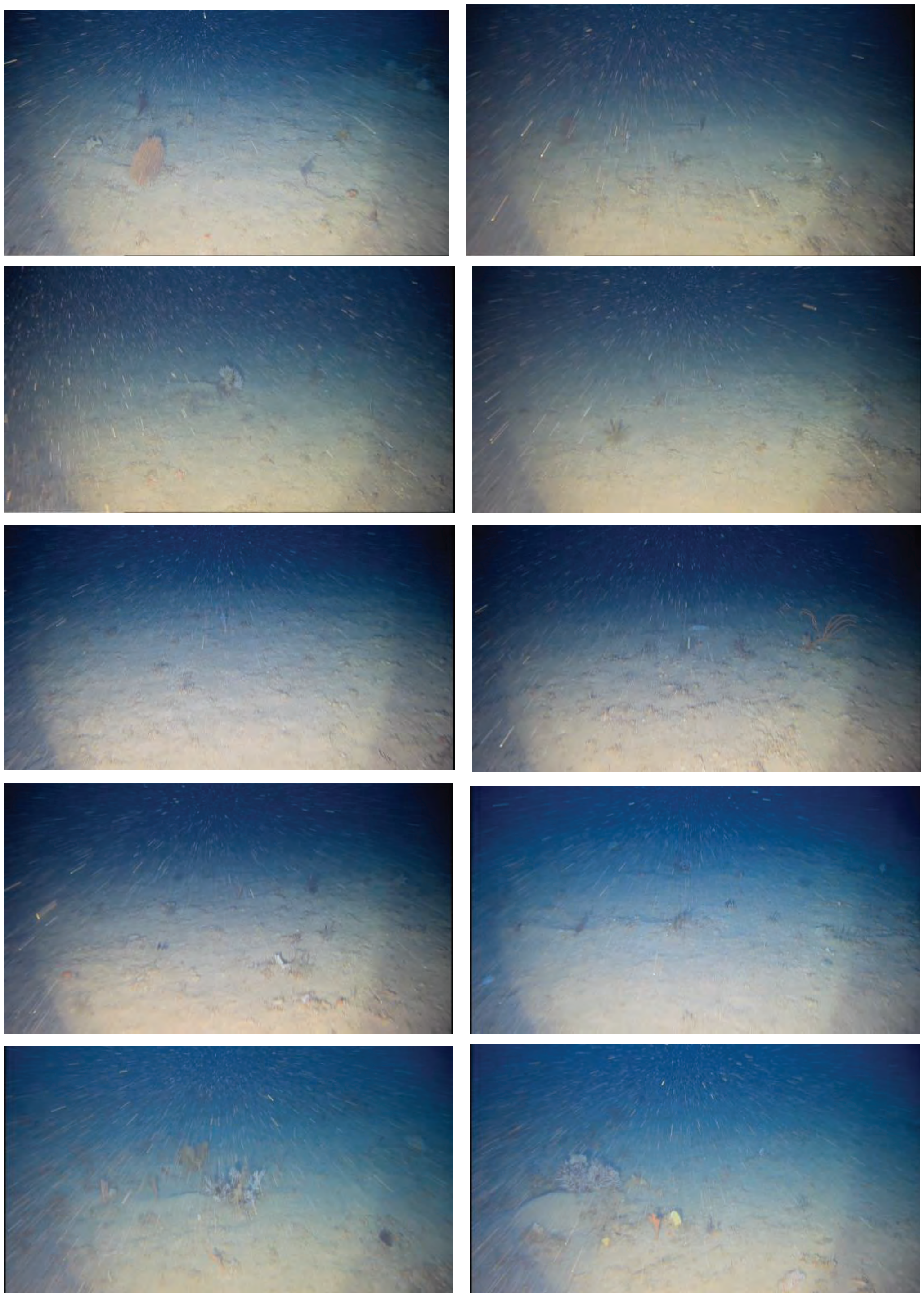













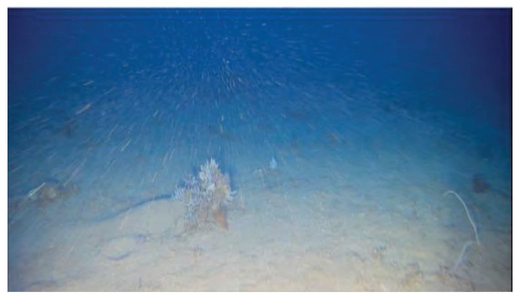
# Appendix E: Additional Images Area 4

# Transect Images – Area 4

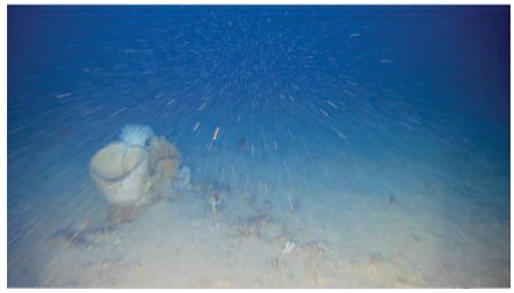
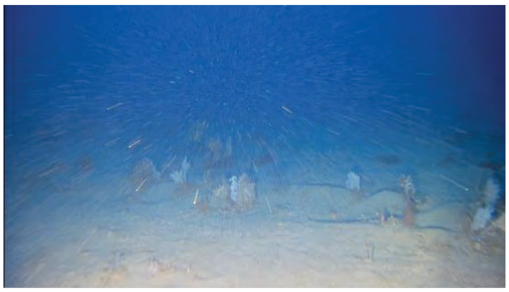
## Area 4 - Transect 4a



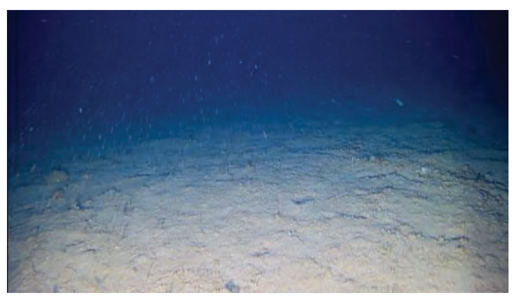


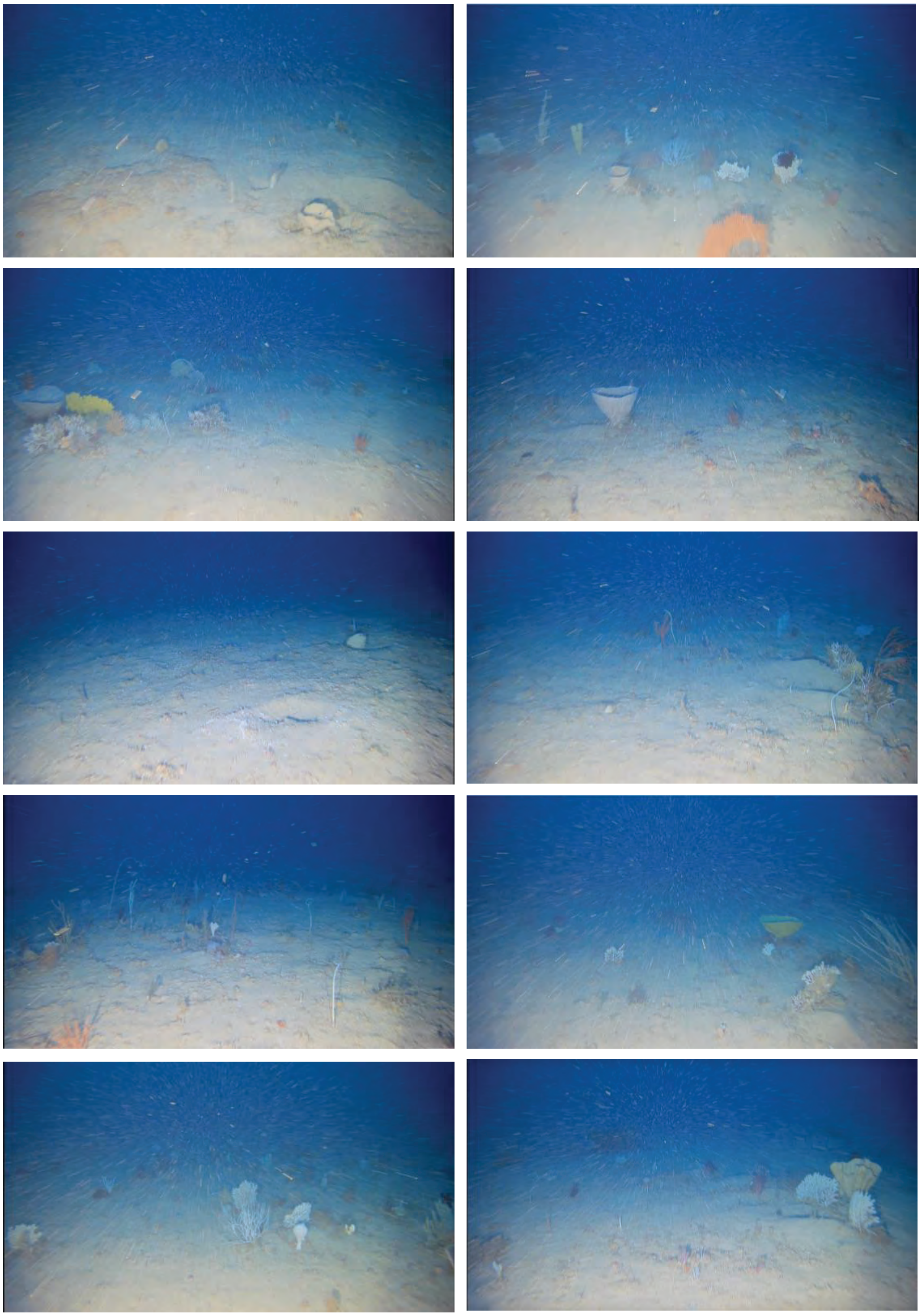





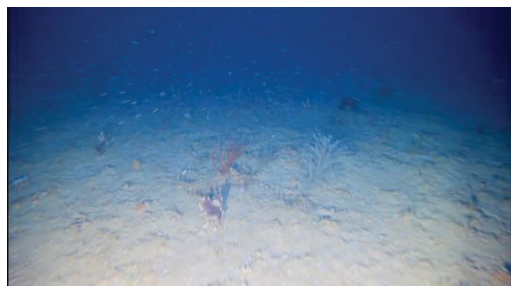


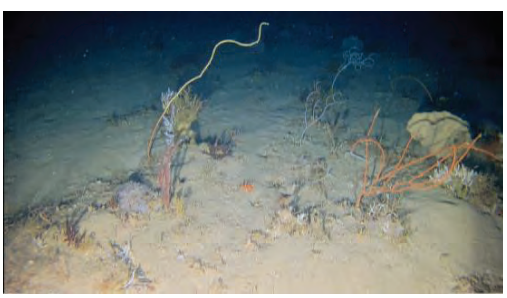
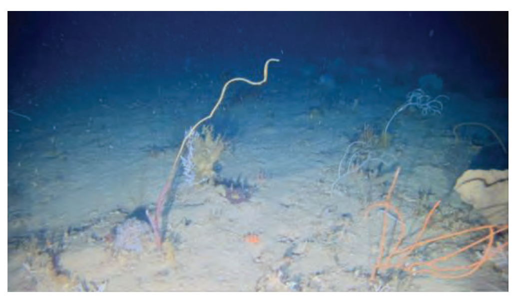


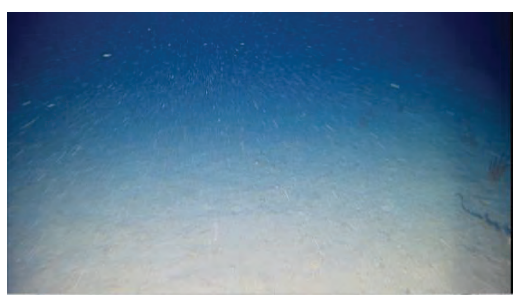




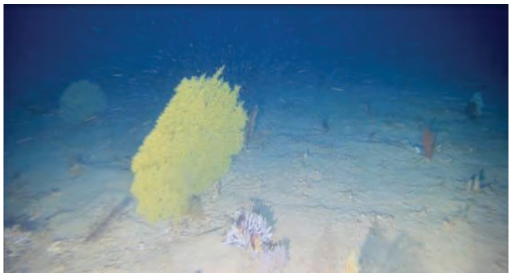
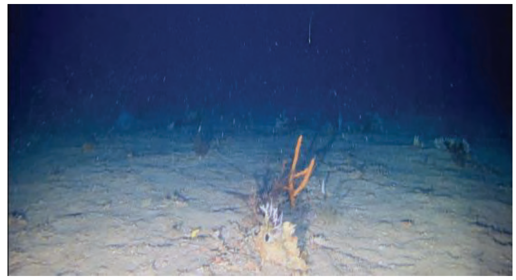



## Area 4 – Transect 4b

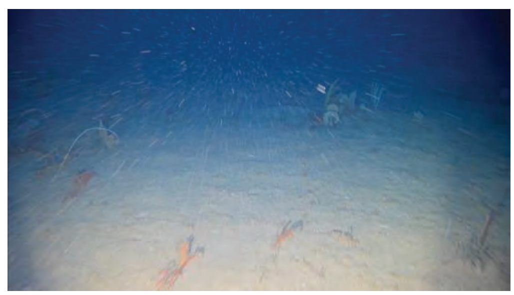





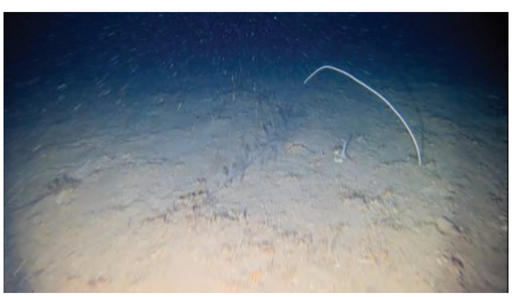




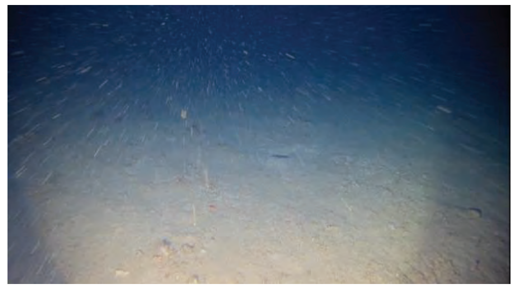


## Area 4 – Transect 4c



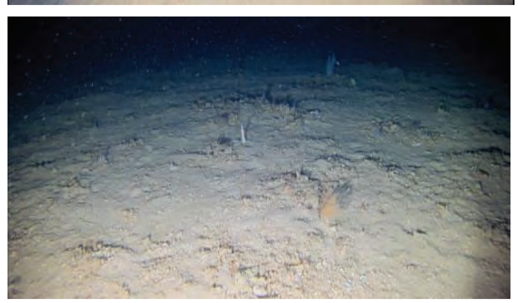


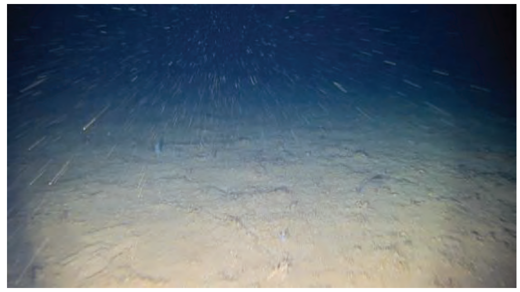
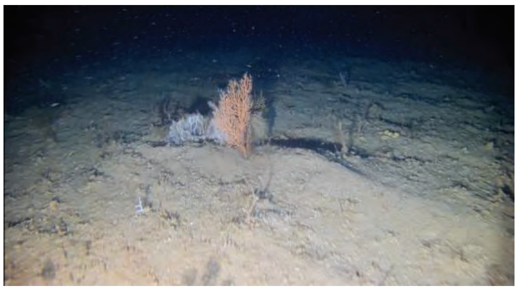




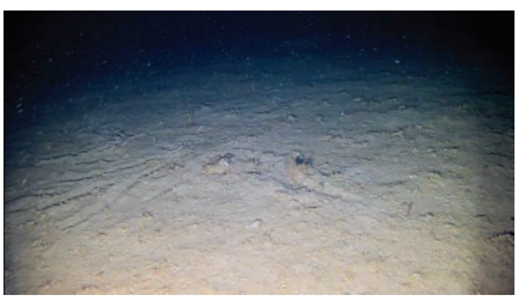
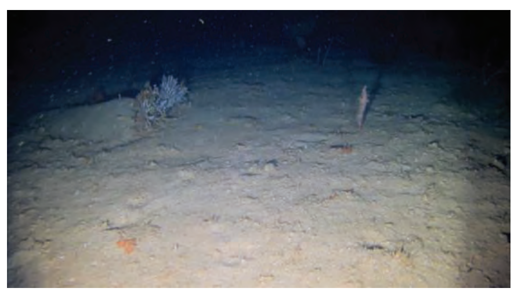
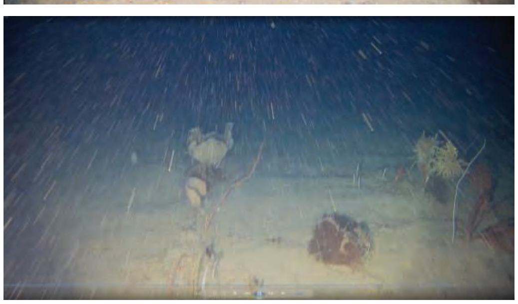
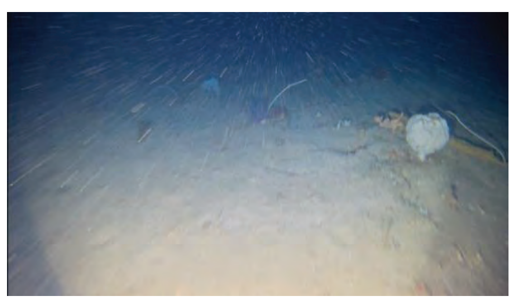














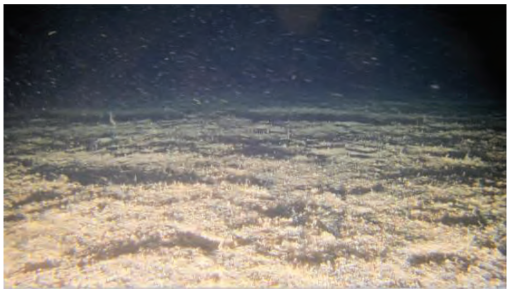
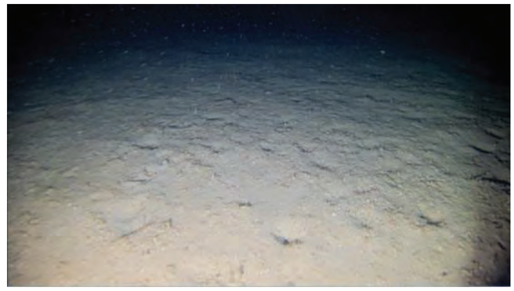


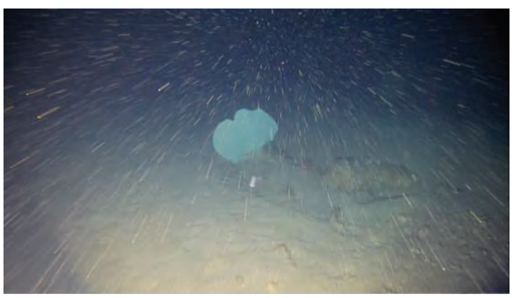



# Appendix F: Additional Images Area 5

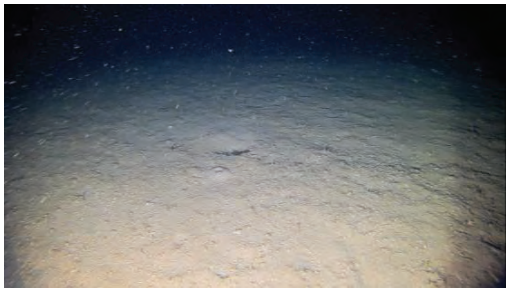
# Transect Images – Area 5

## Area 5 – Transect 5a

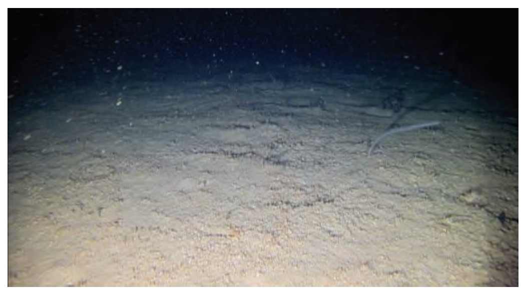



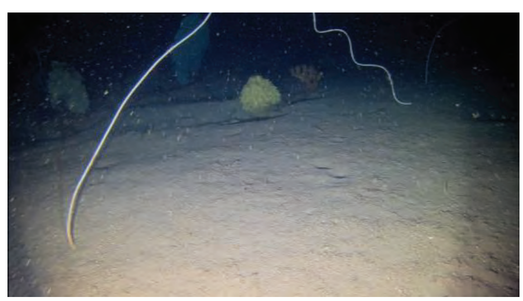


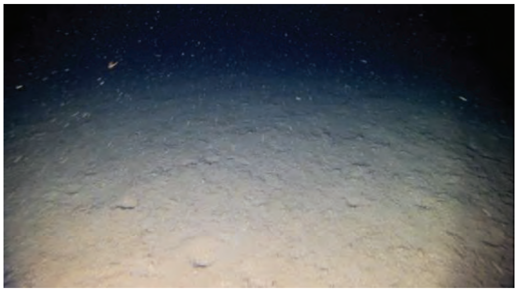



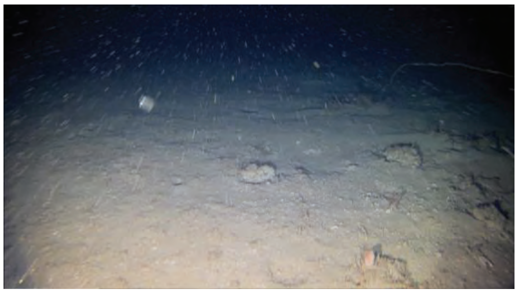
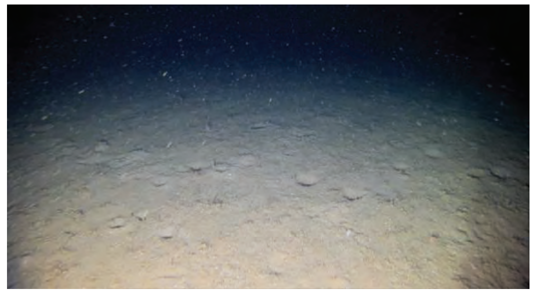


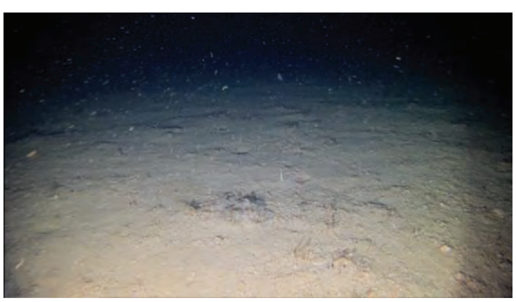


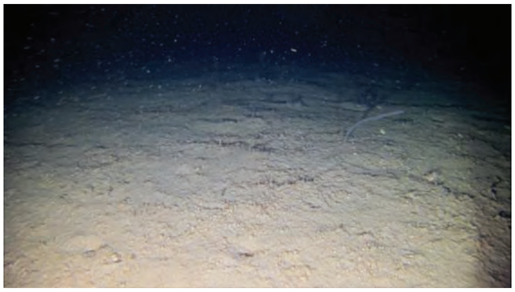









## Transect 5a – Sessile Organisms



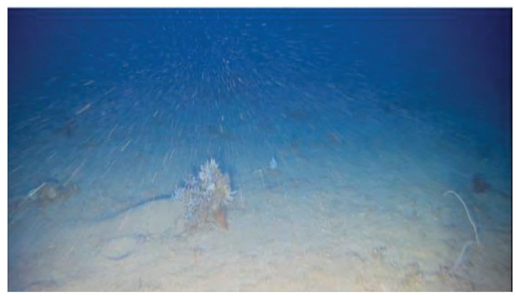



# Transect Images – Area 4

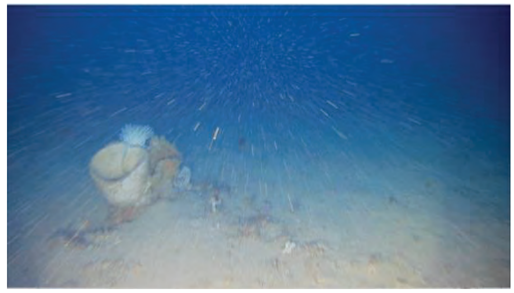
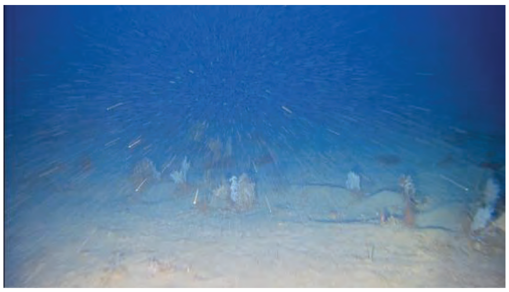
## Area 4 - Transect 4a



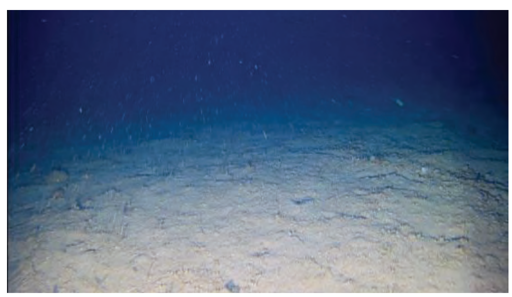


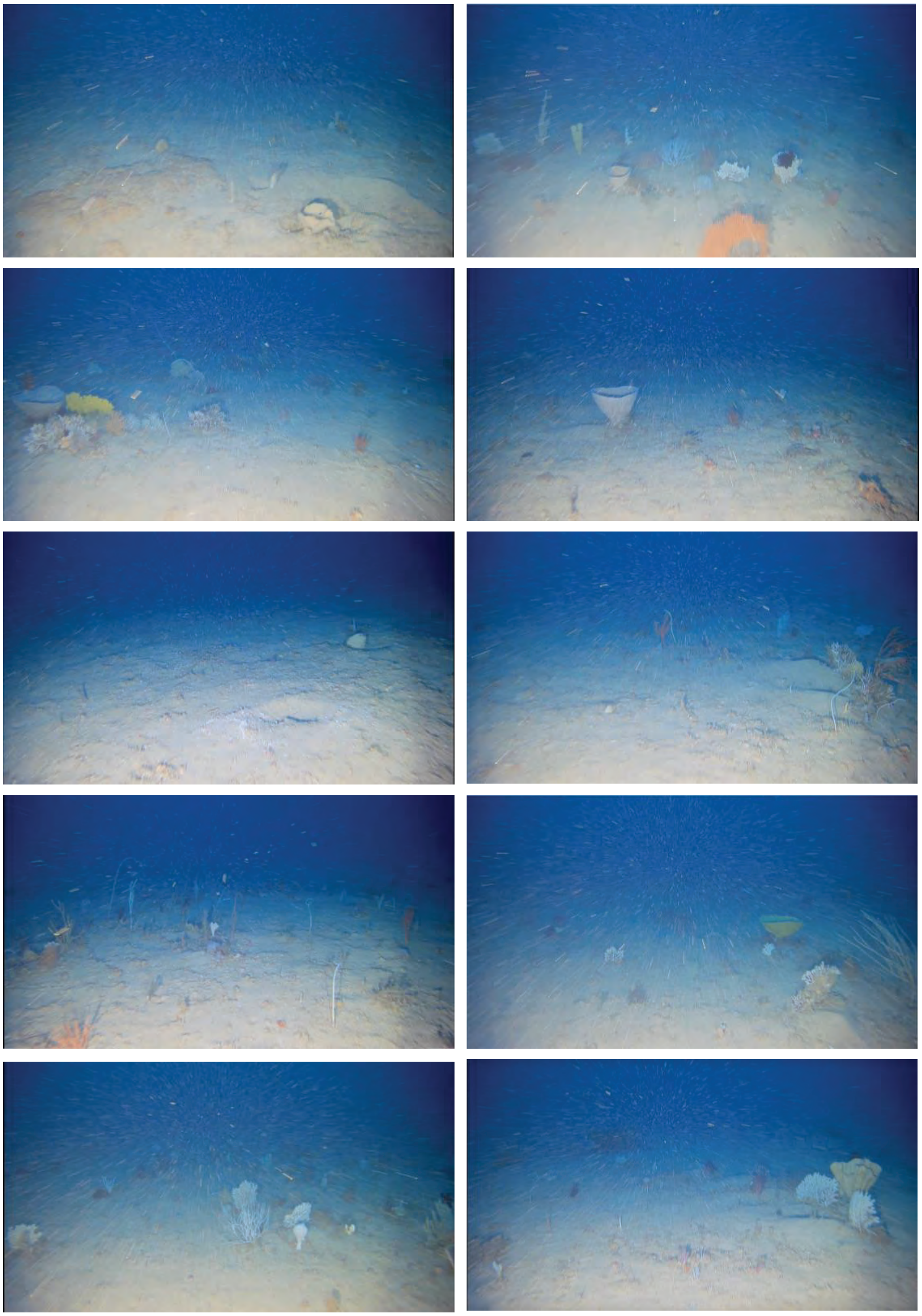





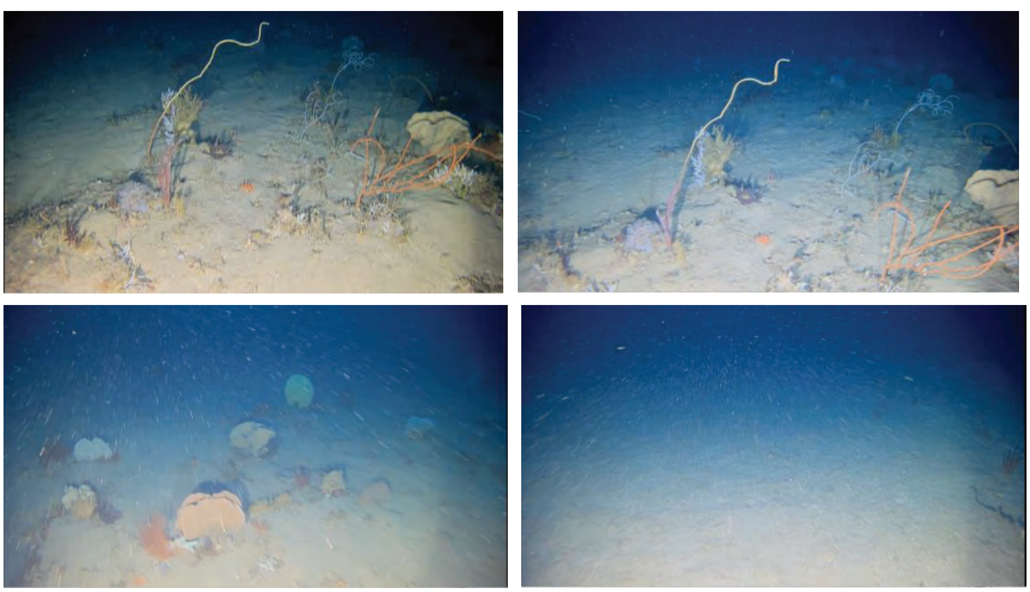






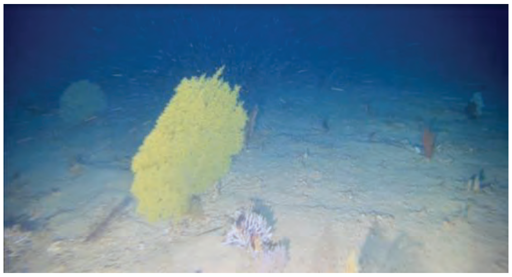
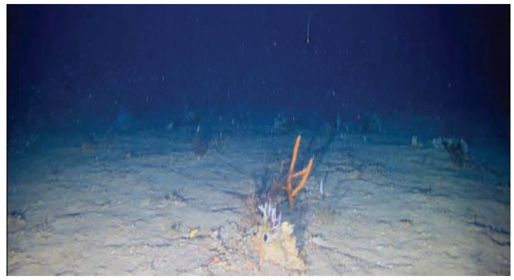





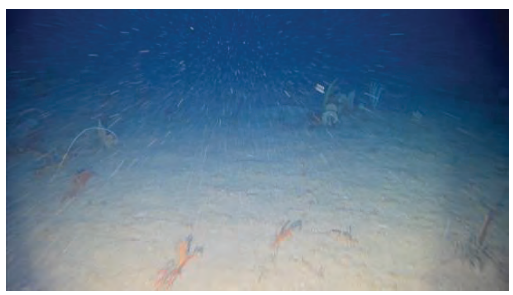
## Area 4 – Transect 4b



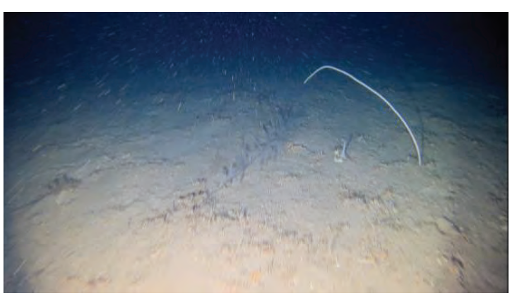




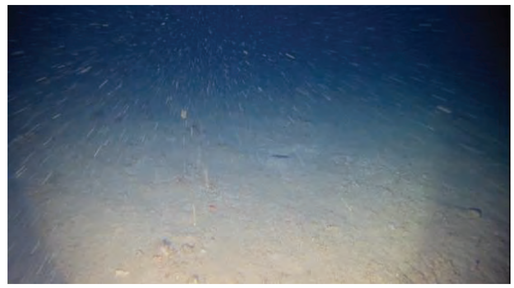


## Area 4 – Transect 4c



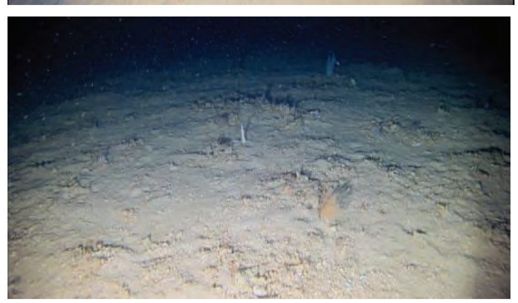
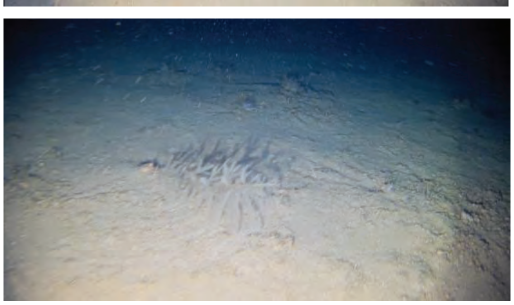


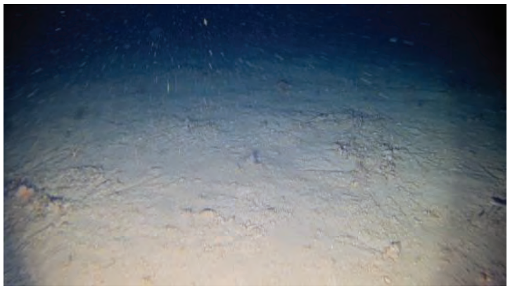
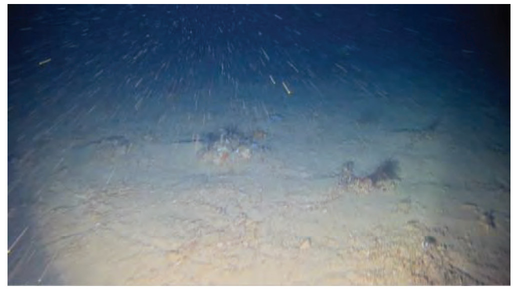


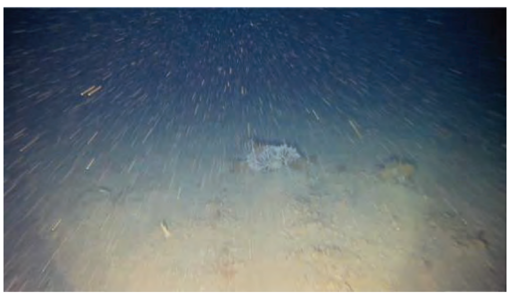


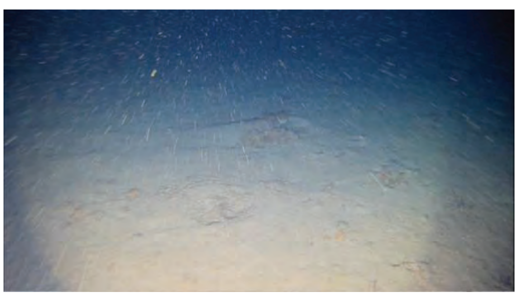




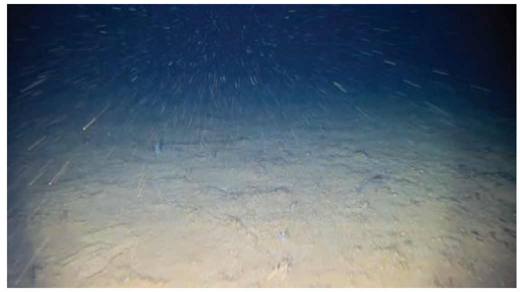
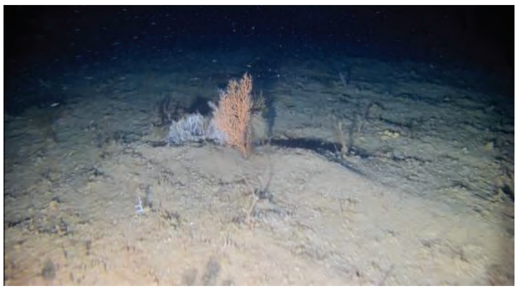



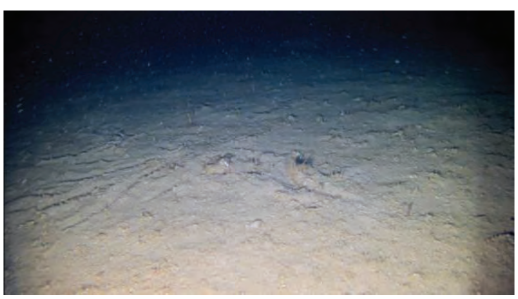
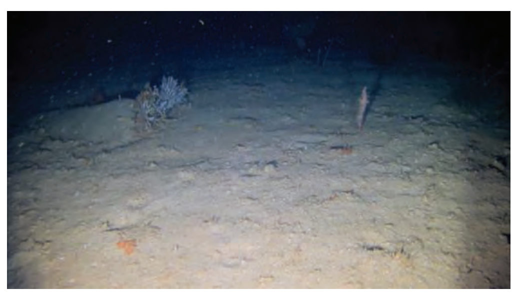
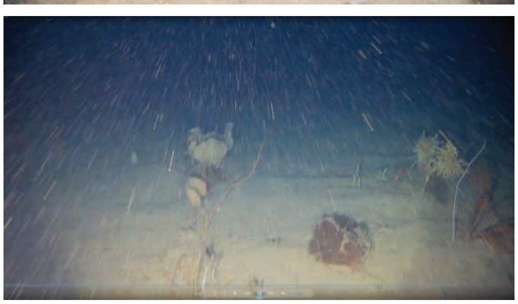
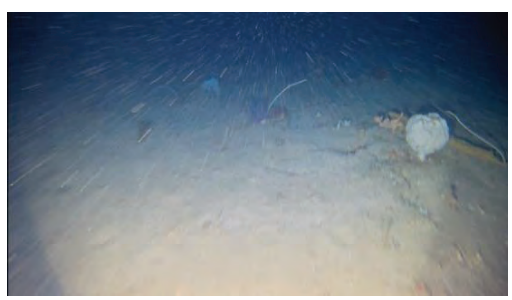




















# Appendix D

## EPBC Act Protected Matters Reports

# 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.

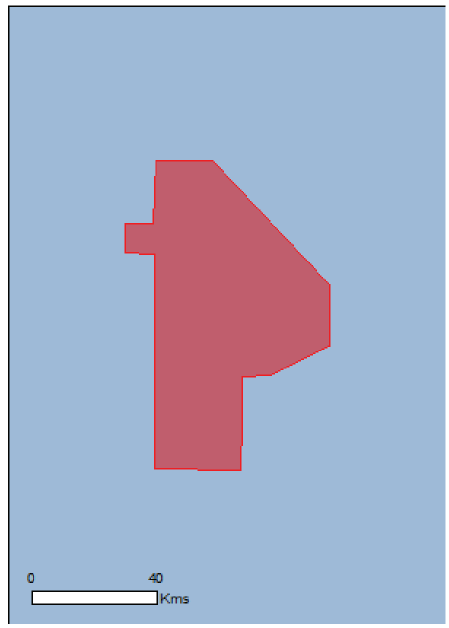
Information on the coverage of this report and qualifications on data supporting this report are contained in the caveat at the end of the report.

Information is available about Environment Assessments and the EPBC Act including significance guidelines, forms and application process details.

Report created: 03/04/19 15:22:24

Summary
Details
- Matters of NES
- Other Matters Protected by the EPBC Act
- Extra Information

Caveat
Acknowledgements






Coordinates
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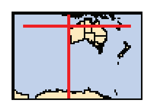

# Summary

## 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: | 12 |
| Listed Migratory Species: | 24 |

## 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: | 15 |
| 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** | | |
| Calidris canutus | | |
| Red Knot, Knot [855] | Endangered | Species or species habitat may occur within area |
| Macronectes giganteus | | |
| Southern Giant-Petrel, Southern Giant Petrel [1060] | 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 habitat may 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 likely to occur within area |

| Name | Status | Type of Presence |
|---|---|---|
| Dermochelys coriacea<br>Leatherback Turtle, Leathery Turtle, Luth [1768] | Endangered | Species or species habitat likely to occur within area |
| Eretmochelys imbricata<br>Hawksbill Turtle [1766] | Vulnerable | Species or species habitat likely to occur within area |
| Natator depressus<br>Flatback Turtle [59257] | Vulnerable | Species or species habitat likely to occur within area |
| **Sharks** | | |
| Carcharodon carcharias<br>White Shark, Great White Shark [64470] | Vulnerable | Species or species habitat may 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<br>Common Noddy [825] | | Species or species habitat may occur within area |
| Fregata ariel<br>Lesser Frigatebird, Least Frigatebird [1012] | | Species or species habitat may occur within area |
| Macronectes giganteus<br>Southern Giant-Petrel, Southern Giant Petrel [1060] | Endangered | Species or species habitat may occur within area |
| **Migratory Marine Species** | | |
| Balaenoptera bonaerensis<br>Antarctic Minke Whale, Dark-shoulder Minke Whale [67812] | | Species or species habitat likely to occur within area |
| Balaenoptera borealis<br>Sei Whale [34] | Vulnerable | Species or species habitat likely to occur within area |
| Balaenoptera edeni<br>Bryde's Whale [35] | | Species or species habitat likely to occur within area |
| Balaenoptera musculus<br>Blue Whale [36] | Endangered | Species or species habitat likely to occur within area |
| Balaenoptera physalus<br>Fin Whale [37] | Vulnerable | Species or species habitat likely to occur within area |
| Carcharodon carcharias<br>White Shark, Great White Shark [64470] | Vulnerable | Species or species habitat may occur within area |
| Caretta caretta<br>Loggerhead Turtle [1763] | Endangered | Species or species habitat likely to occur within area |
| Chelonia mydas<br>Green Turtle [1765] | Vulnerable | Species or species habitat likely to occur within area |
| Dermochelys coriacea<br>Leatherback Turtle, Leathery Turtle, Luth [1768] | Endangered | Species or species habitat likely to occur within area |

| Name | Threatened | Type of Presence |
| --- | --- | --- |
| Eretmochelys imbricata<br>Hawksbill Turtle [1766] | Vulnerable | Species or species habitat likely to occur within area |
| Isurus oxyrinchus<br>Shortfin Mako, Mako Shark [79073] | | Species or species habitat likely to occur within area |
| Isurus paucus<br>Longfin Mako [82947] | | Species or species habitat likely to occur within area |
| Manta birostris<br>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<br>Humpback Whale [38] | Vulnerable | Species or species habitat may occur within area |
| Natator depressus<br>Flatback Turtle [59257] | Vulnerable | Species or species habitat likely to occur within area |
| Orcinus orca<br>Killer Whale, Orca [46] | | Species or species habitat may occur within area |
| Physeter macrocephalus<br>Sperm Whale [59] | | Species or species habitat may occur within area |
| Migratory Wetlands Species | | |
| Actitis hypoleucos<br>Common Sandpiper [59309] | | Species or species habitat may occur within area |
| Calidris acuminata<br>Sharp-tailed Sandpiper [874] | | Species or species habitat may occur within area |
| Calidris canutus<br>Red Knot, Knot [855] | Endangered | Species or species habitat may occur within area |
| Calidris melanotos<br>Pectoral Sandpiper [858] | | 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<br>Common Sandpiper [59309] | | Species or species habitat may occur within area |
| Anous stolidus<br>Common Noddy [825] | | Species or species habitat may occur within area |
| Calidris acuminata<br>Sharp-tailed Sandpiper [874] | | Species or species habitat may occur within area |

| Name | Threatened | Type of Presence |
|---|---|---|
| Calidris canutus<br>Red Knot, Knot [855] | Endangered | Species or species habitat may occur within area |
| Calidris melanotos<br>Pectoral Sandpiper [858] | | Species or species habitat may occur within area |
| Fregata ariel<br>Lesser Frigatebird, Least Frigatebird [1012] | | Species or species habitat may occur within area |
| Macronectes giganteus<br>Southern Giant-Petrel, Southern Giant Petrel [1060] | Endangered | Species or species habitat may occur within area |
| Reptiles | | |
| Aipysurus laevis<br>Olive Seasnake [1120] | | Species or species habitat may occur within area |
| Caretta caretta<br>Loggerhead Turtle [1763] | Endangered | Species or species habitat likely to occur within area |
| Chelonia mydas<br>Green Turtle [1765] | Vulnerable | Species or species habitat likely to occur within area |
| Dermochelys coriacea<br>Leatherback Turtle, Leathery Turtle, Luth [1768] | Endangered | Species or species habitat likely to occur within area |
| Disteira kingii<br>Spectacled Seasnake [1123] | | Species or species habitat may occur within area |
| Eretmochelys imbricata<br>Hawksbill Turtle [1766] | Vulnerable | Species or species habitat likely to occur within area |
| Natator depressus<br>Flatback Turtle [59257] | Vulnerable | Species or species habitat likely to occur within area |
| Pelamis platurus<br>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<br>Minke Whale [33] | | Species or species habitat may occur within area |
| Balaenoptera bonaerensis<br>Antarctic Minke Whale, Dark-shoulder Minke Whale [67812] | | Species or species habitat likely to occur within area |
| Balaenoptera borealis<br>Sei Whale [34] | Vulnerable | Species or species habitat likely to occur within area |
| Balaenoptera edeni<br>Bryde's Whale [35] | | Species or species habitat likely to occur within area |
| Balaenoptera musculus<br>Blue Whale [36] | Endangered | Species or species habitat likely to occur within area |

| Name | Status | Type of Presence |
| --- | --- | --- |
| Balaenoptera physalus<br>Fin Whale [37] | Vulnerable | Species or species habitat likely to occur within area |
| Delphinus delphis<br>Common Dophin, Short-beaked Common Dolphin [60] | | Species or species habitat may occur within area |
| Feresa attenuata<br>Pygmy Killer Whale [61] | | Species or species habitat may occur within area |
| Globicephala macrorhynchus<br>Short-finned Pilot Whale [62] | | Species or species habitat may occur within area |
| Grampus griseus<br>Risso's Dolphin, Grampus [64] | | Species or species habitat may occur within area |
| Kogia breviceps<br>Pygmy Sperm Whale [57] | | Species or species habitat may occur within area |
| Kogia simus<br>Dwarf Sperm Whale [58] | | Species or species habitat may occur within area |
| Lagenodelphis hosei<br>Fraser's Dolphin, Sarawak Dolphin [41] | | Species or species habitat may occur within area |
| Megaptera novaeangliae<br>Humpback Whale [38] | Vulnerable | Species or species habitat may occur within area |
| Mesoplodon densirostris<br>Blainville's Beaked Whale, Dense-beaked Whale [74] | | Species or species habitat may occur within area |
| Orcinus orca<br>Killer Whale, Orca [46] | | Species or species habitat may occur within area |
| Peponocephala electra<br>Melon-headed Whale [47] | | Species or species habitat may occur within area |
| Physeter macrocephalus<br>Sperm Whale [59] | | Species or species habitat may occur within area |
| Pseudorca crassidens<br>False Killer Whale [48] | | Species or species habitat likely to occur within area |
| Stenella attenuata<br>Spotted Dolphin, Pantropical Spotted Dolphin [51] | | Species or species habitat may occur within area |
| Stenella coeruleoalba<br>Striped Dolphin, Euphrosyne Dolphin [52] | | Species or species habitat may occur within area |
| Stenella longirostris<br>Long-snouted Spinner Dolphin [29] | | Species or species habitat may occur within area |
| Steno bredanensis<br>Rough-toothed Dolphin [30] | | Species or species habitat may occur within area |

| Name | Status | Type of Presence |
|---|---|---|
| Tursiops truncatus s. str.<br>Bottlenose Dolphin [68417] | | Species or species habitat may occur within area |
| Ziphius cavirostris<br>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 |
|---|---|
| Exmouth Plateau | 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

-19.165 113.087,-19.165 113.251,-19.5 113.586,-19.666 113.585,-19.746 113.419,-19.751 113.335,-20.002 113.332,-19.998 113.084,-19.418 113.084,-19.415 113.002,-19.333 113.001,-19.333 113.081,-19.165 113.087

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

TRUNKLINE PROJECT AREA
ORIGINAL SEARCH

# 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.

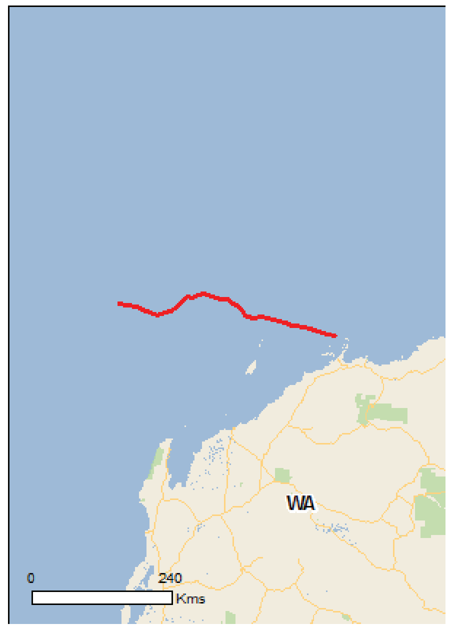
Information on the coverage of this report and qualifications on data supporting this report are contained in the caveat at the end of the report.

Information is available about Environment Assessments and the EPBC Act including significance guidelines, forms and application process details.

Report created: 03/04/19 15:27:24

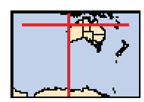

Summary
Details
- Matters of NES
- Other Matters Protected by the EPBC Act
- Extra Information

Caveat
Acknowledgements




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: | 38 |

## 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: | 71 |
| Whales and Other Cetaceans: | 28 |
| Critical Habitats: | None |
| Commonwealth Reserves Terrestrial: | None |
| Australian Marine Parks: | 1 |

## 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) | 3 |

# 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 | | |
| Calidris canutus<br>Red Knot, Knot [855] | Endangered | Species or species habitat may occur within area |
| Calidris ferruginea<br>Curlew Sandpiper [856] | Critically Endangered | Species or species habitat may occur within area |
| Macronectes giganteus<br>Southern Giant-Petrel, Southern Giant Petrel [1060] | Endangered | Species or species habitat may occur within area |
| Numenius madagascariensis<br>Eastern Curlew, Far Eastern Curlew [847] | Critically Endangered | Species or species habitat may occur within area |
| Sternula nereis  nereis<br>Australian Fairy Tern [82950] | Vulnerable | Breeding known to occur within area |
| Mammals | | |
| Balaenoptera borealis<br>Sei Whale [34] | Vulnerable | Species or species habitat likely to occur within area |
| Balaenoptera musculus<br>Blue Whale [36] | Endangered | Migration route known to occur within area |
| Balaenoptera physalus<br>Fin Whale [37] | Vulnerable | Species or species habitat likely to occur within area |
| Megaptera novaeangliae<br>Humpback Whale [38] | Vulnerable | Species or species habitat known to occur within area |

| Name | Status | Type of Presence |
|---|---|---|
| **Reptiles** | | |
| Aipysurus apraefrontalis<br>Short-nosed Seasnake [1115] | Critically Endangered | Species or species habitat likely to occur within area |
| Caretta caretta<br>Loggerhead Turtle [1763] | Endangered | Congregation or aggregation known to occur within area |
| Chelonia mydas<br>Green Turtle [1765] | Vulnerable | Congregation or aggregation known to occur within area |
| Dermochelys coriacea<br>Leatherback Turtle, Leathery Turtle, Luth [1768] | Endangered | Species or species habitat likely to occur within area |
| Eretmochelys imbricata<br>Hawksbill Turtle [1766] | Vulnerable | Congregation or aggregation known to occur within area |
| Natator depressus<br>Flatback Turtle [59257] | Vulnerable | Congregation or aggregation known to occur within area |
| **Sharks** | | |
| Carcharias taurus  (west coast population)<br>Grey Nurse Shark (west coast population) [68752] | Vulnerable | Species or species habitat likely to occur within area |
| Carcharodon carcharias<br>White Shark, Great White Shark [64470] | Vulnerable | Species or species habitat may occur within area |
| Pristis clavata<br>Dwarf Sawfish, Queensland Sawfish [68447] | Vulnerable | Species or species habitat known to occur within area |
| Pristis zijsron<br>Green Sawfish, Dindagubba, Narrowsnout Sawfish [68442] | Vulnerable | Species or species habitat known to occur within area |
| Rhincodon typus<br>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<br>Common Noddy [825] | | Species or species habitat may occur within area |
| Apus pacificus<br>Fork-tailed Swift [678] | | Species or species habitat likely to occur within area |
| Calonectris leucomelas<br>Streaked Shearwater [1077] | | Species or species habitat likely to occur within area |
| Fregata ariel<br>Lesser Frigatebird, Least Frigatebird [1012] | | Species or species habitat likely to occur within area |
| Macronectes giganteus<br>Southern Giant-Petrel, Southern Giant Petrel [1060] | Endangered | Species or species habitat may occur within area |

| Name | Threatened | Type of Presence |
|---|---|---|
| Sterna dougallii<br>Roseate Tern [817] | | Foraging, feeding or related behaviour likely to occur within area |
| **Migratory Marine Species** | | |
| Anoxypristis cuspidata<br>Narrow Sawfish, Knifetooth Sawfish [68448] | | Species or species habitat likely to occur within area |
| Balaenoptera bonaerensis<br>Antarctic Minke Whale, Dark-shoulder Minke Whale [67812] | | Species or species habitat likely to occur within area |
| Balaenoptera borealis<br>Sei Whale [34] | Vulnerable | Species or species habitat likely to occur within area |
| Balaenoptera edeni<br>Bryde's Whale [35] | | Species or species habitat likely to occur within area |
| Balaenoptera musculus<br>Blue Whale [36] | Endangered | Migration route known to occur within area |
| Balaenoptera physalus<br>Fin Whale [37] | Vulnerable | Species or species habitat likely to occur within area |
| Carcharodon carcharias<br>White Shark, Great White Shark [64470] | Vulnerable | Species or species habitat may occur within area |
| Caretta caretta<br>Loggerhead Turtle [1763] | Endangered | Congregation or aggregation known to occur within area |
| Chelonia mydas<br>Green Turtle [1765] | Vulnerable | Congregation or aggregation known to occur within area |
| Dermochelys coriacea<br>Leatherback Turtle, Leathery Turtle, Luth [1768] | Endangered | Species or species habitat likely to occur within area |
| Dugong dugon<br>Dugong [28] | | Species or species habitat known to occur within area |
| Eretmochelys imbricata<br>Hawksbill Turtle [1766] | Vulnerable | Congregation or aggregation known to occur within area |
| Isurus oxyrinchus<br>Shortfin Mako, Mako Shark [79073] | | Species or species habitat likely to occur within area |
| Isurus paucus<br>Longfin Mako [82947] | | Species or species habitat likely to occur within area |
| Manta alfredi<br>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<br>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<br>Humpback Whale [38] | Vulnerable | Species or species habitat known to occur within area |

| Name | Threatened | Type of Presence |
|---|---|---|
| Natator depressus | | |
| Flatback Turtle [59257] | Vulnerable | Congregation or aggregation 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 | 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 |
| Sousa chinensis | | |
| Indo-Pacific Humpback Dolphin [50] | | 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 likely to 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 |
| Pandion haliaetus | | |
| Osprey [952] | | 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<br>Common Sandpiper [59309] | | Species or species habitat may occur within area |
| Anous stolidus<br>Common Noddy [825] | | Species or species habitat may occur within area |
| Apus pacificus<br>Fork-tailed Swift [678] | | Species or species habitat likely to occur within area |
| Calidris acuminata<br>Sharp-tailed Sandpiper [874] | | Species or species habitat may occur within area |
| Calidris canutus<br>Red Knot, Knot [855] | Endangered | Species or species habitat may occur within area |
| Calidris ferruginea<br>Curlew Sandpiper [856] | Critically Endangered | Species or species habitat may occur within area |
| Calidris melanotos<br>Pectoral Sandpiper [858] | | Species or species habitat may occur within area |
| Calonectris leucomelas<br>Streaked Shearwater [1077] | | Species or species habitat likely to occur within area |
| Fregata ariel<br>Lesser Frigatebird, Least Frigatebird [1012] | | Species or species habitat likely to occur within area |
| Macronectes giganteus<br>Southern Giant-Petrel, Southern Giant Petrel [1060] | Endangered | Species or species habitat may occur within area |
| Numenius madagascariensis<br>Eastern Curlew, Far Eastern Curlew [847] | Critically Endangered | Species or species habitat may occur within area |
| Pandion haliaetus<br>Osprey [952] | | Species or species habitat may occur within area |
| Sterna dougallii<br>Roseate Tern [817] | | Foraging, feeding or related behaviour likely to occur within area |
| Fish | | |
| Acentronura larsonae<br>Helen's Pygmy Pipehorse [66186] | | Species or species habitat may occur within area |
| Bulbonaricus brauni<br>Braun's Pughead Pipefish, Pug-headed Pipefish [66189] | | Species or species habitat may occur within area |

| Name | Threatened | Type of Presence |
|---|---|---|
| Campichthys tricarinatus<br>Three-keel Pipefish [66192] | | Species or species habitat may occur within area |
| Choeroichthys brachysoma<br>Pacific Short-bodied Pipefish, Short-bodied Pipefish [66194] | | Species or species habitat may occur within area |
| Choeroichthys latispinosus<br>Muiron Island Pipefish [66196] | | Species or species habitat may occur within area |
| Choeroichthys suillus<br>Pig-snouted Pipefish [66198] | | Species or species habitat may occur within area |
| Corythoichthys flavofasciatus<br>Reticulate Pipefish, Yellow-banded Pipefish, Network Pipefish [66200] | | Species or species habitat may occur within area |
| Cosmocampus banneri<br>Roughridge Pipefish [66206] | | Species or species habitat may occur within area |
| Doryrhamphus dactyliophorus<br>Banded Pipefish, Ringed Pipefish [66210] | | Species or species habitat may occur within area |
| Doryrhamphus excisus<br>Bluestripe Pipefish, Indian Blue-stripe Pipefish, Pacific Blue-stripe Pipefish [66211] | | Species or species habitat may occur within area |
| Doryrhamphus janssi<br>Cleaner Pipefish, Janss' Pipefish [66212] | | Species or species habitat may occur within area |
| Doryrhamphus multiannulatus<br>Many-banded Pipefish [66717] | | Species or species habitat may occur within area |
| Doryrhamphus negrosensis<br>Flagtail Pipefish, Masthead Island Pipefish [66213] | | Species or species habitat may occur within area |
| Festucalex scalaris<br>Ladder Pipefish [66216] | | Species or species habitat may occur within area |
| Filicampus tigris<br>Tiger Pipefish [66217] | | Species or species habitat may occur within area |
| Halicampus brocki<br>Brock's Pipefish [66219] | | Species or species habitat may occur within area |
| Halicampus grayi<br>Mud Pipefish, Gray's Pipefish [66221] | | Species or species habitat may occur within area |
| Halicampus nitidus<br>Glittering Pipefish [66224] | | Species or species habitat may occur within area |
| Halicampus spinirostris<br>Spiny-snout Pipefish [66225] | | Species or species habitat may occur within area |
| Haliichthys taeniophorus<br>Ribboned Pipehorse, Ribboned Seadragon [66226] | | Species or species habitat may occur within area |

| Name | Threatened | Type of Presence |
|---|---|---|
| Hippichthys penicillus<br>Beady Pipefish, Steep-nosed Pipefish [66231] | | Species or species habitat may occur within area |
| Hippocampus angustus<br>Western Spiny Seahorse, Narrow-bellied Seahorse [66234] | | Species or species habitat may occur within area |
| Hippocampus histrix<br>Spiny Seahorse, Thorny Seahorse [66236] | | Species or species habitat may occur within area |
| Hippocampus kuda<br>Spotted Seahorse, Yellow Seahorse [66237] | | Species or species habitat may occur within area |
| Hippocampus planifrons<br>Flat-face Seahorse [66238] | | Species or species habitat may occur within area |
| Hippocampus spinosissimus<br>Hedgehog Seahorse [66239] | | Species or species habitat may occur within area |
| Hippocampus trimaculatus<br>Three-spot Seahorse, Low-crowned Seahorse, Flat-faced Seahorse [66720] | | Species or species habitat may occur within area |
| Micrognathus micronotopterus<br>Tidepool Pipefish [66255] | | Species or species habitat may occur within area |
| Phoxocampus belcheri<br>Black Rock Pipefish [66719] | | Species or species habitat may occur within area |
| Solegnathus hardwickii<br>Pallid Pipehorse, Hardwick's Pipehorse [66272] | | Species or species habitat may occur within area |
| Solegnathus lettiensis<br>Gunther's Pipehorse, Indonesian Pipefish [66273] | | Species or species habitat may occur within area |
| Solenostomus cyanopterus<br>Robust Ghostpipefish, Blue-finned Ghost Pipefish, [66183] | | Species or species habitat may occur within area |
| Syngnathoides biaculeatus<br>Double-end Pipehorse, Double-ended Pipehorse, Alligator Pipefish [66279] | | Species or species habitat may occur within area |
| Trachyrhamphus bicoarctatus<br>Bentstick Pipefish, Bend Stick Pipefish, Short-tailed Pipefish [66280] | | Species or species habitat may occur within area |
| Trachyrhamphus longirostris<br>Straightstick Pipefish, Long-nosed Pipefish, Straight Stick Pipefish [66281] | | Species or species habitat may occur within area |
| **Mammals** | | |
| Dugong dugon<br>Dugong [28] | | Species or species habitat known to occur within area |
| **Reptiles** | | |
| Acalyptophis peronii<br>Horned Seasnake [1114] | | Species or species habitat may occur within area |
| Aipysurus apraefrontalis<br>Short-nosed Seasnake [1115] | Critically Endangered | Species or species habitat likely to occur |

| Name | Threatened | Type of Presence |
|---|---|---|
| | | within area |
| Aipysurus duboisii<br>Dubois' Seasnake [1116] | | Species or species habitat may occur within area |
| Aipysurus eydouxii<br>Spine-tailed Seasnake [1117] | | Species or species habitat may occur within area |
| Aipysurus laevis<br>Olive Seasnake [1120] | | Species or species habitat may occur within area |
| Aipysurus tenuis<br>Brown-lined Seasnake [1121] | | Species or species habitat may occur within area |
| Astrotia stokesii<br>Stokes' Seasnake [1122] | | Species or species habitat may occur within area |
| Caretta caretta<br>Loggerhead Turtle [1763] | Endangered | Congregation or aggregation known to occur within area |
| Chelonia mydas<br>Green Turtle [1765] | Vulnerable | Congregation or aggregation known to occur within area |
| Dermochelys coriacea<br>Leatherback Turtle, Leathery Turtle, Luth [1768] | Endangered | Species or species habitat likely to occur within area |
| Disteira kingii<br>Spectacled Seasnake [1123] | | Species or species habitat may occur within area |
| Disteira major<br>Olive-headed Seasnake [1124] | | Species or species habitat may occur within area |
| Emydocephalus annulatus<br>Turtle-headed Seasnake [1125] | | Species or species habitat may occur within area |
| Ephalophis greyi<br>North-western Mangrove Seasnake [1127] | | Species or species habitat may occur within area |
| Eretmochelys imbricata<br>Hawksbill Turtle [1766] | Vulnerable | Congregation or aggregation known to occur within area |
| Hydrelaps darwiniensis<br>Black-ringed Seasnake [1100] | | Species or species habitat may occur within area |
| Hydrophis czeblukovi<br>Fine-spined Seasnake [59233] | | Species or species habitat may occur within area |
| Hydrophis elegans<br>Elegant Seasnake [1104] | | Species or species habitat may occur within area |
| Hydrophis mcdowelli<br>null [25926] | | Species or species habitat may occur within area |
| Hydrophis ornatus<br>Spotted Seasnake, Ornate Reef Seasnake [1111] | | Species or species habitat may occur within area |

| Name | Threatened | Type of Presence |
| --- | --- | --- |
| Natator depressus | | |
| Flatback Turtle [59257] | Vulnerable | Congregation or aggregation 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 acutorostrata | | |
| Minke Whale [33] | | 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 | 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 | Migration route known 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 known 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 |

| Name | Status | Type of Presence |
|---|---|---|
| | | habitat may occur within area |
| Peponocephala electra<br>Melon-headed Whale [47] | | Species or species habitat may occur within area |
| Physeter macrocephalus<br>Sperm Whale [59] | | Species or species habitat may occur within area |
| Pseudorca crassidens<br>False Killer Whale [48] | | Species or species habitat likely to occur within area |
| Sousa chinensis<br>Indo-Pacific Humpback Dolphin [50] | | Species or species habitat may occur within area |
| Stenella attenuata<br>Spotted Dolphin, Pantropical Spotted Dolphin [51] | | Species or species habitat may occur within area |
| Stenella coeruleoalba<br>Striped Dolphin, Euphrosyne Dolphin [52] | | Species or species habitat may occur within area |
| Stenella longirostris<br>Long-snouted Spinner Dolphin [29] | | Species or species habitat may occur within area |
| Steno bredanensis<br>Rough-toothed Dolphin [30] | | Species or species habitat may occur within area |
| Tursiops aduncus<br>Indian Ocean Bottlenose Dolphin, Spotted Bottlenose Dolphin [68418] | | Species or species habitat likely to occur within area |
| Tursiops aduncus (Arafura/Timor Sea populations)<br>Spotted Bottlenose Dolphin (Arafura/Timor Sea populations) [78900] | | Species or species habitat likely to occur within area |
| Tursiops truncatus s. str.<br>Bottlenose Dolphin [68417] | | Species or species habitat may occur within area |
| Ziphius cavirostris<br>Cuvier's Beaked Whale, Goose-beaked Whale [56] | | Species or species habitat may occur within area |

## Australian Marine Parks [ Resource Information ]

| Name | Label |
|---|---|
| Montebello | Multiple Use Zone (IUCN VI) |

# 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 |
|---|---|

| Name | Region |
| --- | --- |
| Ancient coastline at 125 m depth contour | North-west |
| Continental Slope Demersal Fish Communities | North-west |
| Exmouth Plateau | 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

-19.867 113.336,-19.911 113.628,-19.937 113.725,-20.021 113.937,-19.936 114.18,-19.755 114.403,-19.777 114.483,-19.704 114.638,-19.797 114.925,-19.789 115.025,-19.862 115.116,-19.895 115.193,-19.936 115.232,-20.038 115.284,-20.06 115.426,-20.052 115.532,-20.139 115.918,-20.172 115.997,-20.171 116.078,-20.21 116.299,-20.294 116.56,-20.318 116.672,-20.351 116.699

# 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

TRUNKLINE PROJECT AREA
NEW SEARCH

# 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.

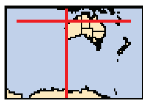
Report created: 09/12/19 17:48:20


- 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: 1.5Km



# 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: | 38 |

## 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: | 71 |
| Whales and Other Cetaceans: | 28 |
| Critical Habitats: | None |
| Commonwealth Reserves Terrestrial: | None |
| Australian Marine Parks: | 1 |

## 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) | 3 |

# 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** | | |
| Calidris canutus<br>Red Knot, Knot [855] | Endangered | Species or species habitat may occur within area |
| Calidris ferruginea<br>Curlew Sandpiper [856] | Critically Endangered | Species or species habitat may occur within area |
| Macronectes giganteus<br>Southern Giant-Petrel, Southern Giant Petrel [1060] | Endangered | Species or species habitat may occur within area |
| Numenius madagascariensis<br>Eastern Curlew, Far Eastern Curlew [847] | Critically Endangered | Species or species habitat may occur within area |
| Sternula nereis  nereis<br>Australian Fairy Tern [82950] | Vulnerable | Breeding known to occur within area |
| **Mammals** | | |
| Balaenoptera borealis<br>Sei Whale [34] | Vulnerable | Species or species habitat likely to occur within area |
| Balaenoptera musculus<br>Blue Whale [36] | Endangered | Migration route known to occur within area |
| Balaenoptera physalus<br>Fin Whale [37] | Vulnerable | Species or species habitat likely to occur within area |
| Megaptera novaeangliae<br>Humpback Whale [38] | Vulnerable | Species or species habitat known to occur within area |

| Name | Status | Type of Presence |
|---|---|---|
| Reptiles | | |
| Aipysurus apraefrontalis<br>Short-nosed Seasnake [1115] | Critically Endangered | Species or species habitat likely to occur within area |
| Caretta caretta<br>Loggerhead Turtle [1763] | Endangered | Congregation or aggregation known to occur within area |
| Chelonia mydas<br>Green Turtle [1765] | Vulnerable | Congregation or aggregation known to occur within area |
| Dermochelys coriacea<br>Leatherback Turtle, Leathery Turtle, Luth [1768] | Endangered | Species or species habitat likely to occur within area |
| Eretmochelys imbricata<br>Hawksbill Turtle [1766] | Vulnerable | Congregation or aggregation known to occur within area |
| Natator depressus<br>Flatback Turtle [59257] | Vulnerable | Congregation or aggregation known to occur within area |
| Sharks | | |
| Carcharias taurus (west coast population)<br>Grey Nurse Shark (west coast population) [68752] | Vulnerable | Species or species habitat likely to occur within area |
| Carcharodon carcharias<br>White Shark, Great White Shark [64470] | Vulnerable | Species or species habitat may occur within area |
| Pristis clavata<br>Dwarf Sawfish, Queensland Sawfish [68447] | Vulnerable | Species or species habitat known to occur within area |
| Pristis zijsron<br>Green Sawfish, Dindagubba, Narrowsnout Sawfish [68442] | Vulnerable | Species or species habitat known to occur within area |
| Rhincodon typus<br>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<br>Common Noddy [825] | | Species or species habitat may occur within area |
| Apus pacificus<br>Fork-tailed Swift [678] | | Species or species habitat likely to occur within area |
| Calonectris leucomelas<br>Streaked Shearwater [1077] | | Species or species habitat likely to occur within area |
| Fregata ariel<br>Lesser Frigatebird, Least Frigatebird [1012] | | Species or species habitat likely to occur within area |
| Macronectes giganteus<br>Southern Giant-Petrel, Southern Giant Petrel [1060] | Endangered | Species or species habitat may occur within area |

| Name | Threatened | Type of Presence |
|---|---|---|
| Sterna dougallii<br>Roseate Tern [817] | | Foraging, feeding or related behaviour likely to occur within area |
| **Migratory Marine Species** | | |
| Anoxypristis cuspidata<br>Narrow Sawfish, Knifetooth Sawfish [68448] | | Species or species habitat likely to occur within area |
| Balaenoptera bonaerensis<br>Antarctic Minke Whale, Dark-shoulder Minke Whale [67812] | | Species or species habitat likely to occur within area |
| Balaenoptera borealis<br>Sei Whale [34] | Vulnerable | Species or species habitat likely to occur within area |
| Balaenoptera edeni<br>Bryde's Whale [35] | | Species or species habitat likely to occur within area |
| Balaenoptera musculus<br>Blue Whale [36] | Endangered | Migration route known to occur within area |
| Balaenoptera physalus<br>Fin Whale [37] | Vulnerable | Species or species habitat likely to occur within area |
| Carcharodon carcharias<br>White Shark, Great White Shark [64470] | Vulnerable | Species or species habitat may occur within area |
| Caretta caretta<br>Loggerhead Turtle [1763] | Endangered | Congregation or aggregation known to occur within area |
| Chelonia mydas<br>Green Turtle [1765] | Vulnerable | Congregation or aggregation known to occur within area |
| Dermochelys coriacea<br>Leatherback Turtle, Leathery Turtle, Luth [1768] | Endangered | Species or species habitat likely to occur within area |
| Dugong dugon<br>Dugong [28] | | Species or species habitat known to occur within area |
| Eretmochelys imbricata<br>Hawksbill Turtle [1766] | Vulnerable | Congregation or aggregation known to occur within area |
| Isurus oxyrinchus<br>Shortfin Mako, Mako Shark [79073] | | Species or species habitat likely to occur within area |
| Isurus paucus<br>Longfin Mako [82947] | | Species or species habitat likely to occur within area |
| Manta alfredi<br>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<br>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<br>Humpback Whale [38] | Vulnerable | Species or species habitat known to occur within area |

| Name | Threatened | Type of Presence |
|---|---|---|
| Natator depressus<br>Flatback Turtle [59257] | Vulnerable | Congregation or aggregation known to occur within area |
| Orcinus orca<br>Killer Whale, Orca [46] | | Species or species habitat may occur within area |
| Physeter macrocephalus<br>Sperm Whale [59] | | Species or species habitat may occur within area |
| Pristis clavata<br>Dwarf Sawfish, Queensland Sawfish [68447] | Vulnerable | Species or species habitat known to occur within area |
| Pristis zijsron<br>Green Sawfish, Dindagubba, Narrowsnout Sawfish [68442] | Vulnerable | Species or species habitat known to occur within area |
| Rhincodon typus<br>Whale Shark [66680] | Vulnerable | Foraging, feeding or related behaviour known to occur within area |
| Sousa chinensis<br>Indo-Pacific Humpback Dolphin [50] | | Species or species habitat may occur within area |
| Tursiops aduncus (Arafura/Timor Sea populations)<br>Spotted Bottlenose Dolphin (Arafura/Timor Sea populations) [78900] | | Species or species habitat likely to occur within area |
| **Migratory Wetlands Species** | | |
| Actitis hypoleucos<br>Common Sandpiper [59309] | | Species or species habitat may occur within area |
| Calidris acuminata<br>Sharp-tailed Sandpiper [874] | | Species or species habitat may occur within area |
| Calidris canutus<br>Red Knot, Knot [855] | Endangered | Species or species habitat may occur within area |
| Calidris ferruginea<br>Curlew Sandpiper [856] | Critically Endangered | Species or species habitat may occur within area |
| Calidris melanotos<br>Pectoral Sandpiper [858] | | Species or species habitat may occur within area |
| Numenius madagascariensis<br>Eastern Curlew, Far Eastern Curlew [847] | Critically Endangered | Species or species habitat may occur within area |
| Pandion haliaetus<br>Osprey [952] | | 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<br>Common Sandpiper [59309] | | Species or species habitat may occur within area |
| Anous stolidus<br>Common Noddy [825] | | Species or species habitat may occur within area |
| Apus pacificus<br>Fork-tailed Swift [678] | | Species or species habitat likely to occur within area |
| Calidris acuminata<br>Sharp-tailed Sandpiper [874] | | Species or species habitat may occur within area |
| Calidris canutus<br>Red Knot, Knot [855] | Endangered | Species or species habitat may occur within area |
| Calidris ferruginea<br>Curlew Sandpiper [856] | Critically Endangered | Species or species habitat may occur within area |
| Calidris melanotos<br>Pectoral Sandpiper [858] | | Species or species habitat may occur within area |
| Calonectris leucomelas<br>Streaked Shearwater [1077] | | Species or species habitat likely to occur within area |
| Fregata ariel<br>Lesser Frigatebird, Least Frigatebird [1012] | | Species or species habitat likely to occur within area |
| Macronectes giganteus<br>Southern Giant-Petrel, Southern Giant Petrel [1060] | Endangered | Species or species habitat may occur within area |
| Numenius madagascariensis<br>Eastern Curlew, Far Eastern Curlew [847] | Critically Endangered | Species or species habitat may occur within area |
| Pandion haliaetus<br>Osprey [952] | | Species or species habitat may occur within area |
| Sterna dougallii<br>Roseate Tern [817] | | Foraging, feeding or related behaviour likely to occur within area |
| Fish | | |
| Acentronura larsonae<br>Helen's Pygmy Pipehorse [66186] | | Species or species habitat may occur within area |
| Bulbonaricus brauni<br>Braun's Pughead Pipefish, Pug-headed Pipefish [66189] | | Species or species habitat may occur within area |

| Name | Threatened | Type of Presence |
| --- | --- | --- |
| Campichthys tricarinatus<br>Three-keel Pipefish [66192] | | Species or species habitat may occur within area |
| Choeroichthys brachysoma<br>Pacific Short-bodied Pipefish, Short-bodied Pipefish [66194] | | Species or species habitat may occur within area |
| Choeroichthys latispinosus<br>Muiron Island Pipefish [66196] | | Species or species habitat may occur within area |
| Choeroichthys suillus<br>Pig-snouted Pipefish [66198] | | Species or species habitat may occur within area |
| Corythoichthys flavofasciatus<br>Reticulate Pipefish, Yellow-banded Pipefish, Network Pipefish [66200] | | Species or species habitat may occur within area |
| Cosmocampus banneri<br>Roughridge Pipefish [66206] | | Species or species habitat may occur within area |
| Doryrhamphus dactyliophorus<br>Banded Pipefish, Ringed Pipefish [66210] | | Species or species habitat may occur within area |
| Doryrhamphus excisus<br>Bluestripe Pipefish, Indian Blue-stripe Pipefish, Pacific Blue-stripe Pipefish [66211] | | Species or species habitat may occur within area |
| Doryrhamphus janssi<br>Cleaner Pipefish, Janss' Pipefish [66212] | | Species or species habitat may occur within area |
| Doryrhamphus multiannulatus<br>Many-banded Pipefish [66717] | | Species or species habitat may occur within area |
| Doryrhamphus negrosensis<br>Flagtail Pipefish, Masthead Island Pipefish [66213] | | Species or species habitat may occur within area |
| Festucalex scalaris<br>Ladder Pipefish [66216] | | Species or species habitat may occur within area |
| Filicampus tigris<br>Tiger Pipefish [66217] | | Species or species habitat may occur within area |
| Halicampus brocki<br>Brock's Pipefish [66219] | | Species or species habitat may occur within area |
| Halicampus grayi<br>Mud Pipefish, Gray's Pipefish [66221] | | Species or species habitat may occur within area |
| Halicampus nitidus<br>Glittering Pipefish [66224] | | Species or species habitat may occur within area |
| Halicampus spinirostris<br>Spiny-snout Pipefish [66225] | | Species or species habitat may occur within area |
| Haliichthys taeniophorus<br>Ribboned Pipehorse, Ribboned Seadragon [66226] | | Species or species habitat may occur within area |

| Name | Threatened | Type of Presence |
|---|---|---|
| Hippichthys penicillus<br>Beady Pipefish, Steep-nosed Pipefish [66231] | | Species or species habitat may occur within area |
| Hippocampus angustus<br>Western Spiny Seahorse, Narrow-bellied Seahorse [66234] | | Species or species habitat may occur within area |
| Hippocampus histrix<br>Spiny Seahorse, Thorny Seahorse [66236] | | Species or species habitat may occur within area |
| Hippocampus kuda<br>Spotted Seahorse, Yellow Seahorse [66237] | | Species or species habitat may occur within area |
| Hippocampus planifrons<br>Flat-face Seahorse [66238] | | Species or species habitat may occur within area |
| Hippocampus spinosissimus<br>Hedgehog Seahorse [66239] | | Species or species habitat may occur within area |
| Hippocampus trimaculatus<br>Three-spot Seahorse, Low-crowned Seahorse, Flat-faced Seahorse [66720] | | Species or species habitat may occur within area |
| Micrognathus micronotopterus<br>Tidepool Pipefish [66255] | | Species or species habitat may occur within area |
| Phoxocampus belcheri<br>Black Rock Pipefish [66719] | | Species or species habitat may occur within area |
| Solegnathus hardwickii<br>Pallid Pipehorse, Hardwick's Pipehorse [66272] | | Species or species habitat may occur within area |
| Solegnathus lettiensis<br>Gunther's Pipehorse, Indonesian Pipefish [66273] | | Species or species habitat may occur within area |
| Solenostomus cyanopterus<br>Robust Ghostpipefish, Blue-finned Ghost Pipefish, [66183] | | Species or species habitat may occur within area |
| Syngnathoides biaculeatus<br>Double-end Pipehorse, Double-ended Pipehorse, Alligator Pipefish [66279] | | Species or species habitat may occur within area |
| Trachyrhamphus bicoarctatus<br>Bentstick Pipefish, Bend Stick Pipefish, Short-tailed Pipefish [66280] | | Species or species habitat may occur within area |
| Trachyrhamphus longirostris<br>Straightstick Pipefish, Long-nosed Pipefish, Straight Stick Pipefish [66281] | | Species or species habitat may occur within area |
| **Mammals** | | |
| Dugong dugon<br>Dugong [28] | | Species or species habitat known to occur within area |
| **Reptiles** | | |
| Acalyptophis peronii<br>Horned Seasnake [1114] | | Species or species habitat may occur within area |
| Aipysurus apraefrontalis<br>Short-nosed Seasnake [1115] | Critically Endangered | Species or species habitat likely to occur |

| Name | Threatened | Type of Presence |
| --- | --- | --- |
| | | within area |
| Aipysurus duboisii<br>Dubois' Seasnake [1116] | | Species or species habitat may occur within area |
| Aipysurus eydouxii<br>Spine-tailed Seasnake [1117] | | Species or species habitat may occur within area |
| Aipysurus laevis<br>Olive Seasnake [1120] | | Species or species habitat may occur within area |
| Aipysurus tenuis<br>Brown-lined Seasnake [1121] | | Species or species habitat may occur within area |
| Astrotia stokesii<br>Stokes' Seasnake [1122] | | Species or species habitat may occur within area |
| Caretta caretta<br>Loggerhead Turtle [1763] | Endangered | Congregation or aggregation known to occur within area |
| Chelonia mydas<br>Green Turtle [1765] | Vulnerable | Congregation or aggregation known to occur within area |
| Dermochelys coriacea<br>Leatherback Turtle, Leathery Turtle, Luth [1768] | Endangered | Species or species habitat likely to occur within area |
| Disteira kingii<br>Spectacled Seasnake [1123] | | Species or species habitat may occur within area |
| Disteira major<br>Olive-headed Seasnake [1124] | | Species or species habitat may occur within area |
| Emydocephalus annulatus<br>Turtle-headed Seasnake [1125] | | Species or species habitat may occur within area |
| Ephalophis greyi<br>North-western Mangrove Seasnake [1127] | | Species or species habitat may occur within area |
| Eretmochelys imbricata<br>Hawksbill Turtle [1766] | Vulnerable | Congregation or aggregation known to occur within area |
| Hydrelaps darwiniensis<br>Black-ringed Seasnake [1100] | | Species or species habitat may occur within area |
| Hydrophis czeblukovi<br>Fine-spined Seasnake [59233] | | Species or species habitat may occur within area |
| Hydrophis elegans<br>Elegant Seasnake [1104] | | Species or species habitat may occur within area |
| Hydrophis mcdowelli<br>null [25926] | | Species or species habitat may occur within area |
| Hydrophis ornatus<br>Spotted Seasnake, Ornate Reef Seasnake [1111] | | Species or species habitat may occur within area |

| Name | Threatened | Type of Presence |
|---|---|---|
| Natator depressus | | |
| Flatback Turtle [59257] | Vulnerable | Congregation or aggregation 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 acutorostrata | | |
| Minke Whale [33] | | 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 | 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 | Migration route known 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 known 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 |

| Name | Status | Type of Presence |
|---|---|---|
| | | habitat may occur within area |
| Peponocephala electra<br>Melon-headed Whale [47] | | Species or species habitat may occur within area |
| Physeter macrocephalus<br>Sperm Whale [59] | | Species or species habitat may occur within area |
| Pseudorca crassidens<br>False Killer Whale [48] | | Species or species habitat likely to occur within area |
| Sousa chinensis<br>Indo-Pacific Humpback Dolphin [50] | | Species or species habitat may occur within area |
| Stenella attenuata<br>Spotted Dolphin, Pantropical Spotted Dolphin [51] | | Species or species habitat may occur within area |
| Stenella coeruleoalba<br>Striped Dolphin, Euphrosyne Dolphin [52] | | Species or species habitat may occur within area |
| Stenella longirostris<br>Long-snouted Spinner Dolphin [29] | | Species or species habitat may occur within area |
| Steno bredanensis<br>Rough-toothed Dolphin [30] | | Species or species habitat may occur within area |
| Tursiops aduncus<br>Indian Ocean Bottlenose Dolphin, Spotted Bottlenose Dolphin [68418] | | Species or species habitat likely to occur within area |
| Tursiops aduncus (Arafura/Timor Sea populations)<br>Spotted Bottlenose Dolphin (Arafura/Timor Sea populations) [78900] | | Species or species habitat likely to occur within area |
| Tursiops truncatus s. str.<br>Bottlenose Dolphin [68417] | | Species or species habitat may occur within area |
| Ziphius cavirostris<br>Cuvier's Beaked Whale, Goose-beaked Whale [56] | | Species or species habitat may occur within area |

## Australian Marine Parks [ Resource Information ]

| Name | Label |
|---|---|
| Montebello | Multiple Use Zone (IUCN VI) |

# 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 |
|---|---|

| Name | Region |
| --- | --- |
| Ancient coastline at 125 m depth contour | North-west |
| Continental Slope Demersal Fish Communities | North-west |
| Exmouth Plateau | 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

-19.867 113.336,-19.911 113.628,-19.937 113.725,-20.021 113.937,-19.936 114.18,-19.755 114.403,-19.777 114.483,-19.704 114.638,-19.797 114.925,-19.789 115.025,-19.862 115.116,-19.895 115.193,-19.936 115.232,-20.038 115.284,-20.06 115.426,-20.052 115.532,-20.139 115.918,-20.172 115.997,-20.171 116.078,-20.21 116.299,-20.294 116.56,-20.318 116.672,-20.351 116.699

# 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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BORROW GROUNDS

# 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: 29/01/19 16:47:06

- Summary
- Details
    - Matters of NES
    - Other Matters Protected by the EPBC Act
    - Extra Information
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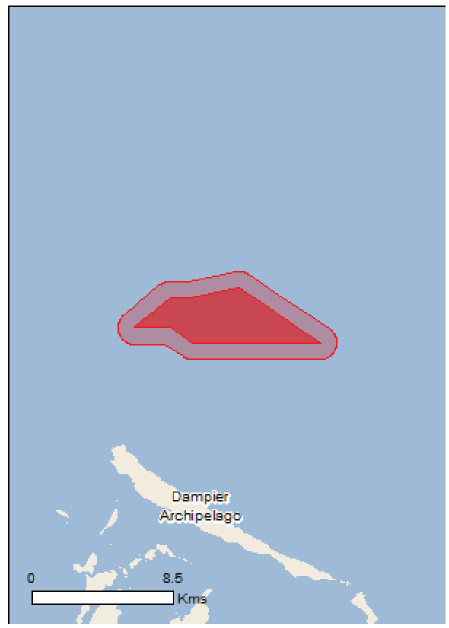
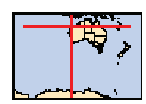
- Acknowledgements






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: | 18 |
| Listed Migratory Species: | 32 |

## 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: | 67 |
| Whales and Other Cetaceans: | 12 |
| Critical Habitats: | None |
| Commonwealth Reserves Terrestrial: | None |
| Australian Marine Parks: | 1 |

## 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) | None |

# 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 | | |
| Calidris canutus<br>Red Knot, Knot [855] | Endangered | Species or species habitat may occur within area |
| Calidris ferruginea<br>Curlew Sandpiper [856] | Critically Endangered | Species or species habitat may occur within area |
| Macronectes giganteus<br>Southern Giant-Petrel, Southern Giant Petrel [1060] | Endangered | Species or species habitat may occur within area |
| Numenius madagascariensis<br>Eastern Curlew, Far Eastern Curlew [847] | Critically Endangered | Species or species habitat may occur within area |
| Sternula nereis nereis<br>Australian Fairy Tern [82950] | Vulnerable | Breeding known to occur within area |
| Mammals | | |
| Balaenoptera musculus<br>Blue Whale [36] | Endangered | Species or species habitat likely to occur within area |
| Megaptera novaeangliae<br>Humpback Whale [38] | Vulnerable | Species or species habitat known to occur within area |
| Reptiles | | |
| Aipysurus apraefrontalis<br>Short-nosed Seasnake [1115] | Critically Endangered | Species or species habitat may occur within area |
| Caretta caretta<br>Loggerhead Turtle [1763] | Endangered | Species or species |

| Name | Status | Type of Presence |
|---|---|---|
| | | habitat known to occur within area |
| Chelonia mydas<br>Green Turtle [1765] | Vulnerable | Species or species habitat known to occur within area |
| Dermochelys coriacea<br>Leatherback Turtle, Leathery Turtle, Luth [1768] | Endangered | Species or species habitat likely to occur within area |
| Eretmochelys imbricata<br>Hawksbill Turtle [1766] | Vulnerable | Species or species habitat known to occur within area |
| Natator depressus<br>Flatback Turtle [59257] | Vulnerable | Congregation or aggregation known to occur within area |
| Sharks | | |
| Carcharias taurus (west coast population)<br>Grey Nurse Shark (west coast population) [68752] | Vulnerable | Species or species habitat likely to occur within area |
| Carcharodon carcharias<br>White Shark, Great White Shark [64470] | Vulnerable | Species or species habitat may occur within area |
| Pristis clavata<br>Dwarf Sawfish, Queensland Sawfish [68447] | Vulnerable | Species or species habitat known to occur within area |
| Pristis zijsron<br>Green Sawfish, Dindagubba, Narrowsnout Sawfish [68442] | Vulnerable | Species or species habitat known to occur within area |
| Rhincodon typus<br>Whale Shark [66680] | Vulnerable | Species or species habitat may 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<br>Common Noddy [825] | | Species or species habitat may occur within area |
| Apus pacificus<br>Fork-tailed Swift [678] | | Species or species habitat likely to occur within area |
| Calonectris leucomelas<br>Streaked Shearwater [1077] | | Species or species habitat likely to occur within area |
| Fregata ariel<br>Lesser Frigatebird, Least Frigatebird [1012] | | Species or species habitat likely to occur within area |
| Macronectes giganteus<br>Southern Giant-Petrel, Southern Giant Petrel [1060] | Endangered | Species or species habitat may occur within area |
| Sterna dougallii<br>Roseate Tern [817] | | Breeding likely to occur within area |
| Migratory Marine Species | | |
| Anoxypristis cuspidata<br>Narrow Sawfish, Knifetooth Sawfish [68448] | | Species or species habitat likely to occur within area |

| Name | Threatened | Type of Presence |
|---|---|---|
| Balaenoptera edeni<br>Bryde's Whale [35] | | Species or species habitat may occur within area |
| Balaenoptera musculus<br>Blue Whale [36] | Endangered | Species or species habitat likely to occur within area |
| Carcharodon carcharias<br>White Shark, Great White Shark [64470] | Vulnerable | Species or species habitat may occur within area |
| Caretta caretta<br>Loggerhead Turtle [1763] | Endangered | Species or species habitat known to occur within area |
| Chelonia mydas<br>Green Turtle [1765] | Vulnerable | Species or species habitat known to occur within area |
| Dermochelys coriacea<br>Leatherback Turtle, Leathery Turtle, Luth [1768] | Endangered | Species or species habitat likely to occur within area |
| Dugong dugon<br>Dugong [28] | | Species or species habitat likely to occur within area |
| Eretmochelys imbricata<br>Hawksbill Turtle [1766] | Vulnerable | Species or species habitat known to occur within area |
| Manta alfredi<br>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<br>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<br>Humpback Whale [38] | Vulnerable | Species or species habitat known to occur within area |
| Natator depressus<br>Flatback Turtle [59257] | Vulnerable | Congregation or aggregation known to occur within area |
| Orcinus orca<br>Killer Whale, Orca [46] | | Species or species habitat may occur within area |
| Pristis clavata<br>Dwarf Sawfish, Queensland Sawfish [68447] | Vulnerable | Species or species habitat known to occur within area |
| Pristis zijsron<br>Green Sawfish, Dindagubba, Narrowsnout Sawfish [68442] | Vulnerable | Species or species habitat known to occur within area |
| Rhincodon typus<br>Whale Shark [66680] | Vulnerable | Species or species habitat may occur within area |
| Sousa chinensis<br>Indo-Pacific Humpback Dolphin [50] | | Species or species habitat may occur within area |
| Tursiops aduncus (Arafura/Timor Sea populations)<br>Spotted Bottlenose Dolphin (Arafura/Timor Sea populations) [78900] | | Species or species habitat likely to occur within area |

Migratory Wetlands Species

| Name | Threatened | Type of Presence |
|---|---|---|
| Actitis hypoleucos<br>Common Sandpiper [59309] | | Species or species habitat may occur within area |
| Calidris acuminata<br>Sharp-tailed Sandpiper [874] | | Species or species habitat may occur within area |
| Calidris canutus<br>Red Knot, Knot [855] | Endangered | Species or species habitat may occur within area |
| Calidris ferruginea<br>Curlew Sandpiper [856] | Critically Endangered | Species or species habitat may occur within area |
| Calidris melanotos<br>Pectoral Sandpiper [858] | | Species or species habitat may occur within area |
| Numenius madagascariensis<br>Eastern Curlew, Far Eastern Curlew [847] | Critically Endangered | Species or species habitat may occur within area |
| Pandion haliaetus<br>Osprey [952] | | 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<br>Common Sandpiper [59309] | | Species or species habitat may occur within area |
| Anous stolidus<br>Common Noddy [825] | | Species or species habitat may occur within area |
| Apus pacificus<br>Fork-tailed Swift [678] | | Species or species habitat likely to occur within area |
| Calidris acuminata<br>Sharp-tailed Sandpiper [874] | | Species or species habitat may occur within area |
| Calidris canutus<br>Red Knot, Knot [855] | Endangered | Species or species habitat may occur within area |
| Calidris ferruginea<br>Curlew Sandpiper [856] | Critically Endangered | Species or species habitat may occur within area |
| Calidris melanotos<br>Pectoral Sandpiper [858] | | Species or species habitat may occur within area |
| Calonectris leucomelas<br>Streaked Shearwater [1077] | | Species or species habitat likely to occur within area |

| Name | Threatened | Type of Presence |
|---|---|---|
| Fregata ariel<br>Lesser Frigatebird, Least Frigatebird [1012] | | Species or species habitat likely to occur within area |
| Macronectes giganteus<br>Southern Giant-Petrel, Southern Giant Petrel [1060] | Endangered | Species or species habitat may occur within area |
| Numenius madagascariensis<br>Eastern Curlew, Far Eastern Curlew [847] | Critically Endangered | Species or species habitat may occur within area |
| Pandion haliaetus<br>Osprey [952] | | Species or species habitat may occur within area |
| Sterna dougallii<br>Roseate Tern [817] | | Breeding likely to occur within area |
| Fish | | |
| Acentronura larsonae<br>Helen's Pygmy Pipehorse [66186] | | Species or species habitat may occur within area |
| Bulbonaricus brauni<br>Braun's Pughead Pipefish, Pug-headed Pipefish [66189] | | Species or species habitat may occur within area |
| Campichthys tricarinatus<br>Three-keel Pipefish [66192] | | Species or species habitat may occur within area |
| Choeroichthys brachysoma<br>Pacific Short-bodied Pipefish, Short-bodied Pipefish [66194] | | Species or species habitat may occur within area |
| Choeroichthys latispinosus<br>Muiron Island Pipefish [66196] | | Species or species habitat may occur within area |
| Choeroichthys suillus<br>Pig-snouted Pipefish [66198] | | Species or species habitat may occur within area |
| Doryrhamphus dactyliophorus<br>Banded Pipefish, Ringed Pipefish [66210] | | Species or species habitat may occur within area |
| Doryrhamphus janssi<br>Cleaner Pipefish, Janss' Pipefish [66212] | | Species or species habitat may occur within area |
| Doryrhamphus multiannulatus<br>Many-banded Pipefish [66717] | | Species or species habitat may occur within area |
| Doryrhamphus negrosensis<br>Flagtail Pipefish, Masthead Island Pipefish [66213] | | Species or species habitat may occur within area |
| Festucalex scalaris<br>Ladder Pipefish [66216] | | Species or species habitat may occur within area |
| Filicampus tigris<br>Tiger Pipefish [66217] | | Species or species habitat may occur within area |
| Halicampus brocki<br>Brock's Pipefish [66219] | | Species or species habitat may occur within area |

| Name | Threatened | Type of Presence |
|---|---|---|
| Halicampus grayi<br>Mud Pipefish, Gray's Pipefish [66221] | | Species or species habitat may occur within area |
| Halicampus nitidus<br>Glittering Pipefish [66224] | | Species or species habitat may occur within area |
| Halicampus spinirostris<br>Spiny-snout Pipefish [66225] | | Species or species habitat may occur within area |
| Haliichthys taeniophorus<br>Ribboned Pipehorse, Ribboned Seadragon [66226] | | Species or species habitat may occur within area |
| Hippichthys penicillus<br>Beady Pipefish, Steep-nosed Pipefish [66231] | | Species or species habitat may occur within area |
| Hippocampus angustus<br>Western Spiny Seahorse, Narrow-bellied Seahorse [66234] | | Species or species habitat may occur within area |
| Hippocampus histrix<br>Spiny Seahorse, Thorny Seahorse [66236] | | Species or species habitat may occur within area |
| Hippocampus kuda<br>Spotted Seahorse, Yellow Seahorse [66237] | | Species or species habitat may occur within area |
| Hippocampus planifrons<br>Flat-face Seahorse [66238] | | Species or species habitat may occur within area |
| Hippocampus trimaculatus<br>Three-spot Seahorse, Low-crowned Seahorse, Flat-faced Seahorse [66720] | | Species or species habitat may occur within area |
| Micrognathus micronotopterus<br>Tidepool Pipefish [66255] | | Species or species habitat may occur within area |
| Phoxocampus belcheri<br>Black Rock  Pipefish [66719] | | Species or species habitat may occur within area |
| Solegnathus hardwickii<br>Pallid Pipehorse, Hardwick's Pipehorse [66272] | | Species or species habitat may occur within area |
| Solegnathus lettiensis<br>Gunther's Pipehorse, Indonesian Pipefish [66273] | | Species or species habitat may occur within area |
| Solenostomus cyanopterus<br>Robust Ghostpipefish, Blue-finned Ghost Pipefish, [66183] | | Species or species habitat may occur within area |
| Syngnathoides biaculeatus<br>Double-end Pipehorse, Double-ended Pipehorse, Alligator Pipefish [66279] | | Species or species habitat may occur within area |
| Trachyrhamphus bicoarctatus<br>Bentstick Pipefish, Bend Stick Pipefish, Short-tailed Pipefish [66280] | | Species or species habitat may occur within area |
| Trachyrhamphus longirostris<br>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<br>Dugong [28] | | Species or species habitat likely to occur within area |
| **Reptiles** | | |
| Acalyptophis peronii<br>Horned Seasnake [1114] | | Species or species habitat may occur within area |
| Aipysurus apraefrontalis<br>Short-nosed Seasnake [1115] | Critically Endangered | Species or species habitat may occur within area |
| Aipysurus duboisii<br>Dubois' Seasnake [1116] | | Species or species habitat may occur within area |
| Aipysurus eydouxii<br>Spine-tailed Seasnake [1117] | | Species or species habitat may occur within area |
| Aipysurus laevis<br>Olive Seasnake [1120] | | Species or species habitat may occur within area |
| Aipysurus tenuis<br>Brown-lined Seasnake [1121] | | Species or species habitat may occur within area |
| Astrotia stokesii<br>Stokes' Seasnake [1122] | | Species or species habitat may occur within area |
| Caretta caretta<br>Loggerhead Turtle [1763] | Endangered | Species or species habitat known to occur within area |
| Chelonia mydas<br>Green Turtle [1765] | Vulnerable | Species or species habitat known to occur within area |
| Dermochelys coriacea<br>Leatherback Turtle, Leathery Turtle, Luth [1768] | Endangered | Species or species habitat likely to occur within area |
| Disteira kingii<br>Spectacled Seasnake [1123] | | Species or species habitat may occur within area |
| Disteira major<br>Olive-headed Seasnake [1124] | | Species or species habitat may occur within area |
| Emydocephalus annulatus<br>Turtle-headed Seasnake [1125] | | Species or species habitat may occur within area |
| Ephalophis greyi<br>North-western Mangrove Seasnake [1127] | | Species or species habitat may occur within area |
| Eretmochelys imbricata<br>Hawksbill Turtle [1766] | Vulnerable | Species or species habitat known to occur within area |
| Hydrelaps darwiniensis<br>Black-ringed Seasnake [1100] | | Species or species habitat may occur within area |
| Hydrophis czeblukovi<br>Fine-spined Seasnake [59233] | | Species or species habitat may occur within area |

| Name | Threatened | Type of Presence |
|---|---|---|
| Hydrophis elegans<br>Elegant Seasnake [1104] | | Species or species habitat may occur within area |
| Hydrophis mcdowelli<br>null [25926] | | Species or species habitat may occur within area |
| Hydrophis ornatus<br>Spotted Seasnake, Ornate Reef Seasnake [1111] | | Species or species habitat may occur within area |
| Natator depressus<br>Flatback Turtle [59257] | Vulnerable | Congregation or aggregation known to occur within area |
| Pelamis platurus<br>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<br>Minke Whale [33] | | Species or species habitat may occur within area |
| Balaenoptera edeni<br>Bryde's Whale [35] | | Species or species habitat may occur within area |
| Balaenoptera musculus<br>Blue Whale [36] | Endangered | Species or species habitat likely to occur within area |
| Delphinus delphis<br>Common Dophin, Short-beaked Common Dolphin [60] | | Species or species habitat may occur within area |
| Grampus griseus<br>Risso's Dolphin, Grampus [64] | | Species or species habitat may occur within area |
| Megaptera novaeangliae<br>Humpback Whale [38] | Vulnerable | Species or species habitat known to occur within area |
| Orcinus orca<br>Killer Whale, Orca [46] | | Species or species habitat may occur within area |
| Sousa chinensis<br>Indo-Pacific Humpback Dolphin [50] | | Species or species habitat may occur within area |
| Stenella attenuata<br>Spotted Dolphin, Pantropical Spotted Dolphin [51] | | Species or species habitat may occur within area |
| Tursiops aduncus<br>Indian Ocean Bottlenose Dolphin, Spotted Bottlenose Dolphin [68418] | | Species or species habitat likely to occur within area |
| Tursiops aduncus (Arafura/Timor Sea populations)<br>Spotted Bottlenose Dolphin (Arafura/Timor Sea populations) [78900] | | Species or species habitat likely to occur within area |
| Tursiops truncatus s. str.<br>Bottlenose Dolphin [68417] | | Species or species habitat may occur within area |

## Australian Marine Parks [ Resource Information ]

| Name | Label |
| --- | --- |
| Dampier | Habitat Protection Zone (IUCN IV) |

## Extra Information

# 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

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# 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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# 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: 05/04/19 18:46:08


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- Details
  - Matters of NES
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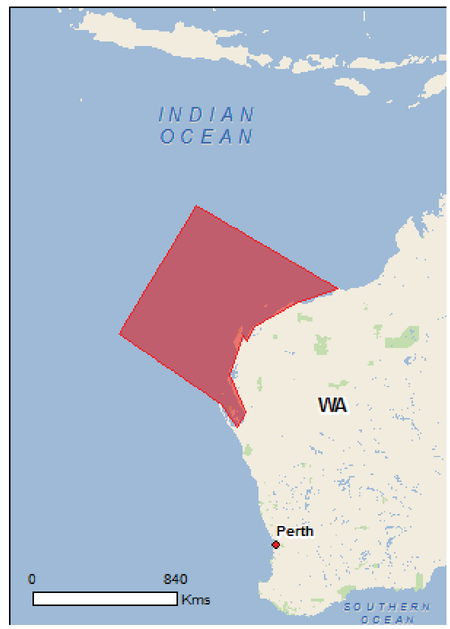
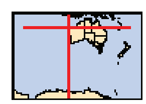





Coordinates
Buffer: 1.0Km



# 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: | 2 |
| National Heritage Places: | 4 |
| Wetlands of International Importance: | None |
| Great Barrier Reef Marine Park: | None |
| Commonwealth Marine Area: | 2 |
| Listed Threatened Ecological Communities: | 1 |
| Listed Threatened Species: | 73 |
| Listed Migratory Species: | 85 |

## 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: | 10 |
| Commonwealth Heritage Places: | 2 |
| Listed Marine Species: | 138 |
| Whales and Other Cetaceans: | 31 |
| Critical Habitats: | None |
| Commonwealth Reserves Terrestrial: | None |
| Australian Marine Parks: | 11 |

## Extra Information

This part of the report provides information that may also be relevant to the area you have nominated.

| | |
|---|---|
| State and Territory Reserves: | 53 |
| Regional Forest Agreements: | None |
| Invasive Species: | 25 |
| Nationally Important Wetlands: | 8 |
| Key Ecological Features (Marine) | 6 |

# Details

## Matters of National Environmental Significance

### World Heritage Properties [ Resource Information ]

| Name | State | Status |
|---|---|---|
| Shark Bay, Western Australia | WA | Declared property |
| The Ningaloo Coast | WA | Declared property |

### National Heritage Properties [ Resource Information ]

| Name | State | Status |
|---|---|---|
| Natural | | |
| Shark Bay, Western Australia | WA | Listed place |
| The Ningaloo Coast | WA | Listed place |
| Indigenous | | |
| Dampier Archipelago (including Burrup Peninsula) | WA | Listed place |
| Historic | | |
| Dirk Hartog Landing Site 1616 - Cape Inscription Area | WA | Listed place |

### 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-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 |
|---|---|---|
| Subtropical and Temperate Coastal Saltmarsh | Vulnerable | Community likely to occur within area |

### Listed Threatened Species [ Resource Information ]

| Name | Status | Type of Presence |
|---|---|---|
| Birds | | |
| Calidris canutus<br>Red Knot, Knot [855] | Endangered | Species or species habitat known to occur within area |
| Calidris ferruginea<br>Curlew Sandpiper [856] | Critically Endangered | Species or species habitat known to occur within area |
| Calidris tenuirostris<br>Great Knot [862] | Critically Endangered | Roosting known to occur within area |
| Charadrius leschenaultii<br>Greater Sand Plover, Large Sand Plover [877] | Vulnerable | Roosting known to occur within area |

| Name | Status | Type of Presence |
| --- | --- | --- |
| Charadrius mongolus<br>Lesser Sand Plover, Mongolian Plover [879] | Endangered | Species or species habitat known to occur within area |
| Diomedea amsterdamensis<br>Amsterdam Albatross [64405] | Endangered | Species or species habitat may occur within area |
| Diomedea exulans<br>Wandering Albatross [89223] | Vulnerable | Species or species habitat may occur within area |
| Leipoa ocellata<br>Malleefowl [934] | Vulnerable | Species or species habitat known to occur within area |
| Limosa lapponica  baueri<br>Bar-tailed Godwit (baueri), Western Alaskan Bar-tailed Godwit [86380] | Vulnerable | Species or species habitat known to occur within area |
| Limosa lapponica  menzbieri<br>Northern Siberian Bar-tailed Godwit, Bar-tailed Godwit (menzbieri) [86432] | Critically Endangered | Species or species habitat likely to occur within area |
| Macronectes giganteus<br>Southern Giant-Petrel, Southern Giant Petrel [1060] | Endangered | Species or species habitat may occur within area |
| Macronectes halli<br>Northern Giant Petrel [1061] | Vulnerable | Species or species habitat may occur within area |
| Malurus leucopterus  edouardi<br>White-winged Fairy-wren (Barrow Island), Barrow Island Black-and-white Fairy-wren [26194] | Vulnerable | Species or species habitat likely to occur within area |
| Malurus leucopterus  leucopterus<br>White-winged Fairy-wren (Dirk Hartog Island), Dirk Hartog Black-and-White Fairy-wren [26004] | Vulnerable | Species or species habitat likely to occur within area |
| Numenius madagascariensis<br>Eastern Curlew, Far Eastern Curlew [847] | Critically Endangered | Species or species habitat known to occur within area |
| Papasula abbotti<br>Abbott's Booby [59297] | Endangered | Species or species habitat may occur within area |
| Pezoporus occidentalis<br>Night Parrot [59350] | Endangered | Species or species habitat may occur within area |
| Pterodroma mollis<br>Soft-plumaged Petrel [1036] | Vulnerable | Foraging, feeding or related behaviour likely to occur within area |
| Rostratula australis<br>Australian Painted-snipe, Australian Painted Snipe [77037] | Endangered | Species or species habitat may occur within area |
| Sternula nereis  nereis<br>Australian Fairy Tern [82950] | Vulnerable | Breeding known to occur within area |
| Thalassarche carteri<br>Indian Yellow-nosed  Albatross [64464] | Vulnerable | Foraging, feeding or related behaviour may occur within area |
| Thalassarche cauta  cauta<br>Shy Albatross, Tasmanian Shy Albatross [82345] | Vulnerable | Species or species habitat may occur within area |
| Thalassarche cauta  steadi<br>White-capped Albatross [82344] | Vulnerable | Foraging, feeding or |

| Name | Status | Type of Presence |
| --- | --- | --- |
| | | related behaviour likely to occur within area |
| Thalassarche impavida<br>Campbell Albatross, Campbell Black-browed Albatross [64459] | Vulnerable | Species or species habitat may occur within area |
| Thalassarche melanophris<br>Black-browed Albatross [66472] | Vulnerable | Species or species habitat may occur within area |
| **Fish** | | |
| Milyeringa veritas<br>Blind Gudgeon [66676] | Vulnerable | Species or species habitat known to occur within area |
| Ophisternon candidum<br>Blind Cave Eel [66678] | Vulnerable | Species or species habitat known to occur within area |
| **Mammals** | | |
| Balaenoptera borealis<br>Sei Whale [34] | Vulnerable | Foraging, feeding or related behaviour likely to occur within area |
| Balaenoptera musculus<br>Blue Whale [36] | Endangered | Migration route known to occur within area |
| Balaenoptera physalus<br>Fin Whale [37] | Vulnerable | Foraging, feeding or related behaviour likely to occur within area |
| Bettongia lesueur  Barrow and Boodie Islands subspecies<br>Boodie, Burrowing Bettong (Barrow and Boodie Islands) [88021] | Vulnerable | Species or species habitat known to occur within area |
| Bettongia lesueur  lesueur<br>Burrowing Bettong (Shark Bay), Boodie [66659] | Vulnerable | Species or species habitat known to occur within area |
| Bettongia penicillata  ogilbyi<br>Woylie [66844] | Endangered | Species or species habitat known to occur within area |
| Dasyurus geoffroii<br>Chuditch, Western Quoll [330] | Vulnerable | Species or species habitat known to occur within area |
| Dasyurus hallucatus<br>Northern Quoll, Digul [Gogo-Yimidir], Wijingadda [Dambimangari], Wiminji [Martu] [331] | Endangered | Species or species habitat known to occur within area |
| Eubalaena australis<br>Southern Right Whale [40] | Endangered | Species or species habitat likely to occur within area |
| Isoodon auratus  barrowensis<br>Golden Bandicoot (Barrow Island) [66666] | Vulnerable | Species or species habitat known to occur within area |
| Lagorchestes conspicillatus  conspicillatus<br>Spectacled Hare-wallaby (Barrow Island) [66661] | Vulnerable | Species or species habitat known to occur within area |
| Lagorchestes hirsutus  Central Australian subspecies<br>Mala, Rufous Hare-Wallaby (Central Australia) [88019] | Endangered | Translocated population known to occur within area |
| Lagorchestes hirsutus  bernieri<br>Rufous Hare-wallaby (Bernier Island) [66662] | Vulnerable | Species or species habitat known to occur within area |
| Lagorchestes hirsutus  dorreae<br>Rufous Hare-wallaby (Dorre Island) [66663] | Vulnerable | Species or species |

| Name | Status | Type of Presence |
| --- | --- | --- |
| | | habitat known to occur within area |
| Lagostrophus fasciatus  fasciatus<br>Banded Hare-wallaby, Merrnine, Marnine, Munning [66664] | Vulnerable | Species or species habitat known to occur within area |
| Leporillus conditor<br>Wopilkara, Greater Stick-nest Rat [137] | Vulnerable | Translocated population known to occur within area |
| Macroderma gigas<br>Ghost Bat [174] | Vulnerable | Species or species habitat likely to occur within area |
| Macrotis lagotis<br>Greater Bilby [282] | Vulnerable | Species or species habitat known to occur within area |
| Megaptera novaeangliae<br>Humpback Whale [38] | Vulnerable | Congregation or aggregation known to occur within area |
| Osphranter robustus  isabellinus<br>Barrow Island Wallaroo, Barrow Island Euro [89262] | Vulnerable | Species or species habitat likely to occur within area |
| Perameles bougainville  bougainville<br>Western Barred Bandicoot (Shark Bay) [66631] | Endangered | Species or species habitat known to occur within area |
| Petrogale lateralis  lateralis<br>Black-flanked Rock-wallaby, Moororong, Black-footed Rock Wallaby [66647] | Endangered | Species or species habitat known to occur within area |
| Pseudomys fieldi<br>Shark Bay Mouse, Djoongari, Alice Springs Mouse [113] | Vulnerable | Species or species habitat likely to occur within area |
| Rhinonicteris aurantia (Pilbara form)<br>Pilbara Leaf-nosed Bat [82790] | Vulnerable | Species or species habitat known to occur within area |
| **Other** | | |
| Idiosoma nigrum<br>Shield-backed Trapdoor Spider, Black Rugose Trapdoor Spider [66798] | Vulnerable | Species or species habitat likely to occur within area |
| Kumonga exleyi<br>Cape Range Remipede [86875] | Vulnerable | Species or species habitat known to occur within area |
| **Plants** | | |
| Caladenia hoffmanii<br>Hoffman's Spider-orchid [56719] | Endangered | Species or species habitat may occur within area |
| Eucalyptus beardiana<br>Beard's Mallee [18933] | Vulnerable | Species or species habitat likely to occur within area |
| **Reptiles** | | |
| Aipysurus apraefrontalis<br>Short-nosed Seasnake [1115] | Critically Endangered | Species or species habitat known to occur within area |
| Aprasia rostrata  rostrata<br>Monte Bello Worm-lizard, Hermite Island Worm-lizard [64481] | Vulnerable | Species or species habitat known to occur within area |
| Caretta caretta<br>Loggerhead Turtle [1763] | Endangered | Breeding known to occur within area |

| Name | Status | Type of Presence |
|---|---|---|
| Chelonia mydas<br>Green Turtle [1765] | Vulnerable | Breeding known to occur within area |
| Ctenotus angusticeps<br>Northwestern Coastal Ctenotus, Airlie Island Ctenotus [25937] | Vulnerable | Species or species habitat known to occur within area |
| Ctenotus zastictus<br>Hamelin Ctenotus [25570] | Vulnerable | Species or species habitat known to occur within area |
| Dermochelys coriacea<br>Leatherback Turtle, Leathery Turtle, Luth [1768] | Endangered | Foraging, feeding or related behaviour known to occur within area |
| Egernia stokesii badia<br>Western Spiny-tailed Skink, Baudin Island Spiny-tailed Skink [64483] | Endangered | Species or species habitat known to occur within area |
| Eretmochelys imbricata<br>Hawksbill Turtle [1766] | Vulnerable | Breeding known to occur within area |
| Lerista nevinae<br>Nevin's Slider [85296] | Endangered | Species or species habitat known to occur within area |
| Liasis olivaceus barroni<br>Olive Python (Pilbara subspecies) [66699] | Vulnerable | Species or species habitat known to occur within area |
| Natator depressus<br>Flatback Turtle [59257] | Vulnerable | Breeding known to occur within area |
| Sharks | | |
| Carcharias taurus (west coast population)<br>Grey Nurse Shark (west coast population) [68752] | Vulnerable | Species or species habitat known to occur within area |
| Carcharodon carcharias<br>White Shark, Great White Shark [64470] | Vulnerable | Species or species habitat known to occur within area |
| Pristis clavata<br>Dwarf Sawfish, Queensland Sawfish [68447] | Vulnerable | Species or species habitat known to occur within area |
| Pristis pristis<br>Freshwater Sawfish, Largetooth Sawfish, River Sawfish, Leichhardt's Sawfish, Northern Sawfish [60756] | Vulnerable | Species or species habitat likely to occur within area |
| Pristis zijsron<br>Green Sawfish, Dindagubba, Narrowsnout Sawfish [68442] | Vulnerable | Species or species habitat known to occur within area |
| Rhincodon typus<br>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<br>Common Noddy [825] | | Species or species habitat likely to occur within area |
| Apus pacificus<br>Fork-tailed Swift [678] | | Species or species habitat likely to occur within area |

| Name | Threatened | Type of Presence |
|---|---|---|
| Ardenna carneipes<br>Flesh-footed Shearwater, Fleshy-footed Shearwater [82404] | | Species or species habitat likely to occur within area |
| Ardenna pacifica<br>Wedge-tailed Shearwater [84292] | | Breeding known to occur within area |
| Calonectris leucomelas<br>Streaked Shearwater [1077] | | Species or species habitat likely to occur within area |
| Diomedea amsterdamensis<br>Amsterdam Albatross [64405] | Endangered | Species or species habitat may occur within area |
| Diomedea exulans<br>Wandering Albatross [89223] | Vulnerable | Species or species habitat may occur within area |
| Fregata ariel<br>Lesser Frigatebird, Least Frigatebird [1012] | | Breeding known to occur within area |
| Fregata minor<br>Great Frigatebird, Greater Frigatebird [1013] | | Species or species habitat may occur within area |
| Hydroprogne caspia<br>Caspian Tern [808] | | Breeding known to occur within area |
| Macronectes giganteus<br>Southern Giant-Petrel, Southern Giant Petrel [1060] | Endangered | Species or species habitat may occur within area |
| Macronectes halli<br>Northern Giant Petrel [1061] | Vulnerable | Species or species habitat may occur within area |
| Onychoprion anaethetus<br>Bridled Tern [82845] | | Breeding known to occur within area |
| Sterna dougallii<br>Roseate Tern [817] | | Breeding known to occur within area |
| Sula leucogaster<br>Brown Booby [1022] | | Breeding known to occur within area |
| Thalassarche carteri<br>Indian Yellow-nosed Albatross [64464] | Vulnerable | Foraging, feeding or related behaviour may occur within area |
| Thalassarche cauta<br>Tasmanian Shy Albatross [89224] | Vulnerable* | Species or species habitat may occur within area |
| Thalassarche impavida<br>Campbell Albatross, Campbell Black-browed Albatross [64459] | Vulnerable | Species or species habitat may occur within area |
| Thalassarche melanophris<br>Black-browed Albatross [66472] | Vulnerable | Species or species habitat may occur within area |
| Thalassarche steadi<br>White-capped Albatross [64462] | Vulnerable* | Foraging, feeding or related behaviour likely to occur within area |
| Migratory Marine Species | | |
| Anoxypristis cuspidata<br>Narrow Sawfish, Knifetooth Sawfish [68448] | | Species or species habitat known to occur within area |
| Balaena glacialis australis<br>Southern Right Whale [75529] | Endangered* | Species or species |

| Name | Threatened | Type of Presence |
|---|---|---|
| | | habitat likely to occur within area |
| Balaenoptera bonaerensis<br>Antarctic Minke Whale, Dark-shoulder Minke Whale [67812] | | Species or species habitat likely to occur within area |
| Balaenoptera borealis<br>Sei Whale [34] | Vulnerable | Foraging, feeding or related behaviour likely to occur within area |
| Balaenoptera edeni<br>Bryde's Whale [35] | | Species or species habitat likely to occur within area |
| Balaenoptera musculus<br>Blue Whale [36] | Endangered | Migration route known to occur within area |
| Balaenoptera physalus<br>Fin Whale [37] | Vulnerable | Foraging, feeding or related behaviour likely to occur within area |
| Carcharodon carcharias<br>White Shark, Great White Shark [64470] | Vulnerable | Species or species habitat known to occur within area |
| Caretta caretta<br>Loggerhead Turtle [1763] | Endangered | Breeding known to occur within area |
| Chelonia mydas<br>Green Turtle [1765] | Vulnerable | Breeding known to occur within area |
| Dermochelys coriacea<br>Leatherback Turtle, Leathery Turtle, Luth [1768] | Endangered | Foraging, feeding or related behaviour known to occur within area |
| Dugong dugon<br>Dugong [28] | | Breeding known to occur within area |
| Eretmochelys imbricata<br>Hawksbill Turtle [1766] | Vulnerable | Breeding known to occur within area |
| Isurus oxyrinchus<br>Shortfin Mako, Mako Shark [79073] | | Species or species habitat likely to occur within area |
| Isurus paucus<br>Longfin Mako [82947] | | Species or species habitat likely to occur within area |
| Lamna nasus<br>Porbeagle, Mackerel Shark [83288] | | Species or species habitat may occur within area |
| Manta alfredi<br>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<br>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<br>Humpback Whale [38] | Vulnerable | Congregation or aggregation known to occur within area |
| Natator depressus<br>Flatback Turtle [59257] | Vulnerable | Breeding known to occur within area |
| Orcinus orca<br>Killer Whale, Orca [46] | | Species or species habitat may occur within area |

| Name | Threatened | Type of Presence |
| --- | --- | --- |
| Physeter macrocephalus<br>Sperm Whale [59] | | Species or species habitat may occur within area |
| Pristis clavata<br>Dwarf Sawfish, Queensland Sawfish [68447] | Vulnerable | Species or species habitat known to occur within area |
| Pristis pristis<br>Freshwater Sawfish, Largetooth Sawfish, River Sawfish, Leichhardt's Sawfish, Northern Sawfish [60756] | Vulnerable | Species or species habitat likely to occur within area |
| Pristis zijsron<br>Green Sawfish, Dindagubba, Narrowsnout Sawfish [68442] | Vulnerable | Species or species habitat known to occur within area |
| Rhincodon typus<br>Whale Shark [66680] | Vulnerable | Foraging, feeding or related behaviour known to occur within area |
| Sousa chinensis<br>Indo-Pacific Humpback Dolphin [50] | | Species or species habitat known to occur within area |
| Tursiops aduncus (Arafura/Timor Sea populations)<br>Spotted Bottlenose Dolphin (Arafura/Timor Sea populations) [78900] | | Species or species habitat known to occur within area |
| Migratory Terrestrial Species | | |
| Cuculus optatus<br>Oriental Cuckoo, Horsfield's Cuckoo [86651] | | Species or species habitat may occur within area |
| Hirundo rustica<br>Barn Swallow [662] | | Species or species habitat known to occur within area |
| Motacilla cinerea<br>Grey Wagtail [642] | | Species or species habitat may occur within area |
| Motacilla flava<br>Yellow Wagtail [644] | | Species or species habitat known to occur within area |
| Migratory Wetlands Species | | |
| Actitis hypoleucos<br>Common Sandpiper [59309] | | Species or species habitat known to occur within area |
| Arenaria interpres<br>Ruddy Turnstone [872] | | Roosting known to occur within area |
| Calidris acuminata<br>Sharp-tailed Sandpiper [874] | | Species or species habitat known to occur within area |
| Calidris alba<br>Sanderling [875] | | Roosting known to occur within area |
| Calidris canutus<br>Red Knot, Knot [855] | Endangered | Species or species habitat known to occur within area |
| Calidris ferruginea<br>Curlew Sandpiper [856] | Critically Endangered | Species or species habitat known to occur within area |
| Calidris melanotos<br>Pectoral Sandpiper [858] | | Species or species habitat known to occur within area |

| Name | Threatened | Type of Presence |
|---|---|---|
| Calidris ruficollis<br>Red-necked Stint [860] | | Roosting known to occur within area |
| Calidris subminuta<br>Long-toed Stint [861] | | Species or species habitat known to occur within area |
| Calidris tenuirostris<br>Great Knot [862] | Critically Endangered | Roosting known to occur within area |
| Charadrius leschenaultii<br>Greater Sand Plover, Large Sand Plover [877] | Vulnerable | Roosting known to occur within area |
| Charadrius mongolus<br>Lesser Sand Plover, Mongolian Plover [879] | Endangered | Species or species habitat known to occur within area |
| Charadrius veredus<br>Oriental Plover, Oriental Dotterel [882] | | Species or species habitat known to occur within area |
| Gallinago megala<br>Swinhoe's Snipe [864] | | Roosting likely to occur within area |
| Gallinago stenura<br>Pin-tailed Snipe [841] | | Roosting likely to occur within area |
| Glareola maldivarum<br>Oriental Pratincole [840] | | Species or species habitat known to occur within area |
| Limicola falcinellus<br>Broad-billed Sandpiper [842] | | Species or species habitat known to occur within area |
| Limosa lapponica<br>Bar-tailed Godwit [844] | | Species or species habitat known to occur within area |
| Limosa limosa<br>Black-tailed Godwit [845] | | Roosting known to occur within area |
| Numenius madagascariensis<br>Eastern Curlew, Far Eastern Curlew [847] | Critically Endangered | Species or species habitat known to occur within area |
| Numenius minutus<br>Little Curlew, Little Whimbrel [848] | | Roosting likely to occur within area |
| Numenius phaeopus<br>Whimbrel [849] | | Roosting known to occur within area |
| Pandion haliaetus<br>Osprey [952] | | Breeding known to occur within area |
| Phalaropus lobatus<br>Red-necked Phalarope [838] | | Species or species habitat known to occur within area |
| Pluvialis fulva<br>Pacific Golden Plover [25545] | | Species or species habitat known to occur within area |
| Pluvialis squatarola<br>Grey Plover [865] | | Roosting known to occur within area |
| Thalasseus bergii<br>Crested Tern [83000] | | Breeding known to occur within area |
| Tringa brevipes<br>Grey-tailed Tattler [851] | | Roosting known to occur within area |

| Name | Threatened | Type of Presence |
|---|---|---|
| Tringa glareola<br>Wood Sandpiper [829] | | Roosting known to occur within area |
| Tringa nebularia<br>Common Greenshank, Greenshank [832] | | Species or species habitat known to occur within area |
| Tringa stagnatilis<br>Marsh Sandpiper, Little Greenshank [833] | | Species or species habitat known to occur within area |
| Tringa totanus<br>Common Redshank, Redshank [835] | | Species or species habitat known to occur within area |
| Xenus cinereus<br>Terek Sandpiper [59300] | | Roosting 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 - |
| Defence - CARNARVON TRAINING DEPOT |
| Defence - EXMOUTH ADMIN & HF TRANSMITTING |
| Defence - EXMOUTH NAVAL HF RECEIVING STATION (H/F Receiving Station, Learmonth, WA) |
| Defence - EXMOUTH VLF TRANSMITTER STATION |
| Defence - LEARMONTH - AIR WEAPONS RANGE |
| Defence - LEARMONTH - RAAF BASE |
| Defence - LEARMONTH RADAR SITE - TWIN TANKS EXMOUTH |
| Defence - LEARMONTH RADAR SITE - VLAMING HEAD EXMOUTH |
| Defence - LEARMONTH TRANSMITTING STATION |

### Commonwealth Heritage Places [ Resource Information ]

| Name | State | Status |
|---|---|---|
| Natural | | |
| Learmonth Air Weapons Range Facility | WA | Listed place |
| Ningaloo Marine Area - Commonwealth Waters | WA | 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 | | |
| Actitis hypoleucos<br>Common Sandpiper [59309] | | Species or species habitat known to occur within area |
| Anous stolidus<br>Common Noddy [825] | | Species or species habitat likely to occur within area |
| Apus pacificus<br>Fork-tailed Swift [678] | | Species or species habitat likely to occur within area |
| Ardea alba<br>Great Egret, White Egret [59541] | | Breeding known to occur within area |
| Ardea ibis<br>Cattle Egret [59542] | | Species or species habitat may occur within area |

| Name | Threatened | Type of Presence |
|---|---|---|
| Arenaria interpres<br>Ruddy Turnstone [872] | | Roosting known to occur within area |
| Calidris acuminata<br>Sharp-tailed Sandpiper [874] | | Species or species habitat known to occur within area |
| Calidris alba<br>Sanderling [875] | | Roosting known to occur within area |
| Calidris canutus<br>Red Knot, Knot [855] | Endangered | Species or species habitat known to occur within area |
| Calidris ferruginea<br>Curlew Sandpiper [856] | Critically Endangered | Species or species habitat known to occur within area |
| Calidris melanotos<br>Pectoral Sandpiper [858] | | Species or species habitat known to occur within area |
| Calidris ruficollis<br>Red-necked Stint [860] | | Roosting known to occur within area |
| Calidris subminuta<br>Long-toed Stint [861] | | Species or species habitat known to occur within area |
| Calidris tenuirostris<br>Great Knot [862] | Critically Endangered | Roosting known to occur within area |
| Calonectris leucomelas<br>Streaked Shearwater [1077] | | Species or species habitat likely to occur within area |
| Catharacta skua<br>Great Skua [59472] | | Species or species habitat may occur within area |
| Charadrius leschenaultii<br>Greater Sand Plover, Large Sand Plover [877] | Vulnerable | Roosting known to occur within area |
| Charadrius mongolus<br>Lesser Sand Plover, Mongolian Plover [879] | Endangered | Species or species habitat known to occur within area |
| Charadrius ruficapillus<br>Red-capped Plover [881] | | Roosting known to occur within area |
| Charadrius veredus<br>Oriental Plover, Oriental Dotterel [882] | | Species or species habitat known to occur within area |
| Chrysococcyx osculans<br>Black-eared Cuckoo [705] | | Species or species habitat known to occur within area |
| Diomedea amsterdamensis<br>Amsterdam Albatross [64405] | Endangered | Species or species habitat may occur within area |
| Diomedea exulans<br>Wandering Albatross [89223] | Vulnerable | Species or species habitat may occur within area |
| Fregata ariel<br>Lesser Frigatebird, Least Frigatebird [1012] | | Breeding known to occur within area |
| Fregata minor<br>Great Frigatebird, Greater Frigatebird [1013] | | Species or species habitat may occur within area |

| Name | Threatened | Type of Presence |
| --- | --- | --- |
| Gallinago megala<br>Swinhoe's Snipe [864] | | Roosting likely to occur within area |
| Gallinago stenura<br>Pin-tailed Snipe [841] | | Roosting likely to occur within area |
| Glareola maldivarum<br>Oriental Pratincole [840] | | Species or species habitat known to occur within area |
| Haliaeetus leucogaster<br>White-bellied Sea-Eagle [943] | | Breeding known to occur within area |
| Heteroscelus brevipes<br>Grey-tailed Tattler [59311] | | Roosting known to occur within area |
| Himantopus himantopus<br>Pied Stilt, Black-winged Stilt [870] | | Roosting known to occur within area |
| Hirundo rustica<br>Barn Swallow [662] | | Species or species habitat known to occur within area |
| Larus novaehollandiae<br>Silver Gull [810] | | Breeding known to occur within area |
| Larus pacificus<br>Pacific Gull [811] | | Breeding known to occur within area |
| Limicola falcinellus<br>Broad-billed Sandpiper [842] | | Species or species habitat known to occur within area |
| Limosa lapponica<br>Bar-tailed Godwit [844] | | Species or species habitat known to occur within area |
| Limosa limosa<br>Black-tailed Godwit [845] | | Roosting known to occur within area |
| Macronectes giganteus<br>Southern Giant-Petrel, Southern Giant Petrel [1060] | Endangered | Species or species habitat may occur within area |
| Macronectes halli<br>Northern Giant Petrel [1061] | Vulnerable | Species or species habitat may occur within area |
| Merops ornatus<br>Rainbow Bee-eater [670] | | Species or species habitat may occur within area |
| Motacilla cinerea<br>Grey Wagtail [642] | | Species or species habitat may occur within area |
| Motacilla flava<br>Yellow Wagtail [644] | | Species or species habitat known to occur within area |
| Numenius madagascariensis<br>Eastern Curlew, Far Eastern Curlew [847] | Critically Endangered | Species or species habitat known to occur within area |
| Numenius minutus<br>Little Curlew, Little Whimbrel [848] | | Roosting likely to occur within area |
| Numenius phaeopus<br>Whimbrel [849] | | Roosting known to occur within area |
| Pandion haliaetus<br>Osprey [952] | | Breeding known to occur within area |

| Name | Threatened | Type of Presence |
|---|---|---|
| Papasula abbotti<br>Abbott's Booby [59297] | Endangered | Species or species habitat may occur within area |
| Phalaropus lobatus<br>Red-necked Phalarope [838] | | Species or species habitat known to occur within area |
| Pluvialis fulva<br>Pacific Golden Plover [25545] | | Species or species habitat known to occur within area |
| Pluvialis squatarola<br>Grey Plover [865] | | Roosting known to occur within area |
| Pterodroma mollis<br>Soft-plumaged Petrel [1036] | Vulnerable | Foraging, feeding or related behaviour likely to occur within area |
| Puffinus carneipes<br>Flesh-footed Shearwater, Fleshy-footed Shearwater [1043] | | Species or species habitat likely to occur within area |
| Puffinus pacificus<br>Wedge-tailed Shearwater [1027] | | Breeding known to occur within area |
| Recurvirostra novaehollandiae<br>Red-necked Avocet [871] | | Roosting known to occur within area |
| Rostratula benghalensis (sensu lato)<br>Painted Snipe [889] | Endangered* | Species or species habitat may occur within area |
| Sterna anaethetus<br>Bridled Tern [814] | | Breeding known to occur within area |
| Sterna bengalensis<br>Lesser Crested Tern [815] | | Breeding known to occur within area |
| Sterna bergii<br>Crested Tern [816] | | Breeding known to occur within area |
| Sterna caspia<br>Caspian Tern [59467] | | Breeding known to occur within area |
| Sterna dougallii<br>Roseate Tern [817] | | Breeding known to occur within area |
| Sterna fuscata<br>Sooty Tern [794] | | Breeding known to occur within area |
| Sterna nereis<br>Fairy Tern [796] | | Breeding known to occur within area |
| Stiltia isabella<br>Australian Pratincole [818] | | Species or species habitat known to occur within area |
| Sula leucogaster<br>Brown Booby [1022] | | Breeding known to occur within area |
| Thalassarche carteri<br>Indian Yellow-nosed  Albatross [64464] | Vulnerable | Foraging, feeding or related behaviour may occur within area |
| Thalassarche cauta<br>Tasmanian Shy Albatross [89224] | Vulnerable* | Species or species habitat may occur within area |
| Thalassarche impavida<br>Campbell Albatross, Campbell Black-browed Albatross [64459] | Vulnerable | Species or species habitat may occur within area |

| Name | Threatened | Type of Presence |
|---|---|---|
| Thalassarche melanophris<br>Black-browed Albatross [66472] | Vulnerable | Species or species habitat may occur within area |
| Thalassarche steadi<br>White-capped Albatross [64462] | Vulnerable* | Foraging, feeding or related behaviour likely to occur within area |
| Thinornis rubricollis<br>Hooded Plover [59510] | | Species or species habitat known to occur within area |
| Tringa glareola<br>Wood Sandpiper [829] | | Roosting known to occur within area |
| Tringa nebularia<br>Common Greenshank, Greenshank [832] | | Species or species habitat known to occur within area |
| Tringa stagnatilis<br>Marsh Sandpiper, Little Greenshank [833] | | Species or species habitat known to occur within area |
| Tringa totanus<br>Common Redshank, Redshank [835] | | Species or species habitat known to occur within area |
| Xenus cinereus<br>Terek Sandpiper [59300] | | Roosting known to occur within area |
| Fish | | |
| Acentronura larsonae<br>Helen's Pygmy Pipehorse [66186] | | Species or species habitat may occur within area |
| Bulbonaricus brauni<br>Braun's Pughead Pipefish, Pug-headed Pipefish [66189] | | Species or species habitat may occur within area |
| Campichthys galei<br>Gale's Pipefish [66191] | | Species or species habitat may occur within area |
| Campichthys tricarinatus<br>Three-keel Pipefish [66192] | | Species or species habitat may occur within area |
| Choeroichthys brachysoma<br>Pacific Short-bodied Pipefish, Short-bodied Pipefish [66194] | | Species or species habitat may occur within area |
| Choeroichthys latispinosus<br>Muiron Island Pipefish [66196] | | Species or species habitat may occur within area |
| Choeroichthys suillus<br>Pig-snouted Pipefish [66198] | | Species or species habitat may occur within area |
| Corythoichthys flavofasciatus<br>Reticulate Pipefish, Yellow-banded Pipefish, Network Pipefish [66200] | | Species or species habitat may occur within area |
| Cosmocampus banneri<br>Roughridge Pipefish [66206] | | Species or species habitat may occur within area |
| Doryrhamphus dactyliophorus<br>Banded Pipefish, Ringed Pipefish [66210] | | Species or species habitat may occur within area |
| Doryrhamphus excisus<br>Bluestripe Pipefish, Indian Blue-stripe Pipefish, | | Species or species |

| Name | Threatened | Type of Presence |
|---|---|---|
| Pacific Blue-stripe Pipefish [66211] | | habitat may occur within area |
| Doryrhamphus janssi<br>Cleaner Pipefish, Janss' Pipefish [66212] | | Species or species habitat may occur within area |
| Doryrhamphus multiannulatus<br>Many-banded Pipefish [66717] | | Species or species habitat may occur within area |
| Doryrhamphus negrosensis<br>Flagtail Pipefish, Masthead Island Pipefish [66213] | | Species or species habitat may occur within area |
| Festucalex scalaris<br>Ladder Pipefish [66216] | | Species or species habitat may occur within area |
| Filicampus tigris<br>Tiger Pipefish [66217] | | Species or species habitat may occur within area |
| Halicampus brocki<br>Brock's Pipefish [66219] | | Species or species habitat may occur within area |
| Halicampus grayi<br>Mud Pipefish, Gray's Pipefish [66221] | | Species or species habitat may occur within area |
| Halicampus nitidus<br>Glittering Pipefish [66224] | | Species or species habitat may occur within area |
| Halicampus spinirostris<br>Spiny-snout Pipefish [66225] | | Species or species habitat may occur within area |
| Haliichthys taeniophorus<br>Ribboned Pipehorse, Ribboned Seadragon [66226] | | Species or species habitat may occur within area |
| Hippichthys penicillus<br>Beady Pipefish, Steep-nosed Pipefish [66231] | | Species or species habitat may occur within area |
| Hippocampus angustus<br>Western Spiny Seahorse, Narrow-bellied Seahorse [66234] | | Species or species habitat may occur within area |
| Hippocampus histrix<br>Spiny Seahorse, Thorny Seahorse [66236] | | Species or species habitat may occur within area |
| Hippocampus kuda<br>Spotted Seahorse, Yellow Seahorse [66237] | | Species or species habitat may occur within area |
| Hippocampus planifrons<br>Flat-face Seahorse [66238] | | Species or species habitat may occur within area |
| Hippocampus spinosissimus<br>Hedgehog Seahorse [66239] | | Species or species habitat may occur within area |
| Hippocampus trimaculatus<br>Three-spot Seahorse, Low-crowned Seahorse, Flat-faced Seahorse [66720] | | Species or species habitat may occur within area |
| Lissocampus fatiloquus<br>Prophet's Pipefish [66250] | | Species or species habitat may occur within |

| Name | Threatened | Type of Presence |
|---|---|---|
| | | area |
| Micrognathus micronotopterus<br>Tidepool Pipefish [66255] | | Species or species habitat may occur within area |
| Nannocampus subosseus<br>Bonyhead Pipefish, Bony-headed Pipefish [66264] | | Species or species habitat may occur within area |
| Phoxocampus belcheri<br>Black Rock Pipefish [66719] | | Species or species habitat may occur within area |
| Solegnathus hardwickii<br>Pallid Pipehorse, Hardwick's Pipehorse [66272] | | Species or species habitat may occur within area |
| Solegnathus lettiensis<br>Gunther's Pipehorse, Indonesian Pipefish [66273] | | Species or species habitat may occur within area |
| Solenostomus cyanopterus<br>Robust Ghostpipefish, Blue-finned Ghost Pipefish, [66183] | | Species or species habitat may occur within area |
| Stigmatopora argus<br>Spotted Pipefish, Gulf Pipefish, Peacock Pipefish [66276] | | Species or species habitat may occur within area |
| Syngnathoides biaculeatus<br>Double-end Pipehorse, Double-ended Pipehorse, Alligator Pipefish [66279] | | Species or species habitat may occur within area |
| Trachyrhamphus bicoarctatus<br>Bentstick Pipefish, Bend Stick Pipefish, Short-tailed Pipefish [66280] | | Species or species habitat may occur within area |
| Trachyrhamphus longirostris<br>Straightstick Pipefish, Long-nosed Pipefish, Straight Stick Pipefish [66281] | | Species or species habitat may occur within area |
| **Mammals** | | |
| Dugong dugon<br>Dugong [28] | | Breeding known to occur within area |
| **Reptiles** | | |
| Acalyptophis peronii<br>Horned Seasnake [1114] | | Species or species habitat may occur within area |
| Aipysurus apraefrontalis<br>Short-nosed Seasnake [1115] | Critically Endangered | Species or species habitat known to occur within area |
| Aipysurus duboisii<br>Dubois' Seasnake [1116] | | Species or species habitat may occur within area |
| Aipysurus eydouxii<br>Spine-tailed Seasnake [1117] | | Species or species habitat may occur within area |
| Aipysurus laevis<br>Olive Seasnake [1120] | | Species or species habitat may occur within area |
| Aipysurus pooleorum<br>Shark Bay Seasnake [66061] | | Species or species habitat may occur within area |
| Aipysurus tenuis<br>Brown-lined Seasnake [1121] | | Species or species habitat may occur within |

| Name | Threatened | Type of Presence |
|---|---|---|
| | | area |
| Astrotia stokesii<br>Stokes' Seasnake [1122] | | Species or species habitat may occur within area |
| Caretta caretta<br>Loggerhead Turtle [1763] | Endangered | Breeding known to occur within area |
| Chelonia mydas<br>Green Turtle [1765] | Vulnerable | Breeding known to occur within area |
| Dermochelys coriacea<br>Leatherback Turtle, Leathery Turtle, Luth [1768] | Endangered | Foraging, feeding or related behaviour known to occur within area |
| Disteira kingii<br>Spectacled Seasnake [1123] | | Species or species habitat may occur within area |
| Disteira major<br>Olive-headed Seasnake [1124] | | Species or species habitat may occur within area |
| Emydocephalus annulatus<br>Turtle-headed Seasnake [1125] | | Species or species habitat may occur within area |
| Ephalophis greyi<br>North-western Mangrove Seasnake [1127] | | Species or species habitat may occur within area |
| Eretmochelys imbricata<br>Hawksbill Turtle [1766] | Vulnerable | Breeding known to occur within area |
| Hydrelaps darwiniensis<br>Black-ringed Seasnake [1100] | | Species or species habitat may occur within area |
| Hydrophis czeblukovi<br>Fine-spined Seasnake [59233] | | Species or species habitat may occur within area |
| Hydrophis elegans<br>Elegant Seasnake [1104] | | Species or species habitat may occur within area |
| Hydrophis mcdowelli<br>null [25926] | | Species or species habitat may occur within area |
| Hydrophis ornatus<br>Spotted Seasnake, Ornate Reef Seasnake [1111] | | Species or species habitat may occur within area |
| Natator depressus<br>Flatback Turtle [59257] | Vulnerable | Breeding known to occur within area |
| Pelamis platurus<br>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<br>Minke Whale [33] | | Species or species habitat may occur within area |
| Balaenoptera bonaerensis<br>Antarctic Minke Whale, Dark-shoulder Minke Whale [67812] | | Species or species habitat likely to occur |

| Name | Status | Type of Presence |
|---|---|---|
| | | within area |
| Balaenoptera borealis<br>Sei Whale [34] | Vulnerable | Foraging, feeding or related behaviour likely to occur within area |
| Balaenoptera edeni<br>Bryde's Whale [35] | | Species or species habitat likely to occur within area |
| Balaenoptera musculus<br>Blue Whale [36] | Endangered | Migration route known to occur within area |
| Balaenoptera physalus<br>Fin Whale [37] | Vulnerable | Foraging, feeding or related behaviour likely to occur within area |
| Delphinus delphis<br>Common Dophin, Short-beaked Common Dolphin [60] | | Species or species habitat may occur within area |
| Eubalaena australis<br>Southern Right Whale [40] | Endangered | Species or species habitat likely to occur within area |
| Feresa attenuata<br>Pygmy Killer Whale [61] | | Species or species habitat may occur within area |
| Globicephala macrorhynchus<br>Short-finned Pilot Whale [62] | | Species or species habitat may occur within area |
| Grampus griseus<br>Risso's Dolphin, Grampus [64] | | Species or species habitat may occur within area |
| Indopacetus pacificus<br>Longman's Beaked Whale [72] | | Species or species habitat may occur within area |
| Kogia breviceps<br>Pygmy Sperm Whale [57] | | Species or species habitat may occur within area |
| Kogia simus<br>Dwarf Sperm Whale [58] | | Species or species habitat may occur within area |
| Lagenodelphis hosei<br>Fraser's Dolphin, Sarawak Dolphin [41] | | Species or species habitat may occur within area |
| Megaptera novaeangliae<br>Humpback Whale [38] | Vulnerable | Congregation or aggregation known to occur within area |
| Mesoplodon densirostris<br>Blainville's Beaked Whale, Dense-beaked Whale [74] | | Species or species habitat may occur within area |
| Mesoplodon ginkgodens<br>Gingko-toothed Beaked Whale, Gingko-toothed Whale, Gingko Beaked Whale [59564] | | Species or species habitat may occur within area |
| Orcinus orca<br>Killer Whale, Orca [46] | | Species or species habitat may occur within area |
| Peponocephala electra<br>Melon-headed Whale [47] | | Species or species habitat may occur within area |

| Name | Status | Type of Presence |
|---|---|---|
| Physeter macrocephalus<br>Sperm Whale [59] | | Species or species habitat may occur within area |
| Pseudorca crassidens<br>False Killer Whale [48] | | Species or species habitat likely to occur within area |
| Sousa chinensis<br>Indo-Pacific Humpback Dolphin [50] | | Species or species habitat known to occur within area |
| Stenella attenuata<br>Spotted Dolphin, Pantropical Spotted Dolphin [51] | | Species or species habitat may occur within area |
| Stenella coeruleoalba<br>Striped Dolphin, Euphrosyne Dolphin [52] | | Species or species habitat may occur within area |
| Stenella longirostris<br>Long-snouted Spinner Dolphin [29] | | Species or species habitat may occur within area |
| Steno bredanensis<br>Rough-toothed Dolphin [30] | | Species or species habitat may occur within area |
| Tursiops aduncus<br>Indian Ocean Bottlenose Dolphin, Spotted Bottlenose Dolphin [68418] | | Species or species habitat likely to occur within area |
| Tursiops aduncus (Arafura/Timor Sea populations)<br>Spotted Bottlenose Dolphin (Arafura/Timor Sea populations) [78900] | | Species or species habitat known to occur within area |
| Tursiops truncatus s. str.<br>Bottlenose Dolphin [68417] | | Species or species habitat may occur within area |
| Ziphius cavirostris<br>Cuvier's Beaked Whale, Goose-beaked Whale [56] | | Species or species habitat may occur within area |

## Australian Marine Parks [ Resource Information ]

| Name | Label |
|---|---|
| Carnarvon Canyon | Habitat Protection Zone (IUCN IV) |
| Dampier | Habitat Protection Zone (IUCN IV) |
| Dampier | Multiple Use Zone (IUCN VI) |
| Dampier | National Park Zone (IUCN II) |
| Gascoyne | Habitat Protection Zone (IUCN IV) |
| Gascoyne | Multiple Use Zone (IUCN VI) |
| Gascoyne | National Park Zone (IUCN II) |
| Montebello | Multiple Use Zone (IUCN VI) |
| Ningaloo | National Park Zone (IUCN II) |
| Ningaloo | Recreational Use Zone (IUCN IV) |
| Shark Bay | Multiple Use Zone (IUCN VI) |

# Extra Information

## State and Territory Reserves [ Resource Information ]

| Name | State |
|---|---|
| Airlie Island | WA |
| Barrow Island | WA |
| Bernier And Dorre Islands | WA |
| Bessieres Island | WA |
| Boodie, Double Middle Islands | WA |
| Bundegi Coastal Park | WA |
| Burnside And Simpson Island | WA |

| Name | State |
| --- | --- |
| Cape Range | WA |
| Chinamans Pool | WA |
| Dirk Hartog Island | WA |
| Faure Island | WA |
| Francois Peron | WA |
| Freycinet, Double Islands etc | WA |
| Giralia | WA |
| Gnandaroo Island | WA |
| Jurabi Coastal Park | WA |
| Koks Island | WA |
| Little Rocky Island | WA |
| Locker Island | WA |
| Lowendal Islands | WA |
| Monkey Mia Reserve | WA |
| Montebello Islands | WA |
| Muiron Islands | WA |
| Murujuga | WA |
| Nanga Station | WA |
| North Sandy Island | WA |
| North Turtle Island | WA |
| One Tree Point | WA |
| Rocky Island | WA |
| Round Island | WA |
| Serrurier Island | WA |
| Shell Beach | WA |
| Tent Island | WA |
| Unnamed WA36907 | WA |
| Unnamed WA36909 | WA |
| Unnamed WA36910 | WA |
| Unnamed WA36913 | WA |
| Unnamed WA36915 | WA |
| Unnamed WA37338 | WA |
| Unnamed WA37383 | WA |
| Unnamed WA37500 | WA |
| Unnamed WA40322 | WA |
| Unnamed WA40828 | WA |
| Unnamed WA40877 | WA |
| Unnamed WA41080 | WA |
| Unnamed WA44665 | WA |
| Unnamed WA44667 | WA |
| Unnamed WA44688 | WA |
| Unnamed WA49144 | WA |
| Victor Island | WA |
| Weld Island | WA |
| Y Island | WA |
| Yaringga | WA |

## 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** | | |
| Columba livia | | |
| Rock Pigeon, Rock Dove, Domestic Pigeon [803] | | Species or species habitat likely to occur within area |
| Passer domesticus | | |
| House Sparrow [405] | | Species or species habitat likely to occur within area |
| Passer montanus | | |
| Eurasian Tree Sparrow [406] | | Species or species habitat likely to occur |

| Name | Status | Type of Presence |
|---|---|---|
| | | within area |
| Streptopelia senegalensis<br>Laughing Turtle-dove, Laughing Dove [781] | | Species or species habitat likely to occur within area |
| **Mammals** | | |
| Camelus dromedarius<br>Dromedary, Camel [7] | | Species or species habitat likely to occur within area |
| Canis lupus  familiaris<br>Domestic Dog [82654] | | Species or species habitat likely to occur within area |
| Capra hircus<br>Goat [2] | | Species or species habitat likely to occur within area |
| Equus asinus<br>Donkey, Ass [4] | | Species or species habitat likely to occur within area |
| Equus caballus<br>Horse [5] | | Species or species habitat likely to occur within area |
| Felis catus<br>Cat, House Cat, Domestic Cat [19] | | Species or species habitat likely to occur within area |
| Mus musculus<br>House Mouse [120] | | Species or species habitat likely to occur within area |
| Oryctolagus cuniculus<br>Rabbit, European Rabbit [128] | | Species or species habitat likely to occur within area |
| Rattus rattus<br>Black Rat, Ship Rat [84] | | Species or species habitat likely to occur within area |
| Sus scrofa<br>Pig [6] | | Species or species habitat likely to occur within area |
| Vulpes vulpes<br>Red Fox, Fox [18] | | Species or species habitat likely to occur within area |
| **Plants** | | |
| Cenchrus ciliaris<br>Buffel-grass, Black Buffel-grass [20213] | | Species or species habitat likely to occur within area |
| Cylindropuntia spp.<br>Prickly Pears [85131] | | Species or species habitat likely to occur within area |
| Jatropha gossypifolia<br>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 |
| Lycium ferocissimum<br>African Boxthorn, Boxthorn [19235] | | Species or species habitat likely to occur within area |
| Opuntia spp.<br>Prickly Pears [82753] | | Species or species habitat likely to occur within area |
| Parkinsonia aculeata<br>Parkinsonia, Jerusalem Thorn, Jelly Bean Tree, | | Species or species |

| Name | Status | Type of Presence |
|---|---|---|
| Horse Bean [12301] | | habitat likely to occur within area |
| Prosopis spp. | | |
| Mesquite, Algaroba [68407] | | Species or species habitat likely to occur within area |
| Tamarix aphylla | | |
| Athel Pine, Athel Tree, Tamarisk, Athel Tamarisk, Athel Tamarix, Desert Tamarisk, Flowering Cypress, Salt Cedar [16018] | | 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 |
| Ramphotyphlops braminus | | |
| Flowerpot Blind Snake, Brahminy Blind Snake, Cacing Besi [1258] | | Species or species habitat likely to occur within area |

## Nationally Important Wetlands [ Resource Information ]

| Name | State |
|---|---|
| Bundera Sinkhole | WA |
| Cape Range Subterranean Waterways | WA |
| Exmouth Gulf East | WA |
| Hamelin Pool | WA |
| Lake MacLeod | WA |
| Learmonth Air Weapons Range - Saline Coastal Flats | WA |
| McNeill Claypan System | WA |
| Shark Bay East | 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 |
|---|---|
| Ancient coastline at 125 m depth contour | North-west |
| Canyons linking the Cuvier Abyssal Plain and the | North-west |
| Commonwealth waters adjacent to Ningaloo Reef | North-west |
| Continental Slope Demersal Fish Communities | North-west |
| Exmouth Plateau | North-west |
| Glomar Shoals | 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

-19.9557 119.0944,-15.8051 111.6964,-22.1384 107.6624,-25.4807 112.9971,-26.602 113.829,-25.914 114.282,-24.149 113.431,-22.222 114.137,-22.511 114.354,-21.801 114.744,-20.678 116.916,-19.9557 119.0944

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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

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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# Appendix E

## Scarborough Gas Development Underwater Noise Modelling Study


MARSHALL DAY Acoustics

# SCARBOROUGH GAS US4A/B DEVELOPMENT

# UNDERWATER NOISE MODELLING STUDY

Rp 001 20181331 | 15 February 2019

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| | |
|---|---|
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| Prepared for: | **Advisian**<br>**Level 4/600 Murray St**<br>**West Perth WA 6005** |
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| Report No.: | **Rp 001 20181331** |



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# 1.0 INTRODUCTION

Advisian has engaged Marshall Day Acoustics (MDA) to carry out modelling of underwater acoustic emissions from selected activities associated with the proposed Scarborough gas field development (the Scarborough project), located in Western Australia's North West Shelf region. The Scarborough project is being developed by Woodside Energy Ltd.

Three key noise generating activities associated with the Scarborough project have been identified by Advisian for detailed modelling as follows:

1. Floating Production Unit (FPU) installation and operation
2. Vessel operations associated with pipelaying
3. Pile driving required for the trunkline connection near the Pluto LNG facility in Dampier.

This report has been prepared to inform an assessment of potential impacts from development activities in Commonwealth waters, to be included in an Offshore Project Proposal (OPP) for submission to the Australian National Offshore Petroleum Safety and Environmental Management Authority NOPSEMA. Since the activities in item 3 in the list above take place in State water, only items 1 and 2 have been considered in this report.

This report outlines details of the noise model inputs, the noise propagation prediction methodology, and a summary of the noise predication results, presented in metrics that are relevant to the various marine fauna species of interest. The predicted underwater noise levels are compared to criteria from widely used scientific studies and international guidelines, as nominated by the project ecologist, to assist with the evaluation of noise impacts.

A glossary of acoustic terms and symbols used herein is provided in Appendix A.

# 2.0 PROJECT DESCRIPTION

The Scarborough gas field is located within the offshore area designated as Permit Area WA-1-R by the National Offshore Petroleum Titles Administrator. The area is located approximately 380 km WNW of the Burrup Peninsula in the North West of Australia where water depths range between 900m and 1000m.

We understand that the Scarborough project proposes drilling of up to 22 subsea gas wells. It is proposed that wells will be tied back to a Floating Production Unit (FPU), with processing facilities on the FPU enabling transport of the gas through a 420-kilometre-long trunkline to the Woodside operated Pluto LNG Facility. The trunkline and associated installation works will occur in both State and Commonwealth waters.

## 2.1 Noise generating activities

A preliminary impact assessment has been carried out by Advisian (document reference US4A/B Noise Modelling Study Scope of work) which has identified activities associated with the proposed Scarborough project that generate noise emissions. Of these, three key noise generating activities in Commonwealth waters have been identified by Advisian for detailed modelling to assess the risk of noise impacts. These impacts include:

- Change in ambient noise;
- Disturbance to fauna behaviour;
- Injury/mortality to fauna; and
- Changes to the functions, interests or activities of other users.

A description of the three activities is presented in Table 1. Each activity has been assigned a scenario reference which will be used throughout this report.

**Table 1: Activities requiring noise modelling**

| Scenario reference | Activity | Description of noise/sources |
|---|---|---|
| 1a. | FPU installation | Impact piling associated with the FPU installation. Involves installation of 20 x 5 m diameter steel anchor piles. Piles located in approximately 950 m deep water at the FPU site. |
| 1b. | FPU operation | Topside equipment noise associated with hydrocarbon processing and transportation to a shore-based refinery situation on the FPU<br>Noise from the operation of dynamic positioning (DP) support vessel |
| 2. | Pipelay vessel operations | Pipelay vessel with support vessels will operate in Commonwealth and State waters. Sources comprise:<br>- Noise from the operation of dynamic positioning (DP) pipelay vessel<br>- Noise from the operation of dynamic positioning (DP) support vessel<br>For modelling purposes, the support vessel used for scenarios 1b and 2 is the same. |

## 2.2 Project area

Each of the three activities will take place at separate locations as indicated in Figure 1 - Figure 2 below. The maps show the modelling calculation areas for each scenario as well as marine parks and relevant biologically important areas (BIAs) that partially overlap with the modelling areas. For some scenarios, BIAs fully overlap the modelled area and this is not easily shown using the maps in Figure 1 - Figure 2. For reference, the BIAs that either partially or fully overlap the modelled areas are listed in Appendix B. Map coordinate details of the source locations are provided in the relevant sections below.

**Figure 1: Project area – Scenario 1a (FPU piling) and Scenario 1b (FPU operations)**

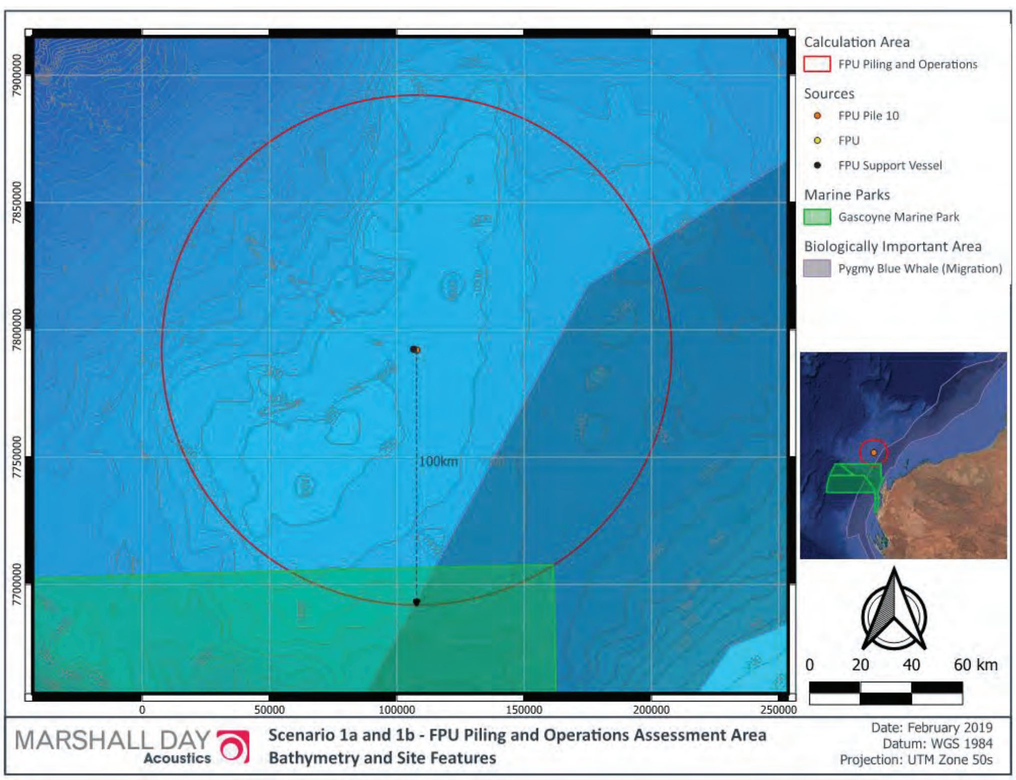
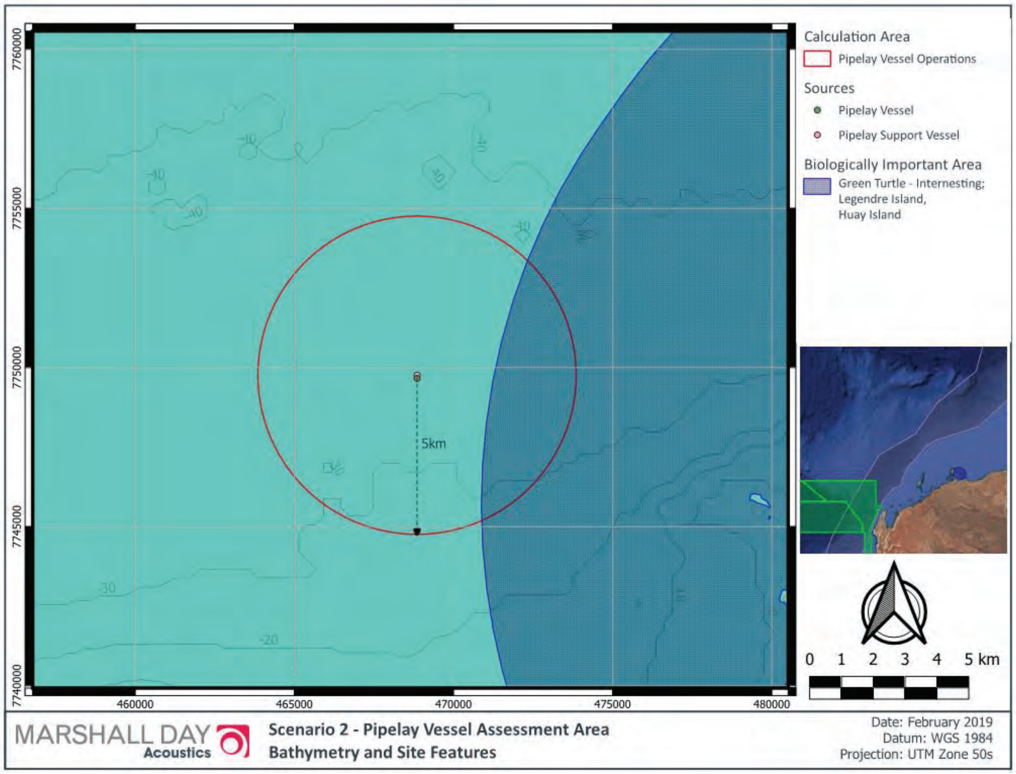


**Figure 2: Project area – Scenario 2 (Vessel operations)**




## 3.0 SPECIES OF INTEREST

The species of interest in the vicinity of the Scarborough project sites have been identified by the project environmental consultant (Advisian). Each species of interest considered in this report has been categorised based on its hearing sensitivity grouping. The guidance used to assess noise impacts set varying criteria for different hearing sensitivity groups. The corresponding hearing sensitive group for each species of interest is therefore provided in Table 2. Further details of the criteria for each species is provide in Section 4.0

**Table 2: Species of interest summary**

| Species | Comment | Hearing Category |
|---|---|---|
| Pygmy blue whales | Presence of migration BIAs identified within the vicinity of the FPU and trunkline corridor. | Low-Frequency Cetaceans |
| Humpback whales | Presence of migration BIAs identified within the trunkline corridor | Low-Frequency Cetaceans |
| Flatback turtle | BIAs and (draft) critical habitat have been identified within the trunkline corridor through the Dampier Archipelago region | Sea turtles |
| Loggerhead turtle | BIAs and (draft) critical habitat have been identified within the trunkline corridor through the Dampier Archipelago region | Sea Turtles |
| Hawksbill turtle | BIAs and (draft) critical habitat have been identified within the trunkline corridor through the Dampier Archipelago region | Sea Turtles |

| Species | Comment | Hearing Category |
|---|---|---|
| Green turtle | BIAs and (draft) critical habitat have been identified within the trunkline corridor through the Dampier Archipelago region | Sea Turtles |
| Fish | Includes whale sharks and fish generally | Fish |

The potential noise impacts on marine fauna from underwater development activity can be categorised into four discrete areas as follows, from highest to lowest in order of the degree of potential impact:

1. Physiological damage that can lead to death or injury of the organism
2. Permanent Threshold Shift (PTS), which is described as a permanent shift in hearing sensitivity and can be considered as an injury
3. Temporary Threshold Shift (TTS), which is described as a temporary effect upon hearing and is often a recoverable impact
4. Behavioural response, which may manifest as avoidance, or a change to movement pathways/migration.

For each of the species hearing categories above, relevant noise criteria have been assigned to assist with the assessment of noise impacts. Details of the noise criteria are outlined in Section 4.0.

# 4.0 NOISE IMPACT CRITERIA

## 4.1 Legislation and policy

The Environment Protection and Biodiversity Conservation Act 1999 (the EPBC Act) is the central piece of environmental legislation relevant to assessments of impacts on marine fauna. It provides the legal framework to protect and manage nationally and internationally important areas, which are defined in the EPBC Act as matters of National Environmental Significance (NES).

When a proposal has the potential to have a significant impact on a matter of national environmental significance, the proposal is assessed on the basis of a 'referral'. A referral should contain sufficient information to provide an adequate basis for a decision on the likely impacts. For noise impacts an assessment would commonly be made with reference to relevant performance criteria.

The EPBC Act Policy Statement 2.1 outlines performance criteria and provides a framework to minimise the risk of underwater acoustic impacts, however this only applies to seismic operations, and only considers impacts on whale species - there are no EPBC policy statements which address other underwater noise sources and marine species.

In the absence of any other Australian specific underwater noise performance criteria, for this assessment, reference has been made to widely used scientific studies and international guidelines in order to evaluate the underwater noise impacts. These impact criteria sources have been nominated by the project marine ecologist.

## 4.2 Underwater noise criteria for marine mammals

The US Department of Commerce National Oceanic and Atmospheric Administration (NOAA) has produced guidance for assessing the effects of anthropogenic (human-made) sound on marine mammals. Details are provided in the following sections.

### 4.2.1 Physiological impacts

NOAA Technical Memorandum[1] provides thresholds for the onset of permanent threshold shift (PTS) and temporary threshold shifts (TTS) [2] in marine mammal hearing for all underwater sound sources. The guidance of the NOAA Technical Memorandum is commonly used in Australia to help evaluate the effects of sound exposure on marine mammal hearing.

Auditory threshold shifts can be caused by both impulsive noise sources (e.g. piling or seismic airguns) and continuous noise sources (e.g. vessel noise). When the source is impulsive, threshold shifts can be caused by peak exposure (momentary, high-level impulsive events such as pile strikes) or from cumulative exposure (lower noise levels over an extended period such as from vibro-piling or multiple pile strikes).

The NOAA Technical Memorandum provide TTS and PTS onset thresholds for marine mammals using $L_{p,pk}$ and '$SEL_{cum}$' assessment descriptors. The $L_{p,pk}$ level is the highest un-weighted instantaneous pressure level recorded during the measurement period, whereas $SEL_{cum}$ is the species-weighted cumulative sound exposure level over a 24-hour period. Table 3 presents the current NOAA thresholds. Explanation of marine mammal auditory frequency weightings is provided in Appendix C.

It should be noted that the $L_{p,pk}$ assessment of noise levels is relevant for impulsive noise sources only. $SEL_{cum}$ assessment is applicable to both impulsive and non-impulsive (continuous) noise sources.

**Table 3: NOAA 2018 threshold criteria**

| | Impulsive | | | | Non-Impulsive | |
|---|---|---|---|---|---|---|
| | $L_{p,pk}$ * | | $SEL_{(cum)}$ † | | $SEL_{(cum)}$ | |
| **Hearing group** | **TTS** | **PTS** | **TTS** | **PTS** | **TTS** | **PTS** |
| Low-Frequency Cetaceans | 213 | 219 | 168 | 183 | 179 | 199 |
| Mid-Frequency Cetaceans | 224 | 230 | 170 | 185 | 178 | 198 |
| High-Frequency Cetaceans | 196 | 202 | 140 | 155 | 153 | 173 |

* The $L_{p,pk}$ is the un-weighted peak instantaneous pressure level

† The $SEL_{(cum)}$ is the weighted cumulative sound exposure level over a 24-hour period

### 4.2.2 Behavioural impacts

Behavioural responses to underwater noise can vary significantly depending on species, the background noise levels, and the frequency content of the noise source. These effects can range from temporary avoidance of the noisy area to masking of biologically important sounds.

[1] National Oceanic and Atmospheric Administration, 2018 *Revision to: Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing (Version 2.0) Underwater Thresholds for Onset of Permanent and Temporary Threshold Shifts.* Available from: https://www.fisheries.noaa.gov/national/marine-mammal-protection/marine-mammal-acoustic-technical-guidance

[2] TTS in humans can be likened to the 'muffled' effect on hearing after being exposed to high noise levels such as at a concert. The effect eventually goes away, but the longer the exposure, the longer the threshold shift lasts. Eventually, the TTS becomes permanent. Long exposure TTS causing PTS in marine mammals is typically associated with continuous noise sources but is unlikely when dealing with impulsive sources due to the understanding that there is TTS recovery in between pulses.

For underwater impulsive noise such as impact piling, NOAA guidance[3] states that behavioural impacts can occur at levels of 160 dB re. 1 μPa rms, and as low as 120 dB re. 1 μPa rms for non-impulsive noise.

**Table 4: NOAA criteria for behavioural impacts**

| | Impulsive<br>$L_{p,rms}$ (dB re. 1 μPa) | Non-Impulsive<br>$L_{p,rms}$ (dB re. 1 μPa) |
|---|---|---|
| Behavioural | 160 | 120 |

## 4.3 Underwater noise criteria for fish

The 2014 publication '*Effects of Sound on Fish and Turtles*'[4] (herein referred to as ASA S3/SC1.4-2014) provides comprehensive sound exposure guidelines for fishes and sea turtles. ASA S3/SC1.4-2014 was prepared by an ANSI-accredited Standards Committee Working Group of experts and was sponsored by the Acoustical Society of America.

ASA S3/SC1.4-2014 outlines hearing category groups based on the way different non-mammalian marine animals detect and respond to sound and provides sound exposure metrics for a ranges of source types for noise impact assessment purposes. ASA S3/SC1.4-2014 divides fishes and sea turtles into five groups as follows:

- Fish with no swim bladder
- Fish with swim bladder not involved with hearing
- Fish with swim bladder that is involved with hearing
- Sea turtles
- Eggs and larvae

### 4.3.1 Physiological impacts

ASA S3/SC1.4-2014 provides guideline noise level criteria for different types of sound sources. Sound levels from a source that are above the guideline criteria are considered likely to result in the stated effect (mortality, injury etc).

A summary of the guideline noise level criteria from ASA S3/SC1.4-2014, for piling noise sources, is provided in Table 5. A summary of the guideline noise levels criteria from ASA S3/SC1.4-2014, for shipping and other continuous noise sources, is provided in Table 6.

Where quantitative criteria have not been provided in the ASA S3/SC1.4-2014, the entry has been shown blank.

[3] https://www.westcoast.fisheries.noaa.gov/protected_species/marine_mammals/threshold_guidance.html

[4] Popper et al, 2014, Sound Exposure Guidelines for Fishes and Sea Turtles: A Technical Report prepared by ANSI Accredited Standards Committee S3/SC 1 and registered with ANSI, ASA Press (ASA S3/SC1.4 TR-2014)

**Table 5: Guidelines for pile driving**

| | | Mortality and potential mortal injury | | Recoverable injury | | TTS |
|---|---|---|---|---|---|---|
| **Group** | **Type of Fish** | **$L_{p,pk}$** | **$SEL_{(cum)}$** | **$L_{p,pk}$** | **$SEL_{(cum)}$** | **$SEL_{(cum)}$** |
| A | Fish: no swim bladder (particle motion detection) | 213 | 219 | 213 | 216 | 186 |
| B | Fish: swim bladder is not involved in hearing (particle motion detection) | 207 | 210 | 207 | 203 | 186 |
| C | Fish: swim bladder involved in hearing (primarily pressure detection) | 207 | 207 | 207 | 203 | 186 |
| D | Sea turtles | 207 | 210 | - | - | - |
| E | Eggs and larvae | 207 | 210 | - | - | - |

**Table 6: Guidelines for shipping and continuous sounds**

| Group | Type of Fish | Mortality and potential mortal injury | Recoverable injury | TTS |
|---|---|---|---|---|
| A | Fish: no swim bladder (particle motion detection) | - | - | - |
| B | Fish: swim bladder is not involved in hearing (particle motion detection) | - | - | - |
| C | Fish: swim bladder involved in hearing (primarily pressure detection) | - | 170 dB rms for 48 hrs | 158 dB rms for 12 h |
| D | Sea turtles | - | - | - |
| E | Eggs and larvae | - | - | - |

### 4.3.2 Behavioural impacts

Studies on the behavioural impacts from noise on fish are very limited and there are no widely accepted or validate guideline criteria. This is partly due to the practicalities of conducting such studies in the field, as well as the potential for large variations in responses across all fish species.

Given the lack of available evidence or validated criteria, quantitative guidelines for the behavioural impact of fish are not provided in ASA S3/SC1.4-2014, and instead a subjective risk assessment approach is used. For this reason, only physiological impacts on fish have been considered in this report. Behavioural impacts for sea turtles are addressed in the following section.

## 4.4 Underwater noise criteria for turtles

### 4.4.1 Physiological impacts

Data on hearing by sea turtles is very limited and specific TTS noise threshold criteria are not available currently[5]. Finneran et al. 2017[6] includes per-strike $L_{p,pk}$ PTS criteria for turtles of 232 dB re 1 µPa.

Physiological impacts risks relating to injury or death also have been assessed, based on ASA S3/SC1.4-2014 guidance as outlined in Table 5 above.

### 4.4.2 Behavioural impacts

*National Science Foundation: Final Programmatic Environmental Impact Statement Overseas Environmental Impact Statement* (OEIS), June 2011 (NSF 2011) provides guideline noise criteria for sea turtle behavioural responses, as presented in Table 7. Also included in the table is criteria for increased behavioural response from McCauley et al. (2000a)[7].

**Table 7: Sea turtle guideline criteria**

| Response | $L_{p,rms}$ (dB re 1 µPa) |
|---|---|
| Behavioural | 166 |
| Turtles (increased response) | 175 dB re 1µPa |

## 5.0 METHODOLOGY

## 5.1 Modelling overview

There is no defined international standard for the prediction or underwater propagation. However, a number of established analytical methods are representative of current industry practice and are routinely used for impact assessment purpose. These methods have been implemented in the proprietary dBSea software to produce noise contours which show the distribution of levels around a source of noise.

It should be noted that modelling of underwater noise can be are highly sensitive to input parameters. Also, while the methods provide high accuracy for a specific environmental condition, in practice, propagation is highly variable and sensitive to temporal and spatial variations in environmental conditions (in contrast to the to the water condition simplifications which are necessary for practical modelling purposes).

## 5.2 Model input parameters

To predict underwater noise levels, the following factors have been considered:

- Source noise level spectra based on in-water measurement or other suitable reference data, as provided by Advisian.
- Source locations and depths as provided by Advisian
- The noise levels are calculated using a dBSea propagation solvers. The particular solvers used for each scenario are outlined in the relevant sections below. A description of solvers can be found in Appendix D.

---

[5] NSF 2011 provides conservative safety radius of 180 dB re 1 µPa above which TTS or PTS is considered possible, however specific threshold criteria are not defined.

[6] Reference detail are required from Advisian

[7] Reference detail are required from Advisian

- Bathymetry of the area as provided by Advisian (9 second longitude grid spacing, ~ 250mx250m)
- The yearly average sound speed profile variations with depth as provided by Advisian. Details and discussion of the sound speed profile are provided in Appendix E.
- Seafloor/seabed sediment properties as provided by Advisian (map in Appendix F). Common to all modelling scenarios.

For this report, three different modelling scenarios have been considered, each involving different sources, geographic locations and environmental inputs. Each scenario is discussed in greater detail in the following sections.

## 5.3 Scenario 1a – FPU installation

For this study, FPU installation refers to piling activity associated with the construction of mooring anchors for the FPU.

### 5.3.1 Piling details

The mooring arrangement drawing provided by Woodside[8] shows 20 anchor piles positioned around the FPU site.

Details of the piling properties, as provided by Woodside, are presented in Table 8. Installation details (strike rate, number of blows) has been provided by Woodside, as determined by a piling drivability assessment.

**Table 8: Piling details**

| Parameter description | Value |
|---|---|
| Pile length | 60 m |
| Pile diameter | 5 m |
| Wall Thickness | 50 mm |
| Material | Steel |
| Water depth | ~950 m |
| Installation depth below sea floor (total driven depth) | 60 m |
| Installation type | Impact |
| Installation rate | 1 pile per day |
| Total blows per pile | 2752 (case #1) |

### 5.3.2 Source levels

Piling noise level predications in underwater environments are commonly made on the basis of measured near-field source levels of similar piling operations (operations that have used comparable pile sizes, pile types and in similar environments). A commonly used source for reference piling noise levels is the CALTRANS *Compendium of Pile Driving Sound Data*[9] (CALTRANS). However, following a

[8] Woodside drawing reference 195369-MA-GAS-015.01 (rev 00)

[9] The document California Department of Transportation's document 'Technical Guidance for Assessment and Mitigation of the Hydroacoustic Effects of Pile Driving on Fish' (referred to as CALTRANS) Appendix I, *Compendium of Pile Driving Sound Data*, provides a summary of measured underwater sound levels for a variety of pile driving situations.

review of CALTRANS and other available literature, no suitable measured noise level data corresponding to the specific configuration proposed could be found.

For this study, reference has been made to the South Australia Pile Driving Guidelines[10] (SA piling guidelines). While this document does not provide specific details of measured piling noise data, it does provide guidance on the typical range of levels. The SA piling guidelines state that '*Typical source levels range from SEL 170–225 dB re 1 µPa²·s for a single pulse….*' For this study, the SEL maximum value of the SA piling guidelines range has been used to represent piling associated with the FPU installation on the basis that the proposed pile size is at the upper end of the typical pile diameter size range[11]. It should be noted there can be significant variation between piling noise level measurements, even when measured at the same site (as a result of poor hammer strikes for example) so the maximum values have been referenced to account for the potential upper emissions of the proposed piling operations.

Source noise levels and other piling details used in this underwater noise modelling scenario are presented in Table 9. The RMS noise levels in Table 9 have been estimated based on analysis of the measured data provided in CALTRANS.

Modelling the sound propagation of peak noise levels requires complex numerical methods that take into account multipath, multi-component (time, frequency, phase etc) interference effects from the seafloor, sea surface and other propagation variables. Such methods require significant computation power and are generally not suited for practical use due to the significant processing times required. Alternative methods that can estimate the $L_{p,pk}$ levels based on the SEL have been developed to overcome these issues. Such methods typically overestimate the $L_{p,pk}$ and are therefore considered to be conservative. For this study, a simple linear regression method outlined in Lippert et. Al. (2015) has been used to estimate the $L_{p,pk}$ level based on the received SEL level, as calculated in the dBSea model. Since the estimated $L_{p,pk}$ level varies with range, a single figure has not been shown in the source levels in Table 9.

Figure 3 shows a plot of the 1/3 octave levels for the source (SEL values shown). The source spectrum is based on in-water measurements of impact driven steel piles[12] between 31.5Hz – 20kHz, scaled to the levels provided in Table 9.

**Table 9: Broadband source levels – Impact piling**

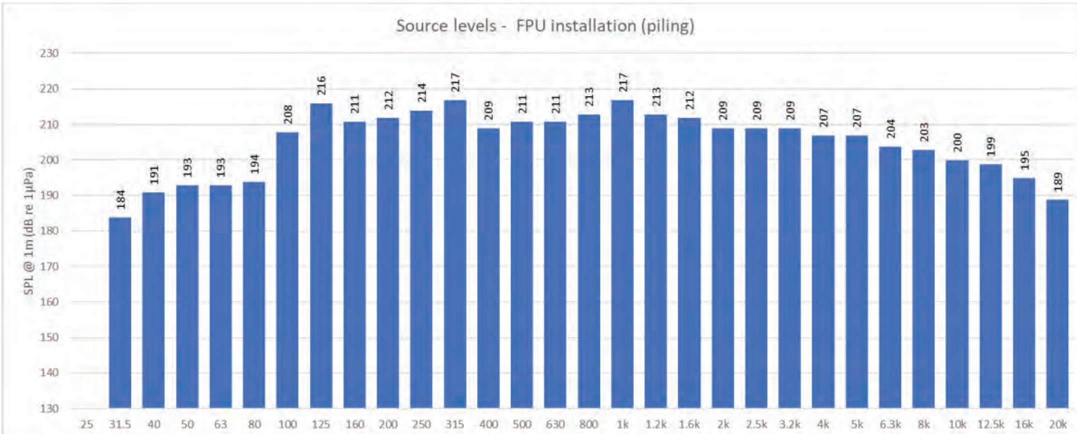
| Type | Size and Method | Source Levels (@ 1m) | | |
|---|---|---|---|---|
| | | Peak | $L_{p,rms,}$ (dB re 1µPa) | $SEL_{(single\ strike),}$ (dB re 1µPa²) |
| Anchor pile | Impact driven 5000mm steel | See discussion above | 235 | 225 |

[10] South Australian Department of Planning, Transport and Infrastructure (DPTI), South Australia Pile Driving Guidelines, November 2012, Document: # 4785592

[11] Pile noise source estimates are supported by analysis of the available large pile data in CALTRANS and reference to other publicly available studies (e.g. Barossa Area Development OPP - www.nopsema.gov.au/assets/OPPs/A598152.pdf)

[12] ITAP –Institut für technische und angewandte Physik GmbH: 'Spektren der Vibrationsramme beim Umspannwerk' (2011)

**Figure 3: 1/3 Octave spectral source levels – Impact piling (per strike)**




### 5.3.3 Source locations

The location coordinates for the noise sources and the assumed source depth are provided in Table 14. The source depth is based on 0m pile penetration on the basis that this would represent a worst-case scenario in terms of noise propagation.

For impact assessment purposes, a single representative pile location only (pile #10) has been considered in the noise model. On the basis that the environmental conditions are similar at each pile location, the results (threshold distances) are considered to be representative for all pile locations i.e. derived threshold distances will be the same for each pile with the subject pile location representing the origin.

**Table 10: Source locations and depths**

| Source description | MGA 94 coordinates (Zone 50K) | | Modelling Source Depth |
|---|---|---|---|
| | Easting (X) | Northing (Y) | |
| Impact piling (pile #10) | 107832.5 | 7792069.4 | 880 m |

### 5.3.4 Underwater modelling parameters

The dbSea modelling software allows various input parameters to be set, based on the specific requirements and limitations of the modelling scenarios. A summary of the key parameter settings for the FPU installation scenario is presented in Table 11.

The maximum model distance was determined using a simplified cylindrical spreading model to estimate the noise levels and then calculate the maximum distance from the source to the lowest threshold level contour.

The frequency range considered is dictated by the range provided in the source data.

The cross over frequency was determined by considering guidance provided in the dBSea documentation (see Appendix D and through sensitivity analysis carried out during preliminary model runs.

**Table 11: Key modelling parameters – Scenario 1a**

| **Propagation Solver Configuration** | |
|---|---|
| Maximum model distance | 100 km |
| Frequency Range | 31.5Hz – 20kHz |
| Azimuthal Increment | 4.5$^{o}$ (80 radials) |
| Crossover frequency | 615Hz |
| Low Frequency Solver | dBSeaPE |
| High Frequency Solver | dBSeaRay |

### 5.3.5 Seabed geoacoustic properties

Information provided in the benthic substrate map (see Appendix F) is limited to a single geoacoustic seabed type. This simplified data provides no information with respect to the presence of shallow layer structures or ocean floor strata. As such, the influence of any complicated sub-surface characteristics has not been evaluated in the model. Review of the benthic substrate map indicates that the sea bed in the vicinity of FPC location is described as 'mud and calcareous clay'. This has been modelled as a halfspace due to insufficient information on shallow layered structures.

This substrate description has been used in in conjunction with literature information on seafloor geoacoustics[13] to determine the properties shown in Table 16.

**Table 12: Geoacoustic properties for Scenario 1**

| **Sediment Description** | **Thickness (m)** | $\rho$ $(kg/m^3)$ | $c_p$ $(m/s)$ | $\alpha_p$ $(dB/\lambda)$ |
|---|---|---|---|---|
| Clay | Halfspace | 1500 | 1500 | 0.2 |

## 5.4 Scenario 1b – FPU operations

### 5.4.1 Source levels

Noise source data has been provided by Advisian. Broadband source noise levels used in this underwater noise modelling scenario are presented in Table 13. Figure 4 shows a plot of the corresponding 1/3 octave levels for the sources. Note that source data for FPU operations is limited to a frequency range of 31.5 Hz to 2.5kHz. Modelling for the FPU operations scenario is accordingly limited to this range only.

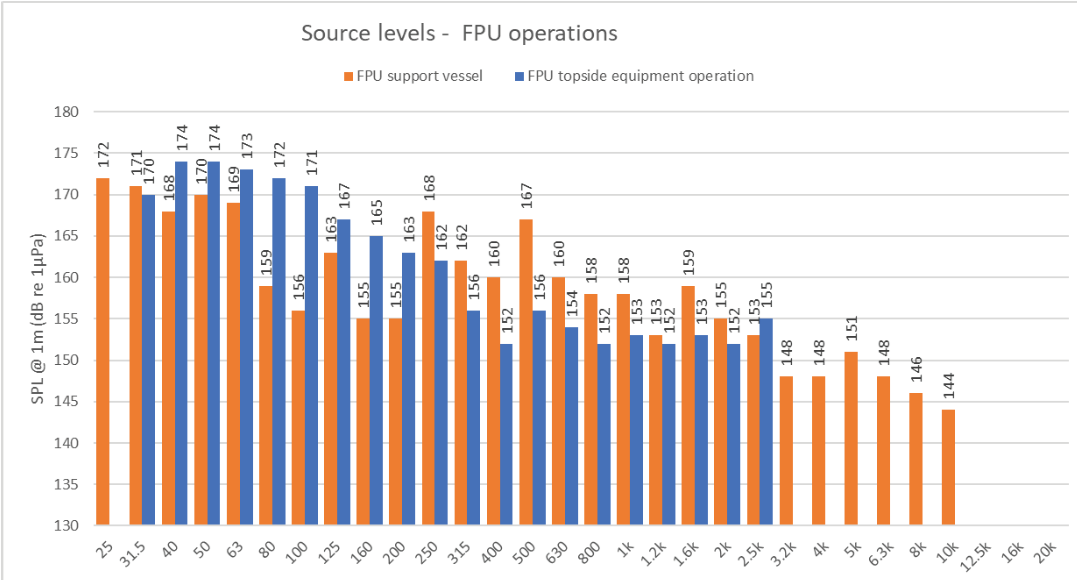
**Table 13: Broadband source levels for noise prediction – Scenario 1b**

| **Source description** | **Details** | **$L_{p,rms}$ @1m (dB re 1 µPa)** |
|---|---|---|
| FPU | Stationary moored, typically FPU topside equipment operating. Data derived from Erbe et al [14] (50$^{th}$ percentile data used) as directed by Advisian. | 180 |

[13] Hamilton, E. L. (1980). Geoacoustic modelling of the sea floor. The Journal of the Acoustical Society of America, 68(5), 1313-1340.

| Source description | Details | $L_{p,rms}$ @1m (dB re 1 µPa) |
|---|---|---|
| Support vessel | Data derived from measured levels of the *Setouchi Surveyor* (Hannay et al. 2004) as directed by Advisian | 186 |

**Figure 4: 1/3 Octave spectral source levels - FPU operations**




### 5.4.2 Source locations

The location coordinates for the noise sources and the assumed source depth location are provided in Table 14.

**Table 14: Source locations and depths**

| Source description | UTM coordinates (MGA94) | | Modelling Source Depth |
|---|---|---|---|
| | Easting (X) | Northing (Y) | |
| FPU | 106450 | 7792300 | 5 m |
| Support vessel | 106450 | 7792500 | 5 m |

### 5.4.3 Underwater modelling parameters

For the FPU operation scenario, the key parameter settings presented in Table 15 have been used for modelling in dbSea.

Maximum model distances, evaluation frequency ranges and solver cross-over frequency have been determined based on the methodologies described in Section 5.3.4.

[14] Erbe, C., McCauley, R., McPherson, C., & Gavrilov, A. (2013). Underwater noise from offshore oil production vessels. *The Journal of the Acoustical Society of America*, *133*(6), EL465-EL470.

**Table 15: Key modelling parameters – Scenario 1b**

| **Propagation Solver Configuration** | |
|---|---|
| Maximum model distance | 100 km |
| Frequency Range | 31.5Hz – 2.5kHz (limited by source data) |
| Azimuthal Increment | 3.6° |
| Crossover frequency | 615kHz |
| Low Frequency Solver | dBSeaPE |
| High Frequency Solver | dBSeaRay |

### 5.4.4 Seabed geoacoustic properties

As the FPU installation and FPU operations activities occur in the same localised area, benthic substrate data and, consequentially, dbSea modelling parameters, are common for the two scenarios, with the same shallow surface layer limitations described in Section 5.3.5. These geoacoustic properties are repeated in Table 16 for convenience.

**Table 16: Geoacoustic properties for Scenario 1**

| **Sediment Description** | **Thickness (m)** | $\rho$ $(kg/m^3)$ | $c_p$ $(m/s)$ | $\alpha_p$ $(dB/\lambda)$ |
|---|---|---|---|---|
| Clay | Halfspace | 1500 | 1500 | 0.2 |

## 5.5 Scenario 2 – Pipelay vessel operations

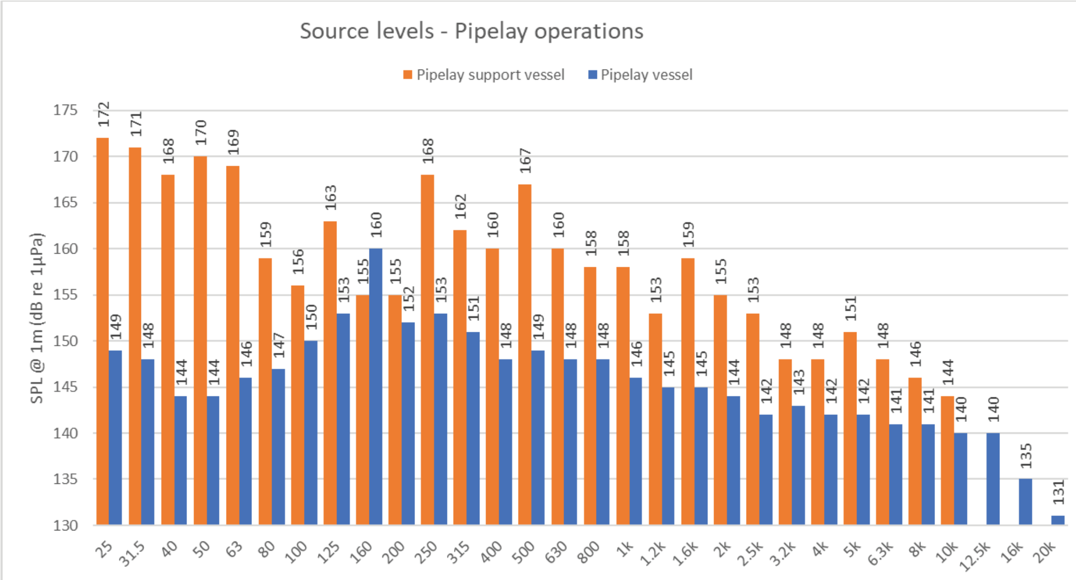
### 5.5.1 Source levels

Noise source data has been provided by Woodside. Broadband source noise levels used in this underwater noise modelling scenario are presented in Table 17. Figure 5 shows a plot of the 1/3 octave levels. Note that source data for support vessel operation is limited to a frequency range of 31.5 Hz to 10kHz. Modelling for the pipelay vessel operation scenario is accordingly limited to this range only.

**Table 17: Broadband source levels for noise prediction – Scenario 1b**

| **Source description** | **Details** | **$L_{p,rms}$ @1m (dB re 1 µPa)** |
|---|---|---|
| Pipelay vessel | Data derived from measured levels of the *Deep Orient*. Length 135 m, Breadth – 27m, Draft 6.85m. Source data based on dynamic positioning in calm seas as directed by Advisian. | 168 |
| Support vessel | Data derived from measured levels of the *Setouchi Surveyor* (Hannay et al. 2004) as directed by Advisian. | 186 |

**Figure 5: 1/3 Octave spectral source levels - Pipelay operations**




### 5.5.2 Source locations

The location coordinates for the noise sources and the assumed source depth location are provided in Table 18.

**Table 18: Source locations and depths**

| Source description | MGA 94 coordinates (Zone 50K) | | Modelling Source Depth |
|---|---|---|---|
| | Easting (X) | Northing (Y) | |
| Pipelay vessel | 468850 | 7749658 | 5 m |
| Support vessel | 468850 | 7749758 | 5 m |

### 5.5.3 Underwater modelling parameters

For the pipelay vessel operation scenario, the key parameter settings presented in Table 19 have been used for modelling in dbSea.

Maximum model distances and evaluation frequency ranges have been determined based on the methodologies described in Section 5.3.4.

Evaluation of pipelay vessel operation noise has been conducted using dbSeaModes normal mode solver. Normal mode calculation techniques are a fundamental concept of underwater noise modelling and have been verified to be appropriate for use in shallow water environments with homogenous bathymetry and sediment composition[15]. Bathymetry and benthic substrate data in the 5km maximum model distance area have minor variations making dbSeaModes an appropriate solver for the subject site. Further information on dBSea solvers provided in Appendix D.

[15] Pedersen R., Keane, M. (2016), V*alidation of dBSea, Underwater Noise Prediction Software. Pile Driving Focus*

**Table 19: Key modelling parameters – Scenario 2**

| **Propagation Solver Configuration** | |
|---|---|
| Maximum model distance | 5 km |
| Frequency Range | 25Hz – 10kHz |
| Azimuthal Increment | 1.2° |
| Solver | dBSeaModes |

### 5.5.4 Seabed geoacoustic properties

Review of the benthic substrate map indicates that the sea bed in the vicinity of FPC location is described as 'gravel.' This substrate description has been used in in conjunction with literature information on seafloor geoacoustics[16] to determine the properties shown in Table 20. As per Section 5.3.5 this has been modelled as a halfspace due to insufficient information on shallow layered structures.

**Table 20: Geoacoustic properties for Scenario 1**

| **Sediment Description** | **Thickness (m)** | $\rho$ $(kg/m^3)$ | $c_p$ $(m/s)$ | $\alpha_p$ $(dB/\lambda)$ |
|---|---|---|---|---|
| Gravel | halfspace | 1800 | 2000 | 0.6 |

## 6.0 MODELLING RESULTS

The following sections outline the results of the noise modelling for each scenario. The results are split into tables based on the species and/or threshold type. The results are presented in the form of a distance from the source to the predicted noise level contour with a value equal to the threshold of interest for each species and type of effect (referred to as the *threshold contour*).

Selected noise contour plots for each scenario are presented in Appendix G. The noise level contours represent the maximum predicted noise level across all water depths at each point (as opposed to presenting the predicted noise level for a single constant depth). This is often referred to as a 'maximum over depth' result.

The distances presented in the tables below are stated in terms of a $R_{max}$ (the maximum radial distance in any direction from the source to the threshold contour) and the $R_{95}$ (the radius of the circular area, equivalent to 95% of the total area encompassed by the threshold contour).

## 6.1 Scenario 1a – FPU installation (anchor piling)

Table 21 through Table 28 present the modelling results for the FPU installation scenario (anchor piling).

[16] Hamilton, E. L. (1980). Geoacoustic modelling of the sea floor. The Journal of the Acoustical Society of America, 68(5), 1313-1340.

**Table 21: $SEL_{cum}$ threshold distances (maximum over depth) - Impulsive noise TTS**

| Hearing group | Threshold criterion | $R_{max}$ (km) | $R_{95\%}$ (km) |
|---|---|---|---|
| Low-frequency cetaceans | 168 re 1µPa$^2$.s | 99.44 | 90.77 |
| Mid-Frequency Cetaceans | 170 re 1µPa$^2$.s | 7.75 | 7.36 |
| High-Frequency Cetaceans | 140 re 1µPa$^2$.s | 42.91 | 39.24 |

**Table 22: $SEL_{(cum)}$ threshold distances (maximum over depth) - Impulsive noise PTS**

| Hearing group | Threshold criterion | $R_{max}$ (km) | $R_{95\%}$ (km) |
|---|---|---|---|
| Low-frequency cetaceans | 183 re 1µPa$^2$.s | 34.34 | 29.13 |
| Mid-Frequency Cetaceans | 185 re 1µPa$^2$.s | 1.14 | 1.02 |
| High-Frequency Cetaceans | 155 re 1µPa$^2$.s | 17.49 | 14.85 |

**Table 23: $L_{p,pk}$ threshold distances (maximum over depth) - Impulsive noise TTS**

| Hearing group | Threshold criterion | $R_{max}$ (km) | $R_{95\%}$ (km) |
|---|---|---|---|
| Low-frequency cetaceans | 213 re 1µPa | 0.751 | 0.440 |
| Mid-Frequency Cetaceans | 224 re 1µPa | 0.468 | 0.282 |
| High-Frequency Cetaceans | 196 re 1µPa | 1.512 | 1.195 |

**Table 24: $L_{p,pk}$ threshold distances (maximum over depth) - Impulsive noise PTS**

| Hearing group | Threshold criterion | $R_{max}$ (km) | $R_{95\%}$ (km) |
|---|---|---|---|
| Low-frequency cetaceans | 219 re 1µPa | 0.59 | 0.35 |
| Mid-Frequency Cetaceans | 230 re 1µPa | 0.31 | 0.19 |
| High-Frequency Cetaceans | 202 re 1µPa | 0.88 | 0.74 |
| Turtle | 232 re 1µPa | 0.26 | 0.17 |

**Table 25: $L_{p,rms}$ threshold distances (maximum over depth) – Impulsive noise behavioural response**

| Hearing group | Threshold criterion | $R_{max}$ (km) | $R_{95\%}$ (km) |
|---|---|---|---|
| Marine mammals | 160 dB re 1µPa | 38.25 | 33.80 |
| Turtles | 166 dB re 1µPa | 24.61 | 21.85 |
| Turtles (increased response | 175 dB re 1µPa | 11.11 | 10.36 |

**Table 26: Fish and sea turtle $SEL_{(cum)}$ threshold distances (maximum over depth) – Impulsive noise mortality and potential mortal injury**

| Hearing group | Threshold criterion | $R_{max}$ (km) | $R_{95\%}$ (km) |
|---|---|---|---|
| Fish: no swim bladder (particle motion detection) | 219 re 1µPa$^2$.s | 0.75 | 0.58 |
| Fish: swim bladder is not involved in hearing (particle motion detection) | 210 re 1µPa$^2$.s | 2.39 | 2.28 |
| Fish: swim bladder involved in hearing (primarily pressure detection) | 207 re 1µPa$^2$.s | 3.50 | 3.28 |
| Sea turtles | 210 re 1µPa$^2$.s | 2.39 | 2.28 |
| Eggs and larvae | 210 re 1µPa$^2$.s | 2.39 | 2.28 |

**Table 27: Fish and sea turtle $SEL_{(cum)}$ threshold distances (maximum over depth) - Impulsive noise recoverable injury**

| Hearing group | Threshold criterion | $R_{max}$ (km) | $R_{95\%}$ (km) |
|---|---|---|---|
| Fish: no swim bladder (particle motion detection) | 216 re 1µPa$^2$.s | 0.99 | 0.89 |
| Fish: swim bladder is not involved in hearing (particle motion detection) | 203 re 1µPa$^2$.s | 9.62 | 9.12 |
| Fish: swim bladder involved in hearing (primarily pressure detection) | 203 re 1µPa$^2$.s | 9.62 | 9.12 |
| Sea turtles | - | | |
| Eggs and larvae | - | | |

**Table 28 Fish $SEL_{(cum)}$ threshold distances (maximum over depth) - Impulsive noise TTS**

| Hearing group | Threshold criterion | $R_{max}$ (km) | $R_{95\%}$ (km) |
|---|---|---|---|
| All fish | 186 re 1µPa$^2$.s | 34.06 | 27.86 |

### 6.1.1 Results summary – Marine mammals

The TTS and PTS cumulative exposure ($SEL_{cum}$) thresholds distances represent a boundary, outside of which, there is predicted to be no significant risk of hearing impairment regardless of the duration a marine mammal is in the project vicinity. These thresholds distances are significantly greater than the thresholds distances for the peak pressure criteria.

If a marine mammal enters a cumulative exposure threshold zone, there is potential for the onset of TTS or PTS. How close the marine mammal gets to the piling determines how fast the cumulative exposure thresholds limits are reached. For this scenario, the low-frequency cetacean TTS threshold contour extends into the pygmy blue whale migration BIA, however this is not the case for the PTS threshold contour, as shown in Appendix G, Figure 8.

### 6.1.2 Results summary – Turtles

The $R_{max}$ distance to the various threshold zone boundaries considered for turtles is as follows:

- Behavioural response -24.61 km (Table 25).
- Possible mortality and potential mortal injury - 2.395 km (Table 26)

### 6.1.3 Results summary – Fish

The greatest $R_{max}$ distance to the various threshold contours, when considering all fish type, is as follows:

- Possible mortality and potential mortal injury – 3.50 km (see Table 26)
- Recoverable injury - 9.62 km (see Table 27)
- Temporary threshold shift - 34.06 km (see Table 28)

## 6.2 Scenario 1b – FPU operations

Table 29 through Table 31 present the modelling results for the FPU operations scenario (FPU topside equipment operating, and support vessel operating).

Threshold distances for PTS and TTS have not been presented on the basis that these effects are unlikely to occur in a real-world situation. To exceed the cumulative PTS or TTS threshold levels would necessarily require marine mammals to remain in vicinity of the vessel over a 24-hour period, which is unlikely. Furthermore, the model is based on a point source representation of the vessels so the predicted levels (and distances to the thresholds) are conservative estimates at close range, given the relatively large scale of the vessels.

**Table 29: SPL threshold distances (maximum over depth) – Continuous noise behavioural response**

| Hearing group | Threshold criterion | $R_{max}$ (km) | $R_{95\%}$ (km) |
|---|---|---|---|
| Marine mammals | 120 dB re 1µPa | 4.55 | 4.29 |
| Turtles | 166 dB re 1µPa | 0.48 | 0.32 |
| Turtles (increased response) | 175 dB re 1µPa | 0.23 | 0.18 |

**Table 30: Fish $SEL_{(cum)}$ threshold distances (maximum over depth) – Continuous noise recoverable injury**

| Hearing group | Threshold criterion | $R_{max}$ (km) | $R_{95\%}$ (km) |
|---|---|---|---|
| Fish: swim bladder involved in hearing (primarily pressure detection) | 170 re 1µPa$^2$.s | 0.36 | 0.26 |

**Table 31 Fish $SEL_{(cum)}$ threshold distances (maximum over depth) -Continuous noise TTS**

| Hearing group | Threshold criterion | $R_{max}$ (km) | $R_{95\%}$ (km) |
|---|---|---|---|
| Fish: swim bladder involved in hearing (primarily pressure detection) | 156 re 1µPa$^2$.s | 0.78 | 0.48 |

### 6.2.1 Results summary – Marine mammals

The $R_{max}$ distance to the behavioural response threshold contour for marine mammals is 4.55 km (Table 29).

The TTS and PTS effects on marine mammals are not a consideration this scenario, as discussed above.

### 6.2.2 Results summary – Turtles

The $R_{max}$ distance to the behavioural response threshold contour for turtles is 0.48 km (Table 29).

### 6.2.3 Results summary – Fish

The greatest $R_{max}$ distance to the various threshold zone boundaries, when considering all fish type, is as follows:

- Recoverable injury - 0.36 km (Table 30)
- Temporary threshold shift (TTS) - 0.78 km (Table 31)

## 6.3 Scenario 2 – Vessel operations

Table 32**Error! Reference source not found.** through Table 34 present the modelling results for the pipelay operations scenario (pipelay vessel and support vessel operating)

As was the case for scenario 1b, threshold distances for PTS and TTS have not been presented on the basis that these effects are unlikely to occur in a real-world situation.

**Table 32: SLP threshold distances (maximum over depth) – Continuous noise behavioural response**

| Hearing group | Threshold criterion | $R_{max}$ (km) | $R_{95\%}$ (km) |
|---|---|---|---|
| Marine mammals | 120 dB re 1µPa | 4.903 | 4.581 |
| Turtles | 166 dB re 1µPa | 0.046 | 0.022 |
| Turtles (increased response) | 175 dB re 1µPa | <0.010 | <0.010 |

**Table 33: Fish $SEL_{(cum)}$ threshold distances (maximum over depth) – Continuous noise recoverable injury**

| Hearing group | Threshold criterion | $R_{max}$ (km) | $R_{95\%}$ (km) |
|---|---|---|---|
| Fish: swim bladder involved in hearing (primarily pressure detection) | 170 re 1µPa$^2$.s | <0.010 | <0.010 |

**Table 34 Fish $SEL_{(cum)}$ threshold distances (maximum over depth) -Continuous noise TTS**

| Hearing group | Threshold criterion | $R_{max}$ (km) | $R_{95\%}$ (km) |
|---|---|---|---|
| Fish: swim bladder involved in hearing (primarily pressure detection) | 156 re 1µPa$^2$.s | 0.097 | 0.063 |

### 6.3.1 Results summary – Marine mammals

The $R_{max}$ distance to the behavioural response threshold contour for marine mammals is 4.903 km (Table 32). .

The TTS and PTS effects on marine mammals are not a consideration this scenario, as discussed in Section 6.2 above.

### 6.3.2 Results summary – Turtles

The $R_{max}$ distance to the behavioural response threshold contour for turtles is 0.046 km (Table 32).

### 6.3.3 Results summary – Fish

The greatest $R_{max}$ distance to the various threshold contours, when considering all fish types, is as follows:

- Recoverable injury - less than 10 m (Table 33)
- Temporary threshold shift (TTS) - 0.097km (Table 34)

## 7.0 SUMMARY

A study of underwater noise levels from the proposed Scarborough gas field development has been carried out to determine the areas over which marine fauna could be impacted. The study has considered three scenarios which represent the main noise generating activities associated with the development.

Noise modelling has been carried out using dBSea software. The model has taken into account various data inputs including the noise sources and locations, bathymetry data, sound speed profile data and seafloor properties. Suitable noise propagation solvers have been configured for each scenario.

There are no prescribed underwater noise criteria that apply to the project. To assist with the assessment of underwater noise impacts, reference has been made to noise level criteria from widely used scientific studies and international guidelines. These impact criteria sources have been nominated by the project marine ecologist.

The results of the noise modelling have been presented in the form of a distance from the various noise sources to the predicted noise level contour representing the particular threshold of interest.

# APPENDIX A GLOSSARY OF TERMINOLOGY

| | |
|---|---|
| **dB** | Decibel<br>The unit of sound level.<br><br>Expressed as a logarithmic ratio of sound pressure P relative to a reference pressure |
| **Frequency** | The number of pressure fluctuation cycles per second of a sound wave. Measured in units of Hertz (Hz). |
| **Hertz (Hz)** | Hertz is the unit of frequency. One hertz is one cycle per second.<br>One thousand hertz is a kilohertz (kHz). |
| **$L_{p,pk}$** | The peak instantaneous pressure level (un-weighted). |
| **PTS** | Permanent Threshold Shift (PTS) is the permanent loss of hearing caused by acoustic trauma. PTS results in irreversible damage to the sensory hair cells of the ear. |
| **$R_{95}$** | The distance defined by the radius of the circular area that is equivalent to 95% of the total area encompassed by the threshold boundary contour. |
| **$R_{max}$** | The maximum radial distance in any direction from the source to the threshold contour boundary. |
| **$L_{p,rms}$** | Root Mean Square (RMS) is the equivalent continuous (time-averaged) sound level commonly referred to as the average level (period matches the event duration). |
| **SEL** | Sound exposure level (SEL) is the total sound energy of an event, normalised to an average sound level over one second. It is the time-integrated, sound-pressure-squared level. SEL is typically used to compare transient sound events having different time durations, pressure levels and temporal characteristics. |
| **$SEL_{cum}$** | The $SEL_{cum}$ is the 'cumulative' sound energy of all events in a 24-hour period, normalised to an average sound level over one second. |
| **TTS** | Temporary Threshold Shift (TTS) is the temporary loss of hearing caused by sound exposure. The duration of TTS varies depending on the nature of the stimulus, but there is generally recovery of full hearing over time. TTS in humans can be likened to the 'muffled' effect on hearing after being exposed to high noise levels such as at a concert. The effect eventually goes away, but the longer the exposure, the longer the threshold shift lasts. Eventually, the TTS becomes permanent (PTS). |
| **Underwater noise** | A sound that is unwanted by, or distracting to, the receiver underwater. |

## APPENDIX B BIA OVERLAP WITH MODELLED AREAS

**Table 35: BIA overlap summary for modelled scenarios**

| Species | BIA type | Scenario 1a | | Scenario 1b | | Scenario 2 | |
|---|---|---|---|---|---|---|---|
| | | Partial | Full | Partial | Full | Partial | Full |
| Pygmy Blue Whale | Migration | ✓ | × | × | × | × | × |
| | Distribution | × | ✓ | × | ✓ | × | × |
| Humpback Whale | Migration | × | × | × | × | × | ✓ |
| Green Turtle | Internesting Buffer;Legendre Island Huay Island | × | × | × | × | ✓ | × |
| | Internesting buffer; Dampier Archipelago (islands to the west of the Burrup Peninsula) | × | × | × | × | × | ✓ |
| Flatback Turtle | Internesting buffer; Dixon Island | × | × | × | × | × | ✓ |
| | Internesting buffer; Intercourse Is | × | × | × | × | × | ✓ |
| | Internesting buffer; Dampier Archipelago (islands to the west of the Burrup Peninsula) | × | × | × | × | × | ✓ |
| | Internesting buffer; Legendre Is, Huay Is | × | × | × | × | × | ✓ |
| | Internesting buffer; Delambre Is | × | × | × | × | × | ✓ |
| | Internesting buffer; West of Cape Lambert | × | × | × | × | × | ✓ |
| Hawksbill Turtle | Internesting buffer; Rosemary Is | × | × | × | × | × | ✓ |
| | Internesting buffer; Dampier Archipelago (islands to the west of the Burrup Peninsula) | × | × | × | × | × | ✓ |
| | Internesting buffer; Delambre Is (and other Dampier Archipelago Islands) | × | × | × | × | × | ✓ |
| Loggerhead Turtle | Internesting buffer; Rosemary Island | × | × | × | × | × | ✓ |
| | Internesting buffer; Cohen Island | × | × | × | × | × | ✓ |

## APPENDIX C MARINE MAMMAL AUDITORY WEIGHTING FUNCTIONS

The following extract from the NOAA Technical Memorandum provides an industry referred explanation of marine mammal auditory weighting functions.

### 2.2 MARINE MAMMAL AUDITORY WEIGHTING FUNCTIONS

The ability to hear sounds varies across a species' hearing range. Most mammal audiograms have a typical "U-shape," with frequencies at the bottom of the "U" being those to which the animal is more sensitive, in terms of hearing (i.e. the animal's best hearing range; for example audiogram, see Glossary, Figure F1). Auditory weighting functions best reflect an animal's ability to hear a sound (and do not necessarily reflect how an animal will perceive and behaviorally react to that sound). To reflect higher hearing sensitivity at particular frequencies, sounds are often weighted. For example, A-weighting for humans deemphasize frequencies below 1 kHz and above 6 kHz based on the inverse of the idealized (smoothed) 40-phon equal loudness hearing function across frequencies, standardized to 0 dB at 1 kHz (e.g., Harris 1998). Other types of weighting functions for humans (e.g., B, C, D) deemphasize different frequencies to different extremes (e.g., flattens equal-loudness perception across wider frequencies with increasing received level; for example, C-weighting is uniform from 50 Hz to 5 kHz; ANSI 2011).

Auditory weighting functions have been proposed for marine mammals, specifically associated with PTS onset thresholds expressed in the weighted $SEL_{cum}$ [17] metric, which take into account what is known about marine mammal hearing (Southall et al. 2007; Erbe et al. 2016). The Finneran Technical Report (Finneran 2016) developed marine mammal auditory weighting functions that reflect new data on:

- Marine mammal hearing (e.g., Sills et al. 2014; Sills et al. 2015; Cranford and Krysl, 2015; Kastelein et al. 2015c)
- Marine mammal equal latency contours (e.g., Reichmuth 2013; Wensveen et al. 2014; Mulsow et al. 2015
- Effects of noise on marine mammal hearing (e.g., Kastelein et al. 2012a; Kastelein et al. 2012b; Finneran and Schlundt 2013; Kastelein et al. 2013a; Kastelein et al. 2013b; Popov et al. 2013; Kastelein et al. 2014a; Kastelein et al. 2014b; Popov et al. 2014; Finneran et al. 2015; Kastelein et al., 2015a; Kastelein et al. 2015b; Popov et al. 2015).

This reflects a transition from auditory weighting functions that have previously been more similar to human dB(C) functions (i.e., M-weighting from Southall et al. 2007) to that more similar to human dB(A) functions. These marine mammal auditory weighting functions also provide a more consistent approach/methodology for all hearing groups.

Upon evaluation, NMFS determined that the proposed methodology in Finneran 2016 reflects the scientific literature and incorporated it directly into this Technical Guidance (Appendix A) following an independent peer review (see Appendix C for details on peer review and link to Peer Review Report).

### 2.2.2 Marine Mammal Auditory Weighting Functions

Frequency-dependent marine mammal auditory weighting functions were derived using data on hearing ability (composite audiograms), effects of noise on hearing, and data on equal latency (Finneran 2016[18]). Separate functions were derived for each marine mammal hearing group (Figures 1 and 2).

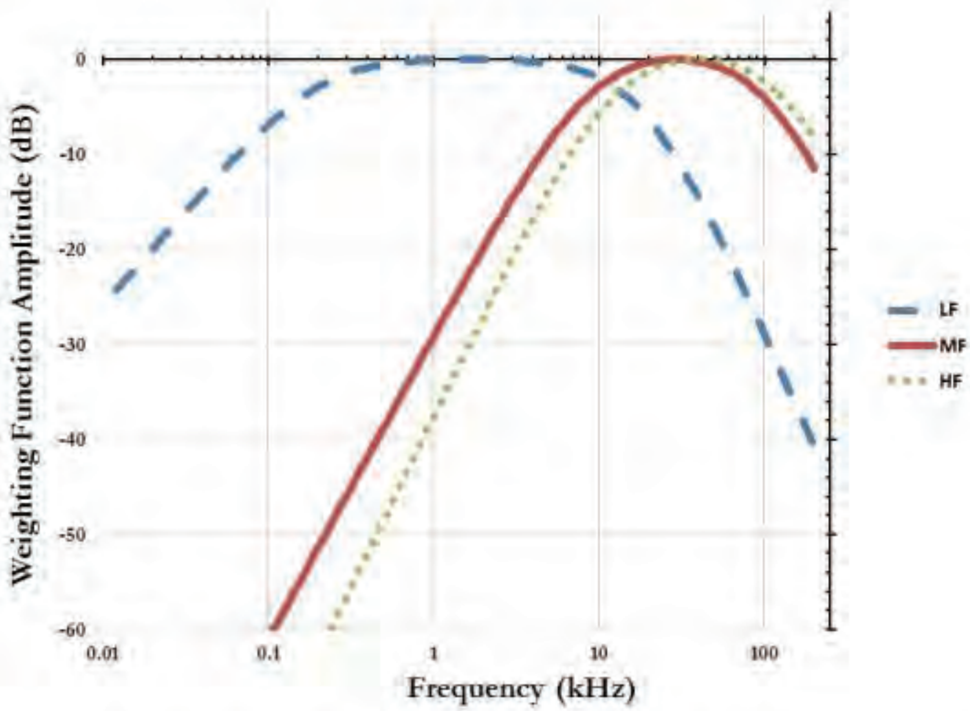



**Figure 1: Auditory weighting functions for low-frequency (LF; dashed line), mid-frequency (MF; solid line), and high-frequency (HF; dotted line) cetaceans.**

## APPENDIX D PROPAGATION SOLVERS

Underwater acoustic propagation is commonly described mathematically by a partial differential called the "Helmholtz Wave Equation". The different solvers available in dBSea each employ various methods and approximations to yield a solution to the wave equation, i.e. the propagation loss. The propagation loss is used to make predictions of acoustic levels. As such each solver has specific scenarios of applicability.

The 3D levels predicted by dBSea are interpolated from 2D slices. All the solvers in dBSea can calculate propagation loss for range-dependent environments. A range-dependant is an environmental where parameters such as, bathymetry, sound speed and/or seabed geoacoustic properties, may vary in range away from the source. dBSea does not yet support elastic geoacoustic properties in the seabed. Approximations can be made where necessary to best derive equivalent fluid parameters to represent elastic seabed layers.

Table 36 provides a summary types of environment where dBSea's numerical solvers are applicable, in general the table follows a similar form to that presented in standard underwater acoustic textbooks[17].

**Table 36: Applicability of dBSea solvers types**

| | **Shallow water** | | **Deep water** | |
|---|---|---|---|---|
| Propagation Solver Type | **Low Frequency** | **High Frequency** | **Low Frequency** | **High Frequency** |
| Parabolic Equations | ● | ◍ | ◍ | ◍ |
| Normal Modes | ● | ◍ | ◍ | ◍ |
| Rays | ○ | ◍ | ● | ● |

Symbol Key:

| | |
|---|---|
| ● | Applicable solver type, fit for purpose and widely used and numerically benchmarked |
| ◍ | Applicable solver type, however there may be limitation due to excessive computation time or accuracy |
| ○ | None applicable |

Shallow water and deep water environments are distinguished by the extent that acoustic waves interact with the seabed. Acoustic wave interact significantly with the seabed in shallow water environments. Typical transition water depths are 50 m – 100 m. Similarly, the cross over between high and low frequencies is not a precisely defined and is also dependent on the water depth. Typical cross over frequencies would be between 100 – 500 Hz, this frequency can be estimated using the equation below,

$$f_{crossover} = 10 * \frac{c_w}{H}$$

Where $c_w$ is the water column wave speed and $H$ is the thickness of the duct or water column.

The dBSea solvers have been validated and benchmarked against accepted analytical solutions. Information on the benchmarking results can be found on dBSea's website[18]. A description of the three main

[17] Etter, P. C. (2013). *Underwater Acoustic Modelling and Simulation*. CRC Press.

[18] http://www.dbsea.co.uk/validation/

propagation solvers is presented below. Refer to textbooks like Jensen et al. (2011)[19] for further detailed information numerical implementations and description of each solver type.

### D1 dBSeaModes

dBSeaModes is a propagation solver is finite difference implementation of a normal mode algorithm. The solver can be used in range-dependent scenarios where there is variation in bathymetry, sound speed and/or seabed geoacoustic properties in range away from the source. Range dependent calculations are based on the outward propagating adiabatic approximation. The adiabatic method is not applicable to scenarios where significant range-dependant variations in parameters occur. Care must be taken in applying dBSeaModes to range-dependent environments.

### D2 dBSeaPE

dBSea's parabolic equation solver (dBSeaPE) is a finite difference implementation of the parabolic equation method. Parabolic equation methods are the preferred low frequency solvers for range-dependent scenarios and have been used extensively in research and commercial applications for underwater propagation modelling. The solver can incorporate range-dependent environmental parameters in bathymetry, sound speed and seabed geoacoustic properties into the propagation loss predictions.

The algorithm is implemented by calculating an initial starting sound field, which is source depth dependent, and is stepped out in range from the source using the PE method. dBSeaPE will use the dBSeaModes solver to generate the starting field. If the modal solver fails to converge to a results Greene's starter is used. If the modal starter fails, the software will prompt with a message 'PE solver used analytical starter', which indicates that the software is using an analytical starter (i.e. Greene's starter) for the specified frequencies and slice numbers.

### D3 dBSeaRay

Ray tracing methods are family of numerical solvers that use a frequency approximation to reduce the Helmholtz equation to a form that can be solved numerically. The ray solver forms a solution by tracing rays from the source out into the sound field. A large number of rays leave the source covering a range of angles, and the sound level at each point in the receiving field is calculated by combining the components from each individual ray.

When multiple seafloor layers are present, rays are not split and traced into the seafloor. A complex reflection coefficient is calculated which is representative of the underlying layers, and this coefficient is applied to the ray at the point of seafloor reflection.

dBSeaRay is used for time domain calculations. Instead of returning a transmission loss at each point in the slice, a list of ray arrivals is returned (with separate entries for each frequency). These arrivals lists can be used to calculate the effective time series at each point in the slice, which is then used to calculate peak, peak to peak, and frequency band SEL levels.

[19] Jensen, F. B., Kuperman, W. A., Porter, M. B., & Schmidt, H. (2011). Computational ocean acoustics. Springer Science & Business Media.

## APPENDIX E WATER COLUMN SOUND SPEED PROPERTIES

Due to the sparse environmental data in deep oceans, a single representative sound speed profile (SSP) has been applied for the entire area considered in the modelling. The average SSP was calculated from temperature and salinity data for Scarborough field, as provided by Woodside. No data was provided for depths below 1000m so a constant sound profile was been assumed below this depth, as directed by Advisian. The resultant SSP is shown in Figure 6 (full depth profile) and Figure 7 (detail of upper 100m).

The yearly average SPP profile in Figure 6 shows no significant surface duct or deep sound channel for the depths considered. It is noted that these SSP characteristics may be more pronounced at particular times of year, however seasonal SPP data for the areas was not provided for this assessment.

**Figure 6: Average sound speed profile**

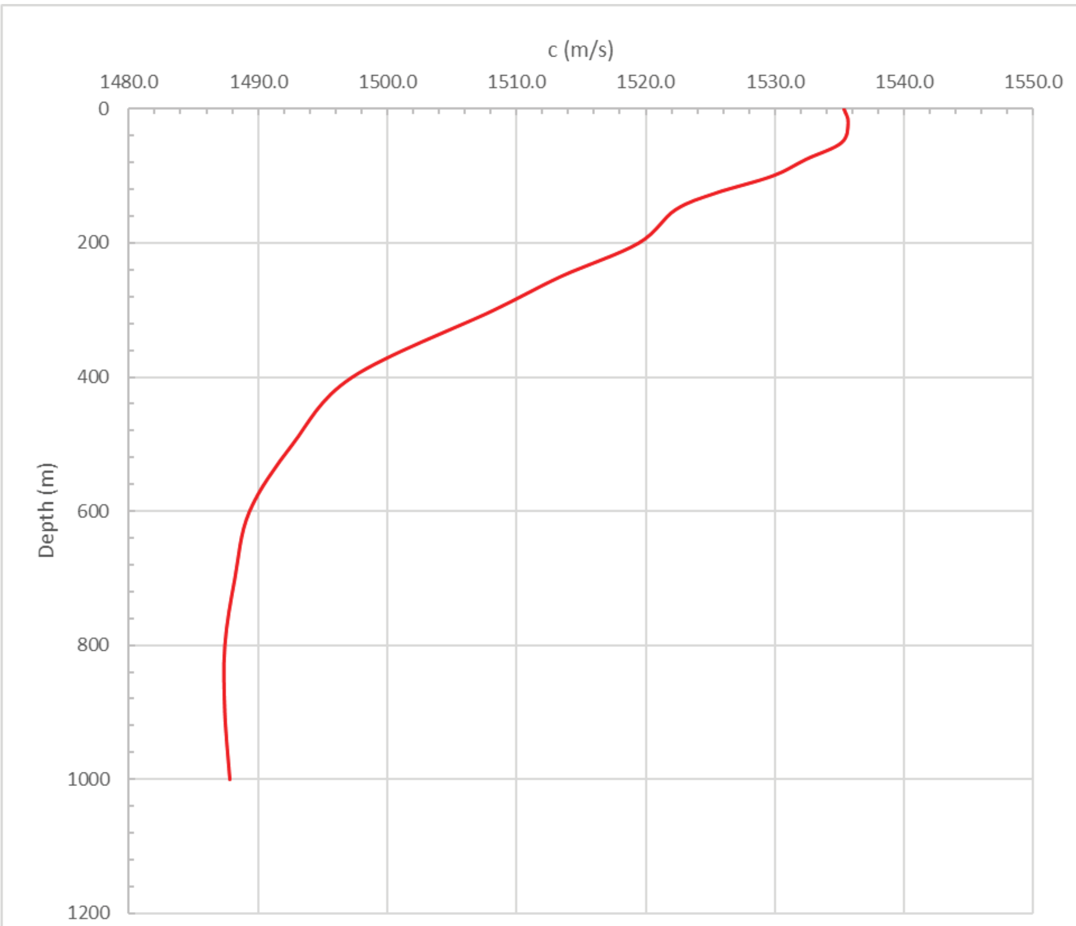
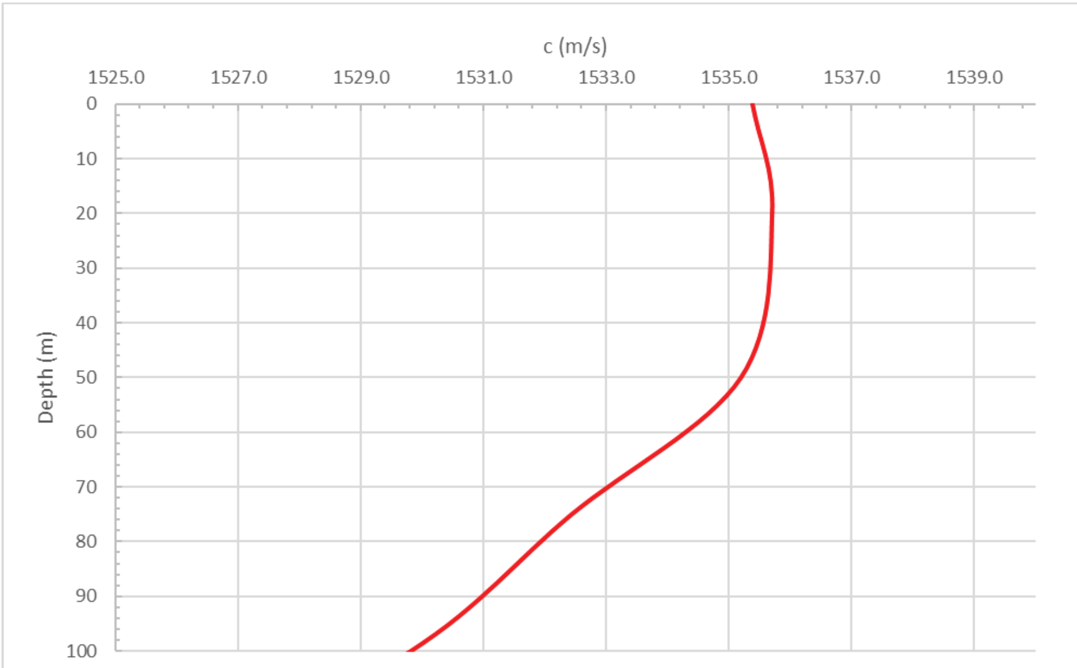
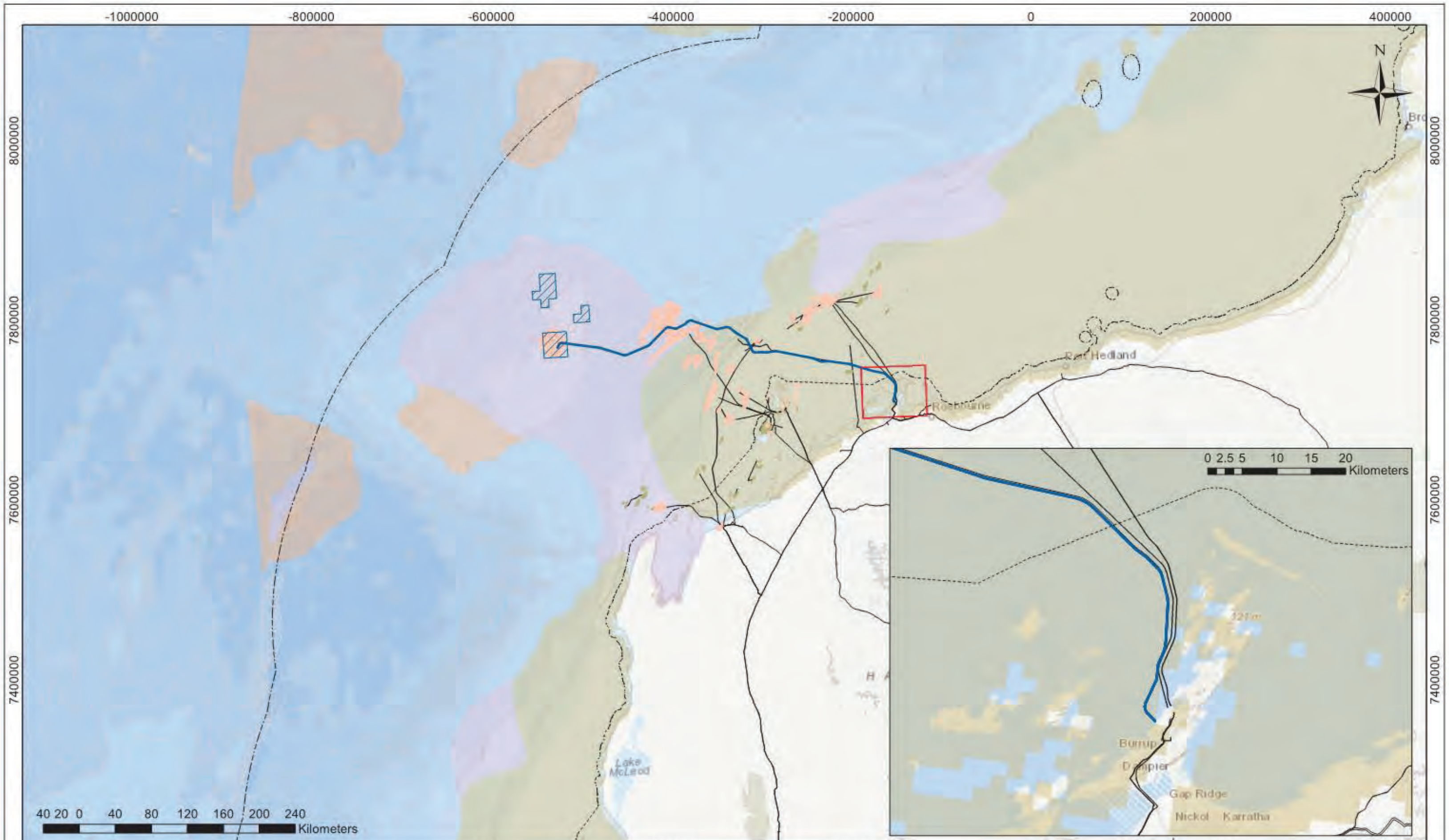


**Figure 7: Average sound speed profile – upper 100m**



## APPENDIX F SEA BED PROPERTIES

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ABN 61 001 279 812

Datum : GDA94
MGA Zone 50

**Legend**

**Oil & Gas Features**
- Petroleum Titles
- Proposed Scarborough Pipeline
- Gas Field
- Oil Field
- Pipeline

**Maritime Boundaries**
- Coastal Water (3 nm)
- Commonwealth Waters (200 nm)

**Bathymetry**
- 500m Contours

**Benthic Substrate**
- Bioslicaous Marl and Calcareous Clay
- Calcareous Gravel, Sand and Silt
- Calcareous Ooze
- Mud and Calcareous Clay

LOCATION

TITLE

BENTHIC SUBSTRATE WITHIN THE VICINITY OF THE SCARBOROUGH DEVELOPMENT

Rev: A

Date: 30 Nov 2018

Author: Cameron Groenheide

## APPENDIX G PREDICTED UNDERWATER NOISE CONTOURS

## G1 Scenario 1a

**Figure 8: Noise contour map - Scenario 1a $SEL_{(cum)}$ unweighted (maximum over depth) – Marine mammal PTS thresholds**

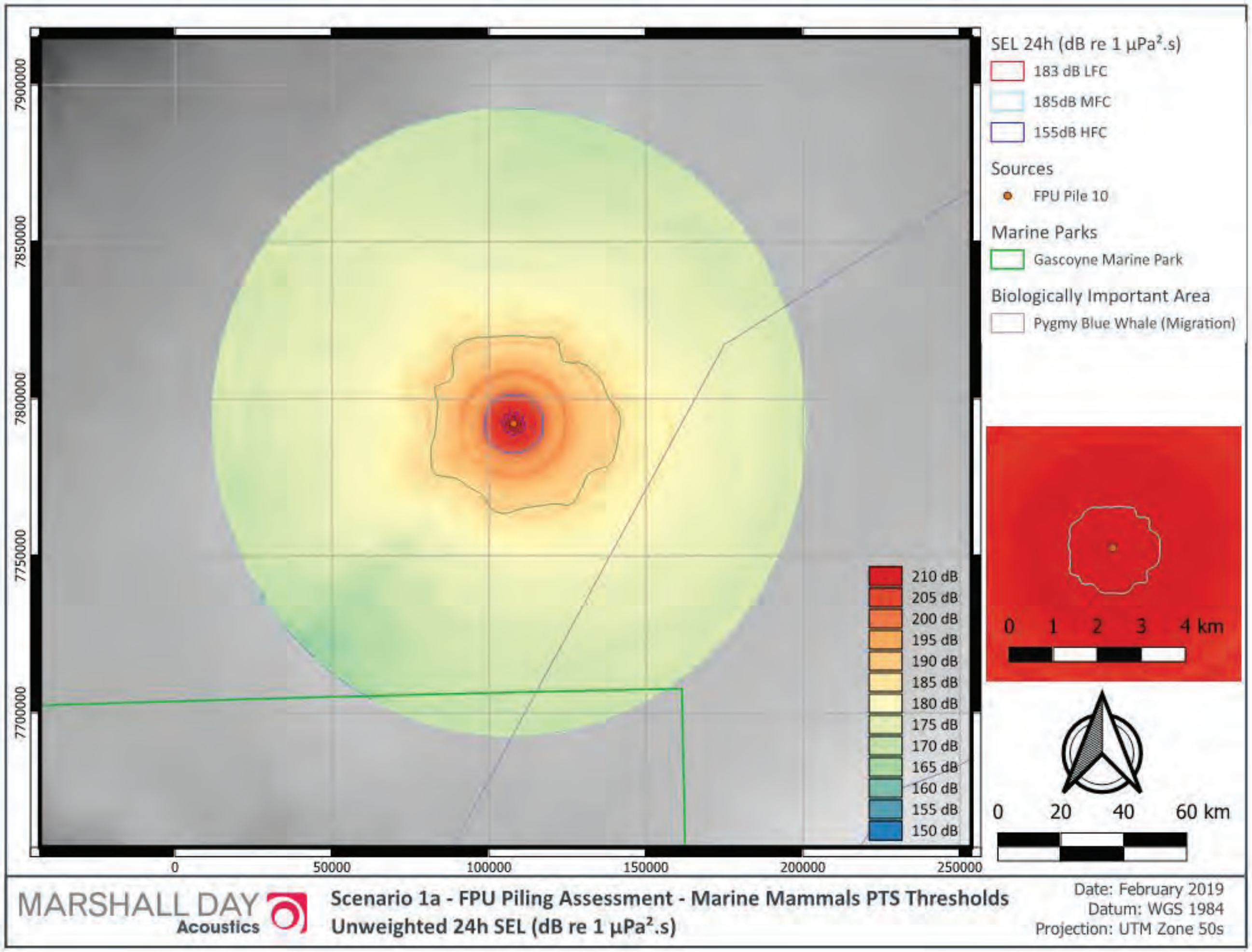


**Figure 9: Noise contour map - Scenario 1a SEL$_{(cum)}$ unweighted (maximum over depth) – Fish and marine turtle thresholds**

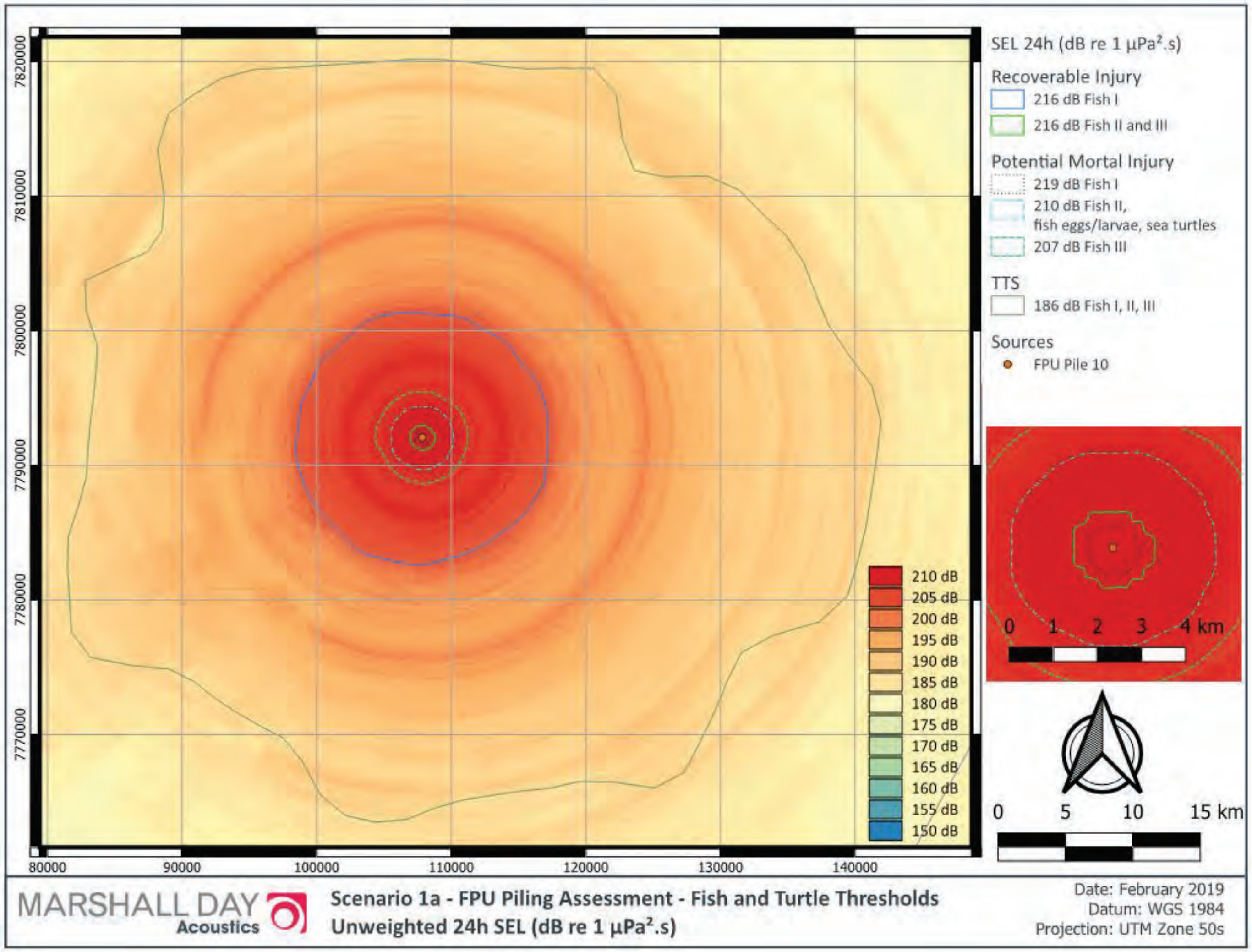
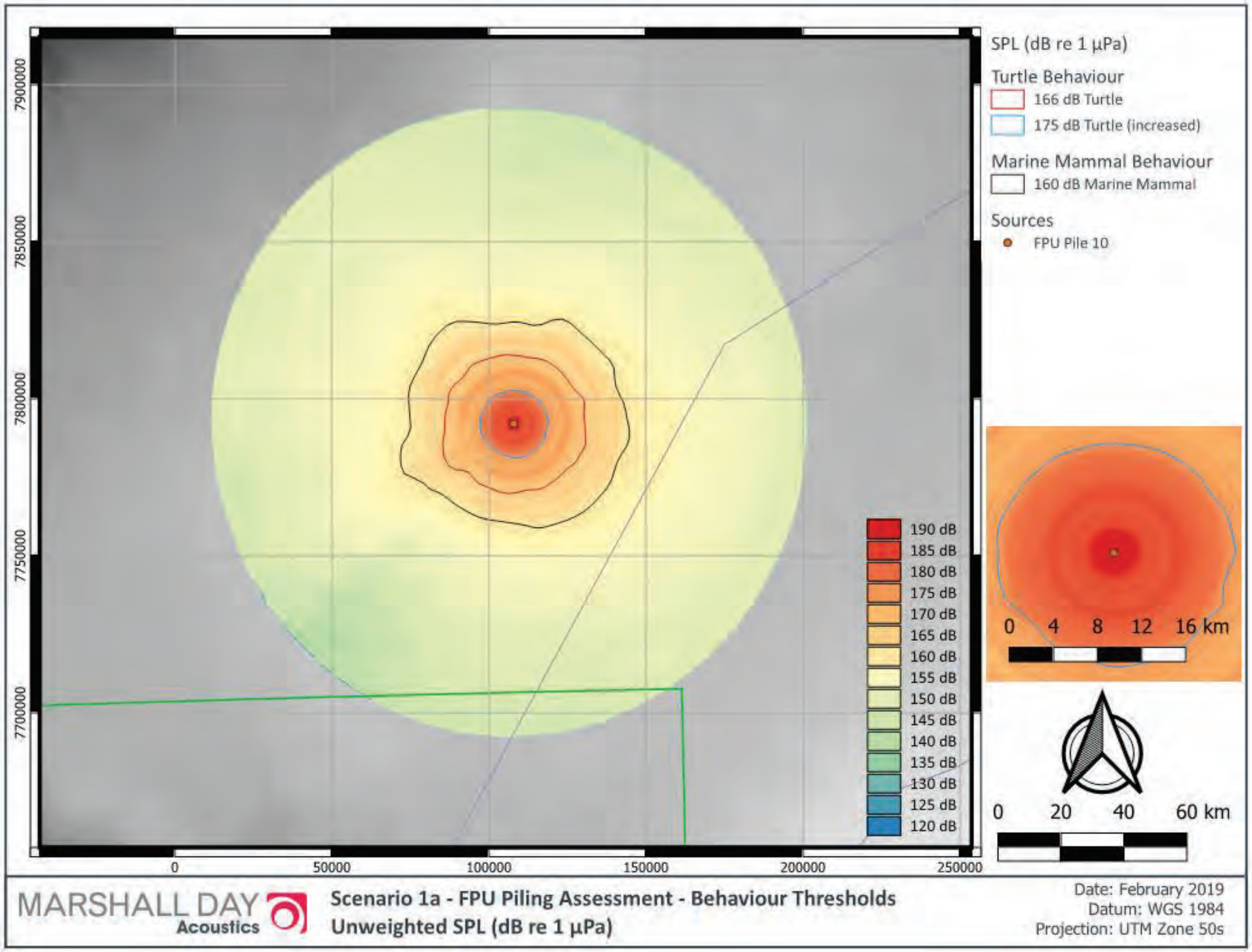


**Figure 10: Noise contour map - Scenario 1a $L_{p,rms}$ (un-weighted) maximum over depth – Behavioural thresholds**



## G2 Scenario 1b

**Figure 11: Noise contour map - Scenario 1b $SEL_{(cum)}$ (unweighted) maximum over depth**

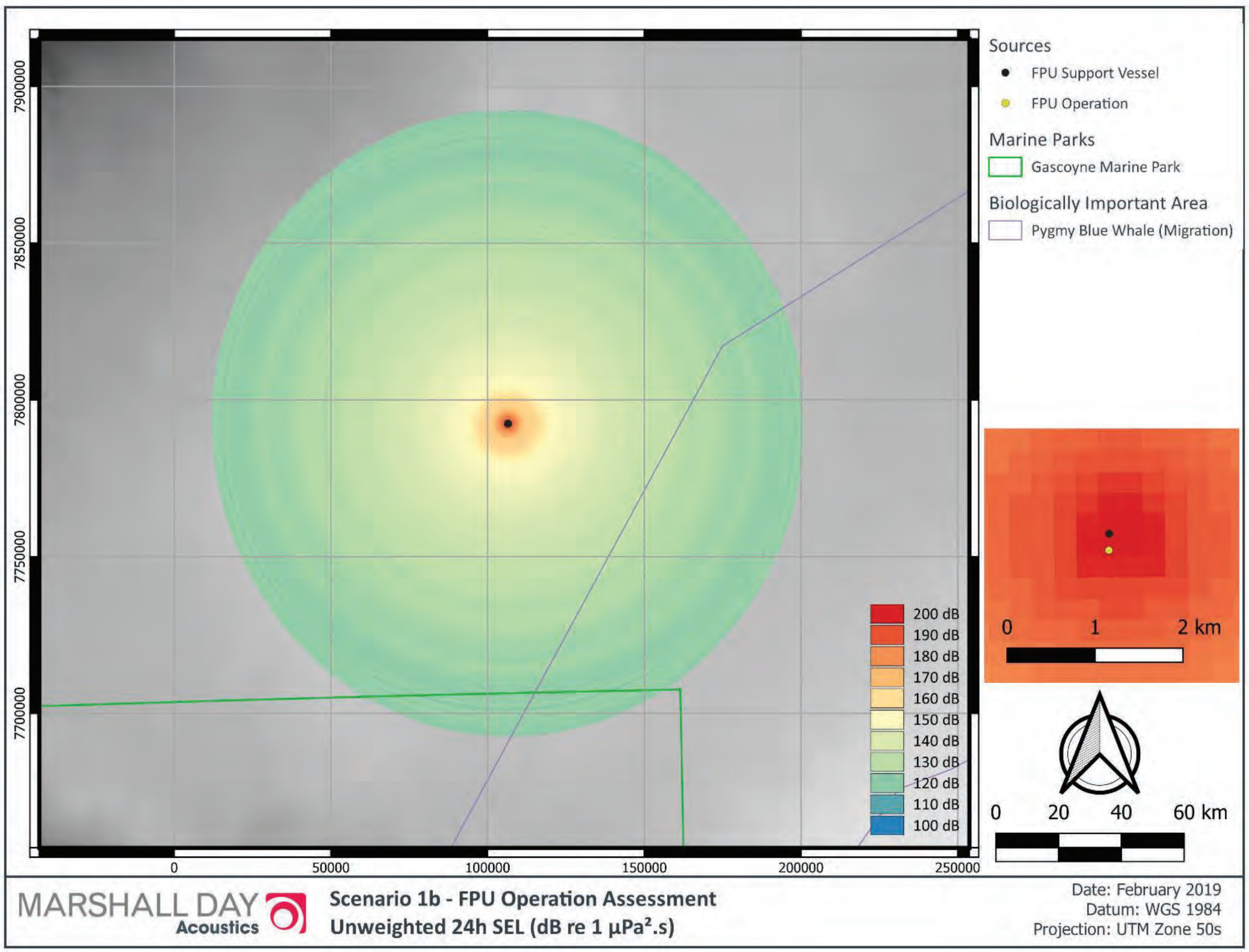
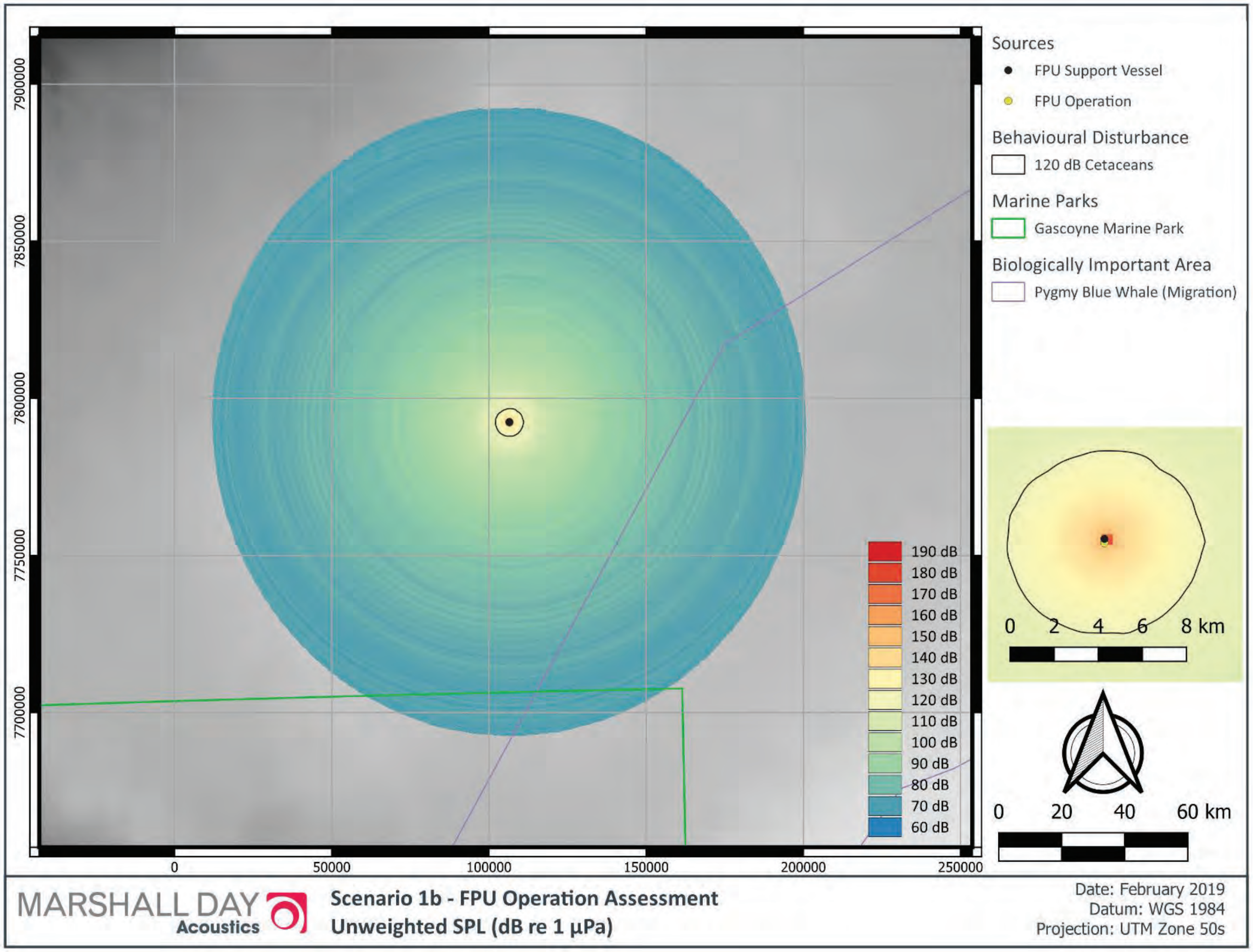


Figure 12: Noise contour map - Scenario 1b $L_{p,rms}$ (un-weighted) maximum over depth



## G3 Scenario 2

**Figure 13: Noise contour map - Scenario 2 $SEL_{(cum)}$ (un-weighted) maximum over depth**

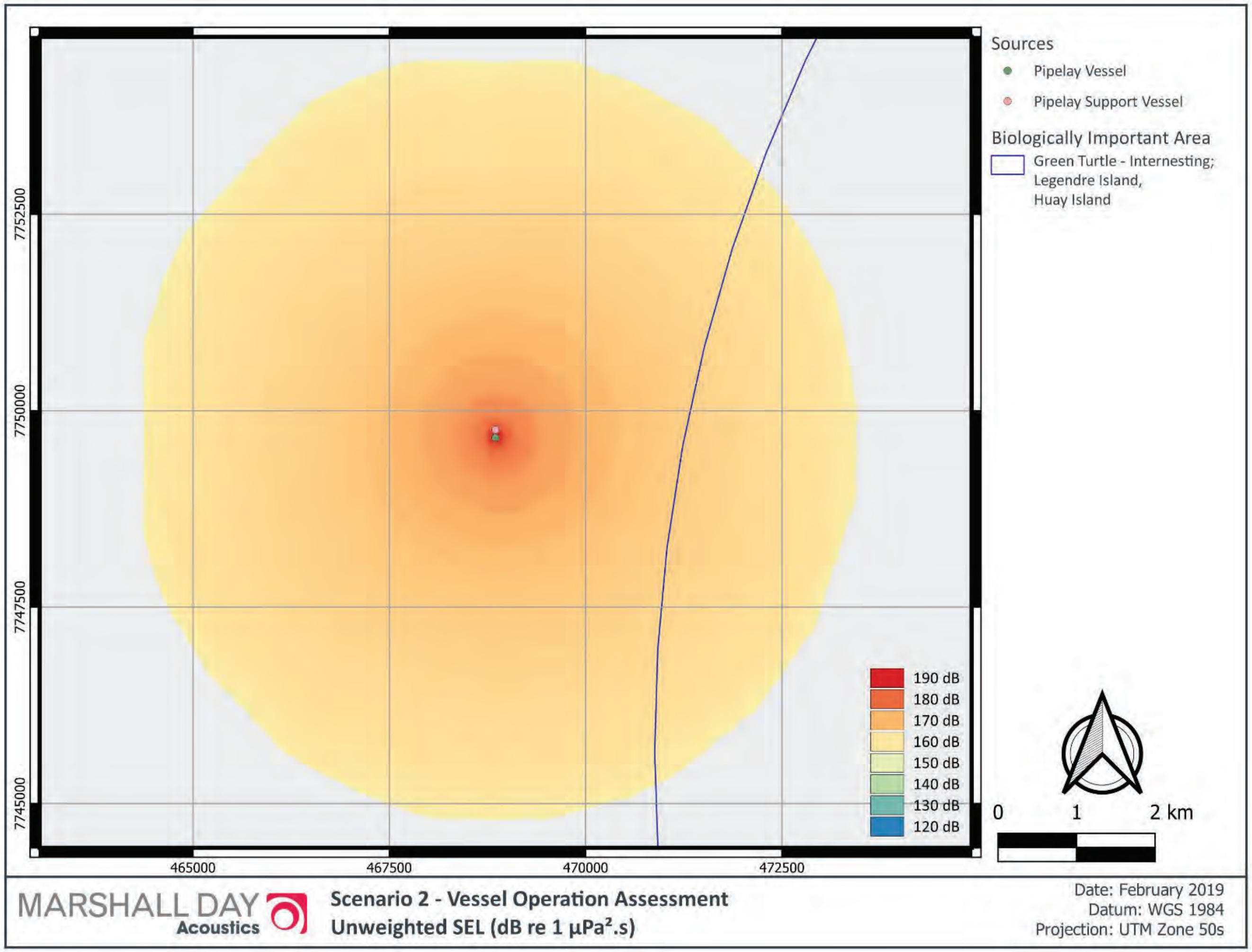
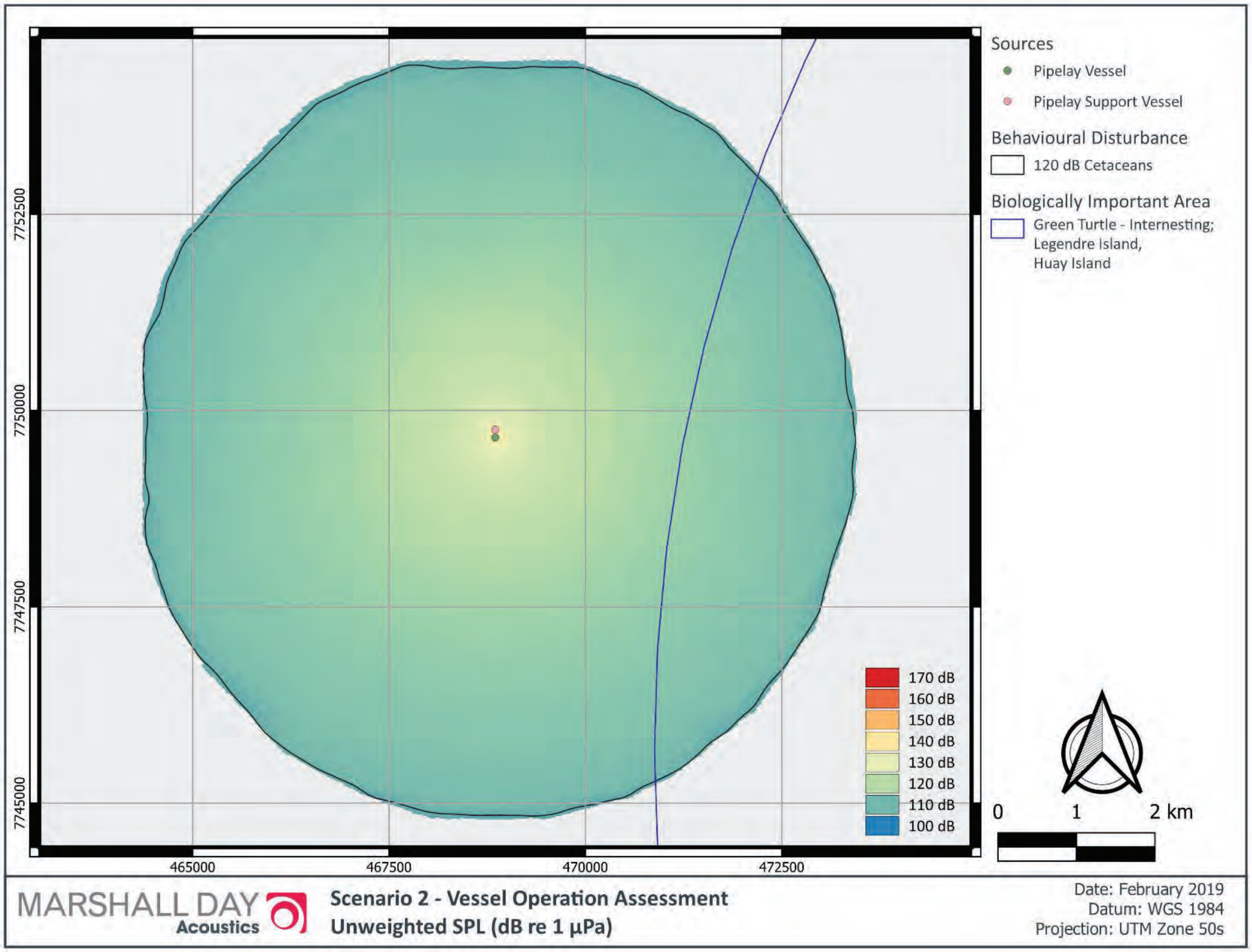


Figure 14: Noise contour map - Scenario 2 $L_{p,rms}$ (un-weighted) maximum over depth



# Appendix F

## Scarborough Gas Development Cooling Water Discharge Modelling Study

# WOODSIDE SCARBOROUGH PROJECT – COOLING WATER DISCHARGE MODELLING

## Report

MAW0764J
Woodside Scarborough Project – Cooling Water Discharge Modelling
Rev 2
17 April 2019

www.rpsgroup.com/mst

## Document status

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Table 3.28 Concentration of chlorine and plume-ambient temperature difference at the end of the near-field stage, the required concentration and temperature threshold, and the number of dilutions for the transitional season. Note from Table 3.26 that dilutions at the 5th, 50th and 95th percentile current speeds were 25.4, 80.6 and 229.7, respectively. Dilution rates highlighted in red indicate that suitable dilution is not achieved during the near-field stage. 39

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# EXECUTIVE SUMMARY

RPS was commissioned by Advisian Pty Ltd (Advisian), on behalf of Woodside Energy Ltd (Woodside), to undertake a marine dispersion modelling study of proposed water discharges from the Scarborough Project's Floating Production Unit (FPU).

The Scarborough gas resource, located in Commonwealth waters approximately 375 km off the Burrup Peninsula, forms part of the Greater Scarborough gas fields, comprising the Scarborough, North Scarborough, Thebe and Jupiter gas fields.

As Operator of the Greater Scarborough gas fields, Woodside is proposing to develop the gas resource through new offshore facilities. These will be connected to the mainland through an approximately 430 km trunkline.

The Scarborough Project will involve the processing of hydrocarbons which will result in the production of cooling water (CW).

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 chlorine in the cooling water (CW) discharge and temperature differential between the discharge and the ambient receiving water. This will indicate whether concentrations of this contaminant and the temperature of the plume are still likely to be above stated 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 CW 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 chlorine in the CW stream from the FPU, dispersion modelling was carried out for flow rates of 165,600 $m^3$/d (45 °C), 64,800 $m^3$/d (57 °C) and 82,800 $m^3$/d (60 °C) at discharge depths of 0 m, 10 m and 30 m below the water surface.

The potential area that may be influenced by the CW 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). An annualised aggregation of outcomes was also assembled.

The main findings of the study are as follows:

## Near-Field Modelling

- 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 0 m (Cases C1, C4 and C7), 10 m (Cases C2, C5 and C8) and 30 m (Cases C3, C6 and C9) below the water surface. The surface discharges are shown to increase the extent of the turbulent mixing zone. Following this initial mixing, the positively-buoyant plumes are predicted to rise in the water column.
- For Cases C1, C4 and C7 (0 m depth discharge), the plume is predicted to plunge up to 14 m below the sea surface, with the highest flow rate yielding the greatest plunge depth due to the vertical orientation of the discharges. For the discharges at depths of 10 m and 30 m, the plumes are predicted

to plunge up to 25 m and 43 m below the sea surface, respectively, with the highest flow rate yielding the greatest plunge depths.

- Increased ambient current strengths are shown to increase the horizontal distance travelled by the plume from the discharge point.
- For a discharge at a 165,600 $m^3$/d flow rate, the maximum horizontal distance travelled by the plume under annualised average current speeds is predicted for a discharge at 30 m depth as 75.0 m. The dilution level for this case is predicted as 1:52.
- For a discharge at a 64,800 $m^3$/d flow rate, the maximum horizontal distance travelled by the plume under annualised average current speeds is predicted for a discharge at 30 m depth as 69.7 m. The dilution level for this case is predicted as 1:77.
- For a discharge at an 82,800 $m^3$/d flow rate, the maximum horizontal distance travelled by the plume under annualised average current speeds is predicted for a discharge at 30 m depth as 59.8 m. The dilution level for this case is predicted as 1:59.
- For a discharge at 0 m depth, the maximum horizontal distance travelled by the plume under annualised average current speeds is predicted for a 165,600 $m^3$/d flow rate discharge as 5.7 m. The dilution level for this case is predicted as 1:6.
- For a discharge at 10 m depth, the maximum horizontal distance travelled by the plume under annualised average current speeds is predicted for a 165,600 $m^3$/d flow rate discharge as 11.1 m. The dilution level for this case is predicted as 1:17.
- For a discharge at 30 m depth, the maximum horizontal distance travelled by the plume under annualised average current speeds is predicted for a 165,600 $m^3$/d flow rate discharge as 24.5 m. The dilution level for this case is predicted as 1:52.
- For each combination of discharge flow rate and depth, 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 surface (or trapping depth, at which the predictions of dispersion are halted due to the plume reaching equilibrium with the ambient receiving water) closer to the discharge point, which slows the rate of dilution.
- The predictions of dilution 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 each combination of discharge flow rate and depth indicate that the chlorine constituent of the CW discharge is not expected to reach the required levels of dilution in the near field mixing zone.
- The temperature differential between the plume and the ambient water meets the required criterion in all conditions for Cases C2, C3, C6 and C9, and in the stronger-current simulations for Cases C1, C5 and C8. For Cases C4 and C7, however, compliance with the temperature differential criterion is not achieved.
- Some failures to reach the required threshold concentration and temperature are attributable to the plume rapidly breaking the surface.

## Far-Field Modelling

- For Cases C1 and C3, dilution to reach threshold concentration is achieved for chlorine within an area of influence extending up to 1.79 km and 2.47 km, respectively, at the 99th percentile. For Cases C4 and C6, the maximum spatial extents of the relevant dilution contour are up to 0.62 km and 0.63 km, respectively, at the 99th percentile.
- For Cases C1 and C3, the areas of exposure defined by the relevant dilution contour are predicted to reach maximums of 4.59 $km^2$ and 6.56 $km^2$, respectively, at the 99th percentile. For Cases C4 and C6, the corresponding maximum areas of exposure are up to 0.40 $km^2$ and 0.68 $km^2$, respectively, at the 99th percentile.
- Maximum depths reached by. the discharges are predicted as 8 m, 38 m, 6 m and 38 m for Cases C1, C3, C4 and C6, respectively.
- Because the 3 °C plume-ambient temperature differential requirement is forecast to be met within a distance of 115 m at the 99th percentile in any case, the limiting factor for the plume's area of influence will be defined by its chlorine constituent rather than its temperature.

## Key Observations

- Due to the similarity in typical magnitude of the hindcast currents throughout the depth range of discharges under consideration, predicted outcomes are broadly similar.
- The greater variability in surface-layer currents may promote the highest levels of mixing and dilution.
- Because the discharge will be initially positively buoyant, it will rise in the water column and may resurface in the vicinity of the discharge point prior to acclimation with ambient receiving water conditions. This outcome is particularly likely for the surface discharge.
- Outcomes show that below-threshold chlorine concentrations are achieved closer to the discharge point for a flow rate of 64,800 $m^3$/d than for a higher flow rate of 165,600 $m^3$/d. This is attributable to the fact that initial peak chlorine concentrations in the water column are lower in the former case, which reduces the average concentrations likely to be recorded in each model grid cell during episodes of recirculation and pooling.

# 1 INTRODUCTION

## 1.1 Background

RPS was commissioned by Advisian Pty Ltd (Advisian), on behalf of Woodside Energy Ltd (Woodside), to undertake a marine dispersion modelling study of proposed water discharges from the Scarborough Project's Floating Production Unit (FPU).

The Scarborough gas resource, located in Commonwealth waters approximately 375 km off the Burrup Peninsula, forms part of the Greater Scarborough gas fields, comprising the Scarborough, North Scarborough, Thebe and Jupiter gas fields.

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The Scarborough Project will involve the processing of hydrocarbons which will result in the production of cooling water (CW).

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 chlorine in the cooling water (CW) discharge and temperature differential between the discharge and the ambient receiving water. This will indicate whether concentrations of this contaminant and the temperature of the plume are still likely to be above stated 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 CW 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 chlorine in the CW stream from the FPU (location shown in Table 1.1), dispersion modelling was carried out for flow rates of 165,600 $m^3/d$ (45 °C), 64,800 $m^3/d$ (57 °C) and 82,800 $m^3/d$ (60 °C) at discharge depths of 0 m, 10 m and 30 m below the water surface.

The potential area that may be influenced by the CW 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). An annualised aggregation of outcomes was also assembled.

All CW discharge characteristics used as input to the modelling are specified in the Model Input Form for this study (Advisian, 2018).

**Table 1.1 Location of the proposed FPU used as the release site for the CW dispersion modelling assessment.**

| Release Site | Latitude (°S) | Longitude (°E) | Water Depth (m) |
|---|---|---|---|
| FPU | 19° 53' 54.715" | 113° 14' 19.561" | 930 |

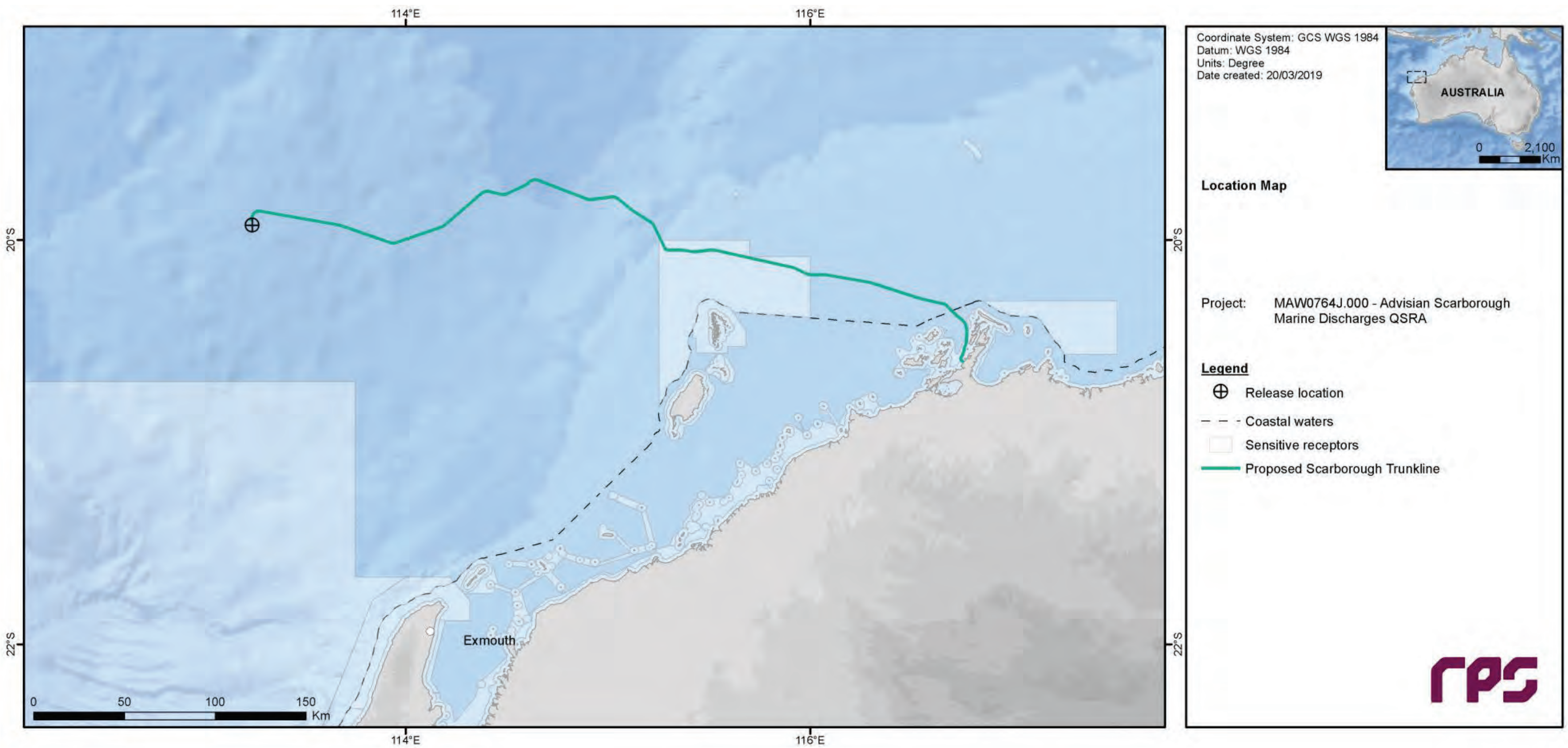



**Figure 1.1 Location of the proposed Scarborough trunkline and FPU on the North West Shelf of Australia.**

## 1.2 Modelling Scope

The physical mixing of the CW 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:

- Collation of a suitable three-dimensional, spatially-varying current data set surrounding the FPU location for a ten-year (2006-2015) 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 metocean data collected in the Scarborough Project area.
- 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.
- Collation of seasonally-varying vertical water density profiles at the FPU location for use as input to the dispersion models.
- 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).
- 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.
- 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.
- 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 CW 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 CW 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 FPU location.

### 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 positively buoyant discharge and the idealised representation of the discharge phases.

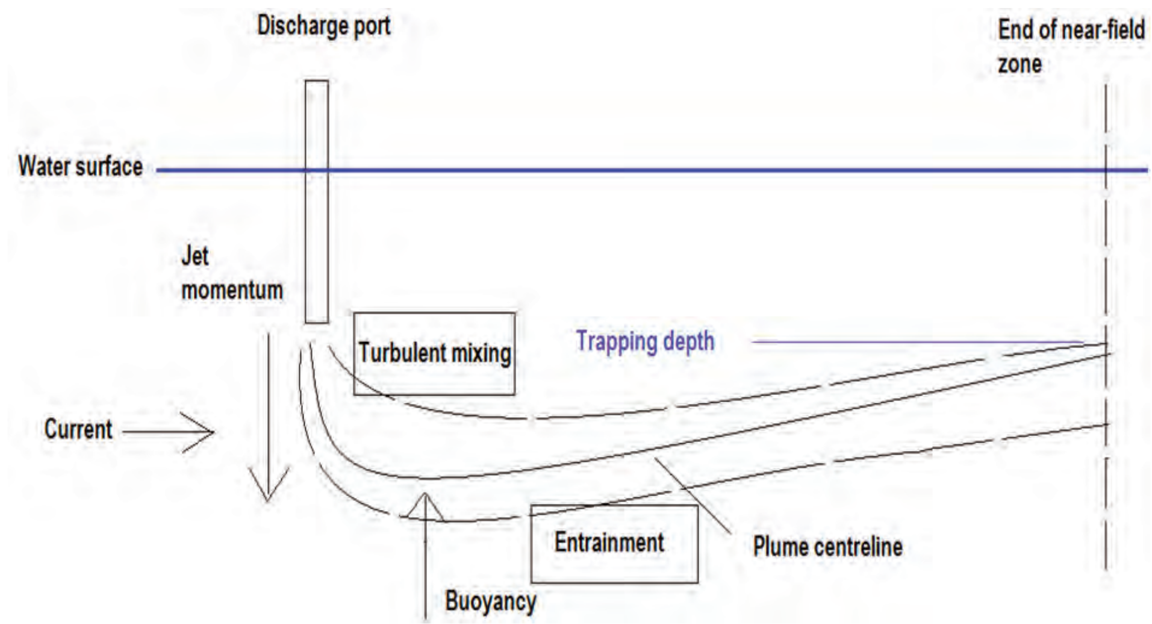



**Figure 2.1 Conceptual diagram showing the general behaviour of positively buoyant discharge.**

## 2.1.3 Setup of Near-Field Model

### 2.1.3.1 Discharge Characteristics

The CW discharge characteristics for Cases C1 to C9 are summarised in Table 2.1.

Cases C1 to C3 were assumed to occur at depths of 0 m below mean sea level (BMSL), 10 m BMSL and 30 m BMSL, respectively. The flow was assumed to occur through a single outlet of 1.4 m diameter at a rate of 165,600 $m^3$/d and have a salinity and temperature of 35 parts per thousand (ppt) and 45 °C, respectively.

Cases C4 to C6 were assumed to occur at depths of 0 m, 10 m and 30 m BMSL, respectively. The flow was assumed to occur through a single outlet of 1.4 m diameter at a rate of 64,800 $m^3$/d and have a salinity and temperature of 35 parts per thousand (ppt) and 57 °C, respectively.

Cases C7 to C9 were assumed to occur at depths of 0 m, 10 m and 30 m BMSL, respectively. The flow was assumed to occur through a single outlet of 1.4 m diameter at a rate of 82,800 $m^3$/d and have a salinity and temperature of 35 parts per thousand (ppt) and 60 °C, respectively.

Concentrations of the constituent of interest (chlorine) within the discharges are described in Table 2.2, along with the required dilution factor to reach the defined threshold concentration (Advisian, 2018).

**Table 2.1 Summary of CW discharge characteristics.**

| Parameter | Case C1 | Case C2 | Case C3 | Case C4 | Case C5 | Case C6 | Case C7 | Case C8 | Case C9 |
|---|---|---|---|---|---|---|---|---|---|
| Flow rate ($m^3$/d) | | 165,600 | | | 64,800 | | | 82,800 | |
| Outlet pipe internal diameter (m) [in] | | | | | 1.4 [55] | | | | |
| Outlet pipe orientation | | | | | Vertical (downwards) | | | | |
| Depth of pipe below sea surface (m) | 0 | 10 | 30 | 0 | 10 | 30 | 0 | 10 | 30 |
| Discharge salinity (ppt) | | | | | 35 | | | | |
| Discharge temperature (°C) | | 45 °C | | | 57 °C | | | 60 °C | |

**Table 2.2 Constituent of interest within the CW discharges and criteria for analysis of exposure.**

| Constituent/Property | Source Concentration or Temperature | Threshold Concentration or Temperature | Required Dilution Factor |
|---|---|---|---|
| Chlorine | 1,000 ppb | 5 ppb | 200 |
| Temperature | 45-60 °C | 3 °C above ambient | - |

## 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 CW plume. These inputs are described in the following sections.

### 2.1.3.2.1 Ambient Temperature and Salinity

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, NOAA) and its co-located World Data Center for Oceanography (Levitus *et al.*, 2013).

Table 2.3 shows the average seasonal water temperature and salinity levels at varying depths from 0 m to 50 m. This data can be considered representative of seasonal conditions at the FPU location.

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 (34.7-34.8 practical salinity unit, PSU), irrespective of season or depth.

**Table 2.3 Average temperature and salinity levels adjacent to the proposed FPU location.**

| Season | Depth (m) | Temperature (°C) | Salinity (PSU) |
|---|---|---|---|
| Summer | 0 | 27.8 | 34.7 |
| | 20 | 27.3 | 34.8 |
| | 50 | 26.2 | 34.8 |
| Transitional | 0 | 26.0 | 34.7 |
| | 20 | 25.7 | 34.7 |
| | 50 | 25.1 | 34.7 |
| Winter | 0 | 26.4 | 34.7 |
| | 20 | 26.3 | 34.7 |
| | 50 | 26.2 | 34.7 |
| Annualised | 0 | 26.6 | 34.7 |
| | 20 | 26.3 | 34.7 |
| | 50 | 25.8 | 34.7 |

### 2.1.3.2.2 Ambient Current

Ocean current data was sourced from a 10-year hindcast data set of combined large-scale ocean (BRAN) and tidal currents. The data was statistically analysed to determine the 5$^{th}$, 50$^{th}$ and 95$^{th}$ percentile current speeds. These statistical current speeds can be considered representative of seasonal conditions at the FPU location.

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:

- 5$^{th}$ percentile current speed: weak currents, low dilution and slow advection.
- 50$^{th}$ percentile (median) current speed: average currents, moderate dilution and advection.
- 95$^{th}$ percentile current speed: strong currents, high dilution and rapid advection to nearby areas.

The 5$^{th}$, 50$^{th}$ and 95$^{th}$ percentile values are referenced as weak, medium and strong current speeds, respectively.

**Table 2.4 Adopted ambient current conditions adjacent to the proposed FPU location.**

| 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 | 2.5 | 0.041 | 0.158 | 0.326 |
| | 22.7 | 0.049 | 0.154 | 0.312 |
| | 56.7 | 0.044 | 0.138 | 0.267 |
| Transitional | 2.5 | 0.045 | 0.177 | 0.375 |
| | 22.7 | 0.045 | 0.173 | 0.369 |
| | 56.7 | 0.043 | 0.157 | 0.322 |
| Winter | 2.5 | 0.044 | 0.172 | 0.395 |
| | 22.7 | 0.043 | 0.166 | 0.375 |
| | 56.7 | 0.039 | 0.156 | 0.341 |
| Annualised | 2.5 | 0.043 | 0.170 | 0.374 |
| | 22.7 | 0.045 | 0.164 | 0.361 |
| | 56.7 | 0.042 | 0.151 | 0.320 |

## 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 (25) 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.

Four CW discharge scenarios were modelled as a continuous discharge using 25 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). The CW discharge characteristics for the selected cases (C1, C3, C4 and C6) are summarised in Table 2.5. These cases were chosen to cover the full range of proposed discharge flow rates and depths.

**Table 2.5 Summary of far-field CW discharge modelling assumptions.**

| Parameter | Case C1 | Case C3 | Case C4 | Case C6 |
|---|---|---|---|---|
| Hindcast modelling period | 2006-2015 | | | |
| Seasons | Summer (December to February)<br>Transitional (March and September to November)<br>Winter (April to August)<br>Annual | | | |
| Flow rate ($m^3$/d) | 165,600 | | 64,800 | |
| Discharge depth (m) | 0 | 30 | 0 | 30 |
| Discharge salinity (ppt) | 35 | | | |
| Discharge temperature (°C) | 45 °C | | 57 °C | |
| Number of simulations | 75 (25 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 CW 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 40 m x 40 m to track the movement and fate of the discharge plume. The extent of the grid region measured approximately 40 km (longitude or x-axis) by 40 km (latitude or y-axis), which was subdivided horizontally into 1,000 x 1,000 cells. The vertical resolution was set to 2 m.

## 2.2.5 Regional Ocean Currents

### 2.2.5.1 Background

The area of interest for this study is typified by strong tidal flows over the shallower regions, particularly along the inshore region of the North West Shelf and among the island groups stretching from the Dampier Archipelago to the North West Cape. 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 slicks 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 pollutants can be variably affected by combinations of tidal, wind-induced and density-induced drift currents. Depending on their local influence, it is critical 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 of pollutants. As measured current data is not available for simultaneous periods over a network of locations covering the wide area of this study, 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 mesoscale ocean models, with estimates of the tidal currents generated by an RPS model set up for the study area.

### 2.2.5.2 Mesoscale Circulation Model

Representation of the drift currents that affect the area were available from the output of the BRAN (Bluelink ReANalysis; Oke *et al.*, 2008, 2009; Schiller *et al.*, 2008) ocean model, which is sponsored by the Australian Government through the Commonwealth Bureau of Meteorology (BoM), Royal Australian Navy, and Commonwealth Scientific and Industrial Research Organisation (CSIRO). BRAN is a data-assimilative, three-dimensional ocean model that has been run as a hindcast for many periods and is now used for ocean forecasting (Schiller *et al.*, 2008).

The BRAN predictions for drift currents are produced at a horizontal spatial resolution of approximately 0.1° over the region, at a frequency of once per day, averaged over the 24-hour period. Hence, the BRAN model data provides estimates of mesoscale circulation with horizontal resolution suitable to resolve eddies of a few tens of kilometres' diameter, as well as connecting stream currents of similar spatial scale. Drift currents that are represented over the inner shelf waters in the BRAN data are principally attributable to wind induced drift.

There are several versions of the BRAN database available. The latest BRAN simulation spans the period of January 1994 to August 2016. From this database, time series of current speed and direction were extracted for all points in the model domain for the years 2006-2015 (inclusive). The data was assumed to be a suitably representative sample of the current conditions over the study area for future years.

Figure 2.2 shows the seasonal distribution of current speeds and directions for the BRAN data point closest to the FPU location. Note that the convention for defining current direction is the direction towards which the current flows.

The data shows that current speeds and directions vary between seasons. In general, during transitional months (March and September to November) currents have the strongest average speed (0.22 m/s with a maximum of 0.56 m/s) and tend to flow south-east. During winter (April to August), current flow conditions are more variable, with lower average speed (0.21 m/s with a maximum of 0.53 m/s). During summer (December to February), the current flow occurs in a predominantly south/south-westerly direction with the lowest average speed (0.20 m/s with a maximum of 0.46 m/s).

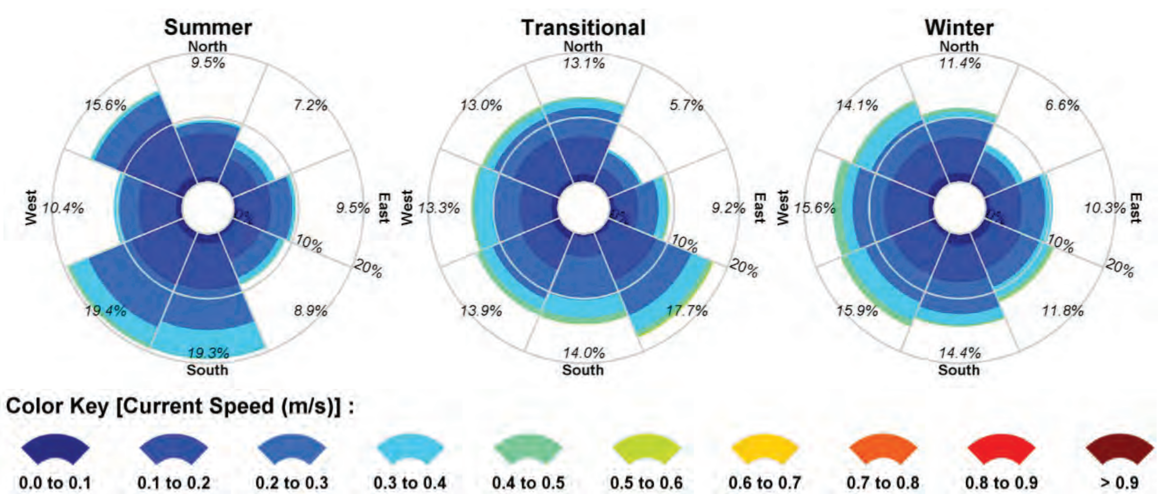



**Figure 2.2 Seasonal current distribution (2006-2015, inclusive) derived from the BRAN database near to the proposed FPU location. The colour key shows the current magnitude, the compass direction provides the direction towards which the current is flowing, and the size of the wedge gives the percentage of the record.**

### 2.2.5.3 Tidal Circulation Model

As the BRAN 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, 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).

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 2.3).

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 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.

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.

For the purpose of verification of the tidal 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 40 tidal stations within the HYDROMAP model domain, ten were used for comparison.

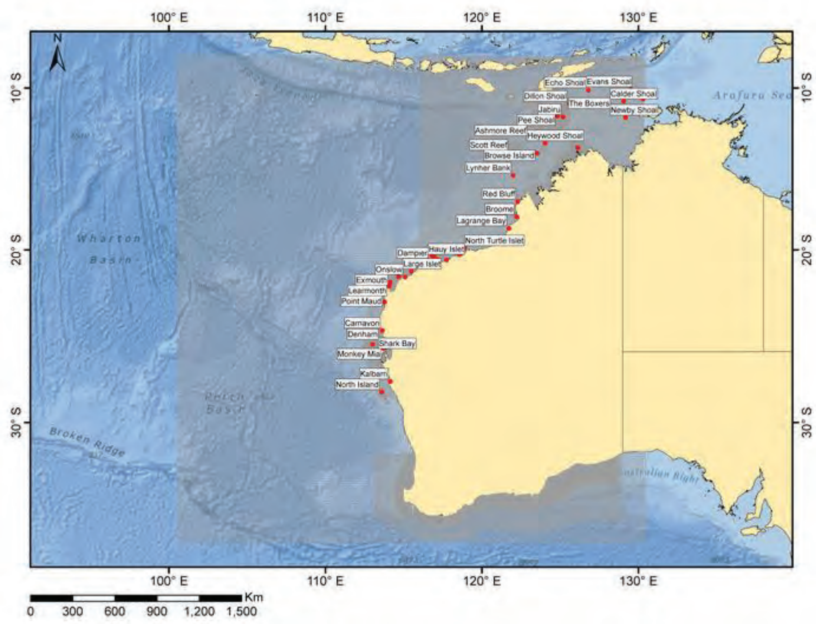
Water level time series for these locations are shown in Figure 2.4 for a one-month period (January 2005). All comparisons show that the model produces a very good match to the known tidal behaviour for a wide range of tidal amplitudes and clearly represents the varying diurnal and semi-diurnal nature of the tidal signal.

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 2.5. 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.

Figure 2.6 shows the seasonal distribution of current speeds and directions for the HYDROMAP data point closest to the FPU location. Note that the convention for defining current direction is the direction towards which the current flows.

The current data indicates cyclical tidal flow directions along a northeast-southwest axis, with maximum speeds of around 0.09 m/s.



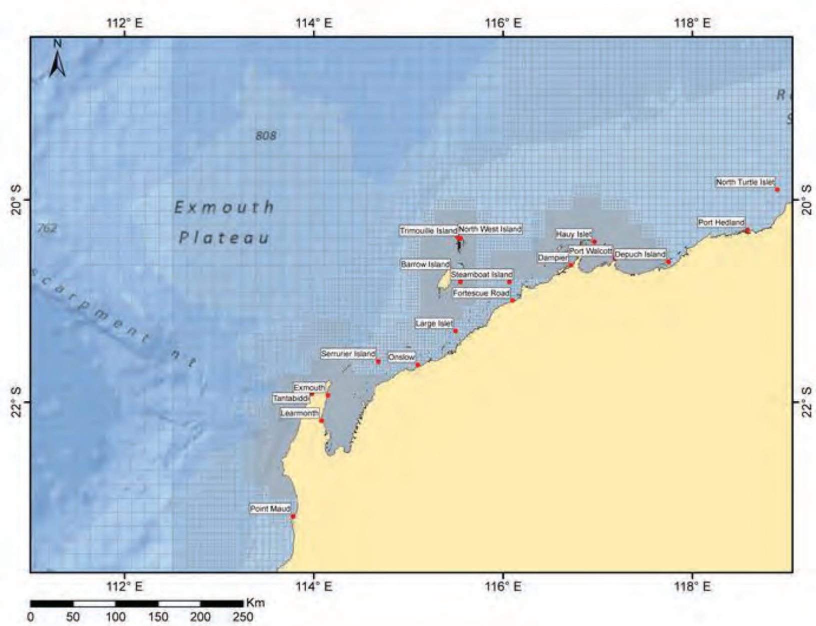




**Figure 2.3** **Hydrodynamic model grid (grey wire mesh) used to generate the tidal currents, showing locations available for tidal comparisons (red labelled dots). The top panel shows the full domain in context with the continental land mass, while the bottom panel shows a zoomed subset near the discharge locations. Higher-resolution areas are indicated by the denser mesh zones.**

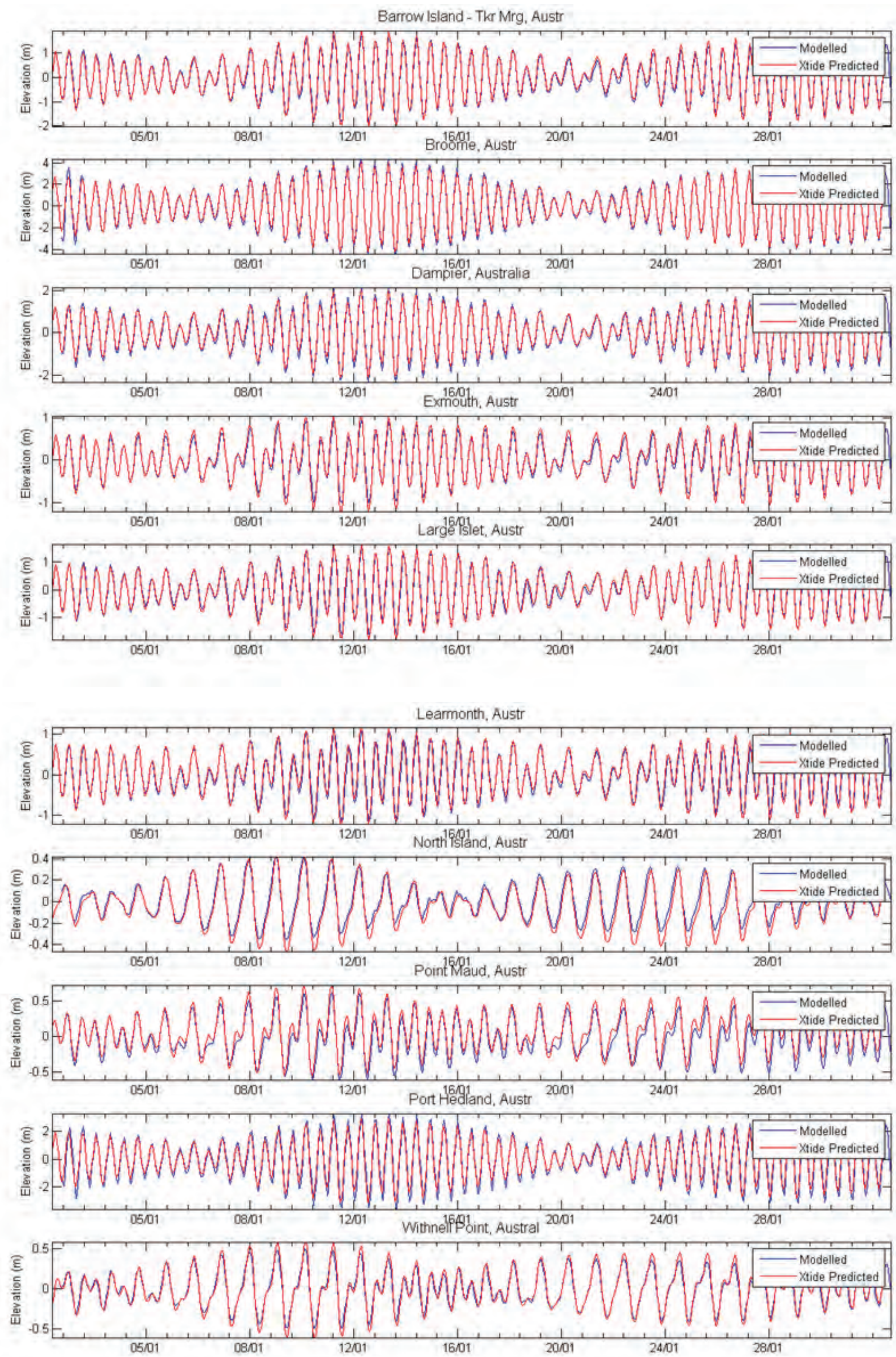
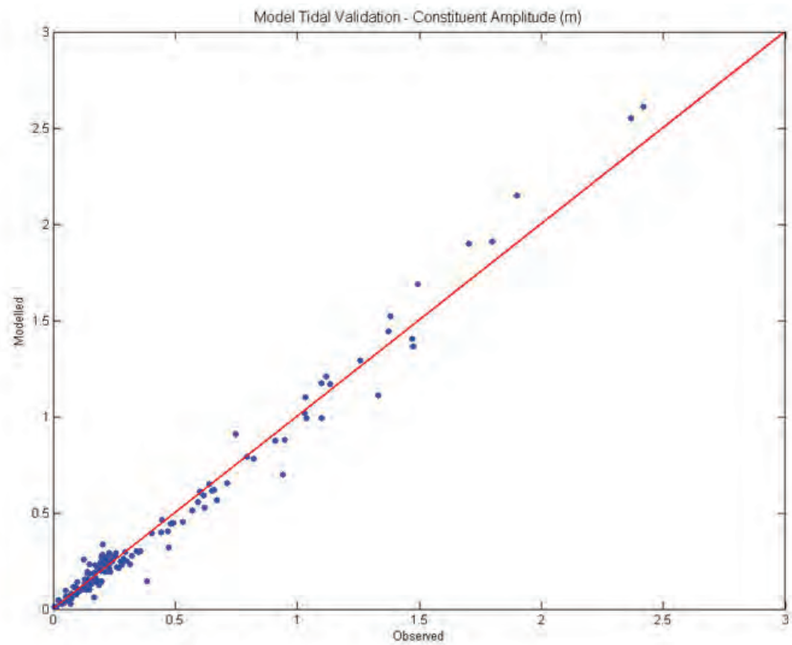



**Figure 2.4 Comparisons between the predicted (blue line) and observed (red line) surface elevation variations at ten locations in the tidal model domain for January 2005.**



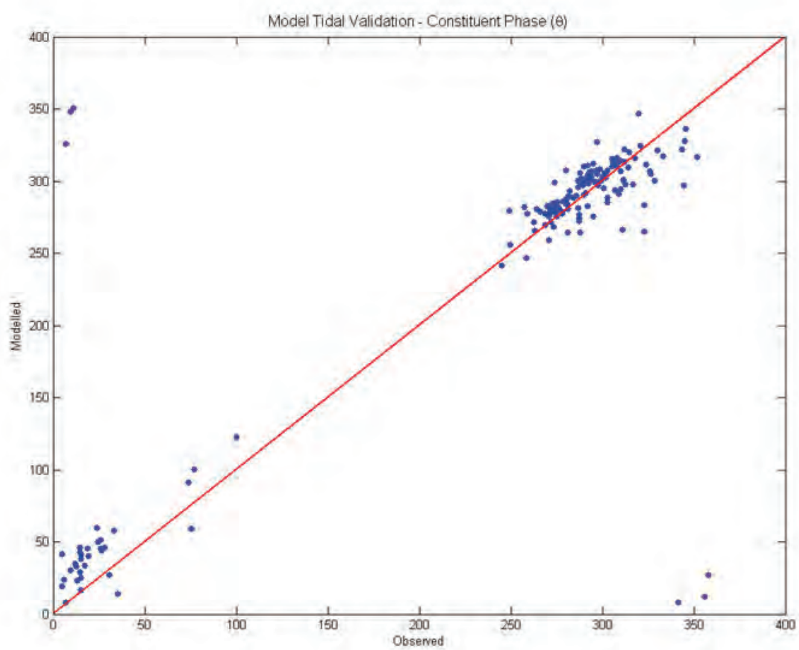




**Figure 2.5 Comparisons between modelled and observed tidal constituent amplitudes (top) and phases (bottom) at all stations in the HYDROMAP model domain. The red line indicates a 1:1 correlation between the modelled and observed data.**

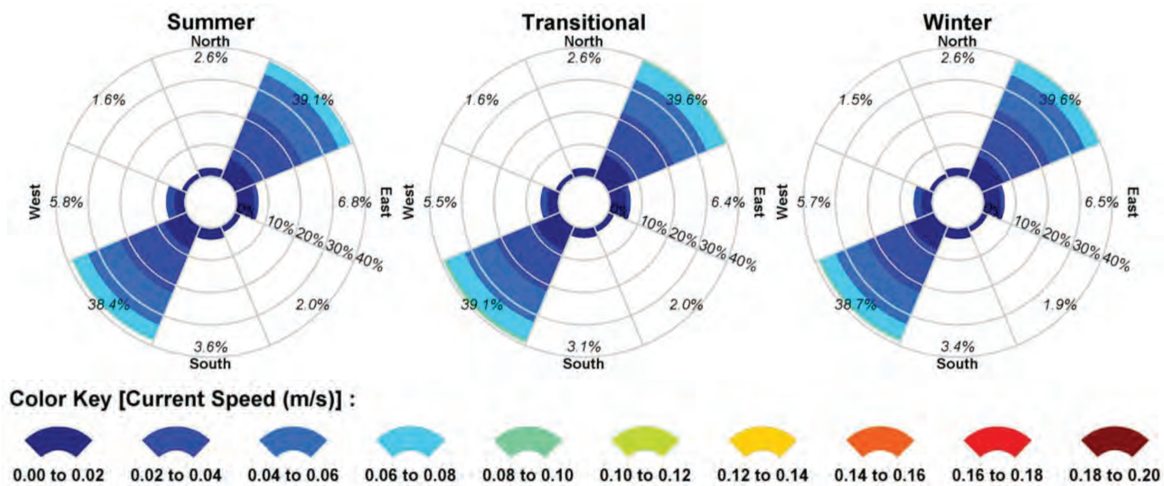



**Figure 2.6** **Seasonal current distribution (2006-2015, inclusive) derived from the HYDROMAP database near to the proposed FPU location. The colour key shows the current magnitude, the compass direction provides the direction towards which the current is flowing, and the size of the wedge gives the percentage of the record.**

# 3 MODELLING RESULTS

## 3.1 Near-Field Modelling

### 3.1.1 Overview

In the following sections, information for each of the modelled discharge cases is presented first in a table summarising the predicted plume characteristics in the near-field mixing zone under varying current speeds, and then in further tables summarising the concentrations of chlorine at the end of the near-field mixing zone, the concentration threshold, and the amount of dilution for each season and for the annual period. 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 3.72 (note the differing x-axis and y-axis aspect ratios) show the change in average dilution and temperature of the plume under varying discharge rates (165,600 $m^3$/day, 64,800 $m^3$/day and 82,800 $m^3$/day), depths (0 m, 10 m and 30 m), seasonal conditions (summer, transitional, winter and annual) 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).

In each figure, the plots have been arranged to: (i) demonstrate the variation in predicted outcomes for the same discharge at different depths under identical current conditions (Sections 3.1.3.1, 3.1.3.2 and 3.1.3.3); and (ii) demonstrate the variation in predicted outcomes for different discharges at the same depth under identical current conditions (Sections 3.1.3.4, 3.1.3.5 and 3.1.3.6).

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 0 m (Cases C1, C4 and C7), 10 m (Cases C2, C5 and C8) and 30 m (Cases C3, C6 and C9) below the water surface. The surface discharges are shown to increase the extent of the turbulent mixing zone. Following this initial mixing, the positively-buoyant plumes are predicted to rise in the water column. For the surface discharges, the plume is predicted to plunge up to 14 m below the sea surface depending on flow rate and season. For the discharges at depths of 10 m and 30 m, the plumes are predicted to plunge up to 25 m and 43 m below the sea surface, respectively, depending on flow rate and season. Increased ambient current strengths are shown to increase the horizontal distance travelled by the plume from the discharge point.

The plume characteristics data for each of the discharge flow rates, depths, seasonal conditions and current speeds show that the plume will reach a maximum horizontal distance of between <1 m and 81 m before surfacing, in the case of the surface discharges, or reaching the trapping depth, in the case of the subsea discharges.

The diameter of the plume at the end of the near-field zone ranged from <1 m to 17 m. Increases in current speed serve to restrict the diameter of the plume.

For most combinations of season, flow rate and discharge depth, 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. Note that predictions of dilution 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 each of the discharge flow rates, depths, seasonal conditions and current speeds indicate that the chlorine constituent of the CW discharge is not expected to reach the required levels of dilution in the near field mixing zone. The temperature differential between the plume and the ambient water meets the required criterion in all conditions for Cases C2, C3, C6 and C9, and in the stronger-current simulations for Cases C1, C5 and C8. For Cases C4 and C7, however, compliance with the temperature differential criterion is not achieved. Some failures to reach the required threshold concentration and temperature are attributable to the plume rapidly breaking the surface.

## 3.1.2 Results – Tables

### 3.1.2.1 Discharge Case C1: Flow Rate of 165,600 $m^3$/day at 0 m Depth (Surface)

**Table 3.1 Predicted plume characteristics at the end of the near-field mixing zone for the 0 m depth (surface) discharge for each season and current speed.**

| Season | Surface Current Speed (m/s) | Plume Diameter (m) at Depth [m] | Plume Temperature (°C) | Plume-Ambient Temperature Difference (°C) | Plume Dilution (1:x) | | Maximum Horizontal Distance (m) |
|---|---|---|---|---|---|---|---|
| | | | | | Minimum | Average | |
| Summer | Weak (0.04) | 15.2 [6.9] | 34.02 | 6.33 | 1.4 | 2.7 | 0.5 |
| | Medium (0.16) | 7.6 [1.9] | 30.44 | 2.64 | 2.8 | 6.4 | 5.6 |
| | Strong (0.33) | 8.4 [3.9] | 29.72 | 1.95 | 2.3 | 8.8 | 10.3 |
| Transitional | Weak (0.05) | 14.4 [6.6] | 33.07 | 3.16 | 1.3 | 2.7 | 0.5 |
| | Medium (0.18) | 7.5 [2.0] | 28.97 | 2.96 | 2.7 | 6.3 | 5.7 |
| | Strong (0.38) | 8.0 [3.7] | 28.09 | 2.12 | 2.2 | 9.0 | 10.7 |
| Winter | Weak (0.04) | 14.7 [6.7] | 33.28 | 6.97 | 1.3 | 2.7 | 0.5 |
| | Medium (0.17) | 7.6 [1.9] | 29.27 | 2.87 | 2.8 | 6.4 | 5.7 |
| | Strong (0.40) | 7.9 [3.8] | 28.40 | 2.03 | 2.2 | 9.1 | 11.1 |
| Annual | Weak (0.04) | 14.8 [6.7] | 33.39 | 6.88 | 1.3 | 2.7 | 0.5 |
| | Medium (0.17) | 7.6 [1.8] | 29.43 | 2.83 | 2.8 | 6.4 | 5.7 |
| | Strong (0.37) | 8.0 [3.8] | 28.61 | 2.04 | 2.2 | 9.0 | 10.8 |

**Table 3.2 Concentration of chlorine and plume-ambient temperature difference at the end of the near-field stage, the required concentration and temperature threshold, and the number of dilutions for the summer season. Note from Table 3.1 that dilutions at the 5th, 50th and 95th percentile current speeds were 2.7, 6.4 and 8.8, respectively. Dilution rates highlighted in red indicate that suitable dilution is not achieved during the near-field stage.**

| Contaminant | Source Concentration or Temperature | End of Near-Field Concentration or ΔT | | | Threshold Concentration or Temperature | Required Dilution Factor |
|---|---|---|---|---|---|---|
| | | 5th %ile | 50th %ile | 95th %ile | | |
| | | 2.7x Dilution | 6.4x Dilution | 8.8x Dilution | | |
| Chlorine in Water (ppb) | 1,000 | 370.4 | 156.3 | 113.6 | 5 | 200 |
| Δ Temperature (°C) | 45 | 6.33 | 6.24 | 1.95 | 3° above ambient | - |

**Table 3.3 Concentration of chlorine and plume-ambient temperature difference at the end of the near-field stage, the required concentration and temperature threshold, and the number of dilutions for the transitional season. Note from Table 3.1 that dilutions at the 5th, 50th and 95th percentile current speeds were 2.7, 6.3 and 9.0, respectively. Dilution rates highlighted in red indicate that suitable dilution is not achieved during the near-field stage.**

| Contaminant | Source Concentration or Temperature | End of Near-Field Concentration or ΔT | | | Threshold Concentration or Temperature | Required Dilution Factor |
|---|---|---|---|---|---|---|
| | | 5th %ile | 50th %ile | 95th %ile | | |
| | | 2.7x Dilution | 6.3x Dilution | 9.0x Dilution | | |
| Chlorine in Water (ppb) | 1,000 | 370.4 | 158.7 | 111.1 | 5 | 200 |
| Δ Temperature (°C) | 45 | 3.16 | 2.96 | 2.12 | 3° above ambient | - |

**Table 3.4 Concentration of chlorine and plume-ambient temperature difference at the end of the near-field stage, the required concentration and temperature threshold, and the number of dilutions for the winter season. Note from Table 3.1 that dilutions at the 5th, 50th and 95th percentile current speeds were 2.7, 6.4 and 9.1, respectively. Dilution rates highlighted in red indicate that suitable dilution is not achieved during the near-field stage.**

| Contaminant | Source Concentration or Temperature | End of Near-Field Concentration or ΔT | | | Threshold Concentration or Temperature | Required Dilution Factor |
|---|---|---|---|---|---|---|
| | | 5th %ile | 50th %ile | 95th %ile | | |
| | | 2.7x Dilution | 6.4x Dilution | 9.1x Dilution | | |
| Chlorine in Water (ppb) | 1,000 | 370.4 | 156.3 | 109.9 | 5 | 200 |
| Δ Temperature (°C) | 45 | 6.97 | 2.87 | 2.03 | 3° above ambient | - |

**Table 3.5 Concentration of chlorine and plume-ambient temperature difference at the end of the near-field stage, the required concentration and temperature threshold, and the number of dilutions for the annual period. Note from Table 3.1 that dilutions at the 5th, 50th and 95th percentile current speeds were 2.7, 6.4 and 9.0, respectively. Dilution rates highlighted in red indicate that suitable dilution is not achieved during the near-field stage.**

| Contaminant | Source Concentration or Temperature | End of Near-Field Concentration or ΔT | | | Threshold Concentration or Temperature | Required Dilution Factor |
|---|---|---|---|---|---|---|
| | | 5th %ile | 50th %ile | 95th %ile | | |
| | | 2.7x Dilution | 6.4x Dilution | 9.0x Dilution | | |
| Chlorine in Water (ppb) | 1,000 | 370.4 | 156.3 | 111.1 | 5 | 200 |
| Δ Temperature (°C) | 45 | 6.88 | 2.83 | 2.04 | 3° above ambient | - |

### 3.1.2.2 Discharge Case C2: Flow Rate of 165,600 m$^3$/day at 10 m Depth

**Table 3.6 Predicted plume characteristics at the end of the near-field mixing zone for the 10 m depth (surface) discharge for each season and current speed.**

| Season | Surface Current Speed (m/s) | Plume Diameter (m) at Depth [m] | Plume Temperature (°C) | Plume-Ambient Temperature Difference (°C) | Plume Dilution (1:x) | | Maximum Horizontal Distance (m) |
|---|---|---|---|---|---|---|---|
| | | | | | Minimum | Average | |
| Summer | Weak (0.04) | 7.5 [0.3] | 29.73 | 1.93 | 4.3 | 8.2 | 2.2 |
| | Medium (0.16) | 12.3 [3.5] | 28.72 | 0.95 | 6.7 | 15.8 | 10.6 |
| | Strong (0.33) | 15.4 [7.1] | 28.13 | 0.44 | 9.0 | 32.4 | 26.7 |
| Transitional | Weak (0.05) | 7.4 [0.1] | 28.16 | 2.16 | 4.3 | 8.3 | 2.3 |
| | Medium (0.18) | 12.6 [3.8] | 26.98 | 1.01 | 6.8 | 16.8 | 11.4 |
| | Strong (0.38) | 15.2 [7.1] | 26.35 | 0.45 | 9.6 | 35.6 | 30.5 |
| Winter | Weak (0.04) | 7.4 [0.2] | 28.52 | 2.12 | 4.2 | 8.2 | 2.3 |
| | Medium (0.17) | 12.4 [3.8] | 27.38 | 1.01 | 6.7 | 16.4 | 11.1 |
| | Strong (0.40) | 15.1 [7.2] | 26.72 | 0.43 | 9.9 | 37.1 | 32.8 |
| Annual | Weak (0.04) | 7.3 [0.3] | 28.72 | 2.12 | 4.2 | 8.1 | 2.2 |
| | Medium (0.17) | 12.5 [3.7] | 27.56 | 0.99 | 6.8 | 16.5 | 11.1 |
| | Strong (0.37) | 15.2 [7.2] | 26.93 | 0.44 | 9.6 | 35.7 | 30.8 |

**Table 3.7 Concentration of chlorine and plume-ambient temperature difference at the end of the near-field stage, the required concentration and temperature threshold, and the number of dilutions for the summer season. Note from Table 3.6 that dilutions at the 5th, 50th and 95th percentile current speeds were 8.2, 15.8 and 32.4, respectively. Dilution rates highlighted in red indicate that suitable dilution is not achieved during the near-field stage.**

| Contaminant | Source Concentration or Temperature | End of Near-Field Concentration or ΔT | | | Threshold Concentration or Temperature | Required Dilution Factor |
|---|---|---|---|---|---|---|
| | | 5th %ile | 50th %ile | 95th %ile | | |
| | | 8.2x Dilution | 15.8x Dilution | 32.4x Dilution | | |
| Chlorine in Water (ppb) | 1,000 | 122.0 | 60.3 | 30.9 | 5 | 200 |
| Δ Temperature (°C) | 45 | 1.93 | 0.95 | 0.44 | 3° above ambient | - |

**Table 3.8 Concentration of chlorine and plume-ambient temperature difference at the end of the near-field stage, the required concentration and temperature threshold, and the number of dilutions for the transitional season. Note from Table 3.6 that dilutions at the 5th, 50th and 95th percentile current speeds were 8.3, 16.8 and 35.6, respectively. Dilution rates highlighted in red indicate that suitable dilution is not achieved during the near-field stage.**

| Contaminant | Source Concentration or Temperature | End of Near-Field Concentration or ΔT | | | Threshold Concentration or Temperature | Required Dilution Factor |
|---|---|---|---|---|---|---|
| | | 5th %ile | 50th %ile | 95th %ile | | |
| | | 8.3x Dilution | 16.8x Dilution | 35.6x Dilution | | |
| Chlorine in Water (ppb) | 1,000 | 120.5 | 59.5 | 28.1 | 5 | 200 |
| Δ Temperature (°C) | 45 | 2.16 | 1.01 | 0.45 | 3° above ambient | - |

**Table 3.9 Concentration of chlorine and plume-ambient temperature difference at the end of the near-field stage, the required concentration and temperature threshold, and the number of dilutions for the winter season. Note from Table 3.6 that dilutions at the 5th, 50th and 95th percentile current speeds were 8.2, 16.4 and 37.1, respectively. Dilution rates highlighted in red indicate that suitable dilution is not achieved during the near-field stage.**

| Contaminant | Source Concentration or Temperature | End of Near-Field Concentration or ΔT | | | Threshold Concentration or Temperature | Required Dilution Factor |
|---|---|---|---|---|---|---|
| | | 5th %ile | 50th %ile | 95th %ile | | |
| | | 8.2x Dilution | 16.4x Dilution | 37.1x Dilution | | |
| Chlorine in Water (ppb) | 1,000 | 121.9 | 60.9 | 26.9 | 5 | 200 |
| Δ Temperature (°C) | 45 | 2.12 | 1.01 | 0.43 | 3° above ambient | - |

**Table 3.10 Concentration of chlorine and plume-ambient temperature difference at the end of the near-field stage, the required concentration and temperature threshold, and the number of dilutions for the annual period. Note from Table 3.6 that dilutions at the 5$^{th}$, 50$^{th}$ and 95$^{th}$ percentile current speeds were 8.1, 16.5 and 35.7, respectively. Dilution rates highlighted in red indicate that suitable dilution is not achieved during the near-field stage.**

| Contaminant | Source Concentration or Temperature | End of Near-Field Concentration or ΔT | | | Threshold Concentration or Temperature | Required Dilution Factor |
|---|---|---|---|---|---|---|
| | | 5th %ile | 50th %ile | 95th %ile | | |
| | | 8.1x Dilution | 16.5x Dilution | 35.7x Dilution | | |
| Chlorine in Water (ppb) | 1,000 | 123.5 | 60.6 | 28.0 | 5 | 200 |
| Δ Temperature (°C) | 45 | 2.12 | 0.99 | 0.44 | 3° above ambient | - |

### 3.1.2.3 Discharge Case C3: Flow Rate of 165,600 $m^3$/day at 30 m Depth

**Table 3.11 Predicted plume characteristics at the end of the near-field mixing zone for the 30 m depth (surface) discharge for each season and current speed.**

| Season | Surface Current Speed (m/s) | Plume Diameter (m) at Depth [m] | Plume Temperature (°C) | Plume-Ambient Temperature Difference (°C) | Plume Dilution (1:x) | | Maximum Horizontal Distance (m) |
|---|---|---|---|---|---|---|---|
| | | | | | Minimum | Average | |
| Summer | Weak (0.04) | 12.7 [0.3] | 28.35 | 0.55 | 9.8 | 19.1 | 4.4 |
| | Medium (0.16) | 24.6 [9.2] | 27.74 | 0.11 | 17.5 | 49.1 | 23.2 |
| | Strong (0.33) | 28.0 [16.9] | 27.45 | 0.00 | 27.3 | 104.1 | 63.1 |
| Transitional | Weak (0.05) | 12.5 [0.6] | 26.67 | 0.67 | 9.8 | 19.1 | 4.6 |
| | Medium (0.18) | 25.1 [10.1] | 25.97 | 0.14 | 18.5 | 54.4 | 25.5 |
| | Strong (0.38) | 28.4 [16.6] | 25.68 | 0.00 | 31.9 | 122.5 | 76.7 |
| Winter | Weak (0.04) | 12.5 [0.7] | 27.05 | 0.65 | 9.8 | 19.0 | 4.5 |
| | Medium (0.17) | 25.0 [9.8] | 26.36 | 0.13 | 18.3 | 53.1 | 24.9 |
| | Strong (0.40) | 27.8 [17.2] | 26.06 | 0.00 | 31.9 | 123.2 | 80.7 |
| Annual | Weak (0.04) | 12.4 [0.8] | 27.24 | 0.64 | 9.7 | 18.8 | 4.4 |
| | Medium (0.17) | 24.9 [9.8] | 26.56 | 0.13 | 18.1 | 52.2 | 24.5 |
| | Strong (0.37) | 27.9 [17.1] | 26.26 | 0.00 | 30.7 | 117.9 | 75.0 |

**Table 3.12 Concentration of chlorine and plume-ambient temperature difference at the end of the near-field stage, the required concentration and temperature threshold, and the number of dilutions for the summer season. Note from Table 3.11 that dilutions at the 5th, 50th and 95th percentile current speeds were 19.1, 49.1 and 104.1, respectively. Dilution rates highlighted in red indicate that suitable dilution is not achieved during the near-field stage.**

| Contaminant | Source Concentration or Temperature | End of Near-Field Concentration or ΔT | | | Threshold Concentration or Temperature | Required Dilution Factor |
|---|---|---|---|---|---|---|
| | | 5th %ile | 50th %ile | 95th %ile | | |
| | | 19.1x Dilution | 49.1x Dilution | 104.1x Dilution | | |
| Chlorine in Water (ppb) | 1,000 | 52.4 | 20.4 | 9.6 | 5 | 200 |
| Δ Temperature (°C) | 45 | 0.55 | 0.11 | 0.00 | 3° above ambient | - |

**Table 3.13 Concentration of chlorine and plume-ambient temperature difference at the end of the near-field stage, the required concentration and temperature threshold, and the number of dilutions for the transitional season. Note from Table 3.11 that dilutions at the 5$^{th}$, 50$^{th}$ and 95$^{th}$ percentile current speeds were 19.1, 54.4 and 122.5, respectively. Dilution rates highlighted in red indicate that suitable dilution is not achieved during the near-field stage.**

| Contaminant | Source Concentration or Temperature | End of Near-Field Concentration or ΔT | | | Threshold Concentration or Temperature | Required Dilution Factor |
|---|---|---|---|---|---|---|
| | | 5th %ile | 50th %ile | 95th %ile | | |
| | | 19.1x Dilution | 54.4x Dilution | 122.5x Dilution | | |
| Chlorine in Water (ppb) | 1,000 | 52.4 | 18.4 | 8.2 | 5 | 200 |
| Δ Temperature (°C) | 45 | 0.67 | 0.14 | 0.00 | 3° above ambient | - |

**Table 3.14 Concentration of chlorine and plume-ambient temperature difference at the end of the near-field stage, the required concentration and temperature threshold, and the number of dilutions for the winter season. Note from Table 3.11 that dilutions at the 5$^{th}$, 50$^{th}$ and 95$^{th}$ percentile current speeds were 19.0, 53.1 and 123.2, respectively. Dilution rates highlighted in red indicate that suitable dilution is not achieved during the near-field stage.**

| Contaminant | Source Concentration or Temperature | End of Near-Field Concentration or ΔT | | | Threshold Concentration or Temperature | Required Dilution Factor |
|---|---|---|---|---|---|---|
| | | 5th %ile | 50th %ile | 95th %ile | | |
| | | 19.0x Dilution | 53.1x Dilution | 123.2x Dilution | | |
| Chlorine in Water (ppb) | 1,000 | 52.6 | 18.8 | 8.1 | 5 | 200 |
| Δ Temperature (°C) | 45 | 0.65 | 0.13 | 0.00 | 3° above ambient | - |

**Table 3.15 Concentration of chlorine and plume-ambient temperature difference at the end of the near-field stage, the required concentration and temperature threshold, and the number of dilutions for the annual period. Note from Table 3.11 that dilutions at the 5th, 50th and 95th percentile current speeds were 18.8, 52.2 and 117.9, respectively. Dilution rates highlighted in red indicate that suitable dilution is not achieved during the near-field stage.**

| Contaminant | Source Concentration or Temperature | End of Near-Field Concentration or ΔT | | | Threshold Concentration or Temperature | Required Dilution Factor |
|---|---|---|---|---|---|---|
| | | 5th %ile | 50th %ile | 95th %ile | | |
| | | 18.8x Dilution | 52.2x Dilution | 117.9x Dilution | | |
| Chlorine in Water (ppb) | 1,000 | 53.2 | 19.2 | 8.5 | 5 | 200 |
| Δ Temperature (°C) | 45 | 0.64 | 0.13 | 0.00 | 3° above ambient | - |

### 3.1.2.4 Discharge Case C4: Flow Rate of 64,800 m³/day at 0 m Depth (Surface)

**Table 3.16 Predicted plume characteristics at the end of the near-field mixing zone for the 0 m depth (surface) discharge for each season and current speed.**

| Season | Surface Current Speed (m/s) | Plume Diameter (m) at Depth [m] | Plume Temperature (°C) | Plume-Ambient Temperature Difference (°C) | Plume Dilution (1:x) | | Maximum Horizontal Distance (m) |
|---|---|---|---|---|---|---|---|
| | | | | | Minimum | Average | |
| Summer | Weak (0.04) | 6.5 [0.9] | 51.43 | 23.63 | 1.0 | 1.2 | <0.1 |
| | Medium (0.16) | 3.7 [0.9] | 48.64 | 20.84 | 1.0 | 1.4 | 0.1 |
| | Strong (0.33) | 2.7 [0.7] | 47.58 | 19.78 | 1.0 | 1.5 | 0.2 |
| Transitional | Weak (0.05) | 6.3 [0.9] | 51.18 | 25.15 | 1.0 | 1.2 | <0.1 |
| | Medium (0.18) | 3.5 [0.8] | 48.08 | 22.08 | 1.0 | 1.4 | 0.1 |
| | Strong (0.38) | 2.5 [0.7] | 47.42 | 21.42 | 1.0 | 1.4 | 0.1 |
| Winter | Weak (0.04) | 6.4 [0.9] | 51.24 | 24.84 | 1.0 | 1.2 | <0.1 |
| | Medium (0.17) | 3.6 [0.9] | 48.21 | 21.81 | 1.0 | 1.4 | 0.1 |
| | Strong (0.40) | 2.4 [0.7] | 47.62 | 21.22 | 1.0 | 1.4 | 0.1 |
| Annual | Weak (0.04) | 6.4 [0.9] | 51.28 | 24.68 | 1.0 | 1.2 | <0.1 |
| | Medium (0.17) | 3.6 [0.9] | 48.27 | 21.67 | 1.0 | 1.4 | 0.1 |
| | Strong (0.37) | 2.5 [0.7] | 47.55 | 20.95 | 1.0 | 1.4 | 0.1 |

**Table 3.17 Concentration of chlorine and plume-ambient temperature difference at the end of the near-field stage, the required concentration and temperature threshold, and the number of dilutions for the summer season. Note from Table 3.16 that dilutions at the 5th, 50th and 95th percentile current speeds were 1.2, 1.4 and 1.5, respectively. Dilution rates highlighted in red indicate that suitable dilution is not achieved during the near-field stage.**

| Contaminant | Source Concentration or Temperature | End of Near-Field Concentration or ΔT | | | Threshold Concentration or Temperature | Required Dilution Factor |
|---|---|---|---|---|---|---|
| | | 5th %ile | 50th %ile | 95th %ile | | |
| | | 1.2x Dilution | 1.4x Dilution | 1.5x Dilution | | |
| Chlorine in Water (ppb) | 1,000 | 833.3 | 714.3 | 666.7 | 5 | 200 |
| Δ Temperature (°C) | 57 | 23.63 | 20.84 | 19.78 | 3° above ambient | - |

**Table 3.18 Concentration of chlorine and plume-ambient temperature difference at the end of the near-field stage, the required concentration and temperature threshold, and the number of dilutions for the transitional season. Note from Table 3.16 that dilutions at the 5th, 50th and 95th percentile current speeds were 1.2, 1.4 and 1.4, respectively. Dilution rates highlighted in red indicate that suitable dilution is not achieved during the near-field stage.**

| Contaminant | Source Concentration or Temperature | End of Near-Field Concentration or ΔT | | | Threshold Concentration or Temperature | Required Dilution Factor |
|---|---|---|---|---|---|---|
| | | 5th %ile | 50th %ile | 95th %ile | | |
| | | 1.2x Dilution | 1.4x Dilution | 1.4x Dilution | | |
| Chlorine in Water (ppb) | 1,000 | 833.3 | 714.3 | 714.3 | 5 | 200 |
| Δ Temperature (°C) | 57 | 25.15 | 22.08 | 21.42 | 3° above ambient | - |

**Table 3.19 Concentration of chlorine and plume-ambient temperature difference at the end of the near-field stage, the required concentration and temperature threshold, and the number of dilutions for the winter season. Note from Table 3.16 that dilutions at the 5th, 50th and 95th percentile current speeds were 1.2, 1.4 and 1.4, respectively. Dilution rates highlighted in red indicate that suitable dilution is not achieved during the near-field stage.**

| Contaminant | Source Concentration or Temperature | End of Near-Field Concentration or ΔT | | | Threshold Concentration or Temperature | Required Dilution Factor |
|---|---|---|---|---|---|---|
| | | 5th %ile | 50th %ile | 95th %ile | | |
| | | 1.2x Dilution | 1.4x Dilution | 1.4x Dilution | | |
| Chlorine in Water (ppb) | 1,000 | 833.3 | 714.3 | 714.3 | 5 | 200 |
| Δ Temperature (°C) | 57 | 25.15 | 22.08 | 21.42 | 3° above ambient | - |

**Table 3.20 Concentration of chlorine and plume-ambient temperature difference at the end of the near-field stage, the required concentration and temperature threshold, and the number of dilutions for the annual period. Note from Table 3.16 that dilutions at the 5th, 50th and 95th percentile current speeds were 1.2, 1.4 and 1.5, respectively. Dilution rates highlighted in red indicate that suitable dilution is not achieved during the near-field stage.**

| Contaminant | Source Concentration or Temperature | End of Near-Field Concentration or ΔT | | | Threshold Concentration or Temperature | Required Dilution Factor |
|---|---|---|---|---|---|---|
| | | 5th %ile | 50th %ile | 95th %ile | | |
| | | 1.2x Dilution | 1.4x Dilution | 1.5x Dilution | | |
| Chlorine in Water (ppb) | 1,000 | 833.3 | 714.3 | 714.3 | 5 | 200 |
| Δ Temperature (°C) | 57 | 24.68 | 21.67 | 20.95 | 3° above ambient | - |

### 3.1.2.5 Discharge Case C5: Flow Rate of 64,800 $m^3$/day at 10 m Depth

**Table 3.21 Predicted plume characteristics at the end of the near-field mixing zone for the 10 m depth (surface) discharge for each season and current speed.**

| Season | Surface Current Speed (m/s) | Plume Diameter (m) at Depth [m] | Plume Temperature (°C) | Plume-Ambient Temperature Difference (°C) | Plume Dilution (1:x) | | Maximum Horizontal Distance (m) |
|---|---|---|---|---|---|---|---|
| | | | | | Minimum | Average | |
| Summer | Weak (0.04) | 3.8 [0.1] | 32.22 | 4.42 | 3.3 | 6.4 | 0.7 |
| | Medium (0.16) | 6.3 [1.5] | 30.11 | 2.31 | 5.5 | 12.1 | 3.9 |
| | Strong (0.33) | 8.8 [4.0] | 28.75 | 0.99 | 8.0 | 27.7 | 11.0 |
| Transitional | Weak (0.05) | 3.8 [<0.1] | 30.66 | 4.66 | 3.4 | 6.5 | 0.7 |
| | Medium (0.18) | 6.7 [1.8] | 28.19 | 2.19 | 5.8 | 13.6 | 4.3 |
| | Strong (0.38) | 9.0 [4.2] | 26.86 | 0.90 | 8.9 | 32.3 | 14.9 |
| Winter | Weak (0.04) | 3.8 [0.1] | 31.01 | 4.61 | 3.4 | 6.5 | 0.7 |
| | Medium (0.17) | 6.6 [1.7] | 28.61 | 2.21 | 5.8 | 13.3 | 4.3 |
| | Strong (0.40) | 9.1 [4.3] | 27.18 | 0.82 | 9.4 | 34.6 | 14.9 |
| Annual | Weak (0.04) | 3.8 [0.1] | 31.19 | 4.59 | 3.3 | 6.5 | 0.7 |
| | Medium (0.17) | 6.5 [1.7] | 28.85 | 2.25 | 5.7 | 13.0 | 4.2 |
| | Strong (0.37) | 9.0 [4.2] | 27.44 | 0.88 | 8.9 | 32.3 | 13.5 |

**Table 3.22 Concentration of chlorine and plume-ambient temperature difference at the end of the near-field stage, the required concentration and temperature threshold, and the number of dilutions for the summer season. Note from Table 3.21 that dilutions at the 5th, 50th and 95th percentile current speeds were 6.4, 12.1 and 27.7, respectively. Dilution rates highlighted in red indicate that suitable dilution is not achieved during the near-field stage.**

| Contaminant | Source Concentration or Temperature | End of Near-Field Concentration or ΔT | | | Threshold Concentration or Temperature | Required Dilution Factor |
|---|---|---|---|---|---|---|
| | | 5th %ile | 50th %ile | 95th %ile | | |
| | | 6.4x Dilution | 12.1x Dilution | 27.7x Dilution | | |
| Chlorine in Water (ppb) | 1,000 | 156.3 | 82.6 | 36.1 | 5 | 200 |
| Δ Temperature (°C) | 57 | 4.42 | 2.31 | 0.99 | 3° above ambient | - |

**Table 3.23 Concentration of chlorine and plume-ambient temperature difference at the end of the near-field stage, the required concentration and temperature threshold, and the number of dilutions for the transitional season. Note from Table 3.21 that dilutions at the 5th, 50th and 95th percentile current speeds were 6.5, 13.6 and 32.3, respectively. Dilution rates highlighted in red indicate that suitable dilution is not achieved during the near-field stage.**

| Contaminant | Source Concentration or Temperature | End of Near-Field Concentration or ΔT | | | Threshold Concentration or Temperature | Required Dilution Factor |
|---|---|---|---|---|---|---|
| | | 5th %ile | 50th %ile | 95th %ile | | |
| | | 6.5x Dilution | 13.6x Dilution | 32.3x Dilution | | |
| Chlorine in Water (ppb) | 1,000 | 153.8 | 73.5 | 30.9 | 5 | 200 |
| Δ Temperature (°C) | 57 | 4.66 | 2.19 | 0.90 | 3° above ambient | - |

**Table 3.24 Concentration of chlorine and plume-ambient temperature difference at the end of the near-field stage, the required concentration and temperature threshold, and the number of dilutions for the winter season. Note from Table 3.21 that dilutions at the 5th, 50th and 95th percentile current speeds were 6.5, 13.3 and 34.6, respectively. Dilution rates highlighted in red indicate that suitable dilution is not achieved during the near-field stage.**

| Contaminant | Source Concentration or Temperature | End of Near-Field Concentration or ΔT | | | Threshold Concentration or Temperature | Required Dilution Factor |
|---|---|---|---|---|---|---|
| | | 5th %ile | 50th %ile | 95th %ile | | |
| | | 6.5x Dilution | 13.3x Dilution | 34.6x Dilution | | |
| Chlorine in Water (ppb) | 1,000 | 153.8 | 75.2 | 28.9 | 5 | 200 |
| Δ Temperature (°C) | 57 | 4.61 | 2.21 | 0.82 | 3° above ambient | - |

**Table 3.25 Concentration of chlorine and plume-ambient temperature difference at the end of the near-field stage, the required concentration and temperature threshold, and the number of dilutions for the annual period. Note from Table 3.21 that dilutions at the 5th, 50th and 95th percentile current speeds were 6.6, 13.0 and 32.3, respectively. Dilution rates highlighted in red indicate that suitable dilution is not achieved during the near-field stage.**

| Contaminant | Source Concentration or Temperature | End of Near-Field Concentration or ΔT | | | Threshold Concentration or Temperature | Required Dilution Factor |
|---|---|---|---|---|---|---|
| | | 5th %ile | 50th %ile | 95th %ile | | |
| | | 6.6x Dilution | 13.0x Dilution | 32.3x Dilution | | |
| Chlorine in Water (ppb) | 1,000 | 151.5 | 76.9 | 31.0 | 5 | 200 |
| Δ Temperature (°C) | 57 | 4.59 | 2.25 | 0.88 | 3° above ambient | - |

### 3.1.2.6 Discharge Case C6: Flow Rate of 64,800 m³/day at 30 m Depth

**Table 3.26 Predicted plume characteristics at the end of the near-field mixing zone for the 30 m depth (surface) discharge for each season and current speed.**

| Season | Surface Current Speed (m/s) | Plume Diameter (m) at Depth [m] | Plume Temperature (°C) | Plume-Ambient Temperature Difference (°C) | Plume Dilution (1:x) | | Maximum Horizontal Distance (m) |
|---|---|---|---|---|---|---|---|
| | | | | | Minimum | Average | |
| Summer | Weak (0.04) | 8.9 [0.5] | 28.72 | 0.92 | 12.7 | 24.6 | 2.8 |
| | Medium (0.16) | 18.1 [6.7] | 27.92 | 0.22 | 25.0 | 69.2 | 16.2 |
| | Strong (0.33) | 24.0 [11.9] | 27.57 | 0.00 | 51.5 | 196.6 | 57.1 |
| Transitional | Weak (0.05) | 9.0 [0.3] | 26.98 | 0.98 | 13.0 | 25.4 | 3.1 |
| | Medium (0.18) | 19.2 [7.8] | 26.10 | 0.22 | 27.1 | 80.6 | 18.9 |
| | Strong (0.38) | 24.3 [12.1] | 25.78 | 0.00 | 59.6 | 229.7 | 70.9 |
| Winter | Weak (0.04) | 9.0 [0.2] | 27.36 | 0.96 | 13.0 | 25.3 | 3.0 |
| | Medium (0.17) | 18.9 [7.5] | 26.51 | 0.23 | 26.5 | 77.5 | 18.1 |
| | Strong (0.40) | 23.6 [12.8] | 26.16 | 0.00 | 59.1 | 228.3 | 73.4 |
| Annual | Weak (0.04) | 8.9 [0.6] | 27.58 | 0.98 | 12.7 | 24.8 | 2.9 |
| | Medium (0.17) | 18.9 [7.3] | 26.71 | 0.22 | 26.5 | 76.8 | 18.0 |
| | Strong (0.37) | 24.0 [12.3] | 26.37 | 0.00 | 58.2 | 224.0 | 69.7 |

**Table 3.27 Concentration of chlorine and plume-ambient temperature difference at the end of the near-field stage, the required concentration and temperature threshold, and the number of dilutions for the summer season. Note from Table 3.26 that dilutions at the 5th, 50th and 95th percentile current speeds were 24.6, 69.2 and 196.6, respectively. Dilution rates highlighted in red indicate that suitable dilution is not achieved during the near-field stage.**

| Contaminant | Source Concentration or Temperature | End of Near-Field Concentration or ΔT | | | Threshold Concentration or Temperature | Required Dilution Factor |
|---|---|---|---|---|---|---|
| | | 5th %ile | 50th %ile | 95th %ile | | |
| | | 24.6x Dilution | 69.2x Dilution | 196.6x Dilution | | |
| Chlorine in Water (ppb) | 1,000 | 40.7 | 14.5 | 5.1 | 5 | 200 |
| Δ Temperature (°C) | 57 | 0.92 | 0.22 | 0.00 | 3° above ambient | - |

**Table 3.28 Concentration of chlorine and plume-ambient temperature difference at the end of the near-field stage, the required concentration and temperature threshold, and the number of dilutions for the transitional season. Note from Table 3.26 that dilutions at the 5th, 50th and 95th percentile current speeds were 25.4, 80.6 and 229.7, respectively. Dilution rates highlighted in red indicate that suitable dilution is not achieved during the near-field stage.**

| Contaminant | Source Concentration or Temperature | End of Near-Field Concentration or ΔT | | | Threshold Concentration or Temperature | Required Dilution Factor |
|---|---|---|---|---|---|---|
| | | 5th %ile | 50th %ile | 95th %ile | | |
| | | 25.4x Dilution | 80.6x Dilution | 229.7x Dilution | | |
| Chlorine in Water (ppb) | 1,000 | 39.4 | 12.4 | 4.4 | 5 | 200 |
| Δ Temperature (°C) | 57 | 0.98 | 0.22 | 0.00 | 3° above ambient | - |

**Table 3.29 Concentration of chlorine and plume-ambient temperature difference at the end of the near-field stage, the required concentration and temperature threshold, and the number of dilutions for the winter season. Note from Table 3.26 that dilutions at the 5th, 50th and 95th percentile current speeds were 25.3, 77.5 and 228.3, respectively. Dilution rates highlighted in red indicate that suitable dilution is not achieved during the near-field stage.**

| Contaminant | Source Concentration or Temperature | End of Near-Field Concentration or ΔT | | | Threshold Concentration or Temperature | Required Dilution Factor |
|---|---|---|---|---|---|---|
| | | 5th %ile | 50th %ile | 95th %ile | | |
| | | 25.3x Dilution | 77.5x Dilution | 228.3x Dilution | | |
| Chlorine in Water (ppb) | 1,000 | 39.5 | 12.9 | 4.4 | 5 | 200 |
| Δ Temperature (°C) | 57 | 0.96 | 0.23 | 0.00 | 3° above ambient | - |

**Table 3.30 Concentration of chlorine and plume-ambient temperature difference at the end of the near-field stage, the required concentration and temperature threshold, and the number of dilutions for the annual period. Note from Table 3.26 that dilutions at the 5$^{th}$, 50$^{th}$ and 95$^{th}$ percentile current speeds were 24.8, 76.8 and 224.0, respectively. Dilution rates highlighted in red indicate that suitable dilution is not achieved during the near-field stage.**

| Contaminant | Source Concentration or Temperature | End of Near-Field Concentration or ΔT | | | Threshold Concentration or Temperature | Required Dilution Factor |
|---|---|---|---|---|---|---|
| | | 5th %ile | 50th %ile | 95th %ile | | |
| | | 24.8x Dilution | 76.8x Dilution | 224.0x Dilution | | |
| Chlorine in Water (ppb) | 1,000 | 40.3 | 13.0 | 4.5 | 5 | 200 |
| Δ Temperature (°C) | 57 | 0.98 | 0.22 | 0.00 | 3° above ambient | - |

### 3.1.2.7 Discharge Case C7: Flow Rate of 82,800 m³/day at 0 m Depth (Surface)

**Table 3.31 Predicted plume characteristics at the end of the near-field mixing zone for the 0 m depth (surface) discharge for each season and current speed.**

| Season | Surface Current Speed (m/s) | Plume Diameter (m) at Depth [m] | Plume Temperature (°C) | Plume-Ambient Temperature Difference (°C) | Plume Dilution (1:x) | | Maximum Horizontal Distance (m) |
|---|---|---|---|---|---|---|---|
| | | | | | Minimum | Average | |
| Summer | Weak (0.04) | 7.5 [1.3] | 52.22 | 24.42 | 1.0 | 1.3 | <0.1 |
| | Medium (0.16) | 4.4 [1.2] | 49.01 | 21.21 | 1.0 | 1.5 | 0.2 |
| | Strong (0.33) | 3.2 [1.0] | 46.97 | 19.17 | 1.0 | 1.7 | 0.3 |
| Transitional | Weak (0.05) | 7.2 [1.3] | 51.92 | 25.92 | 1.0 | 1.3 | <0.1 |
| | Medium (0.18) | 4.1 [1.2] | 48.24 | 22.24 | 1.0 | 1.5 | 0.2 |
| | Strong (0.38) | 3.0 [0.1] | 46.45 | 20.45 | 1.0 | 1.7 | 0.3 |
| Winter | Weak (0.04) | 7.3 [1.3] | 51.99 | 25.59 | 1.0 | 1.3 | <0.1 |
| | Medium (0.17) | 4.2 [1.2] | 48.43 | 22.03 | 1.0 | 1.5 | 0.2 |
| | Strong (0.40) | 2.9 [0.9] | 46.55 | 20.15 | 1.0 | 1.7 | 0.3 |
| Annual | Weak (0.04) | 7.4 [1.3] | 52.03 | 25.43 | 1.0 | 1.3 | <0.1 |
| | Medium (0.17) | 4.2 [1.2] | 48.51 | 21.91 | 1.0 | 1.5 | 0.2 |
| | Strong (0.37) | 3.0 [1.0] | 46.58 | 19.98 | 1.0 | 1.7 | 0.3 |

**Table 3.32 Concentration of chlorine and plume-ambient temperature difference at the end of the near-field stage, the required concentration and temperature threshold, and the number of dilutions for the summer season. Note from Table 3.31 that dilutions at the 5th, 50th and 95th percentile current speeds were 1.3, 1.5 and 1.7, respectively. Dilution rates highlighted in red indicate that suitable dilution is not achieved during the near-field stage.**

| Contaminant | Source Concentration or Temperature | End of Near-Field Concentration or ΔT | | | Threshold Concentration or Temperature | Required Dilution Factor |
|---|---|---|---|---|---|---|
| | | 5th %ile | 50th %ile | 95th %ile | | |
| | | 1.3x Dilution | 1.5x Dilution | 1.7x Dilution | | |
| Chlorine in Water (ppb) | 1,000 | 769.2 | 666.7 | 588.2 | 5 | 200 |
| Δ Temperature (°C) | 60 | 24.42 | 21.21 | 19.17 | 3° above ambient | - |

**Table 3.33 Concentration of chlorine and plume-ambient temperature difference at the end of the near-field stage, the required concentration and temperature threshold, and the number of dilutions for the transitional season. Note from Table 3.31 that dilutions at the 5th, 50th and 95th percentile current speeds were 1.3, 1.5 and 1.7, respectively. Dilution rates highlighted in red indicate that suitable dilution is not achieved during the near-field stage.**

| Contaminant | Source Concentration or Temperature | End of Near-Field Concentration or ΔT | | | Threshold Concentration or Temperature | Required Dilution Factor |
|---|---|---|---|---|---|---|
| | | 5th %ile | 50th %ile | 95th %ile | | |
| | | 1.3x Dilution | 1.5x Dilution | 1.7x Dilution | | |
| Chlorine in Water (ppb) | 1,000 | 769.2 | 666.7 | 588.2 | 5 | 200 |
| Δ Temperature (°C) | 57 | 25.92 | 22.24 | 20.45 | 3° above ambient | - |

**Table 3.34 Concentration of chlorine and plume-ambient temperature difference at the end of the near-field stage, the required concentration and temperature threshold, and the number of dilutions for the winter season. Note from Table 3.31 that dilutions at the 5th, 50th and 95th percentile current speeds were 1.3, 1.5 and 1.7, respectively. Dilution rates highlighted in red indicate that suitable dilution is not achieved during the near-field stage.**

| Contaminant | Source Concentration or Temperature | End of Near-Field Concentration or ΔT | | | Threshold Concentration or Temperature | Required Dilution Factor |
|---|---|---|---|---|---|---|
| | | 5th %ile | 50th %ile | 95th %ile | | |
| | | 1.3x Dilution | 1.5x Dilution | 1.7x Dilution | | |
| Chlorine in Water (ppb) | 1,000 | 769.2 | 666.7 | 588.2 | 5 | 200 |
| Δ Temperature (°C) | 60 | 25.59 | 22.03 | 20.15 | 3° above ambient | - |

**Table 3.35 Concentration of chlorine and plume-ambient temperature difference at the end of the near-field stage, the required concentration and temperature threshold, and the number of dilutions for the annual period. Note from Table 3.31 that dilutions at the 5$^{th}$, 50$^{th}$ and 95$^{th}$ percentile current speeds were 1.3, 1.5 and 1.7, respectively. Dilution rates highlighted in red indicate that suitable dilution is not achieved during the near-field stage.**

| Contaminant | Source Concentration or Temperature | End of Near-Field Concentration or ΔT | | | Threshold Concentration or Temperature | Required Dilution Factor |
|---|---|---|---|---|---|---|
| | | 5th %ile | 50th %ile | 95th %ile | | |
| | | 1.3x Dilution | 1.5x Dilution | 1.7x Dilution | | |
| Chlorine in Water (ppb) | 1,000 | 769.2 | 666.7 | 588.2 | 5 | 200 |
| Δ Temperature (°C) | 60 | 25.43 | 21.91 | 19.98 | 3° above ambient | - |

### 3.1.2.8 Discharge Case C8: Flow Rate of 82,800 $m^3$/day at 10 m Depth

**Table 3.36 Predicted plume characteristics at the end of the near-field mixing zone for the 10 m depth (surface) discharge for each season and current speed.**

| Season | Surface Current Speed (m/s) | Plume Diameter (m) at Depth [m] | Plume Temperature (°C) | Plume-Ambient Temperature Difference (°C) | Plume Dilution (1:x) | | Maximum Horizontal Distance (m) |
|---|---|---|---|---|---|---|---|
| | | | | | Minimum | Average | |
| Summer | Weak (0.04) | 4.1 [<0.1] | 32.77 | 4.97 | 3.3 | 6.3 | 0.7 |
| | Medium (0.16) | 6.3 [1.3] | 30.65 | 2.85 | 5.1 | 10.9 | 3.7 |
| | Strong (0.33) | 9.1 [3.9] | 29.04 | 1.28 | 7.1 | 27.3 | 10.2 |
| Transitional | Weak (0.05) | 4.1 [0.1] | 31.30 | 5.30 | 3.2 | 6.3 | 0.7 |
| | Medium (0.18) | 6.7 [1.6] | 28.76 | 2.76 | 5.3 | 11.8 | 4.2 |
| | Strong (0.38) | 9.3 [4.2] | 27.13 | 1.17 | 7.8 | 27.5 | 12.4 |
| Winter | Weak (0.04) | 4.1 [0.1] | 31.65 | 5.25 | 3.2 | 6.2 | 0.7 |
| | Medium (0.17) | 6.6 [1.6] | 29.20 | 2.80 | 5.2 | 11.6 | 4.1 |
| | Strong (0.40) | 9.3 [4.4] | 27.45 | 1.09 | 8.0 | 28.9 | 13.4 |
| Annual | Weak (0.04) | 4.1 [0.1] | 31.84 | 5.24 | 3.2 | 6.2 | 0.7 |
| | Medium (0.17) | 6.5 [1.5] | 29.41 | 2.81 | 5.2 | 11.5 | 4.0 |
| | Strong (0.37) | 9.3 [4.3] | 27.71 | 1.15 | 7.7 | 27.3 | 12.3 |

**Table 3.37 Concentration of chlorine and plume-ambient temperature difference at the end of the near-field stage, the required concentration and temperature threshold, and the number of dilutions for the summer season. Note from Table 3.36 that dilutions at the 5th, 50th and 95th percentile current speeds were 6.3, 10.9 and 27.3, respectively. Dilution rates highlighted in red indicate that suitable dilution is not achieved during the near-field stage.**

| Contaminant | Source Concentration or Temperature | End of Near-Field Concentration or ΔT | | | Threshold Concentration or Temperature | Required Dilution Factor |
|---|---|---|---|---|---|---|
| | | 5th %ile | 50th %ile | 95th %ile | | |
| | | 6.3x Dilution | 10.9x Dilution | 27.3x Dilution | | |
| Chlorine in Water (ppb) | 1,000 | 158.7 | 91.7 | 36.6 | 5 | 200 |
| Δ Temperature (°C) | 60 | 4.97 | 2.85 | 1.28 | 3° above ambient | - |

**Table 3.38 Concentration of chlorine and plume-ambient temperature difference at the end of the near-field stage, the required concentration and temperature threshold, and the number of dilutions for the transitional season. Note from Table 3.36 that dilutions at the 5$^{th}$, 50$^{th}$ and 95$^{th}$ percentile current speeds were 6.3, 11.8 and 27.5, respectively. Dilution rates highlighted in red indicate that suitable dilution is not achieved during the near-field stage.**

| Contaminant | Source Concentration or Temperature | End of Near-Field Concentration or ΔT | | | Threshold Concentration or Temperature | Required Dilution Factor |
|---|---|---|---|---|---|---|
| | | 5th %ile | 50th %ile | 95th %ile | | |
| | | 6.3x Dilution | 11.8x Dilution | 27.5x Dilution | | |
| Chlorine in Water (ppb) | 1,000 | 158.7 | 84.7 | 36.4 | 5 | 200 |
| Δ Temperature (°C) | 60 | 5.30 | 2.76 | 1.17 | 3° above ambient | - |

**Table 3.39 Concentration of chlorine and plume-ambient temperature difference at the end of the near-field stage, the required concentration and temperature threshold, and the number of dilutions for the winter season. Note from Table 3.36 that dilutions at the 5$^{th}$, 50$^{th}$ and 95$^{th}$ percentile current speeds were 6.2, 11.6 and 28.9, respectively. Dilution rates highlighted in red indicate that suitable dilution is not achieved during the near-field stage.**

| Contaminant | Source Concentration or Temperature | End of Near-Field Concentration or ΔT | | | Threshold Concentration or Temperature | Required Dilution Factor |
|---|---|---|---|---|---|---|
| | | 5th %ile | 50th %ile | 95th %ile | | |
| | | 6.2x Dilution | 11.6x Dilution | 28.9x Dilution | | |
| Chlorine in Water (ppb) | 1,000 | 161.3 | 86.2 | 34.6 | 5 | 200 |
| Δ Temperature (°C) | 60 | 5.25 | 2.80 | 1.09 | 3° above ambient | - |

**Table 3.40 Concentration of chlorine and plume-ambient temperature difference at the end of the near-field stage, the required concentration and temperature threshold, and the number of dilutions for the annual period. Note from Table 3.36 that dilutions at the 5$^{th}$, 50$^{th}$ and 95$^{th}$ percentile current speeds were 6.2, 11.5 and 27.3, respectively. Dilution rates highlighted in red indicate that suitable dilution is not achieved during the near-field stage.**

| Contaminant | Source Concentration or Temperature | End of Near-Field Concentration or ΔT | | | Threshold Concentration or Temperature | Required Dilution Factor |
|---|---|---|---|---|---|---|
| | | 5th %ile | 50th %ile | 95th %ile | | |
| | | 6.2x Dilution | 11.5x Dilution | 27.3x Dilution | | |
| Chlorine in Water (ppb) | 1,000 | 161.3 | 86.9 | 36.6 | 5 | 200 |
| Δ Temperature (°C) | 60 | 5.24 | 2.81 | 1.15 | 3° above ambient | - |

### 3.1.2.9 Discharge Case C9: Flow Rate of 82,800 m$^3$/day at 30 m Depth

**Table 3.41 Predicted plume characteristics at the end of the near-field mixing zone for the 30 m depth (surface) discharge for each season and current speed.**

| Season | Surface Current Speed (m/s) | Plume Diameter (m) at Depth [m] | Plume Temperature (°C) | Plume-Ambient Temperature Difference (°C) | Plume Dilution (1:x) | | Maximum Horizontal Distance (m) |
|---|---|---|---|---|---|---|---|
| | | | | | Minimum | Average | |
| Summer | Weak (0.04) | 9.1 [0.1] | 28.94 | 1.14 | 11.7 | 22.7 | 2.6 |
| | Medium (0.16) | 17.0 [5.7] | 28.10 | 0.38 | 21.4 | 53.9 | 14.1 |
| | Strong (0.33) | 24.0 [11.7] | 27.63 | 0.05 | 41.6 | 155.6 | 47.2 |
| Transitional | Weak (0.05) | 9.1 [0.1] | 27.22 | 1.22 | 11.9 | 23.0 | 2.8 |
| | Medium (0.18) | 18.4 [6.7] | 26.25 | 0.35 | 23.3 | 63.6 | 16.6 |
| | Strong (0.38) | 24.7 [11.9] | 25.83 | 0.04 | 49.1 | 187.1 | 60.1 |
| Winter | Weak (0.04) | 9.0 [0.5] | 27.63 | 1.23 | 11.6 | 22.5 | 2.7 |
| | Medium (0.17) | 18.0 [6.4] | 26.67 | 0.36 | 22.8 | 60.9 | 16.0 |
| | Strong (0.40) | 24.6 [12.1] | 26.21 | 0.03 | 51.1 | 195.6 | 65.0 |
| Annual | Weak (0.04) | 9.1 [0.1] | 27.80 | 1.20 | 11.8 | 22.9 | 2.7 |
| | Medium (0.17) | 17.8 [6.4] | 26.88 | 0.37 | 22.4 | 59.2 | 15.5 |
| | Strong (0.37) | 24.6 [11.2] | 26.41 | 0.03 | 48.7 | 185.7 | 59.8 |

**Table 3.42 Concentration of chlorine and plume-ambient temperature difference at the end of the near-field stage, the required concentration and temperature threshold, and the number of dilutions for the summer season. Note from Table 3.41 that dilutions at the 5$^{th}$, 50$^{th}$ and 95$^{th}$ percentile current speeds were 22.7, 53.9 and 155.6, respectively. Dilution rates highlighted in red indicate that suitable dilution is not achieved during the near-field stage.**

| Contaminant | Source Concentration or Temperature | End of Near-Field Concentration or ΔT | | | Threshold Concentration or Temperature | Required Dilution Factor |
|---|---|---|---|---|---|---|
| | | 5th %ile | 50th %ile | 95th %ile | | |
| | | 22.7x Dilution | 53.9x Dilution | 155.6x Dilution | | |
| Chlorine in Water (ppb) | 1,000 | 44.1 | 18.6 | 6.4 | 5 | 200 |
| Δ Temperature (°C) | 60 | 1.14 | 0.38 | 0.05 | 3° above ambient | - |

**Table 3.43 Concentration of chlorine and plume-ambient temperature difference at the end of the near-field stage, the required concentration and temperature threshold, and the number of dilutions for the transitional season. Note from Table 3.41 that dilutions at the 5th, 50th and 95th percentile current speeds were 23.0, 63.6 and 187.1, respectively. Dilution rates highlighted in red indicate that suitable dilution is not achieved during the near-field stage.**

| Contaminant | Source Concentration or Temperature | End of Near-Field Concentration or ΔT | | | Threshold Concentration or Temperature | Required Dilution Factor |
|---|---|---|---|---|---|---|
| | | 5th %ile | 50th %ile | 95th %ile | | |
| | | 23.0x Dilution | 63.6x Dilution | 187.1x Dilution | | |
| Chlorine in Water (ppb) | 1,000 | 43.5 | 15.7 | 5.3 | 5 | 200 |
| Δ Temperature (°C) | 60 | 1.22 | 0.35 | 0.04 | 3° above ambient | - |

**Table 3.44 Concentration of chlorine and plume-ambient temperature difference at the end of the near-field stage, the required concentration and temperature threshold, and the number of dilutions for the winter season. Note from Table 3.41 that dilutions at the 5th, 50th and 95th percentile current speeds were 22.5, 60.9 and 195.6, respectively. Dilution rates highlighted in red indicate that suitable dilution is not achieved during the near-field stage.**

| Contaminant | Source Concentration or Temperature | End of Near-Field Concentration or ΔT | | | Threshold Concentration or Temperature | Required Dilution Factor |
|---|---|---|---|---|---|---|
| | | 5th %ile | 50th %ile | 95th %ile | | |
| | | 22.5x Dilution | 60.9x Dilution | 195.6x Dilution | | |
| Chlorine in Water (ppb) | 1,000 | 44.4 | 16.4 | 5.1 | 5 | 200 |
| Δ Temperature (°C) | 60 | 1.23 | 0.36 | 0.03 | 3° above ambient | - |

**Table 3.45 Concentration of chlorine and plume-ambient temperature difference at the end of the near-field stage, the required concentration and temperature threshold, and the number of dilutions for the annual period. Note from Table 3.41 that dilutions at the 5th, 50th and 95th percentile current speeds were 22.9, 59.2 and 185.7, respectively. Dilution rates highlighted in red indicate that suitable dilution is not achieved during the near-field stage.**

| Contaminant | Source Concentration or Temperature | End of Near-Field Concentration or ΔT | | | Threshold Concentration or Temperature | Required Dilution Factor |
|---|---|---|---|---|---|---|
| | | 5th %ile | 50th %ile | 95th %ile | | |
| | | 22.9x Dilution | 59.2x Dilution | 185.7x Dilution | | |
| Chlorine in Water (ppb) | 1,000 | 43.7 | 16.9 | 5.4 | 5 | 200 |
| Δ Temperature (°C) | 60 | 1.20 | 0.37 | 0.03 | 3° above ambient | - |

## 3.1.3 Results – Figures

### 3.1.3.1 Discharge Flow Rate of 165,600 m$^3$/day at Varying Depths

#### 3.1.3.1.1 Annualised

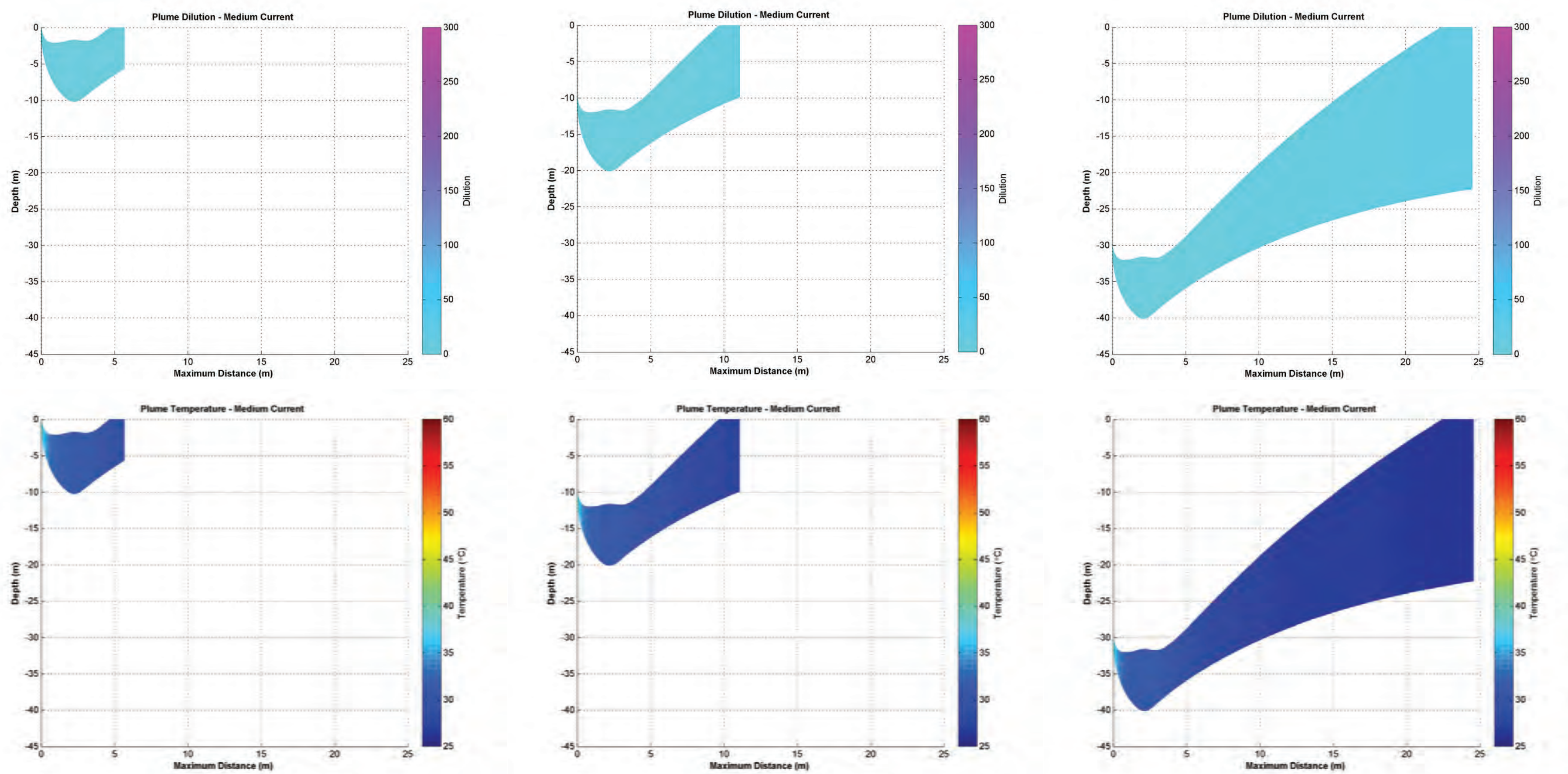



Figure 3.1 Near-field average dilution and temperature results for constant medium annualised currents with a discharge flow rate of 165,600 m$^3$/d at discharge depths of 0 m (Case C1; left column), 10 m (Case C2; middle column) and 30 m (Case C3; right column).

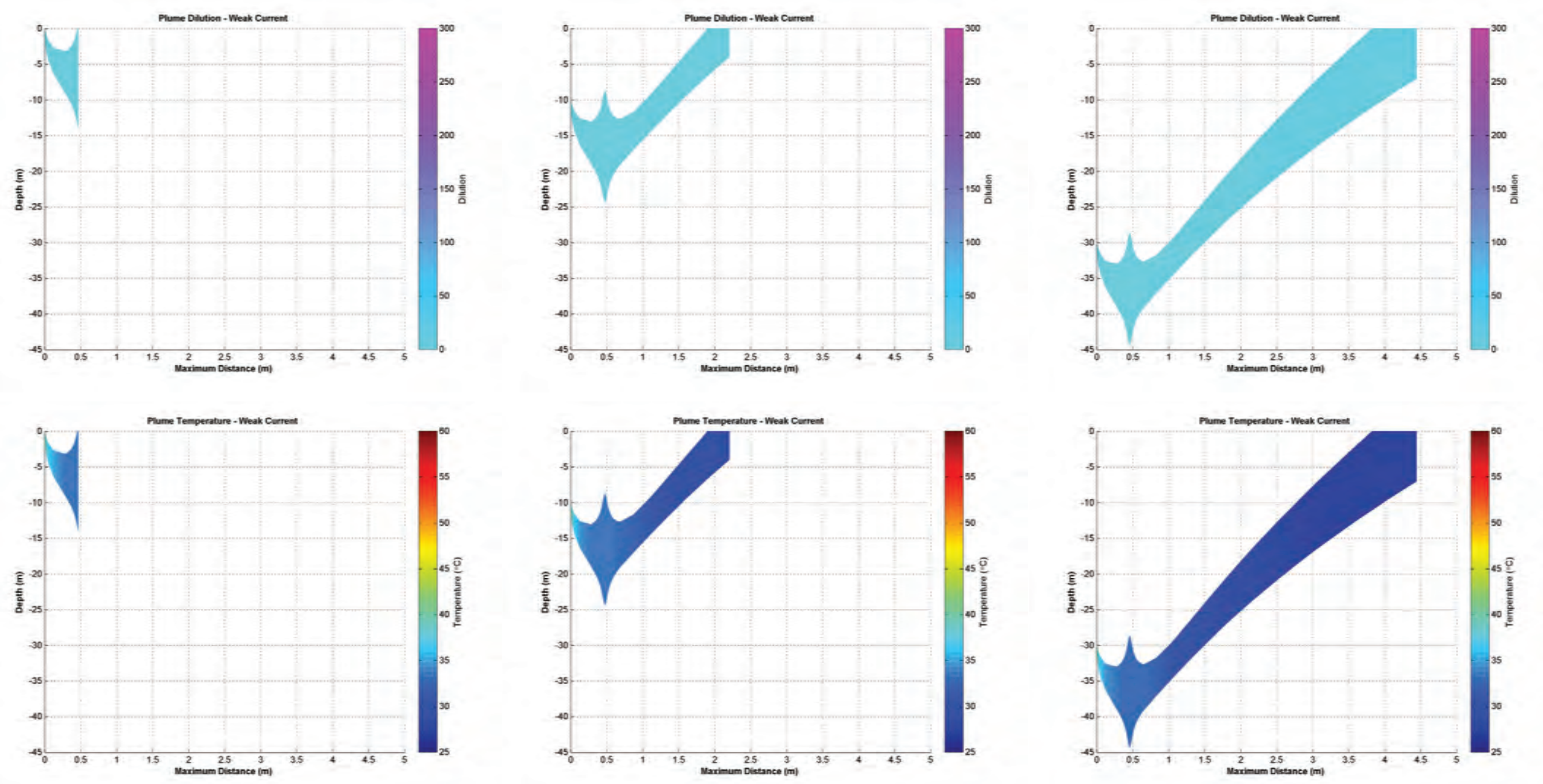



**Figure 3.2** **Near-field average dilution and temperature results for constant weak annualised currents with a discharge flow rate of 165,600 $m^3$/d at discharge depths of 0 m (Case C1; left column), 10 m (Case C2; middle column) and 30 m (Case C3; right column).**

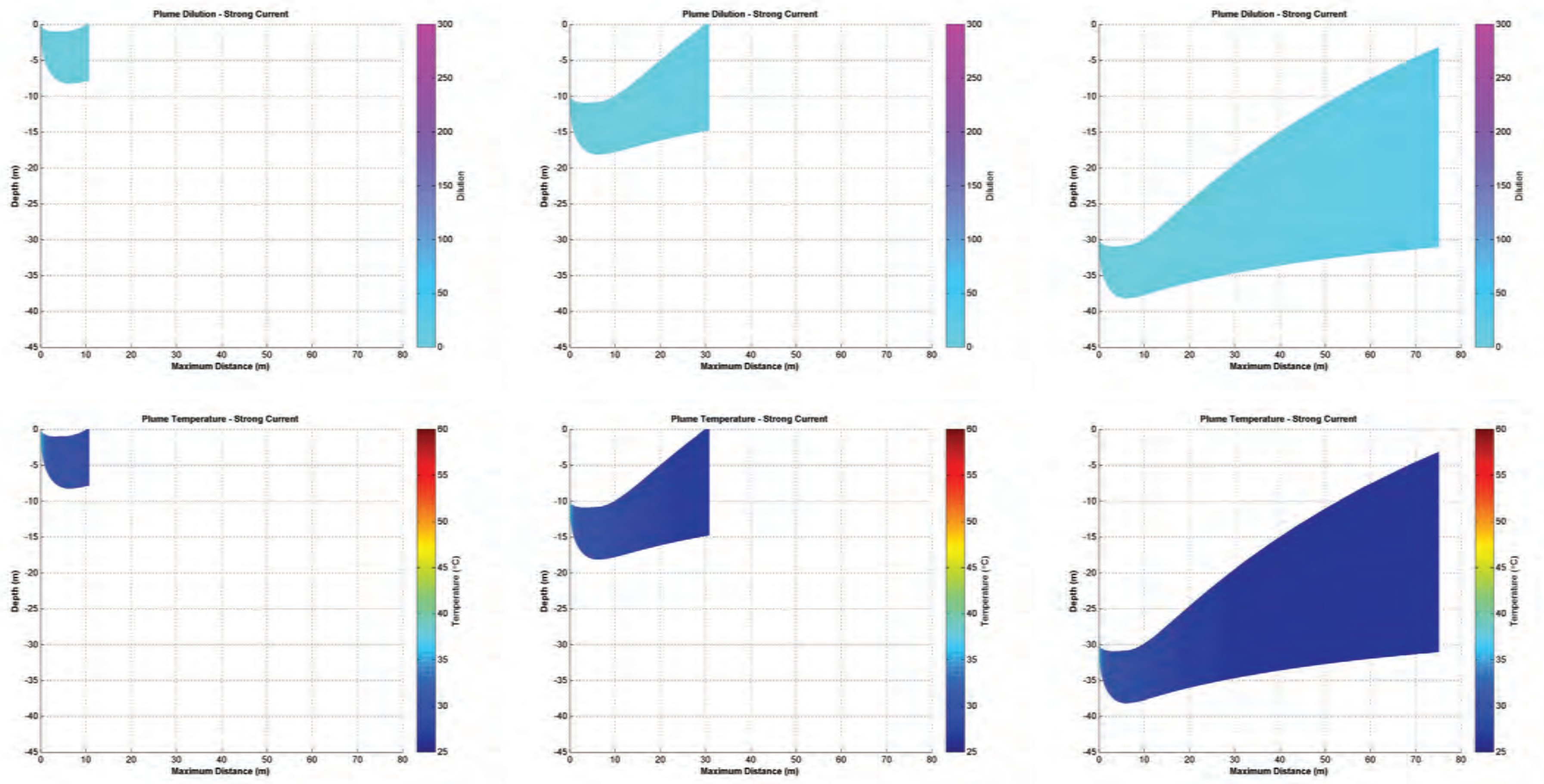



**Figure 3.3** **Near-field average dilution and temperature results for constant strong annualised currents with a discharge flow rate of 165,600 m³/d at discharge depths of 0 m (Case C1; left column), 10 m (Case C2; middle column) and 30 m (Case C3; right column).**

#### 3.1.3.1.2 Summer

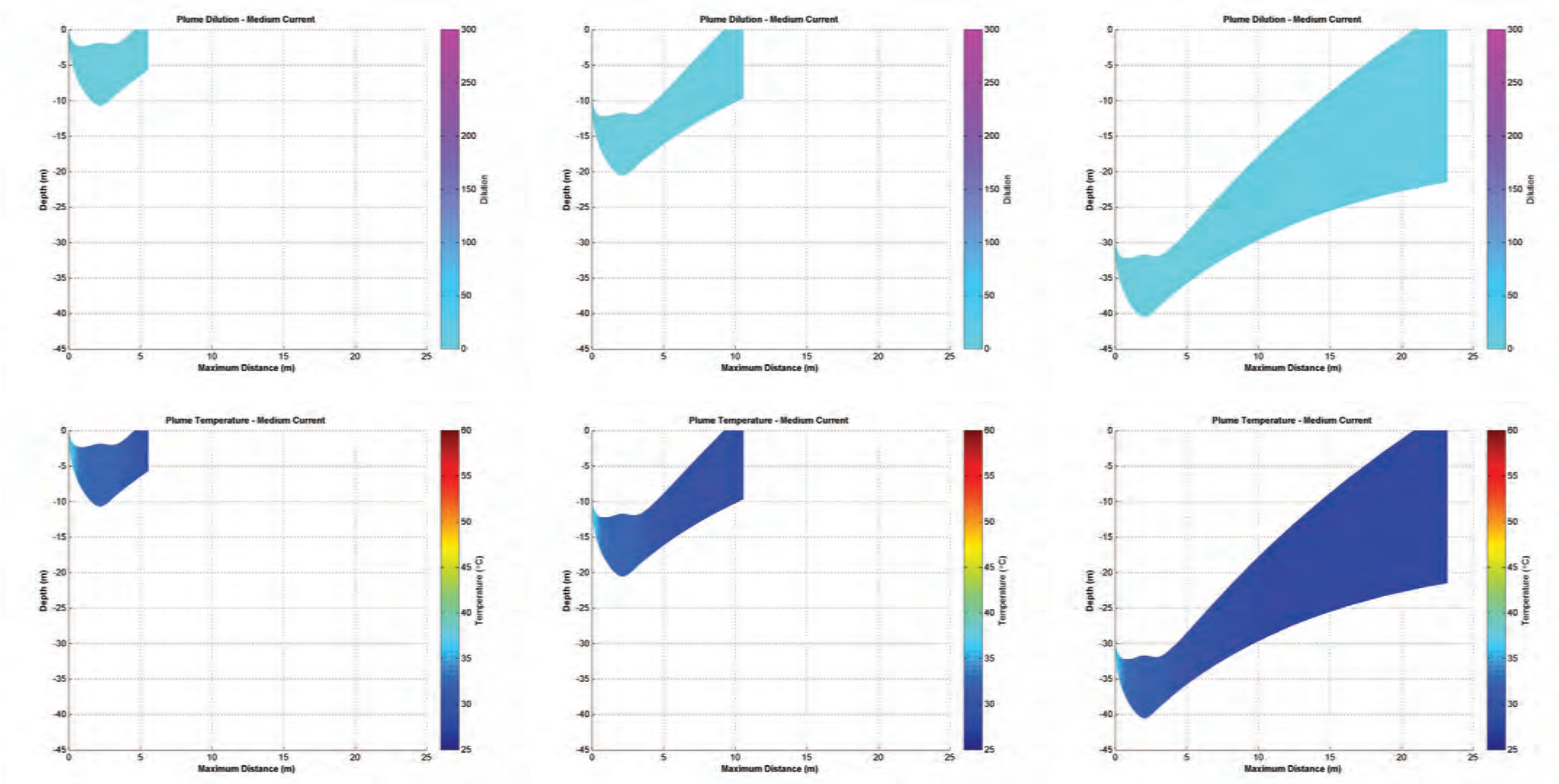



**Figure 3.4** **Near-field average dilution and temperature results for constant medium summer currents with a discharge flow rate of 165,600 $m^3/d$ at discharge depths of 0 m (Case C1; left column), 10 m (Case C2; middle column) and 30 m (Case C3; right column).**

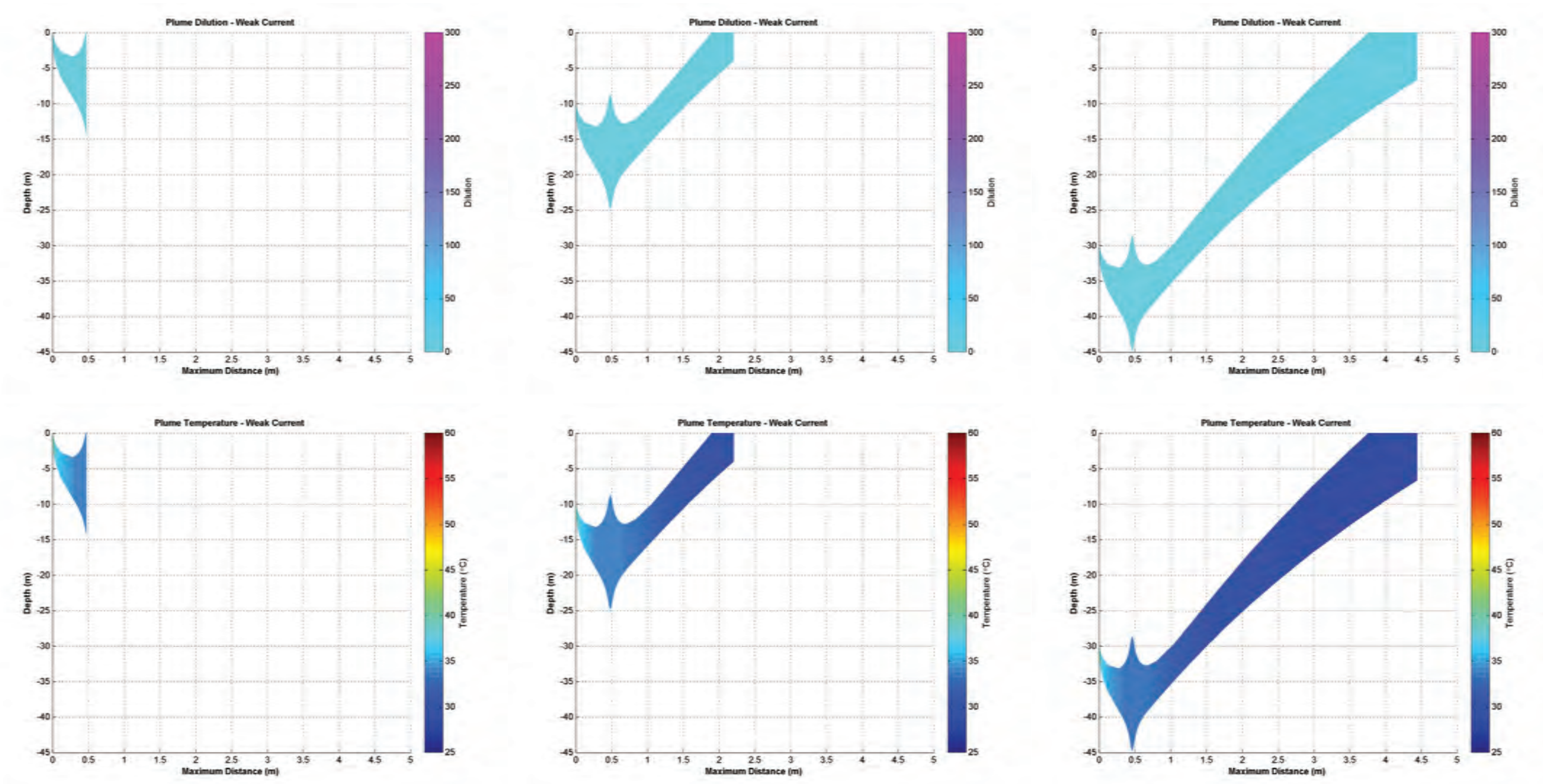



**Figure 3.5 Near-field average dilution and temperature results for constant weak summer currents with a discharge flow rate of 165,600 m³/d at discharge depths of 0 m (Case C1; left column), 10 m (Case C2; middle column) and 30 m (Case C3; right column).**

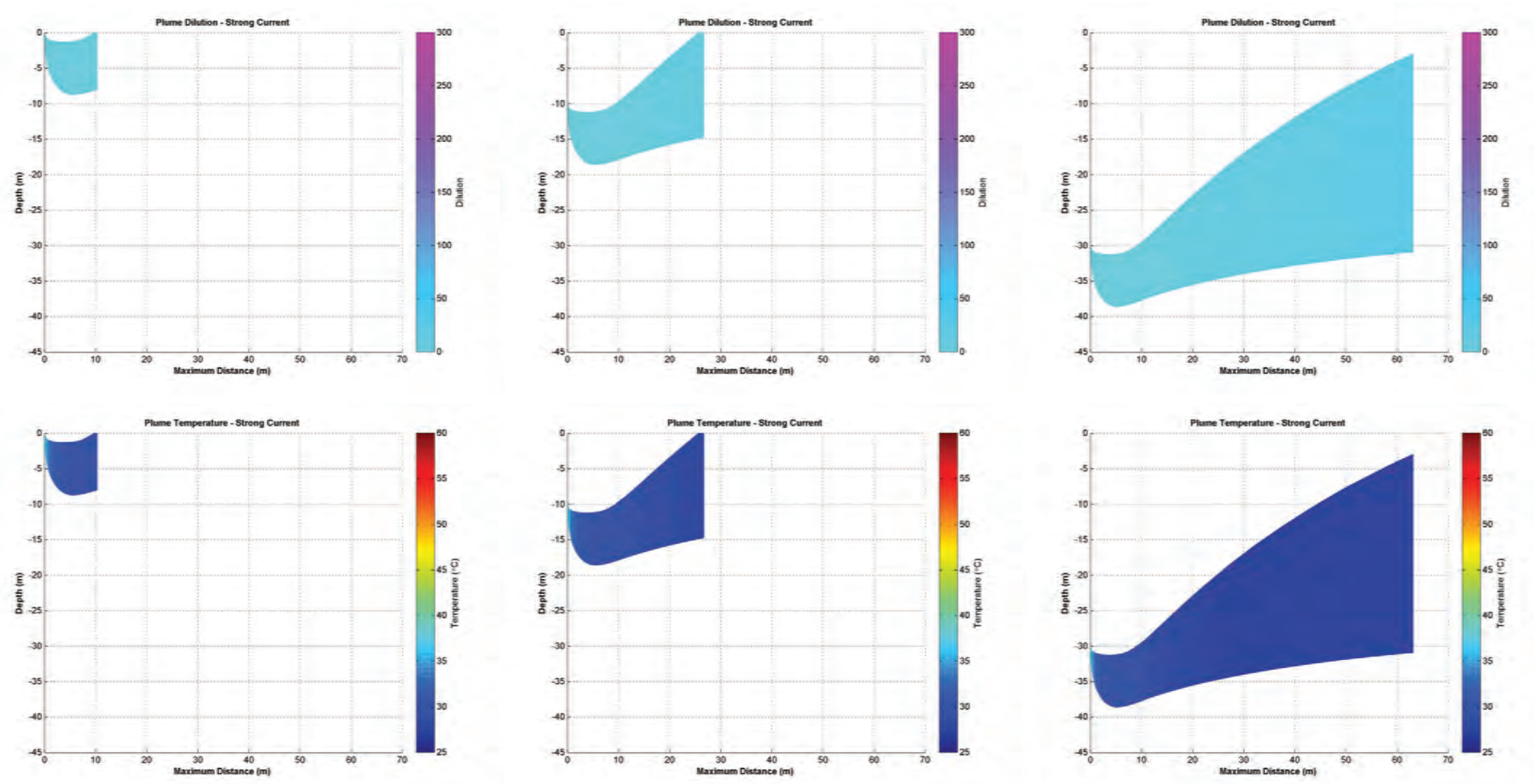



**Figure 3.6** Near-field average dilution and temperature results for constant strong summer currents with a discharge flow rate of 165,600 $m^3/d$ at discharge depths of 0 m (Case C1; left column), 10 m (Case C2; middle column) and 30 m (Case C3; right column).

### 3.1.3.1.3 Transitional

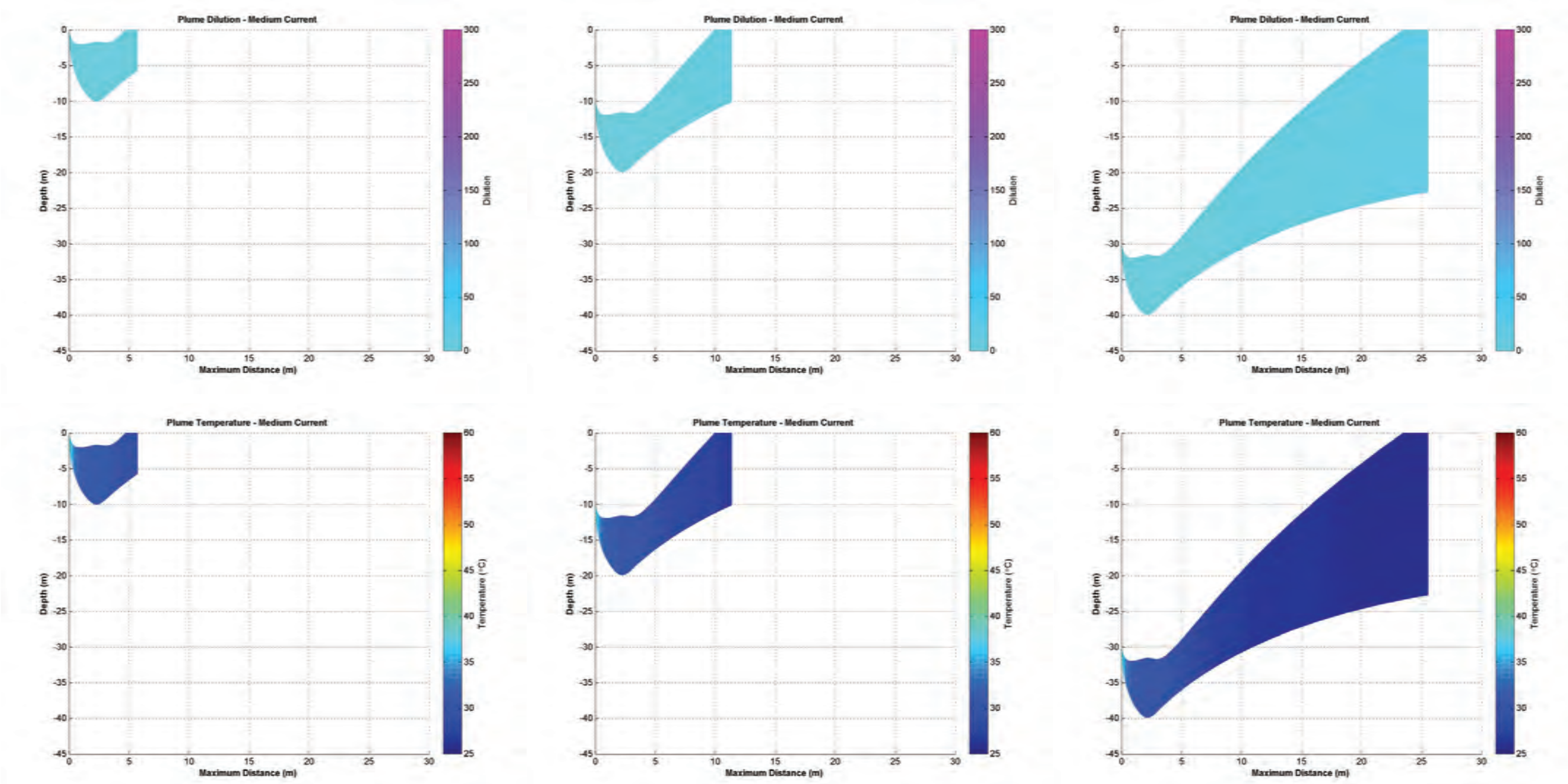



**Figure 3.7 Near-field average dilution and temperature results for constant medium transitional currents with a discharge flow rate of 165,600 m³/d at discharge depths of 0 m (Case C1; left column), 10 m (Case C2; middle column) and 30 m (Case C3; right column).**

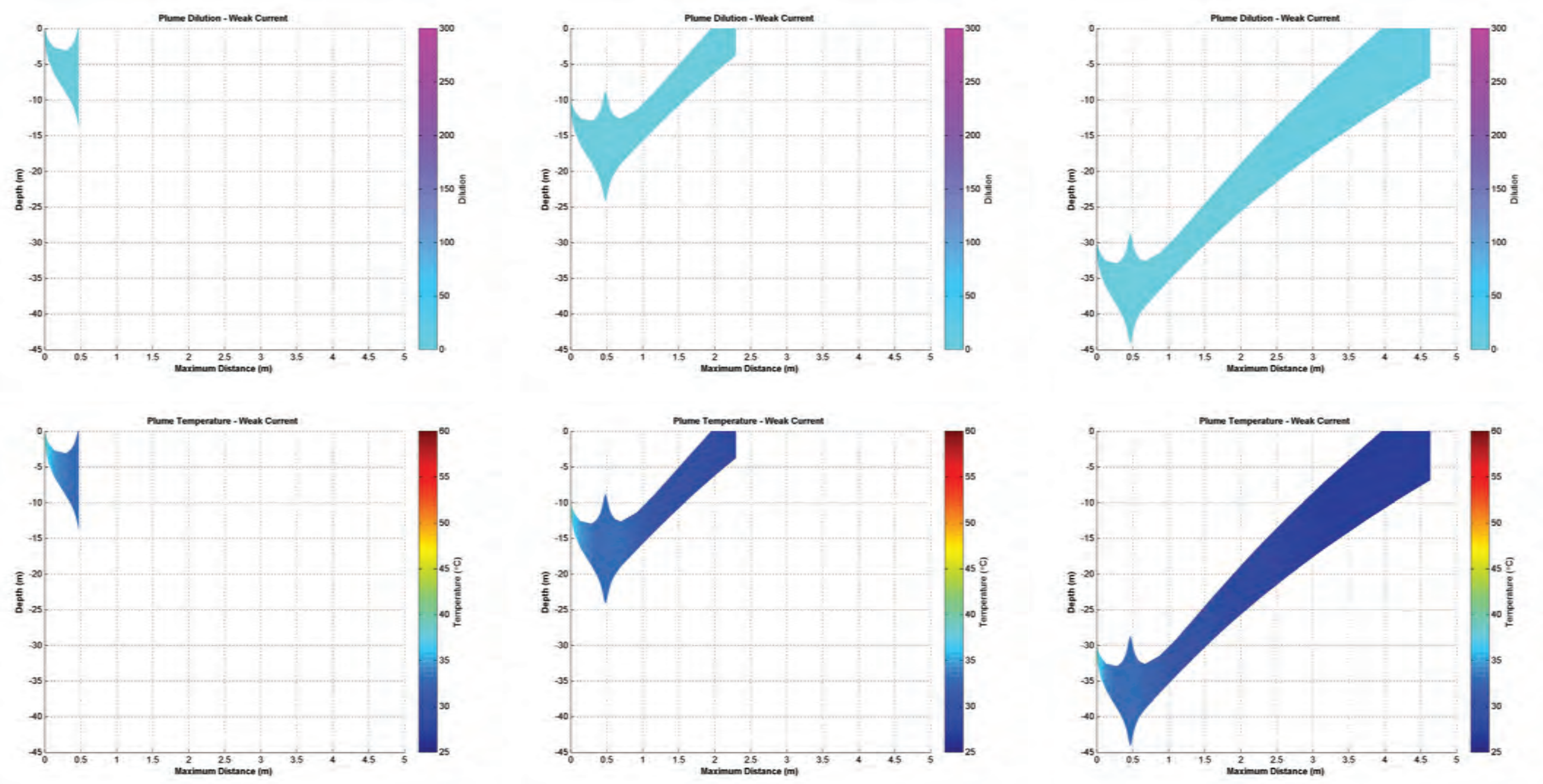



**Figure 3.8** Near-field average dilution and temperature results for constant weak transitional currents with a discharge flow rate of 165,600 m$^3$/d at discharge depths of 0 m (Case C1; left column), 10 m (Case C2; middle column) and 30 m (Case C3; right column).

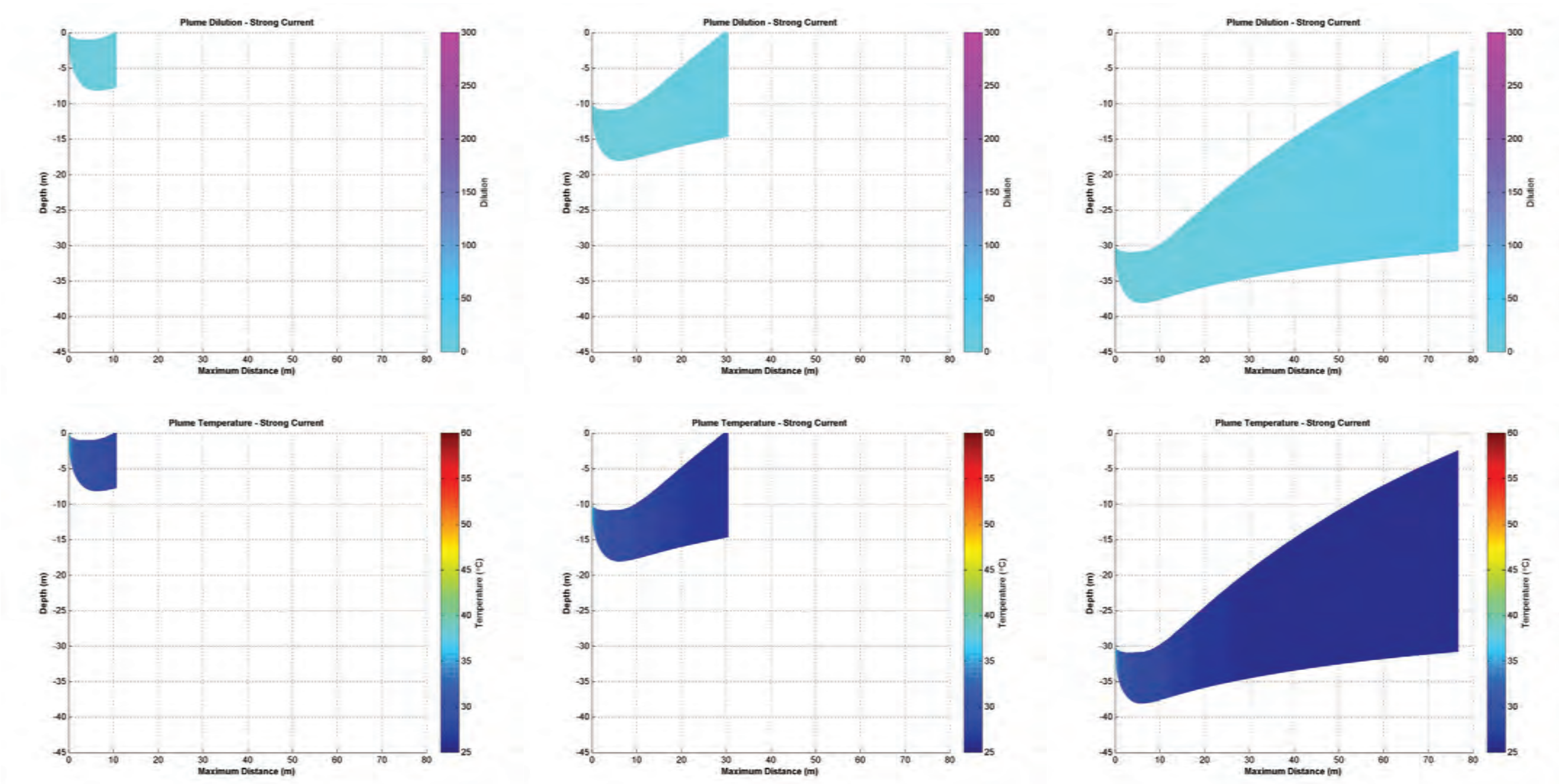



**Figure 3.9** **Near-field average dilution and temperature results for constant strong transitional currents with a discharge flow rate of 165,600 $m^3$/d at discharge depths of 0 m (Case C1; left column), 10 m (Case C2; middle column) and 30 m (Case C3; right column).**

### 3.1.3.1.4 Winter

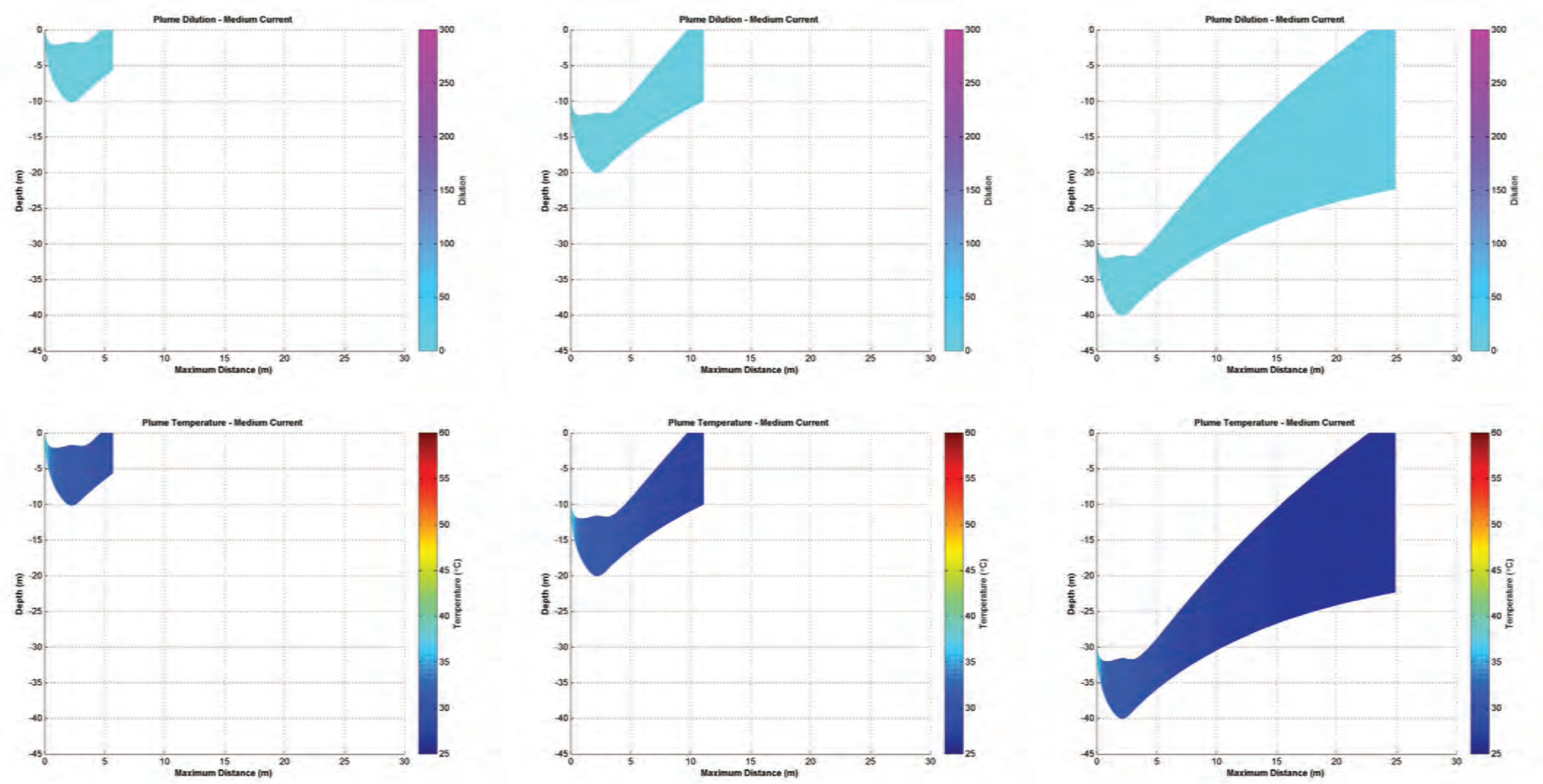



**Figure 3.10 Near-field average dilution and temperature results for constant medium winter currents with a discharge flow rate of 165,600 m$^3$/d at discharge depths of 0 m (Case C1; left column), 10 m (Case C2; middle column) and 30 m (Case C3; right column).**

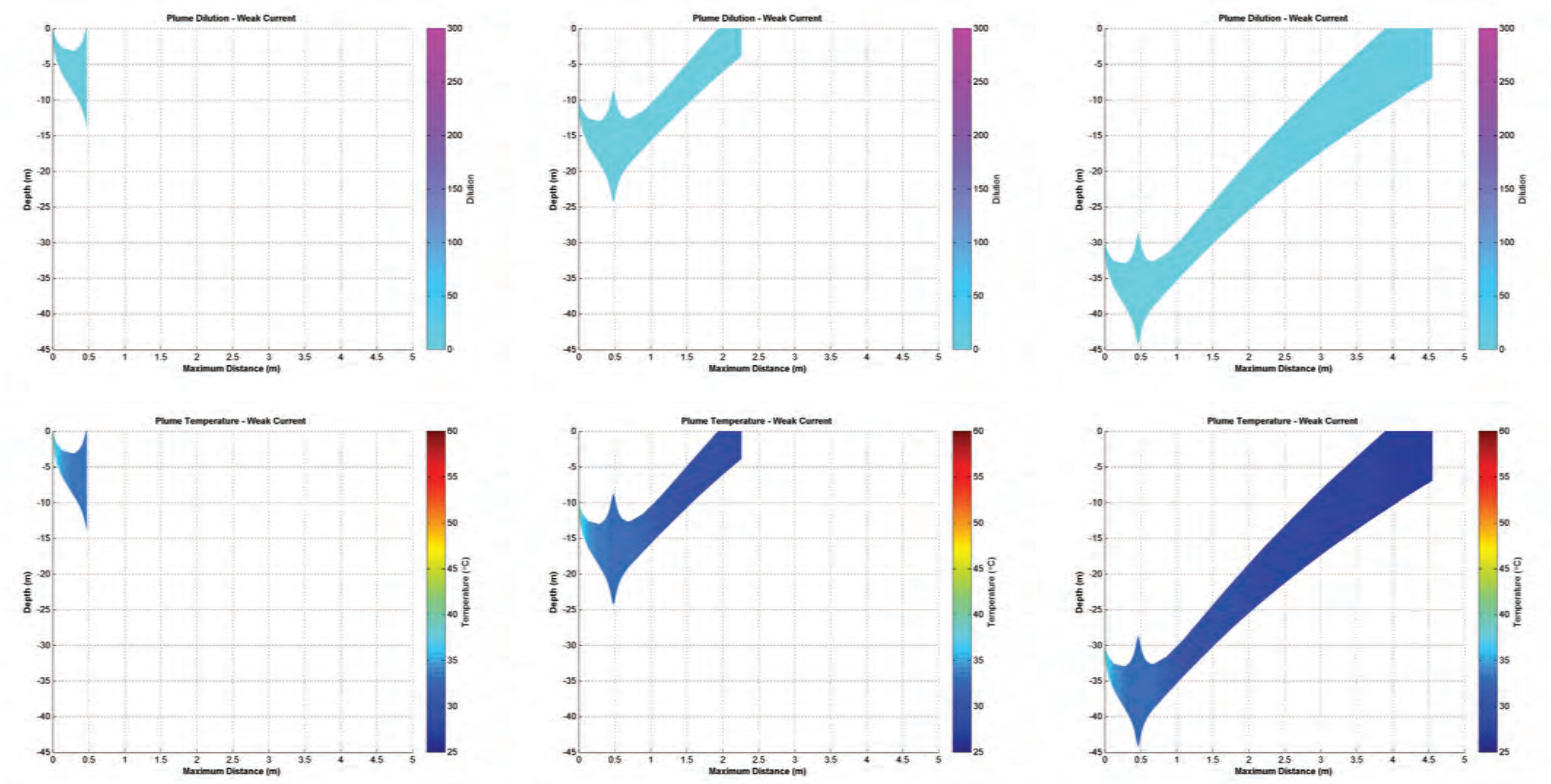



**Figure 3.11 Near-field average dilution and temperature results for constant weak winter currents with a discharge flow rate of 165,600 m³/d at discharge depths of 0 m (Case C1; left column), 10 m (Case C2; middle column) and 30 m (Case C3; right column).**

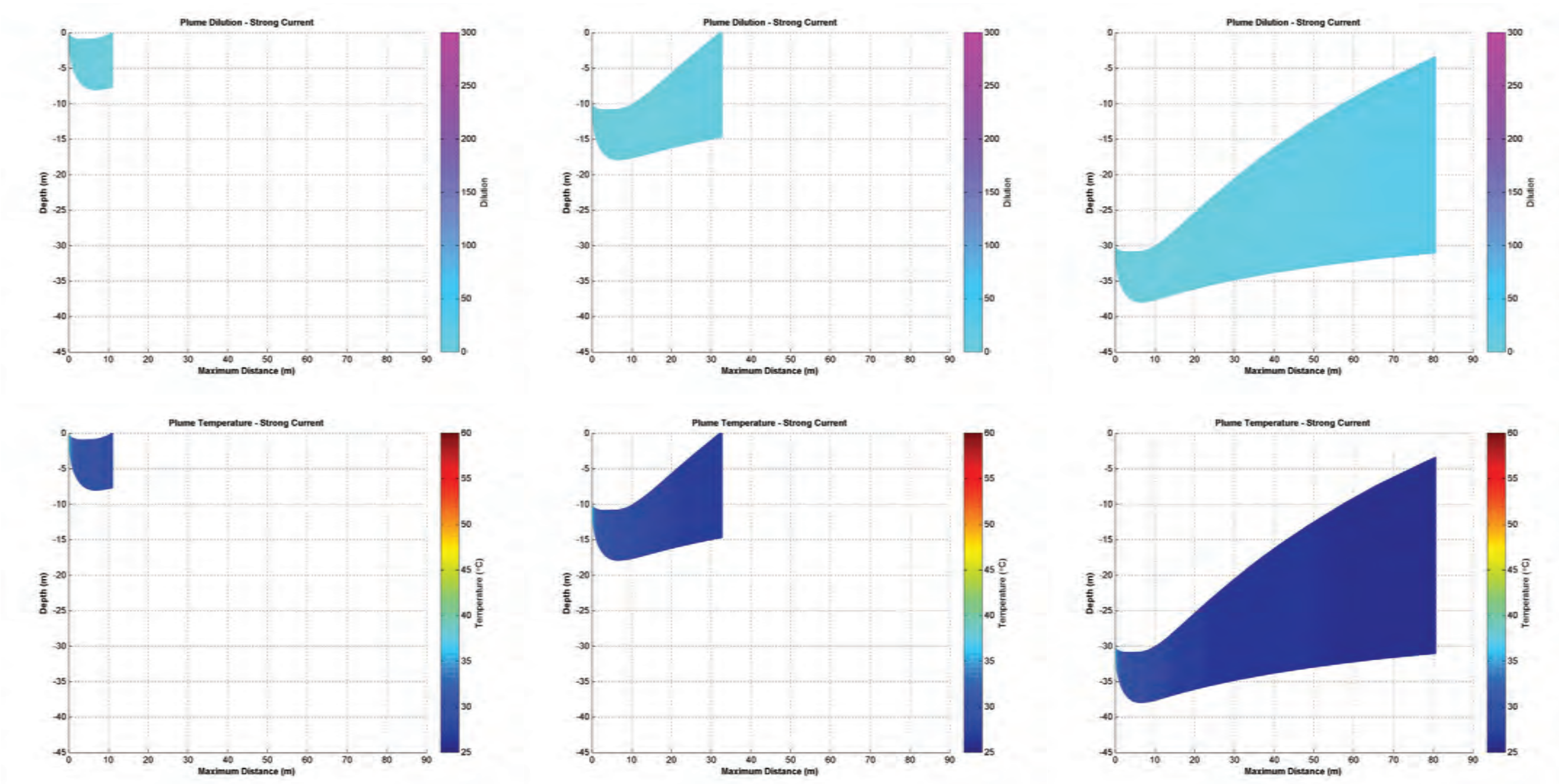



Figure 3.12 Near-field average dilution and temperature results for constant strong winter currents with a discharge flow rate of 165,600 $m^3/d$ at discharge depths of 0 m (Case C1; left column), 10 m (Case C2; middle column) and 30 m (Case C3; right column).

### 3.1.3.2 Discharge Flow Rate of 64,800 m³/day at Varying Depths

#### 3.1.3.2.1 Annualised

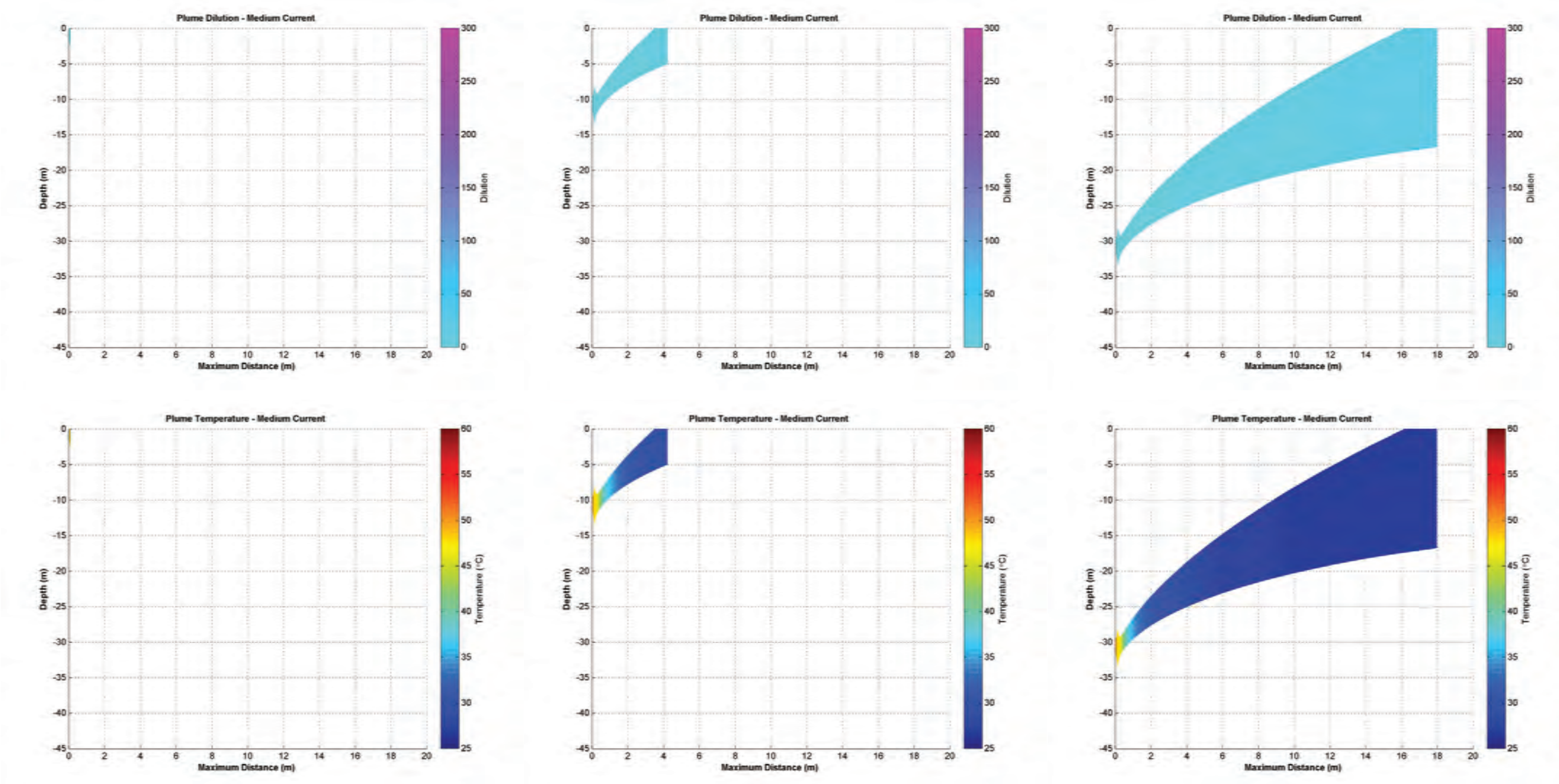



Figure 3.13 Near-field average dilution and temperature results for constant medium annualised currents with a discharge flow rate of 64,800 m³/d at discharge depths of 0 m (Case C1; left column), 10 m (Case C2; middle column) and 30 m (Case C3; right column).

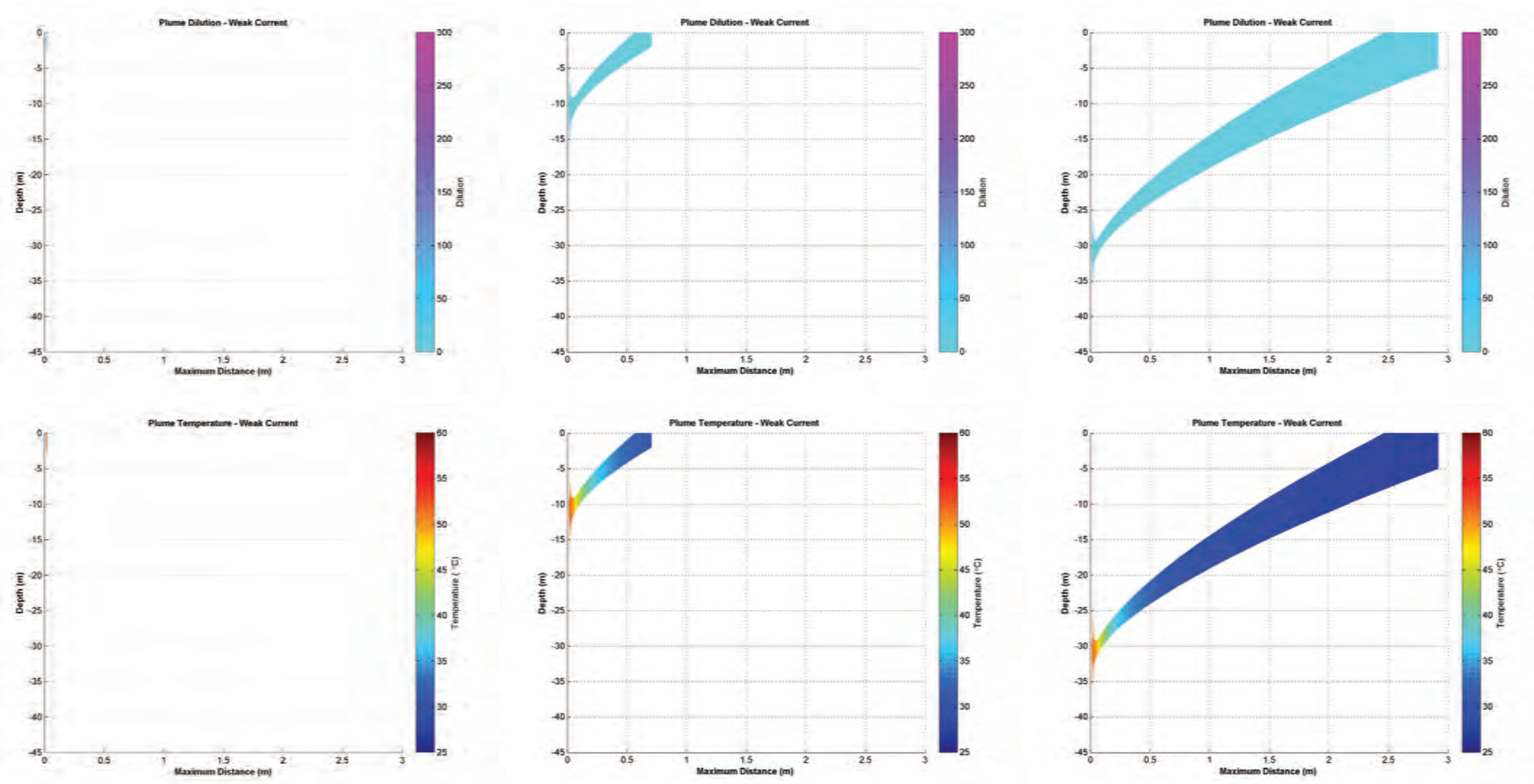



**Figure 3.14 Near-field average dilution and temperature results for constant weak annualised currents with a discharge flow rate of 64,800 m³/d at discharge depths of 0 m (Case C1; left column), 10 m (Case C2; middle column) and 30 m (Case C3; right column).**

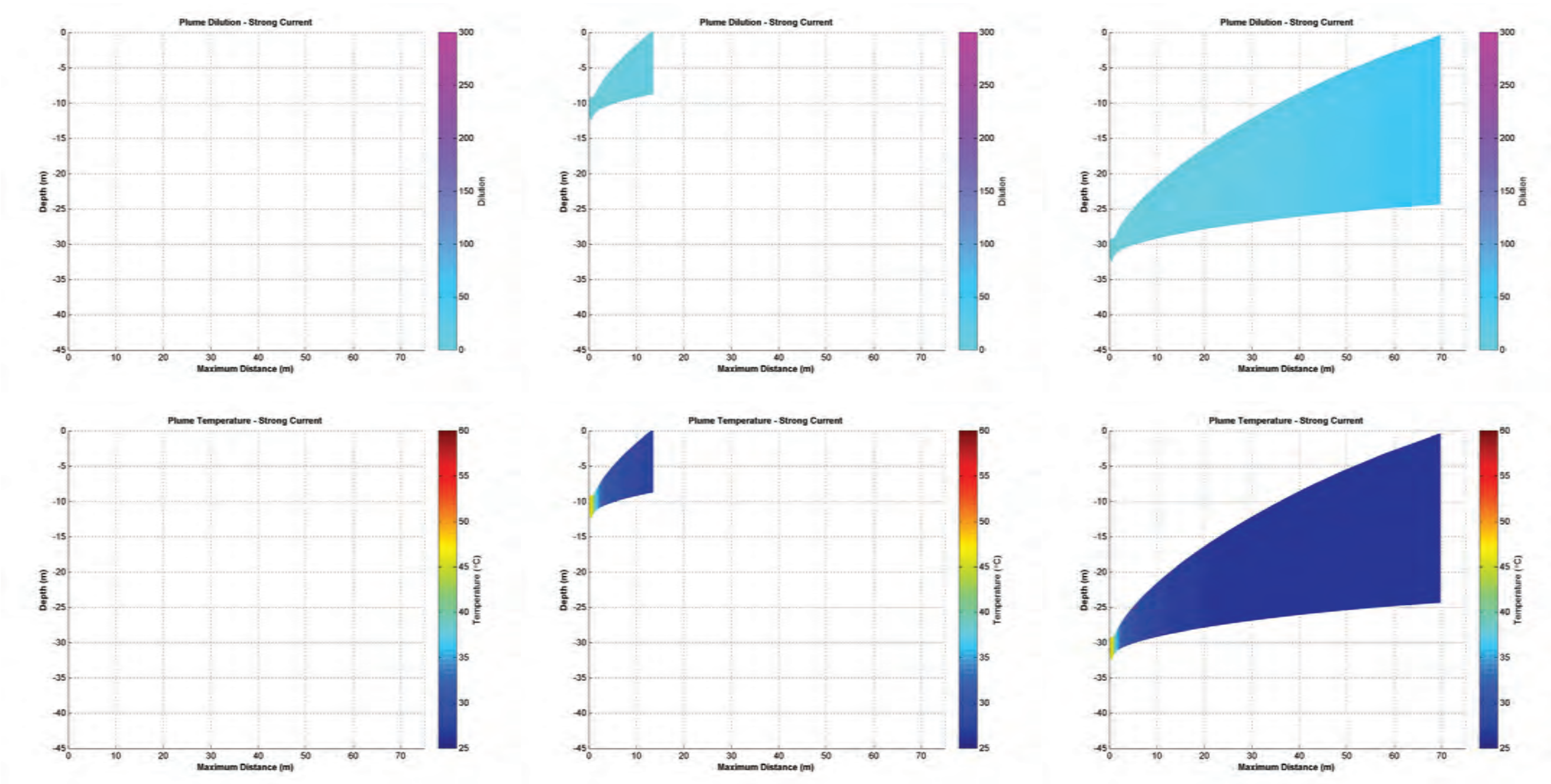



**Figure 3.15** **Near-field average dilution and temperature results for constant strong annualised currents with a discharge flow rate of 64,800 m³/d at discharge depths of 0 m (Case C1; left column), 10 m (Case C2; middle column) and 30 m (Case C3; right column).**

### 3.1.3.2.2 Summer

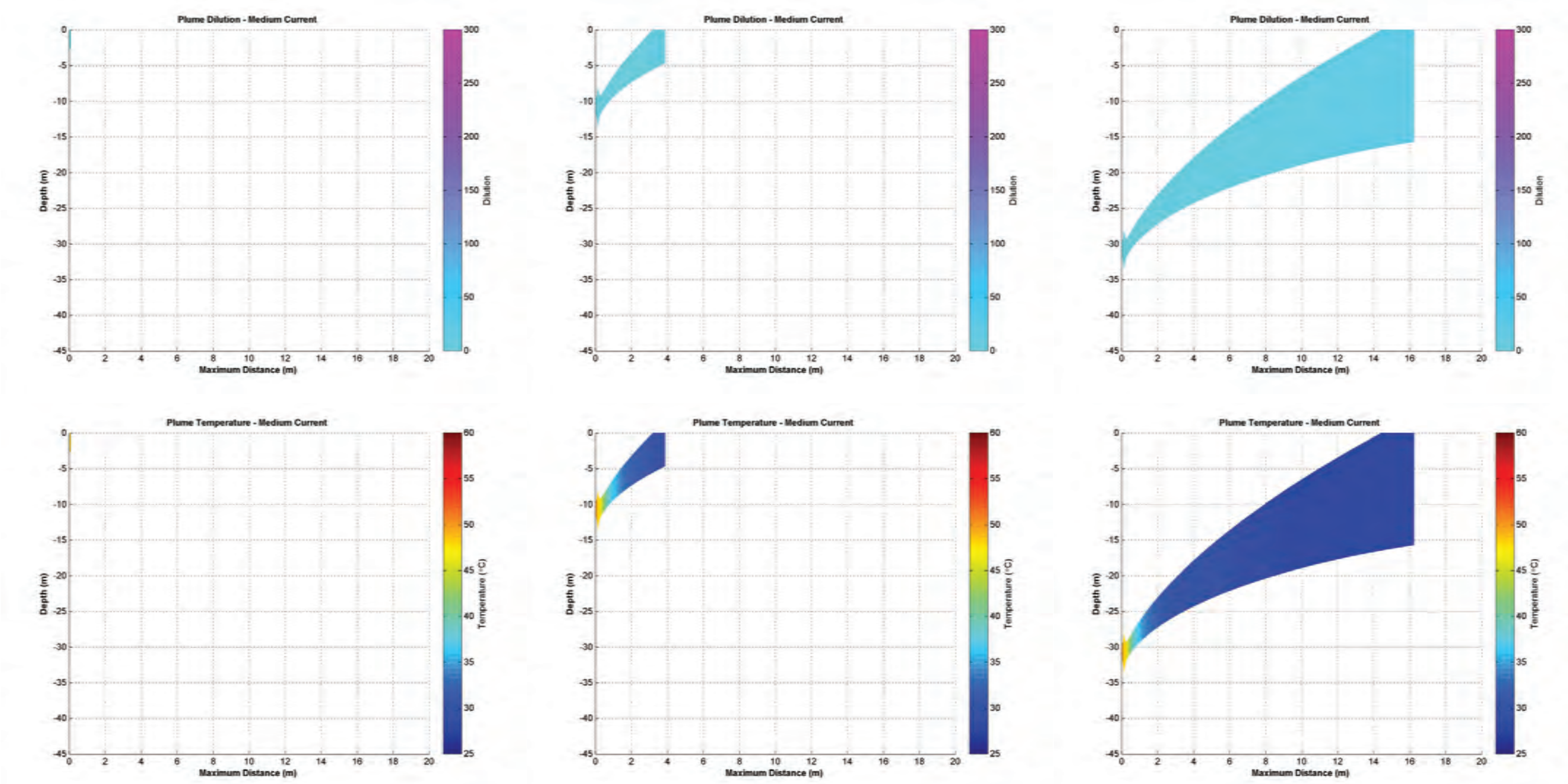



**Figure 3.16 Near-field average dilution and temperature results for constant medium summer currents with a discharge flow rate of 64,800 m³/d at discharge depths of 0 m (Case C1; left column), 10 m (Case C2; middle column) and 30 m (Case C3; right column).**

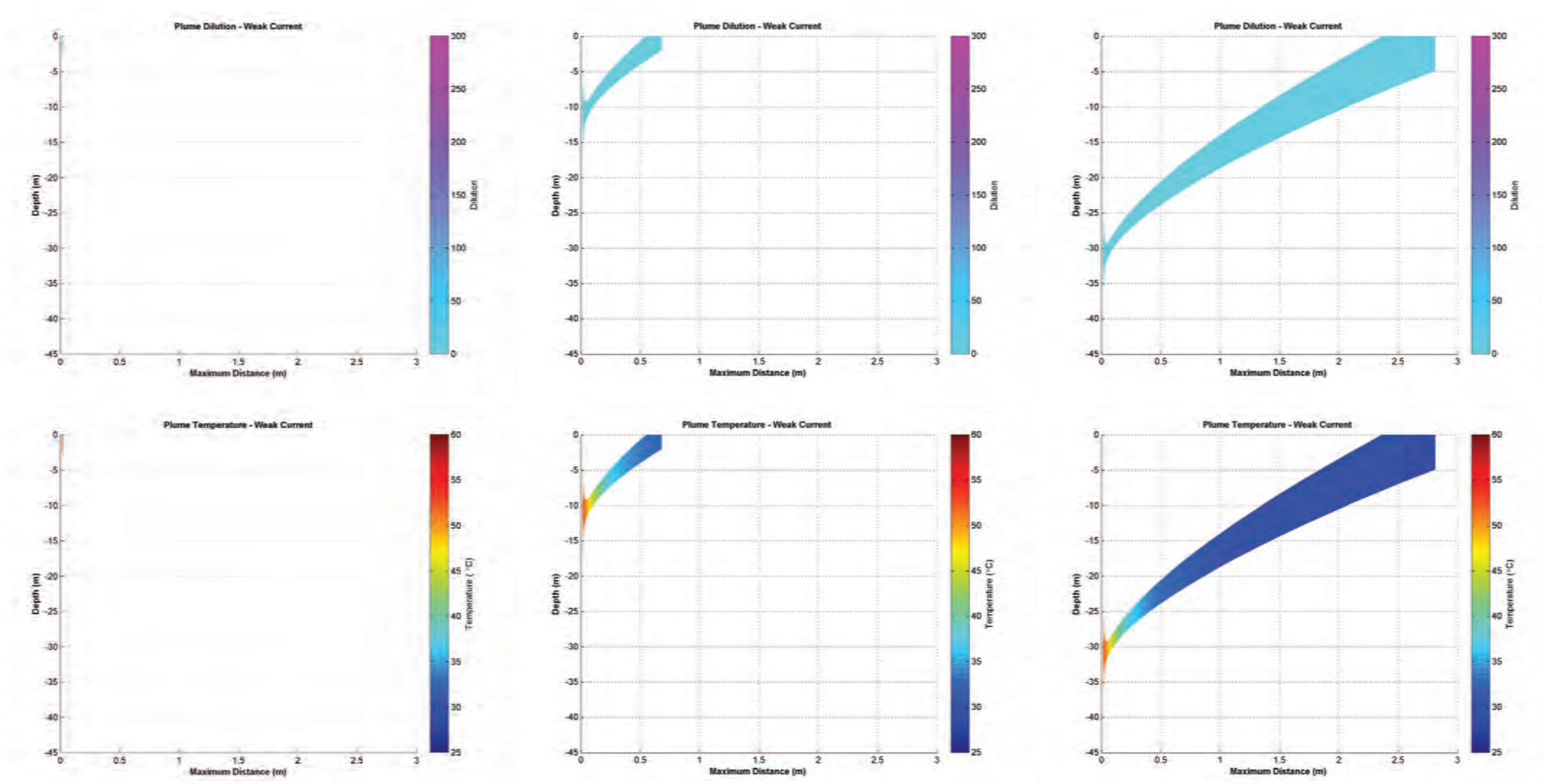



**Figure 3.17** **Near-field average dilution and temperature results for constant weak summer currents with a discharge flow rate of 64,800 m³/d at discharge depths of 0 m (Case C1; left column), 10 m (Case C2; middle column) and 30 m (Case C3; right column).**

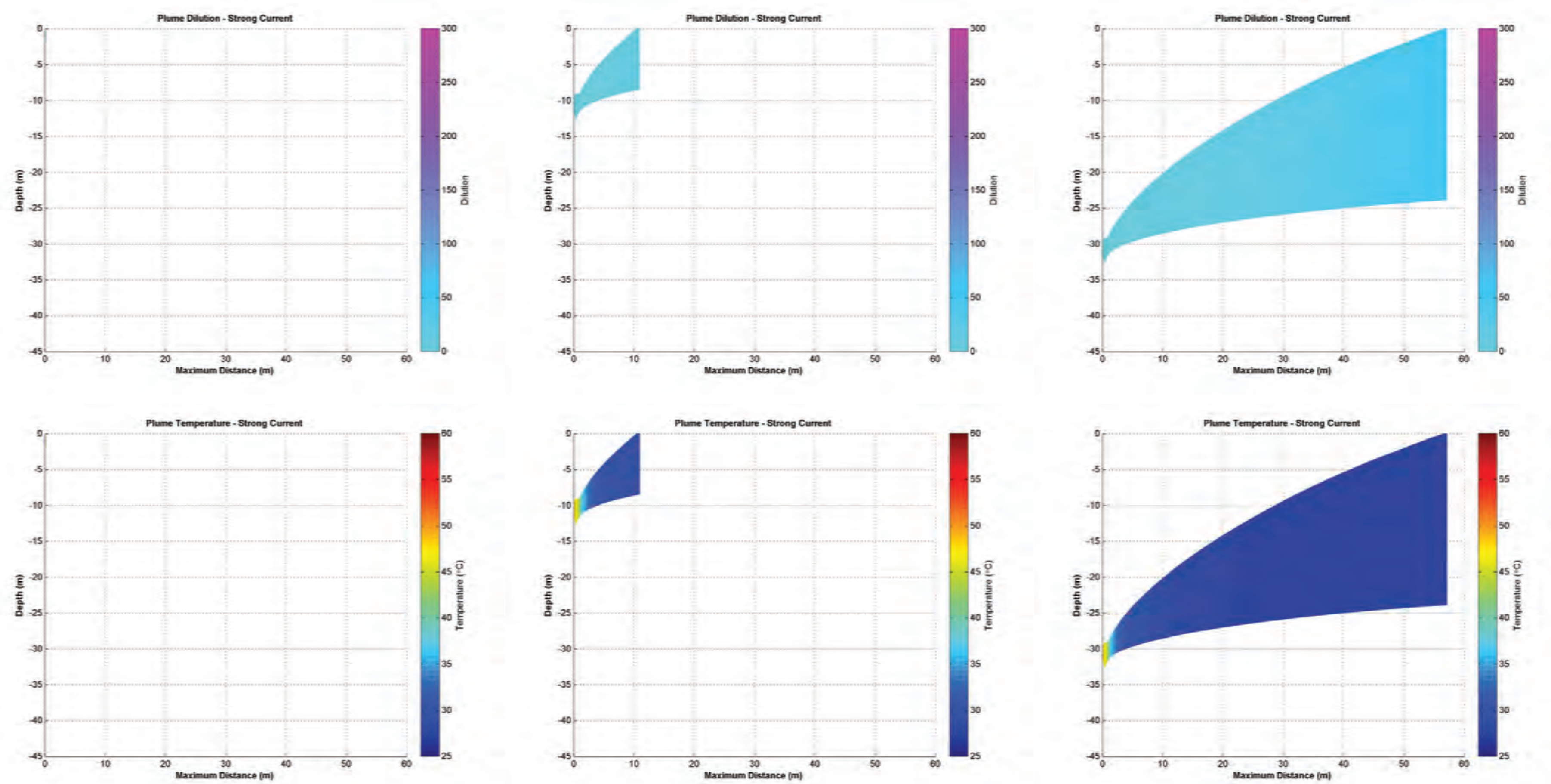



**Figure 3.18 Near-field average dilution and temperature results for constant strong summer currents with a discharge flow rate of 64,800 $m^3$/d at discharge depths of 0 m (Case C1; left column), 10 m (Case C2; middle column) and 30 m (Case C3; right column).**

#### 3.1.3.2.3 Transitional

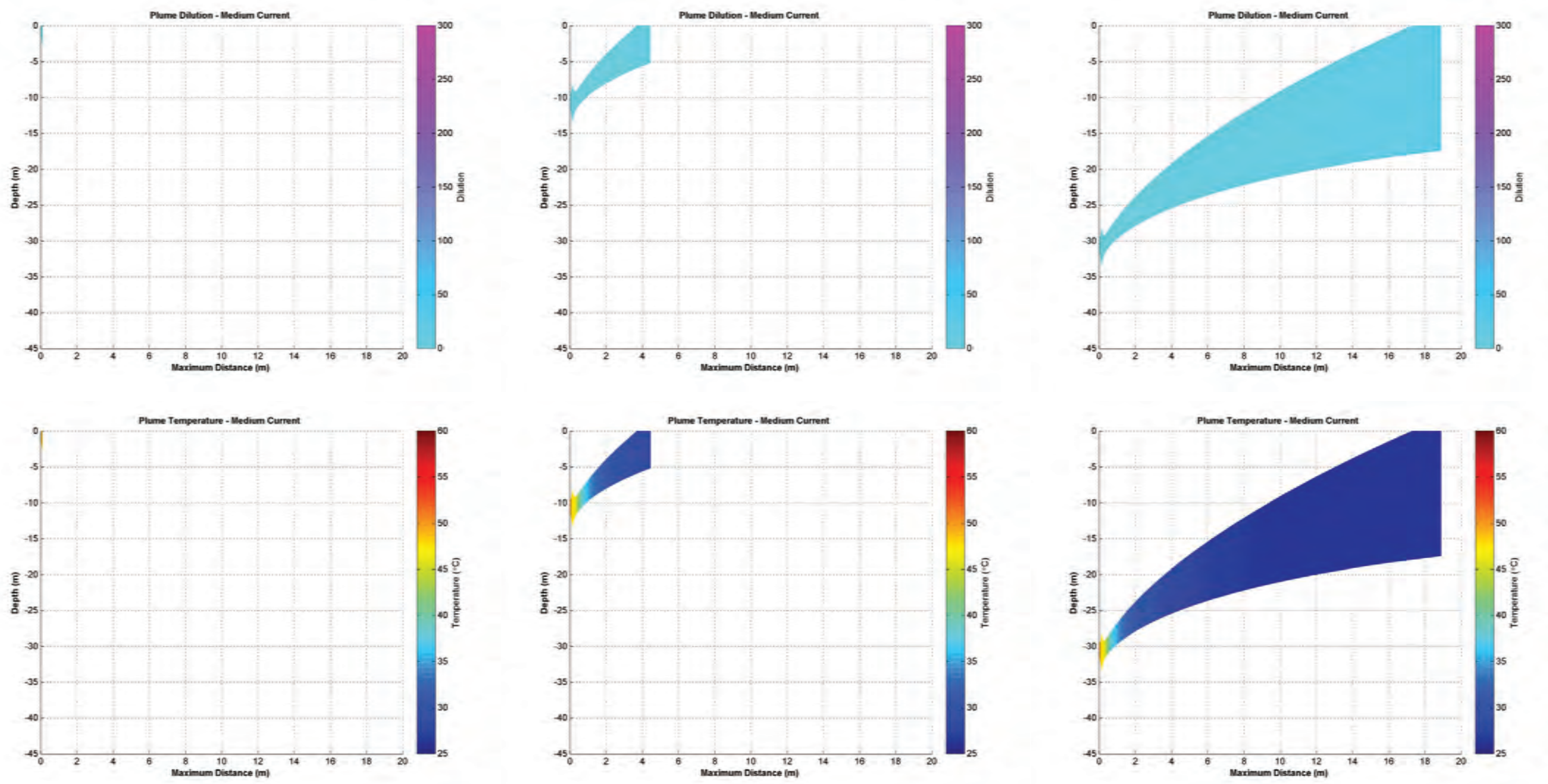



**Figure 3.19 Near-field average dilution and temperature results for constant medium transitional currents with a discharge flow rate of 64,800 $m^3/d$ at discharge depths of 0 m (Case C1; left column), 10 m (Case C2; middle column) and 30 m (Case C3; right column).**

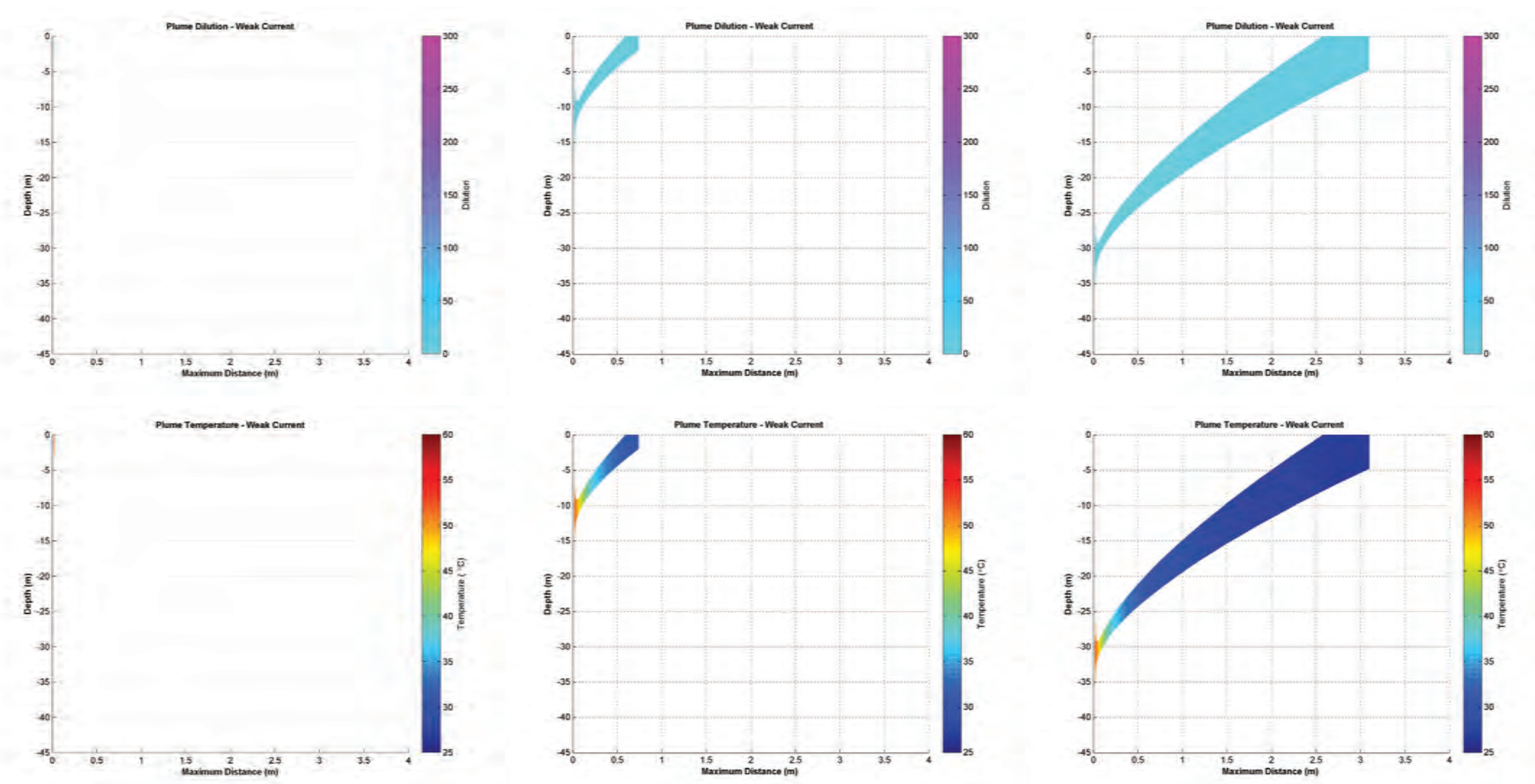



**Figure 3.20 Near-field average dilution and temperature results for constant weak transitional currents with a discharge flow rate of 64,800 m$^3$/d at discharge depths of 0 m (Case C1; left column), 10 m (Case C2; middle column) and 30 m (Case C3; right column).**

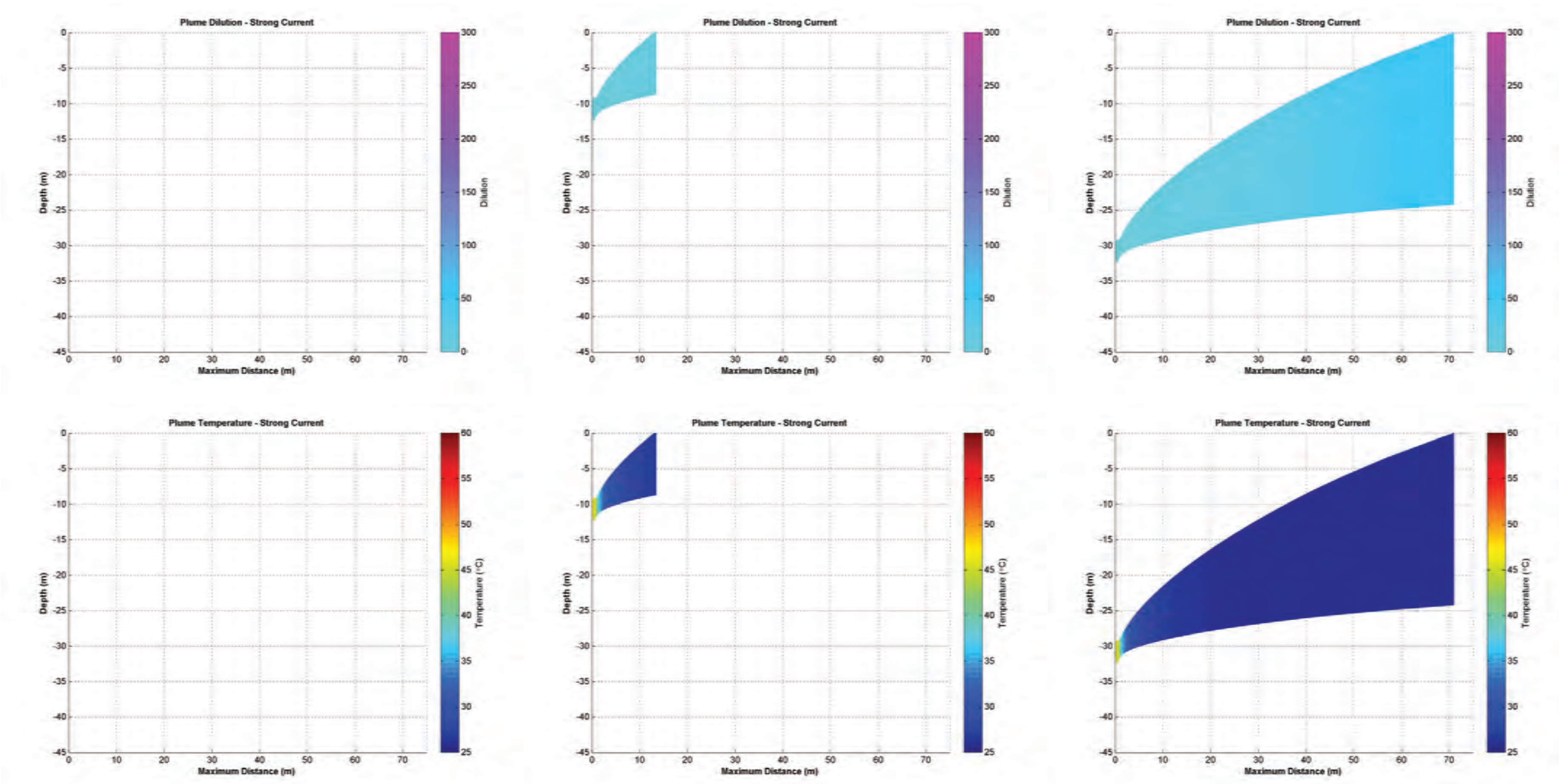



Figure 3.21 Near-field average dilution and temperature results for constant strong transitional currents with a discharge flow rate of 64,800 m³/d at discharge depths of 0 m (Case C1; left column), 10 m (Case C2; middle column) and 30 m (Case C3; right column).

### 3.1.3.2.4 Winter

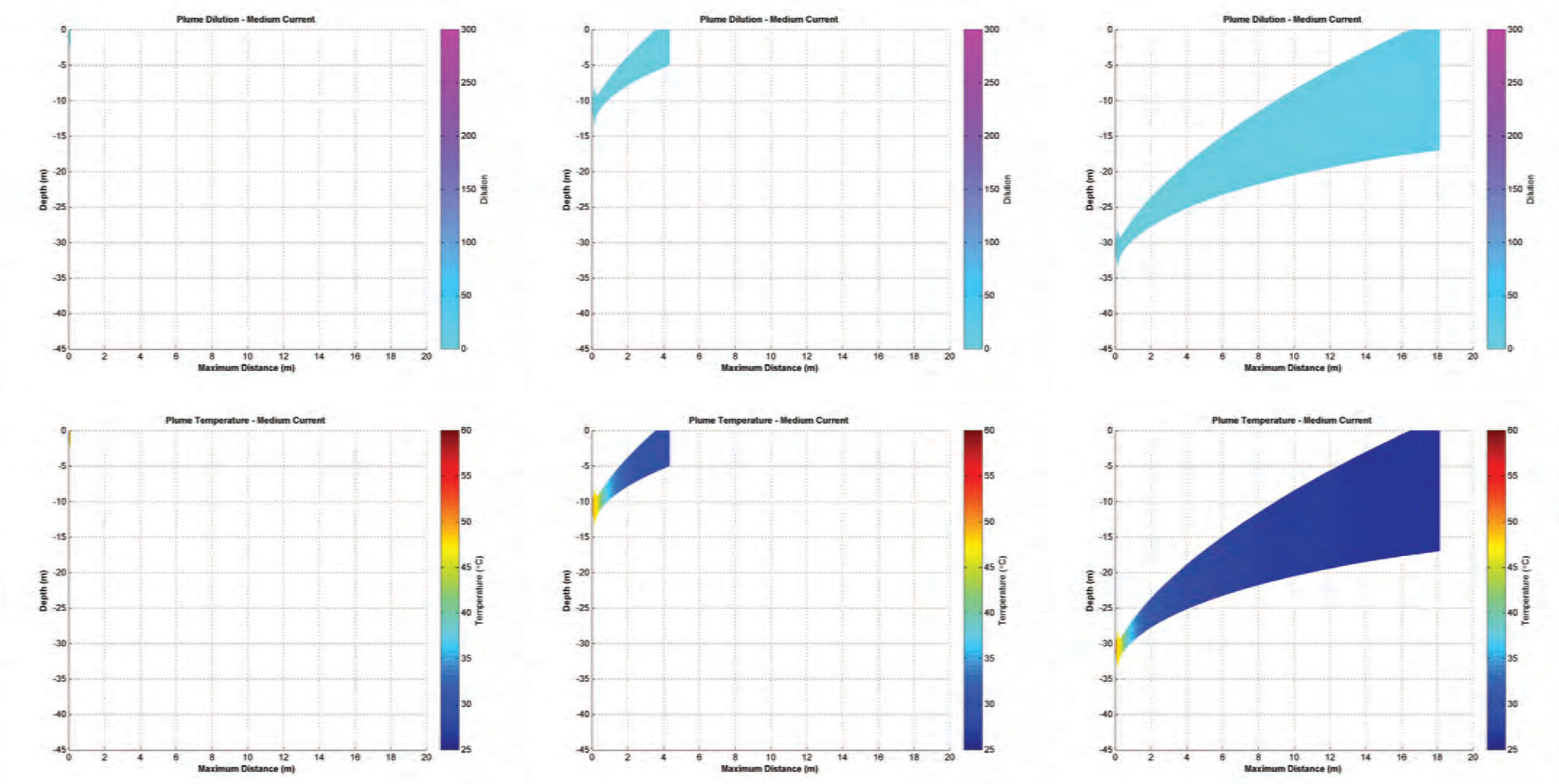



Figure 3.22 Near-field average dilution and temperature results for constant medium winter currents with a discharge flow rate of 64,800 m$^3$/d at discharge depths of 0 m (Case C1; left column), 10 m (Case C2; middle column) and 30 m (Case C3; right column).

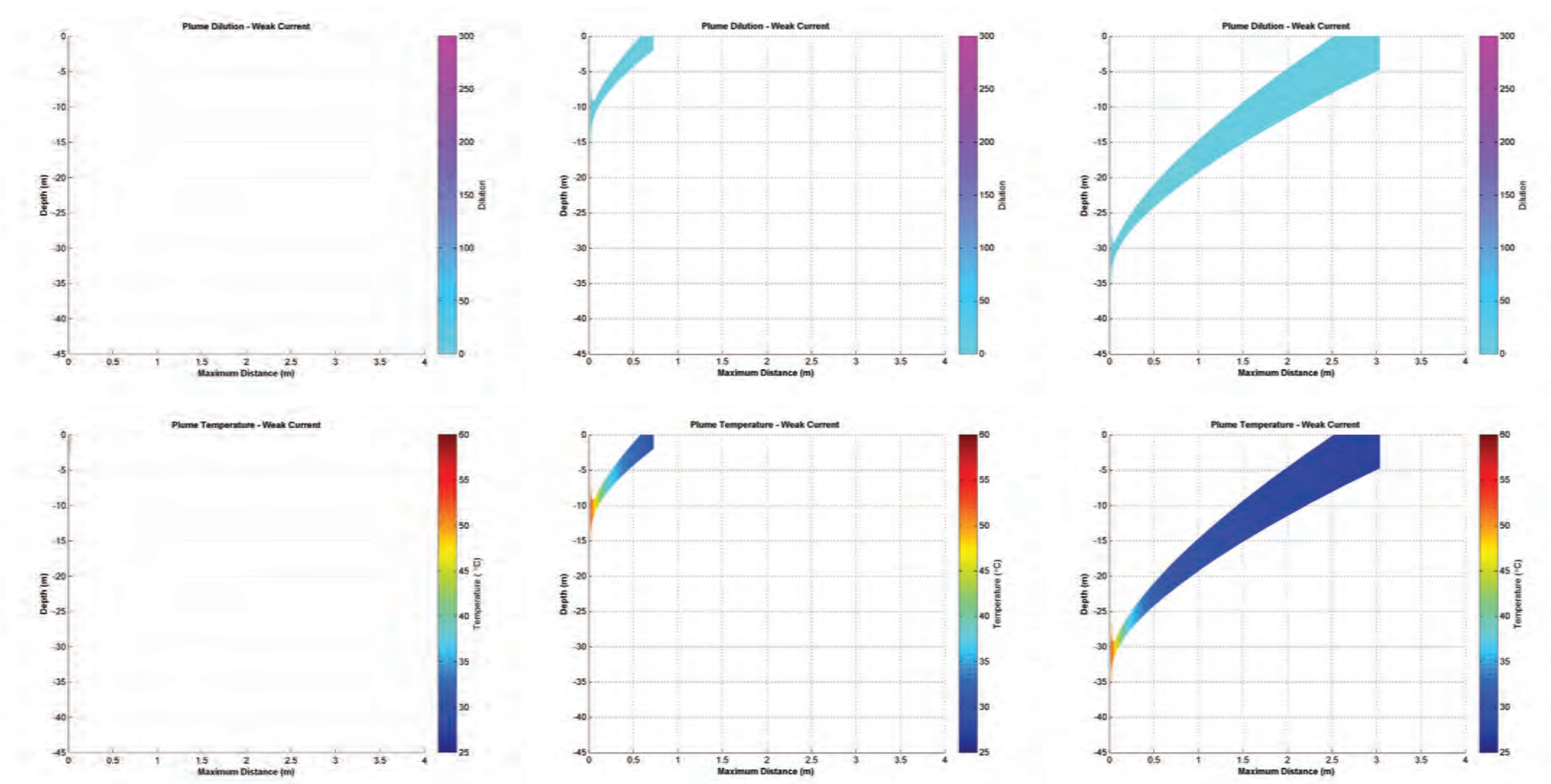



**Figure 3.23 Near-field average dilution and temperature results for constant weak winter currents with a discharge flow rate of 64,800 $m^3/d$ at discharge depths of 0 m (Case C1; left column), 10 m (Case C2; middle column) and 30 m (Case C3; right column).**

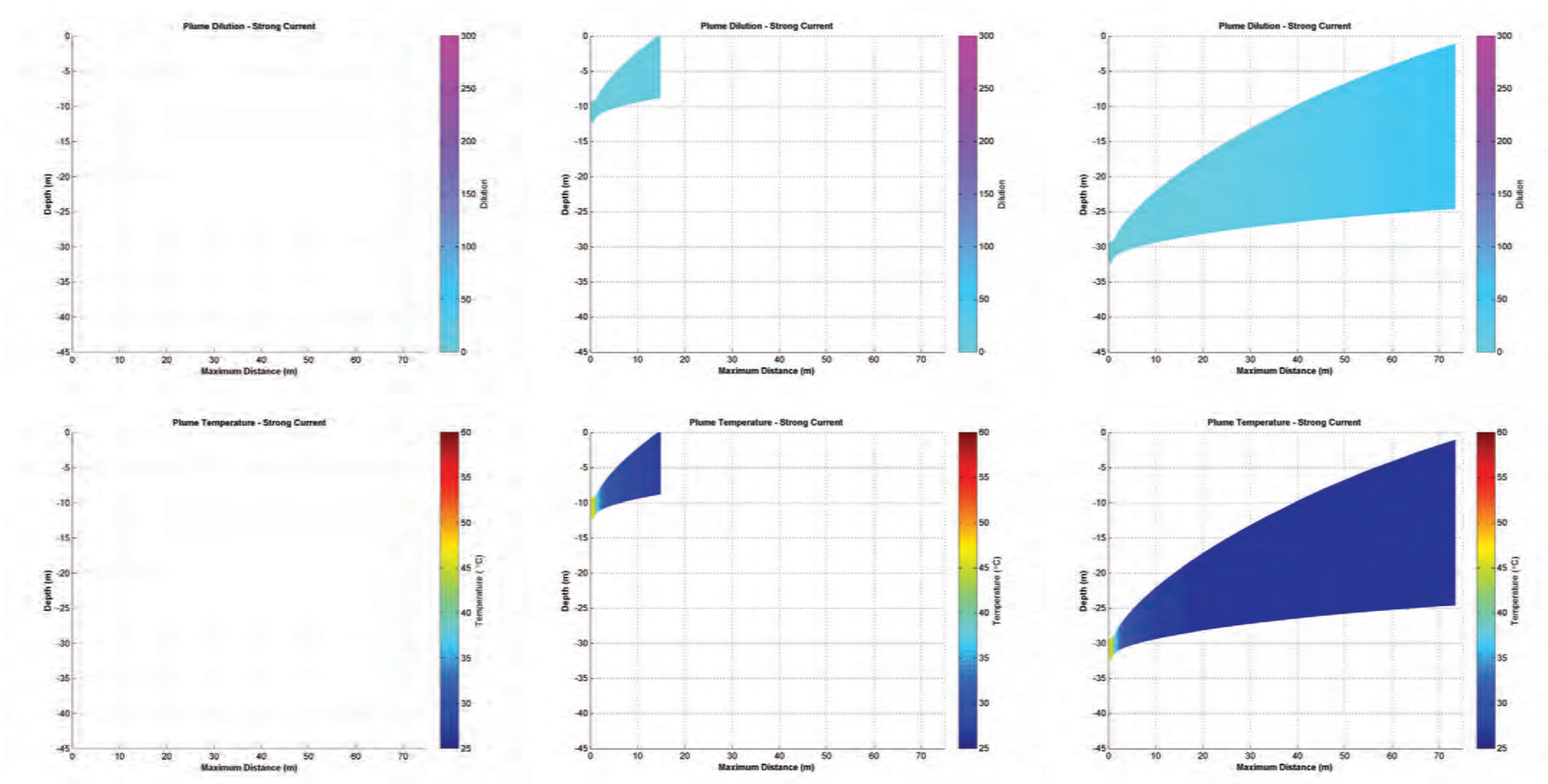



**Figure 3.24 Near-field average dilution and temperature results for constant strong winter currents with a discharge flow rate of 64,800 $m^3/d$ at discharge depths of 0 m (Case C1; left column), 10 m (Case C2; middle column) and 30 m (Case C3; right column).**

### 3.1.3.3 Discharge Flow Rate of 82,800 m$^3$/day at Varying Depths

#### 3.1.3.3.1 Annualised

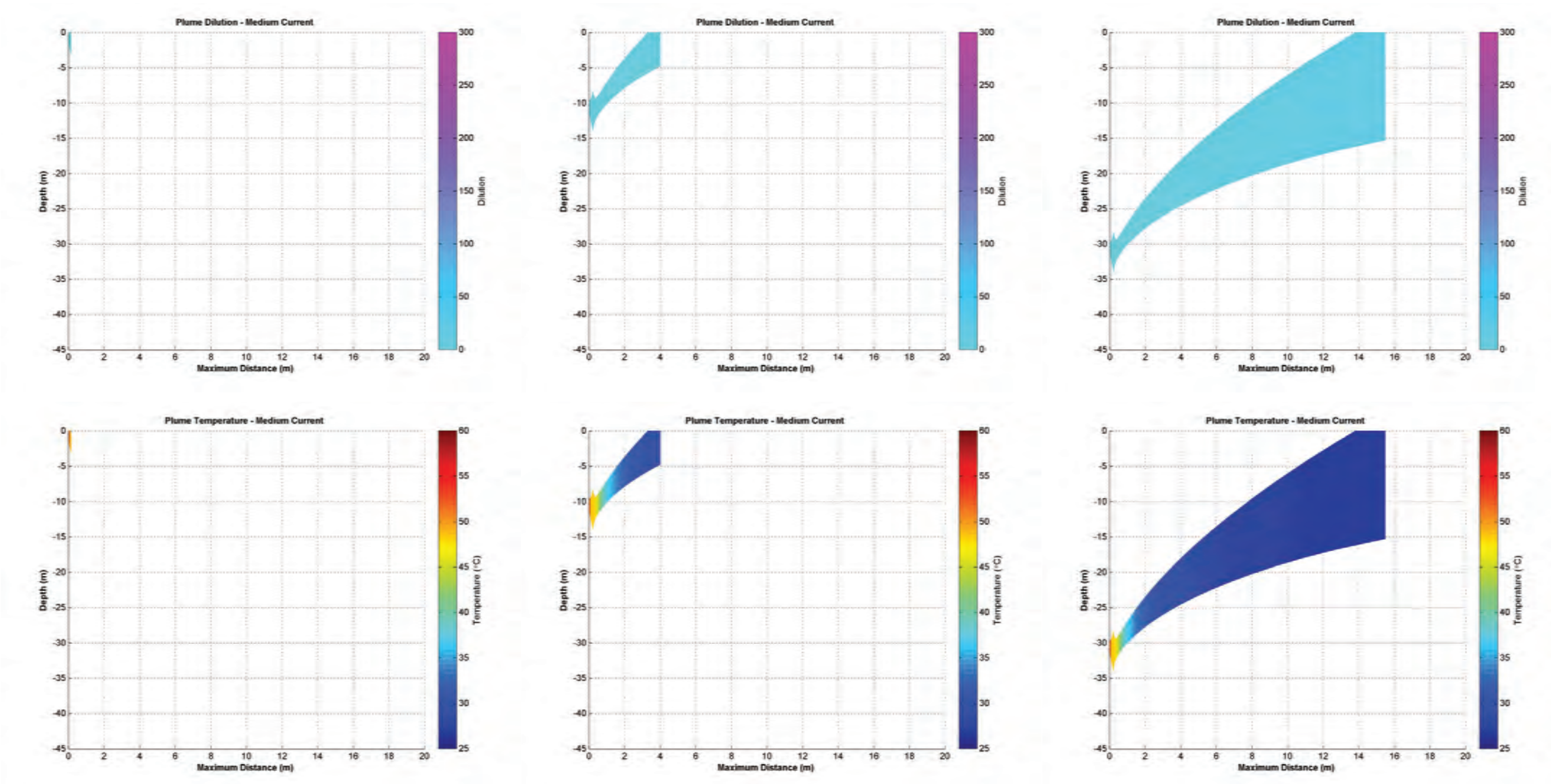



Figure 3.25 Near-field average dilution and temperature results for constant medium annualised currents with a discharge flow rate of 82,800 m$^3$/d at discharge depths of 0 m (Case C1; left column), 10 m (Case C2; middle column) and 30 m (Case C3; right column).

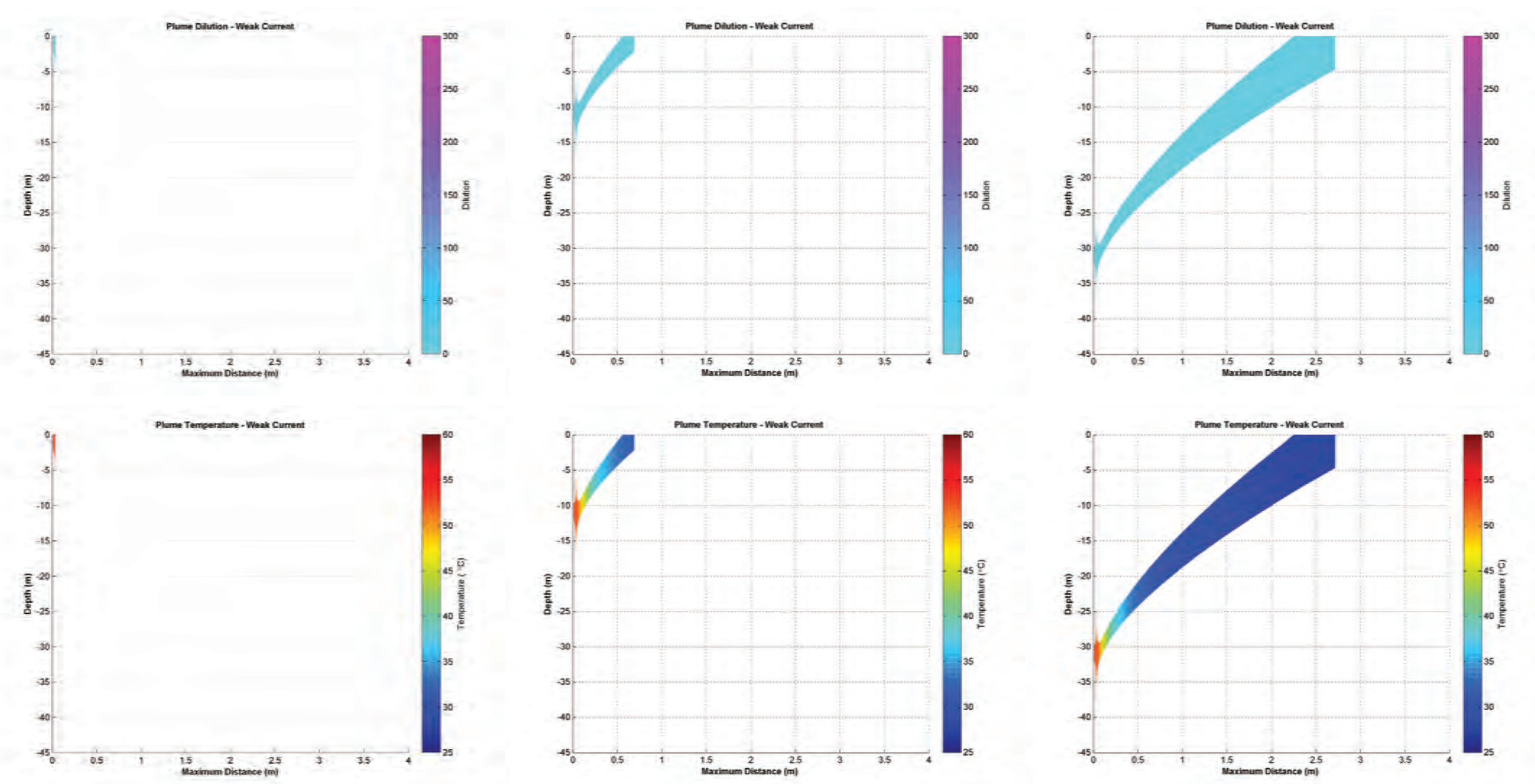



**Figure 3.26 Near-field average dilution and temperature results for constant weak annualised currents with a discharge flow rate of 82,800 m$^3$/d at discharge depths of 0 m (Case C1; left column), 10 m (Case C2; middle column) and 30 m (Case C3; right column).**

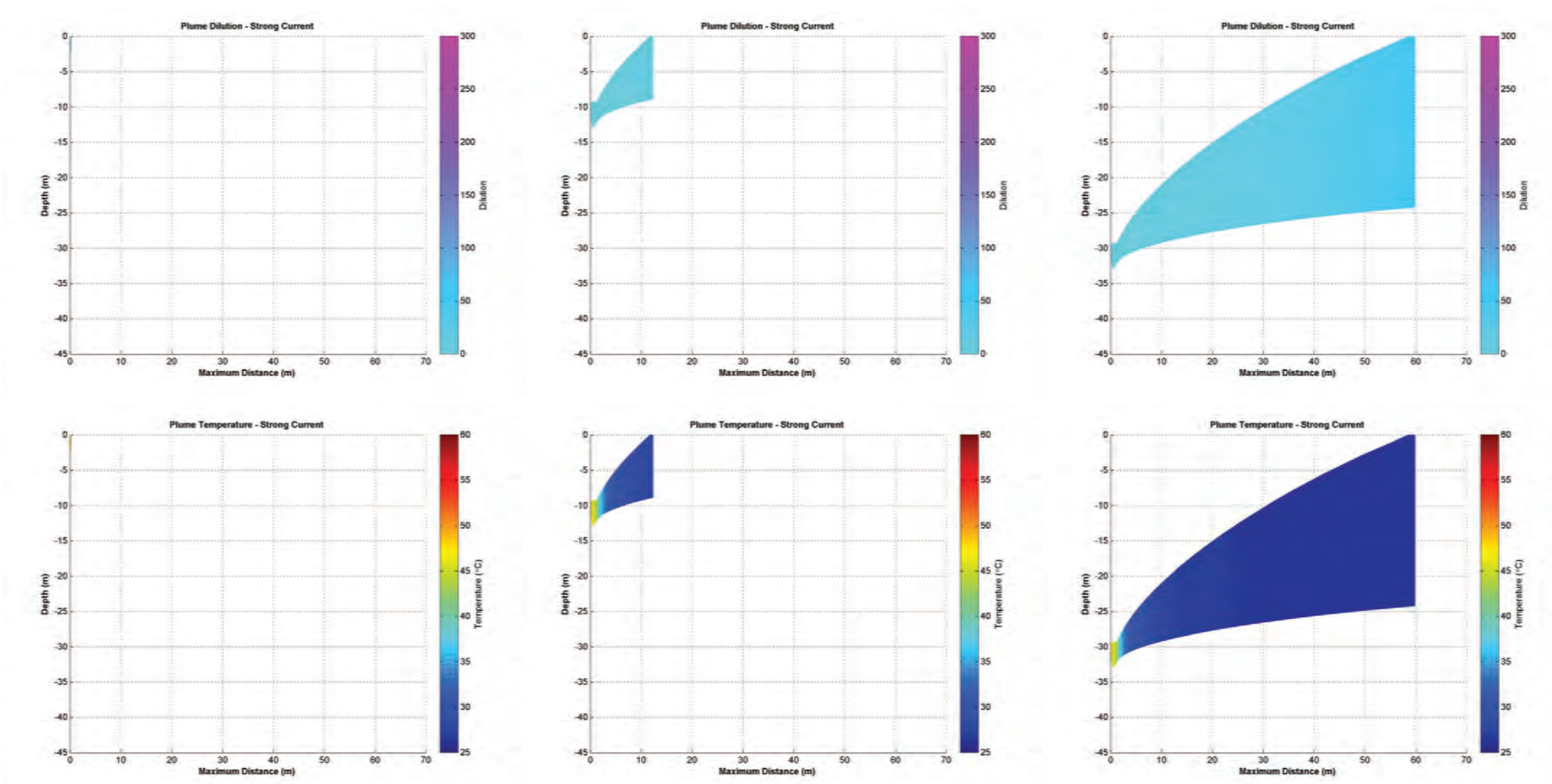



Figure 3.27 Near-field average dilution and temperature results for constant strong annualised currents with a discharge flow rate of 82,800 $m^3$/d at discharge depths of 0 m (Case C1; left column), 10 m (Case C2; middle column) and 30 m (Case C3; right column).

#### 3.1.3.3.2 Summer

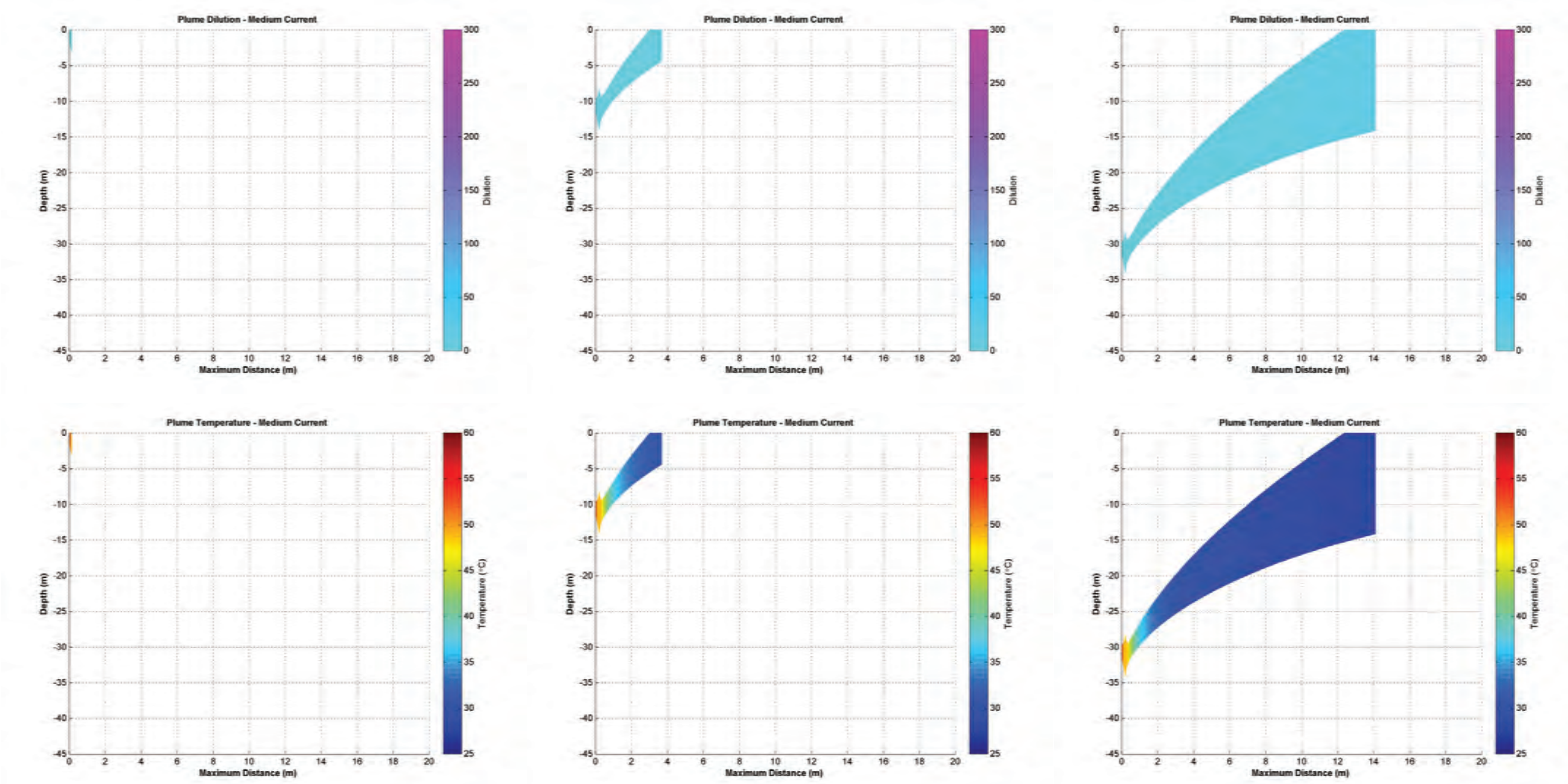



**Figure 3.28 Near-field average dilution and temperature results for constant medium summer currents with a discharge flow rate of 82,800 m³/d at discharge depths of 0 m (Case C1; left column), 10 m (Case C2; middle column) and 30 m (Case C3; right column).**

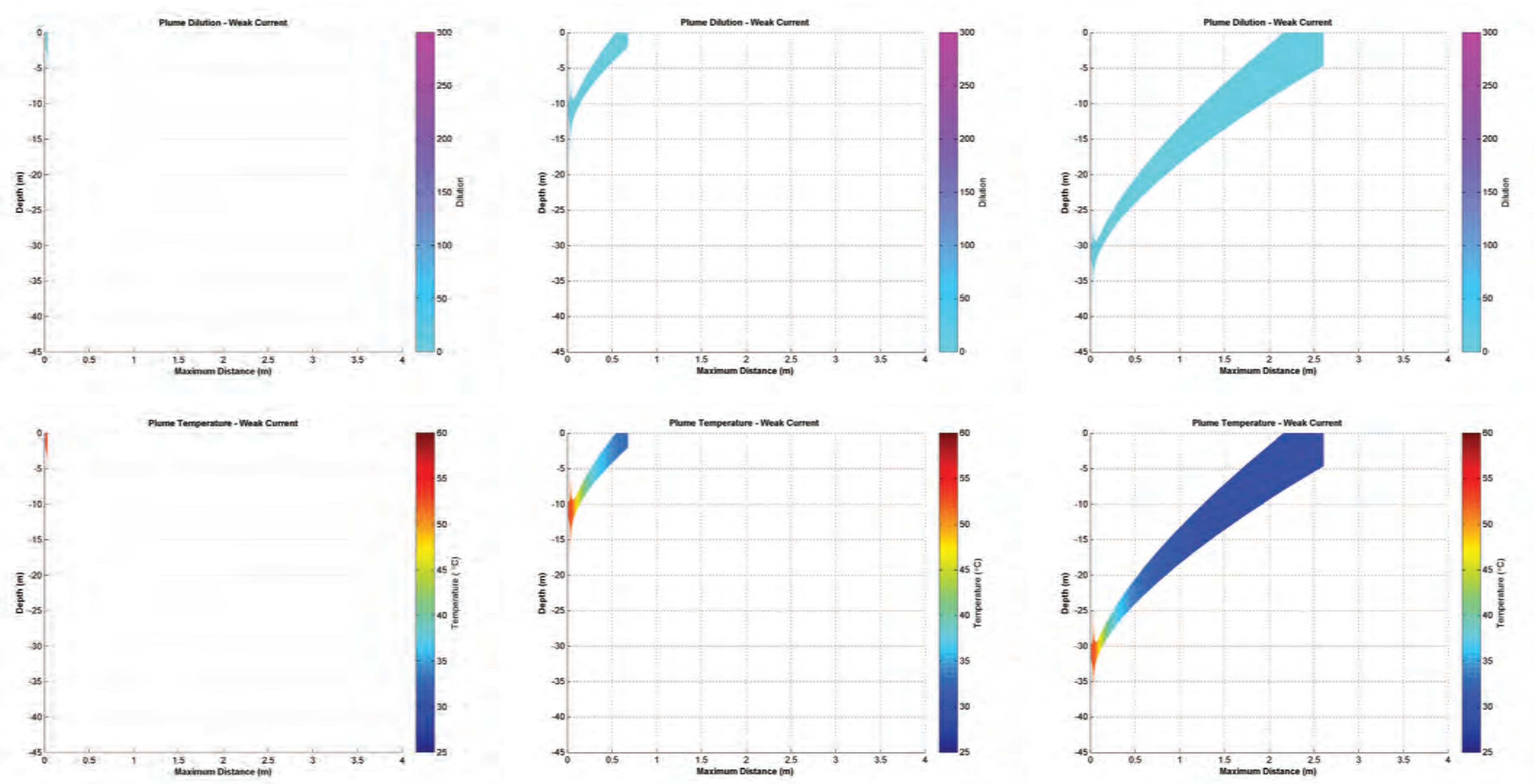



**Figure 3.29 Near-field average dilution and temperature results for constant weak summer currents with a discharge flow rate of 82,800 $m^3/d$ at discharge depths of 0 m (Case C1; left column), 10 m (Case C2; middle column) and 30 m (Case C3; right column).**

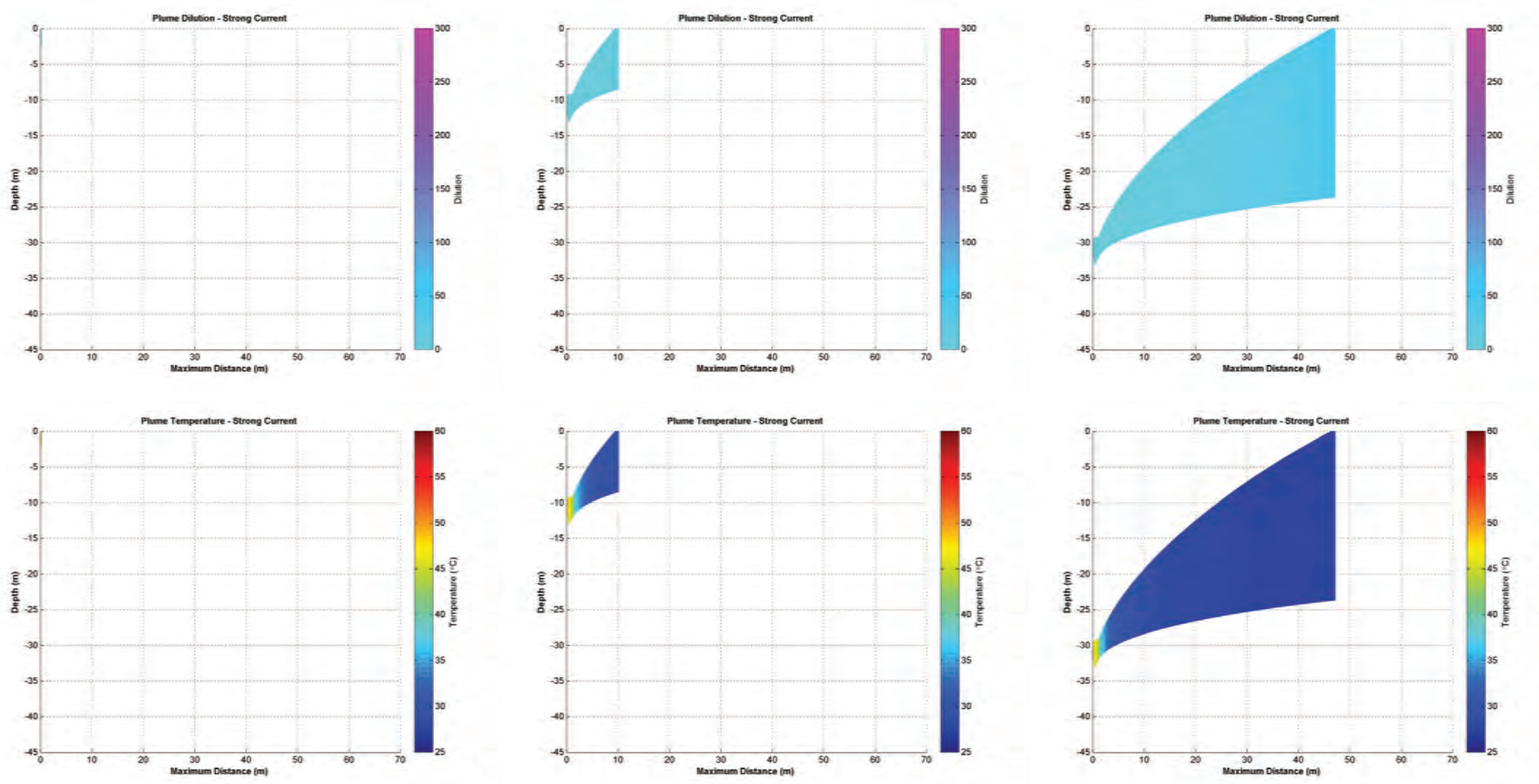



Figure 3.30 **Near-field average dilution and temperature results for constant strong summer currents with a discharge flow rate of 82,800 $m^3/d$ at discharge depths of 0 m (Case C1; left column), 10 m (Case C2; middle column) and 30 m (Case C3; right column).**

#### 3.1.3.3.3 Transitional

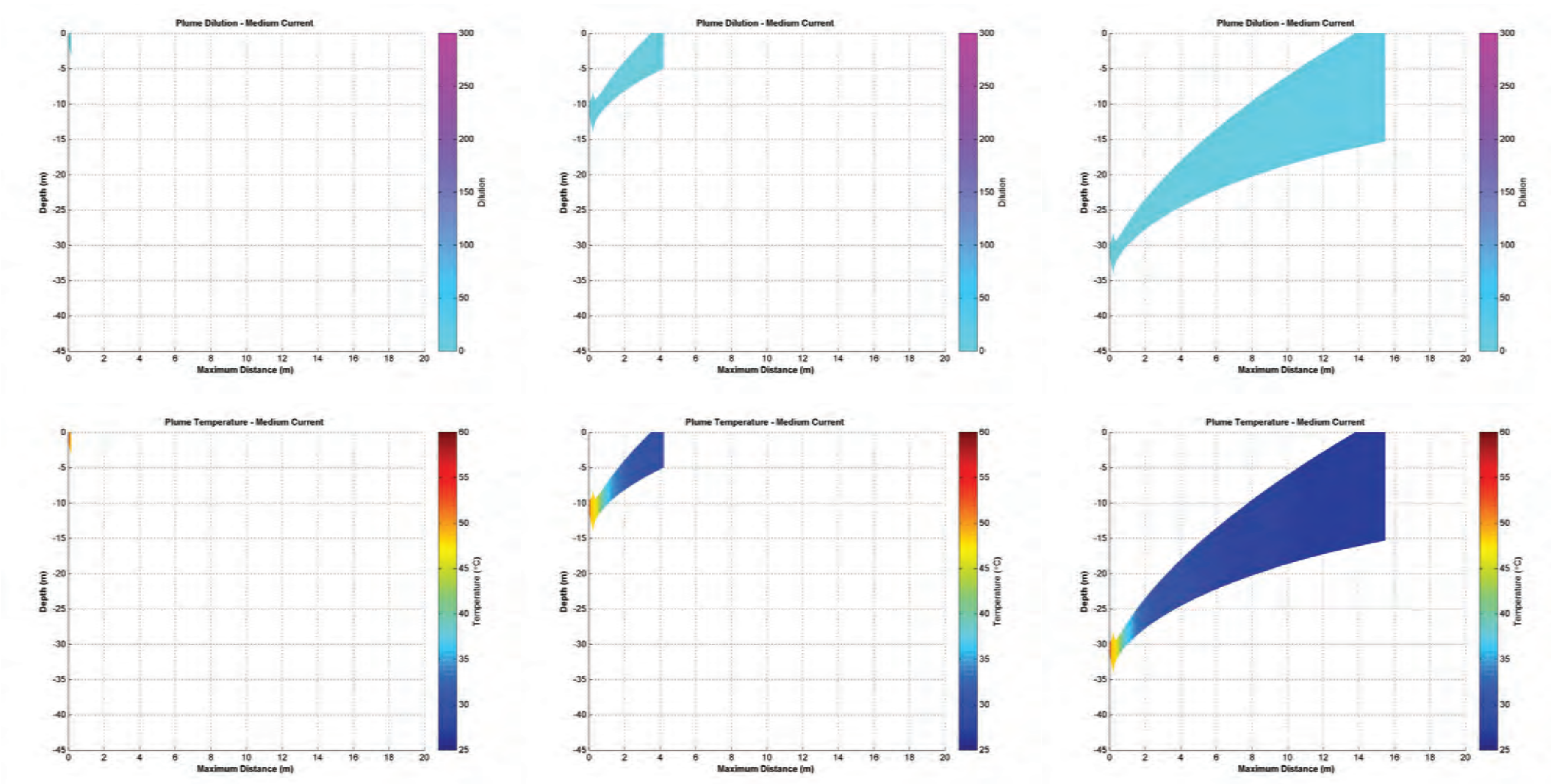



**Figure 3.31 Near-field average dilution and temperature results for constant medium transitional currents with a discharge flow rate of 82,800 $m^3$/d at discharge depths of 0 m (Case C1; left column), 10 m (Case C2; middle column) and 30 m (Case C3; right column).**

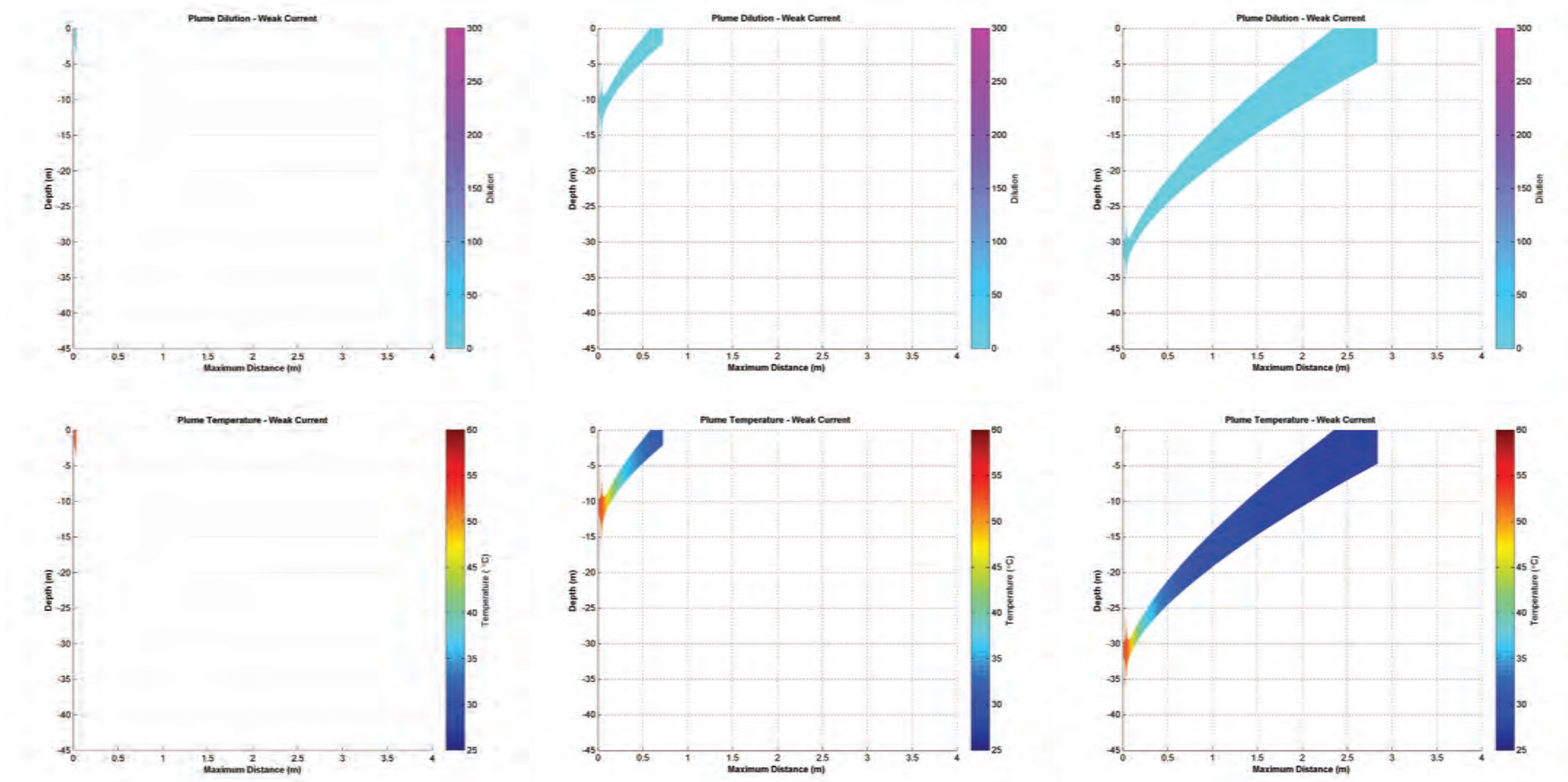



Figure 3.32 Near-field average dilution and temperature results for constant weak transitional currents with a discharge flow rate of 82,800 $m^3/d$ at discharge depths of 0 m (Case C1; left column), 10 m (Case C2; middle column) and 30 m (Case C3; right column).

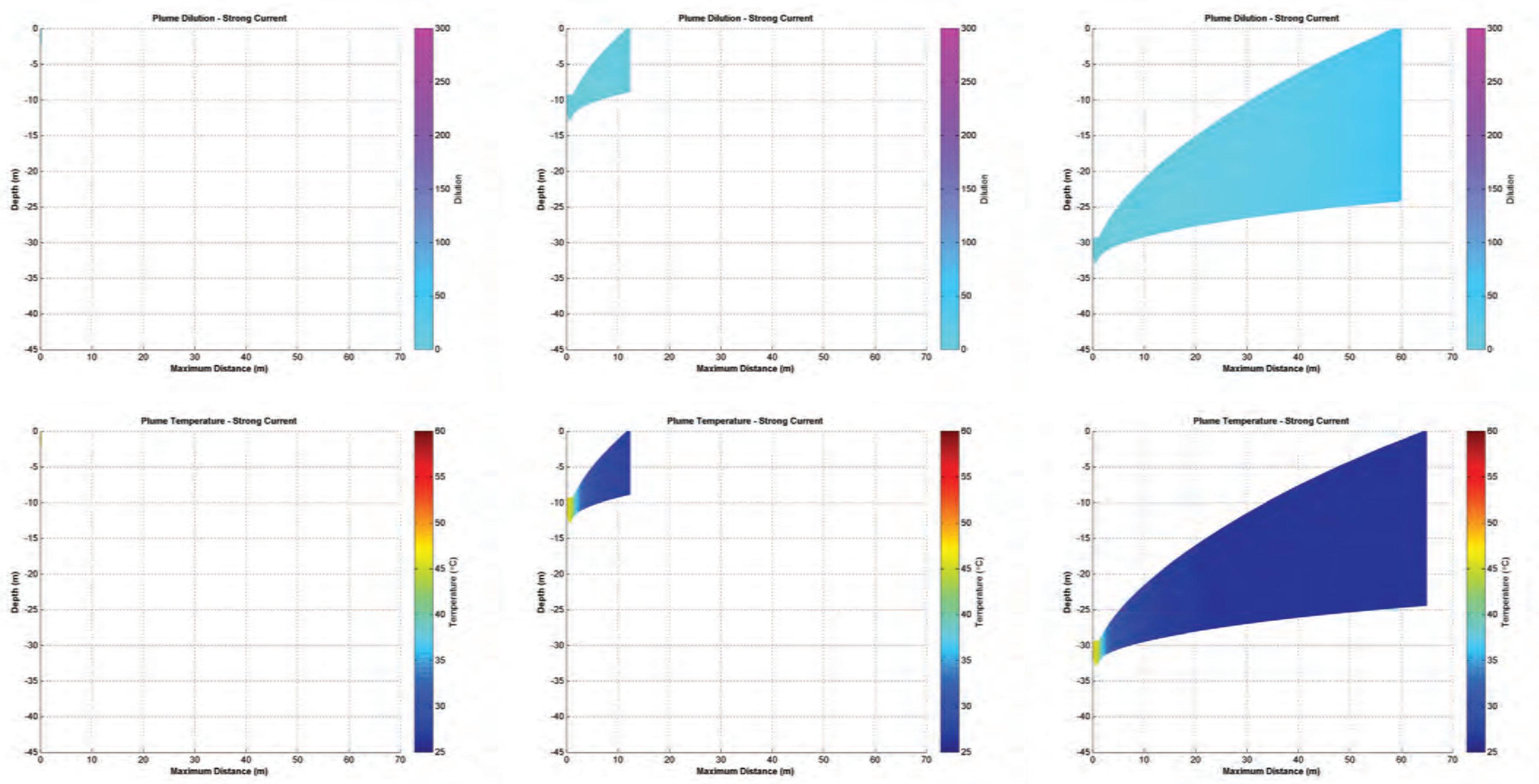



Figure 3.33 Near-field average dilution and temperature results for constant strong transitional currents with a discharge flow rate of 82,800 m³/d at discharge depths of 0 m (Case C1; left column), 10 m (Case C2; middle column) and 30 m (Case C3; right column).

### 3.1.3.3.4 Winter

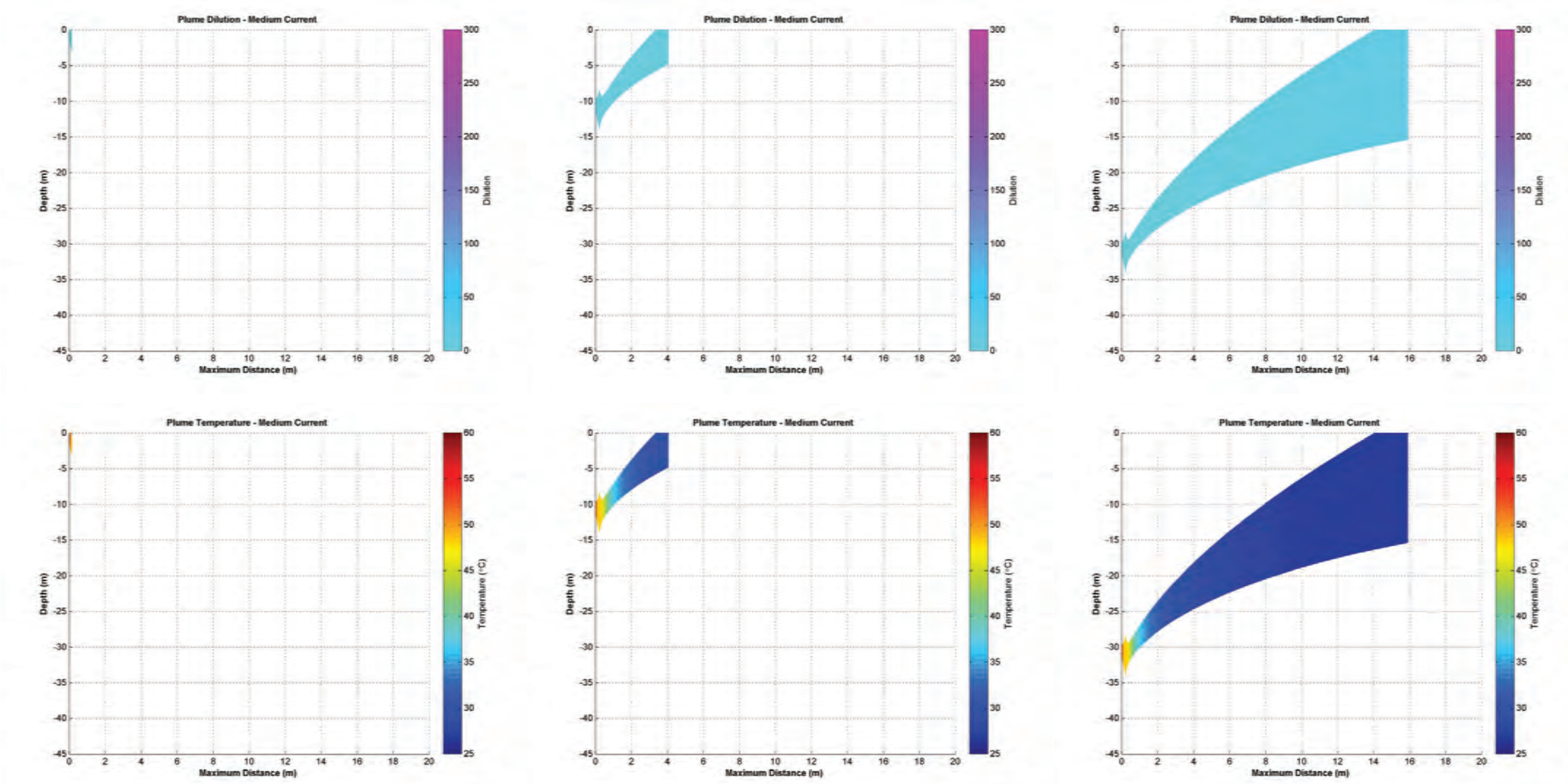



**Figure 3.34 Near-field average dilution and temperature results for constant medium winter currents with a discharge flow rate of 82,800 m³/d at discharge depths of 0 m (Case C1; left column), 10 m (Case C2; middle column) and 30 m (Case C3; right column).**

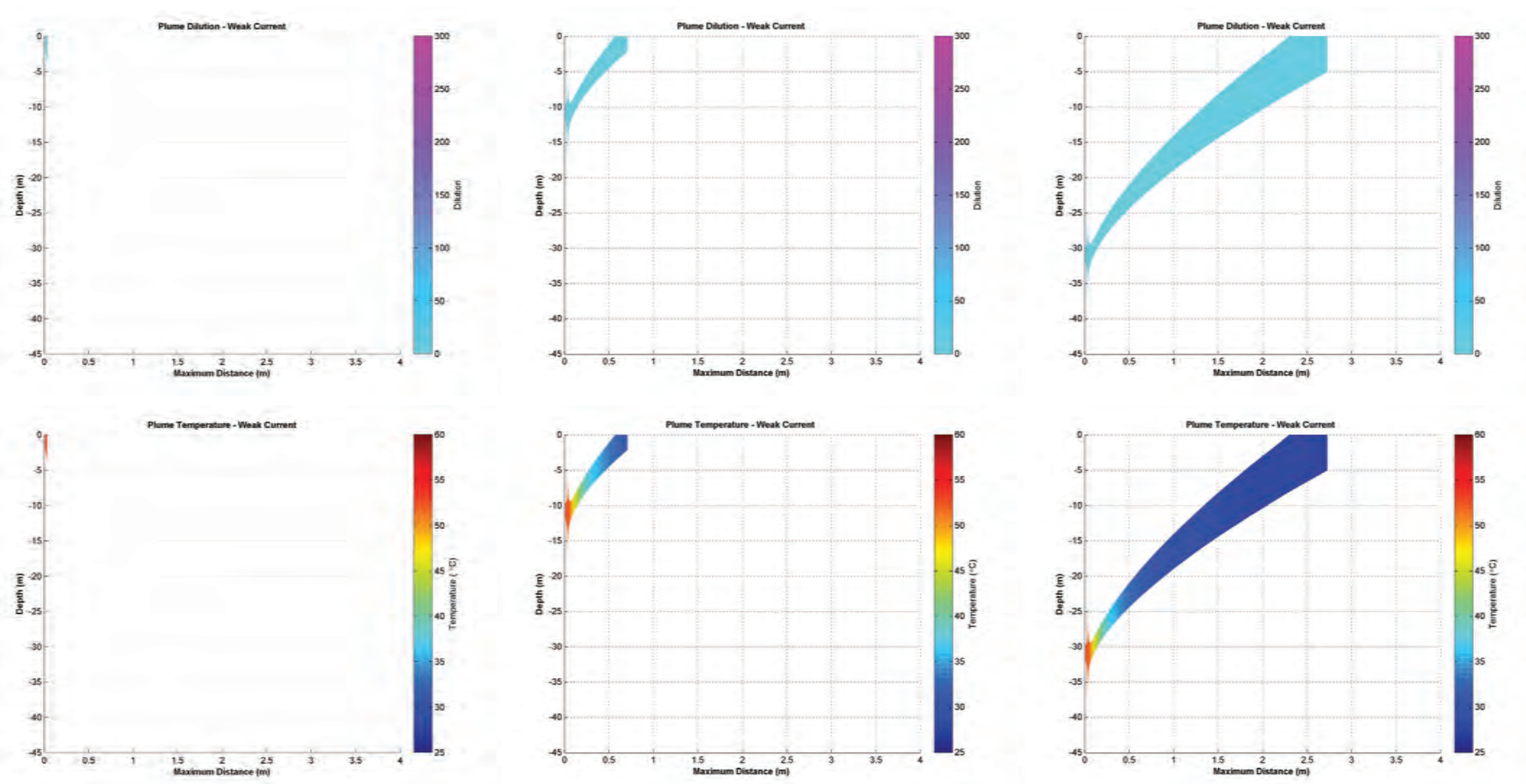



Figure 3.35 Near-field average dilution and temperature results for constant weak winter currents with a discharge flow rate of 82,800 m³/d at discharge depths of 0 m (Case C1; left column), 10 m (Case C2; middle column) and 30 m (Case C3; right column).

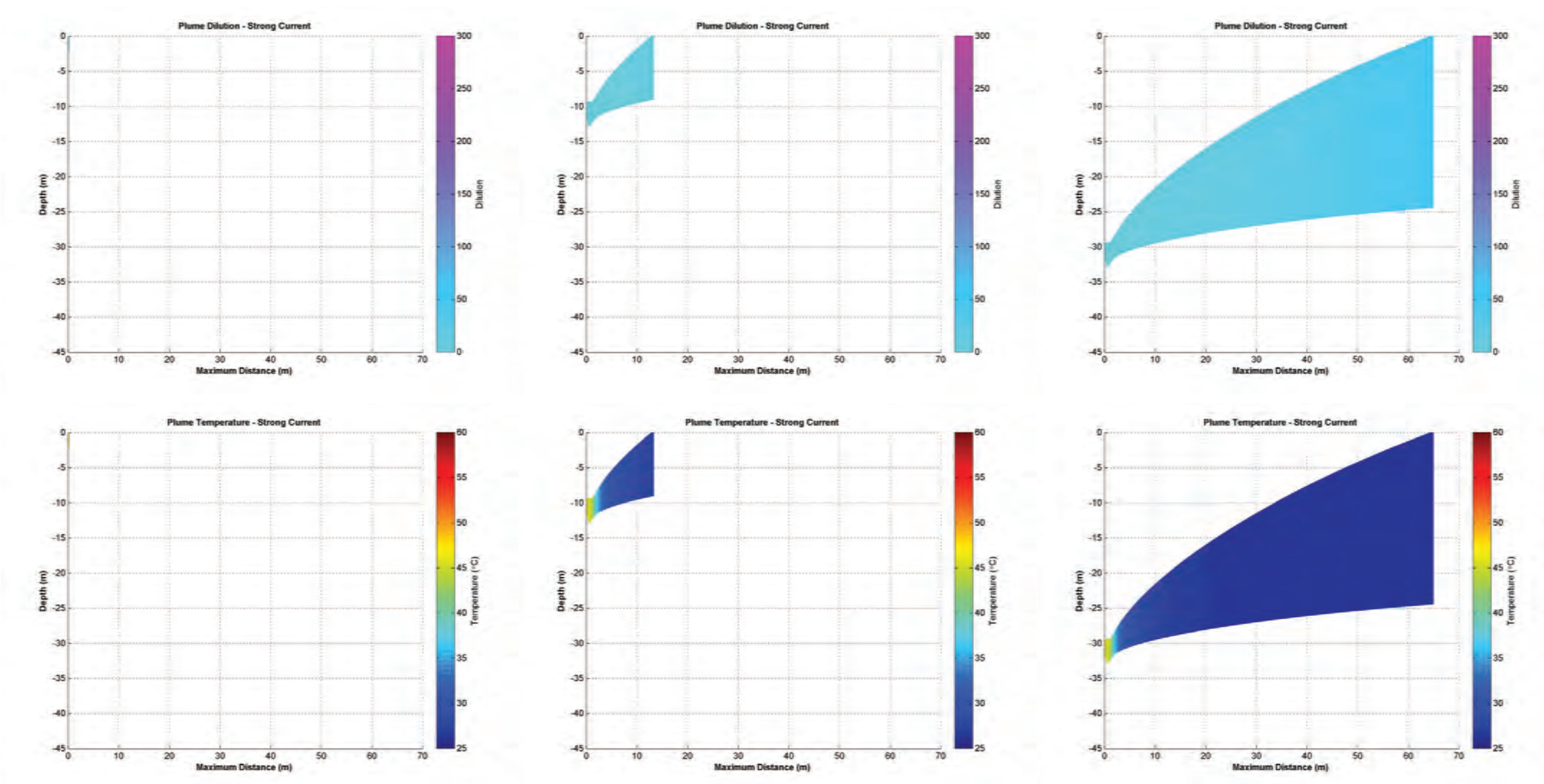



**Figure 3.36 Near-field average dilution and temperature results for constant strong winter currents with a discharge flow rate of 82,800 m$^3$/d at discharge depths of 0 m (Case C1; left column), 10 m (Case C2; middle column) and 30 m (Case C3; right column).**

### 3.1.3.4 Discharge Depth of 0 m (Surface) with Varying Flow Rates

#### 3.1.3.4.1 Annualised

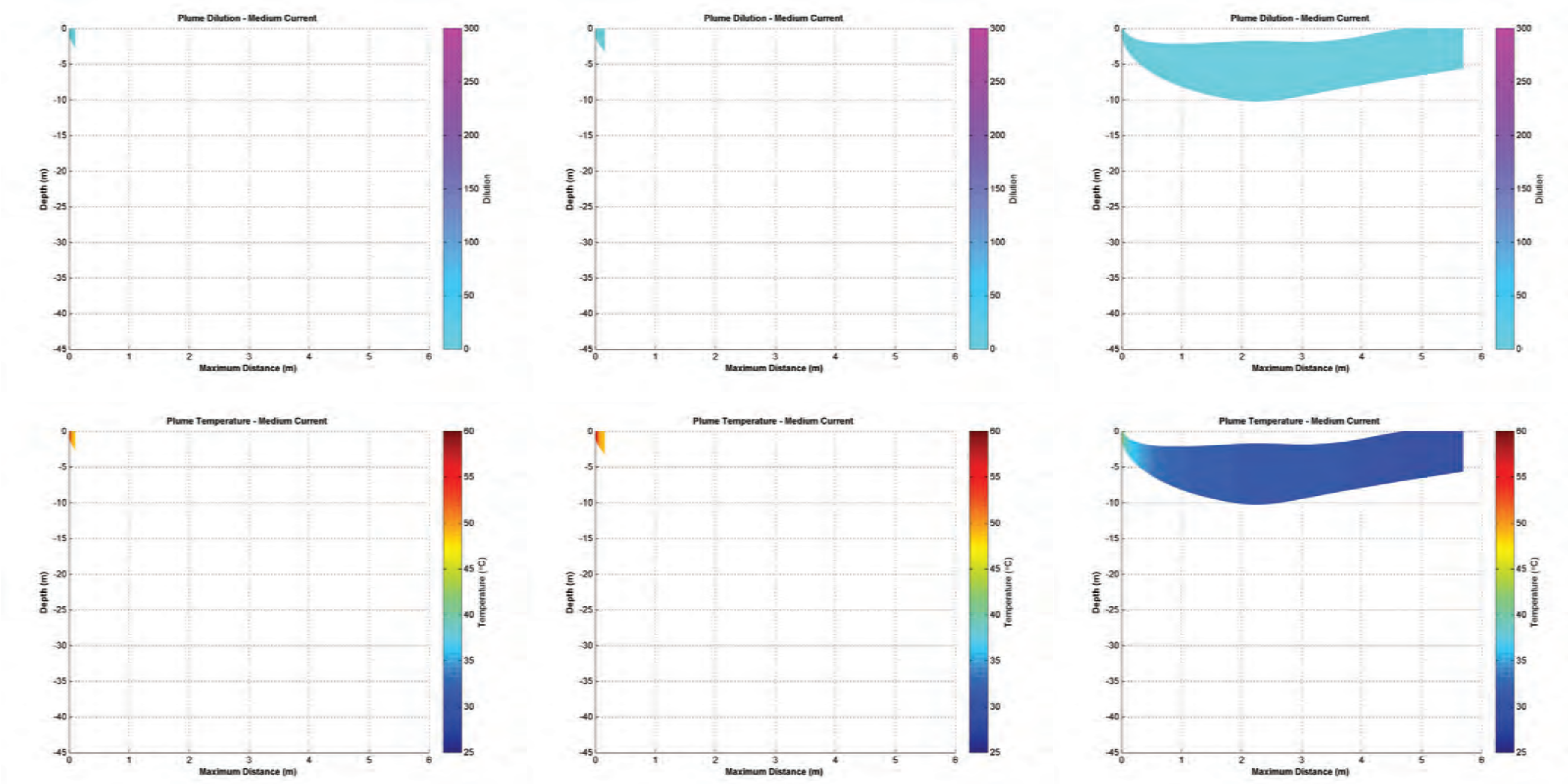



Figure 3.37 Near-field average dilution and temperature results for constant medium annualised currents with discharge flow rates of 64,800 $m^3/d$ (Case C4; left column), 82,800 $m^3/d$ (Case C7; middle column) and 165,600 $m^3/d$ (Case C1; right column) at a discharge depth of 0 m.

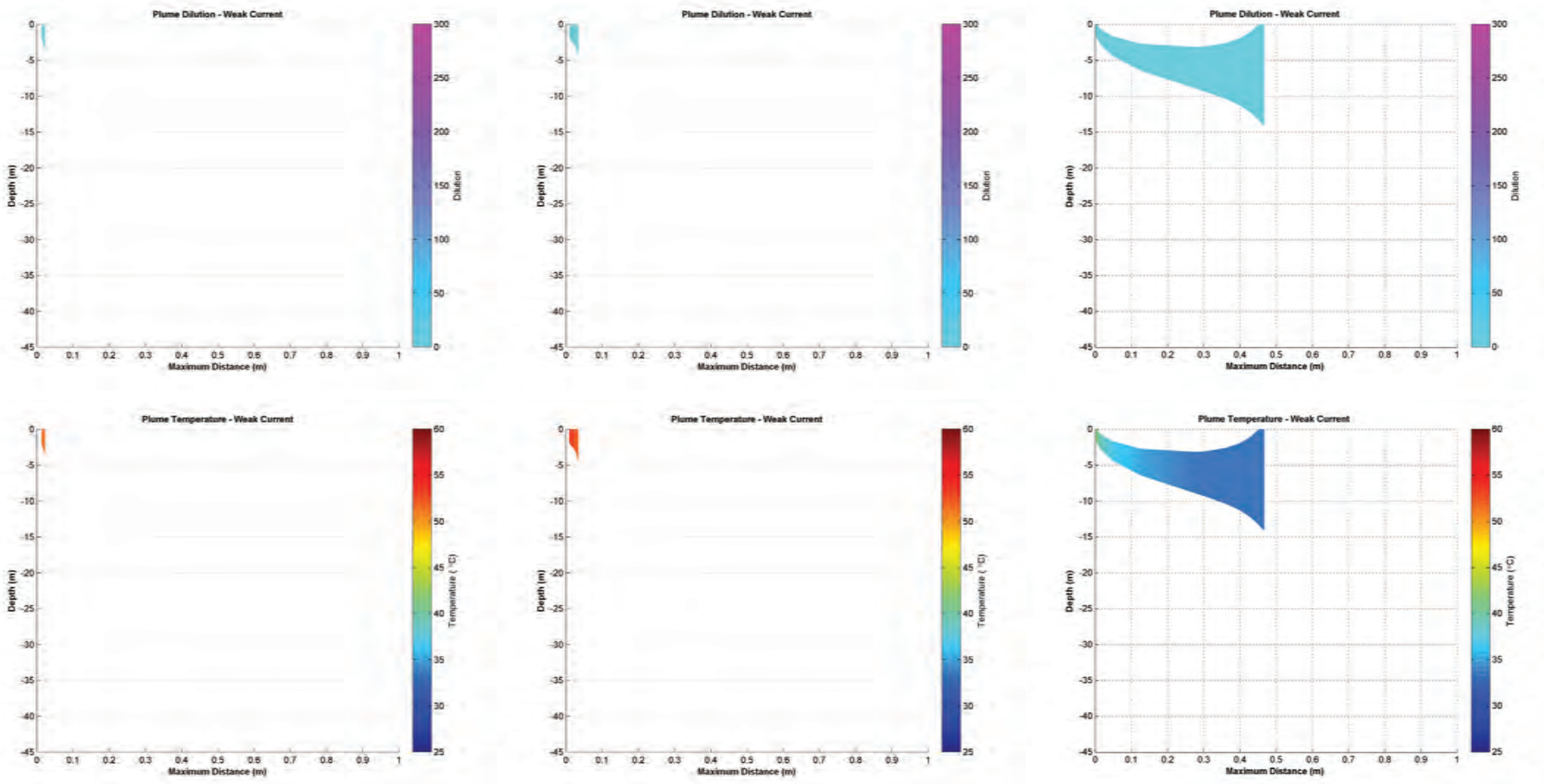



Figure 3.38 Near-field average dilution and temperature results for constant weak annualised currents with discharge flow rates of 64,800 $m^3$/d (Case C4; left column), 82,800 $m^3$/d (Case C7; middle column) and 165,600 $m^3$/d (Case C1; right column) at a discharge depth of 0 m.

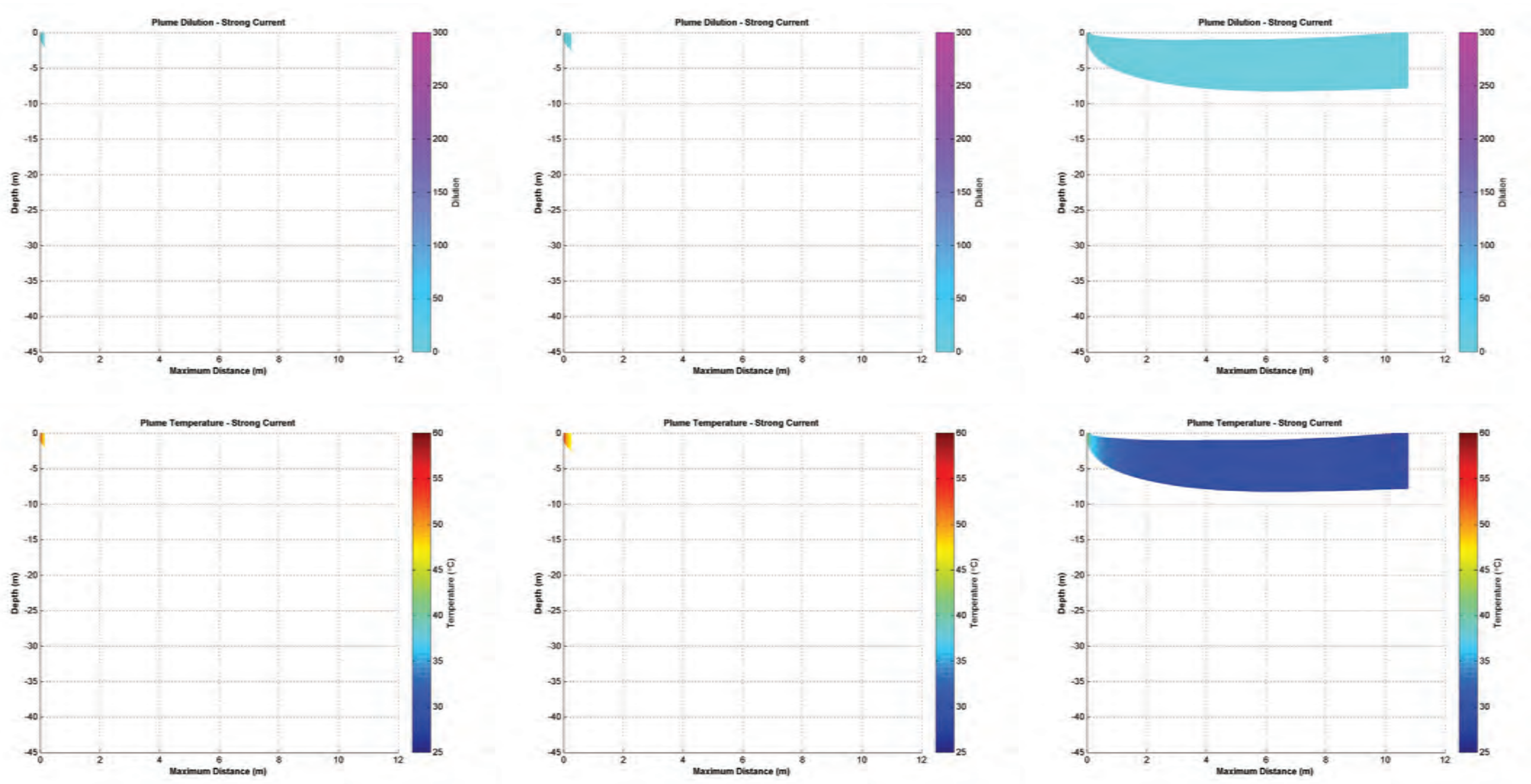



**Figure 3.39 Near-field average dilution and temperature results for constant strong annualised currents with discharge flow rates of 64,800 $m^3/d$ (Case C4; left column), 82,800 $m^3/d$ (Case C7; middle column) and 165,600 $m^3/d$ (Case C1; right column) at a discharge depth of 0 m.**

### 3.1.3.4.2 Summer

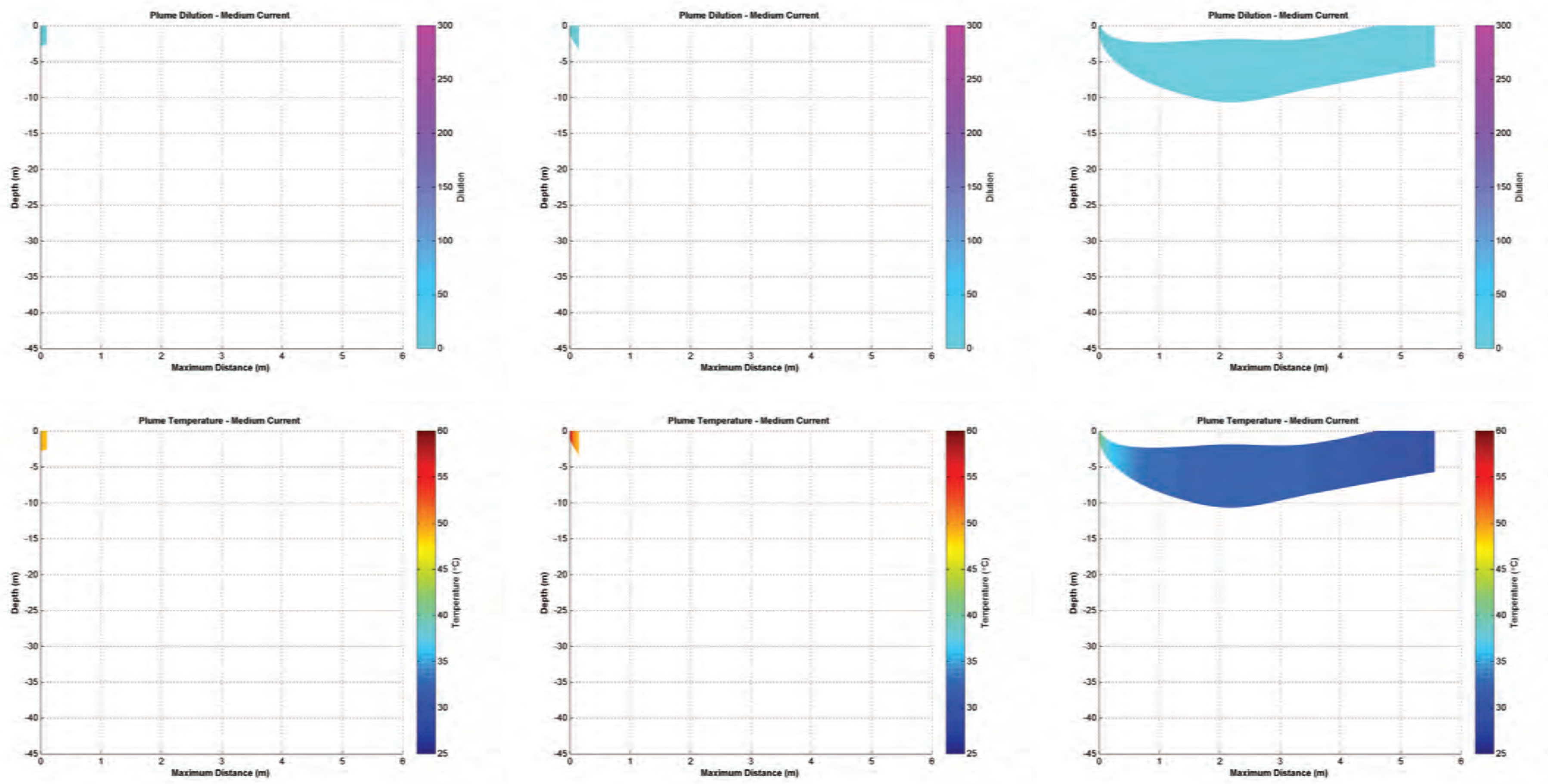



**Figure 3.40 Near-field average dilution and temperature results for constant medium summer currents with discharge flow rates of 64,800 $m^3$/d (Case C4; left column), 82,800 $m^3$/d (Case C7; middle column) and 165,600 $m^3$/d (Case C1; right column) at a discharge depth of 0 m.**

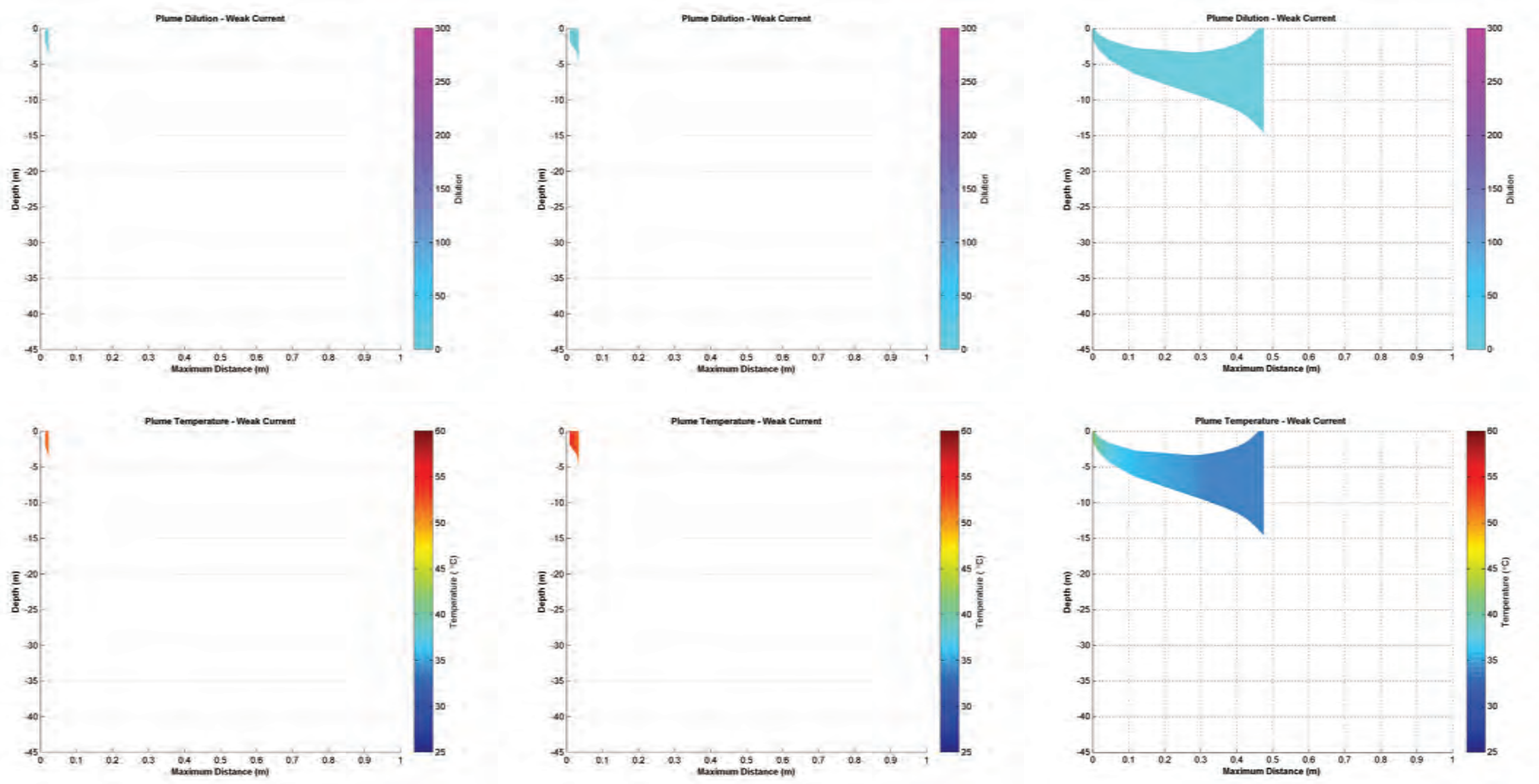



**Figure 3.41** Near-field average dilution and temperature results for constant weak summer currents with discharge flow rates of 64,800 $m^3/d$ (Case C4; left column), 82,800 $m^3/d$ (Case C7; middle column) and 165,600 $m^3/d$ (Case C1; right column) at a discharge depth of 0 m.

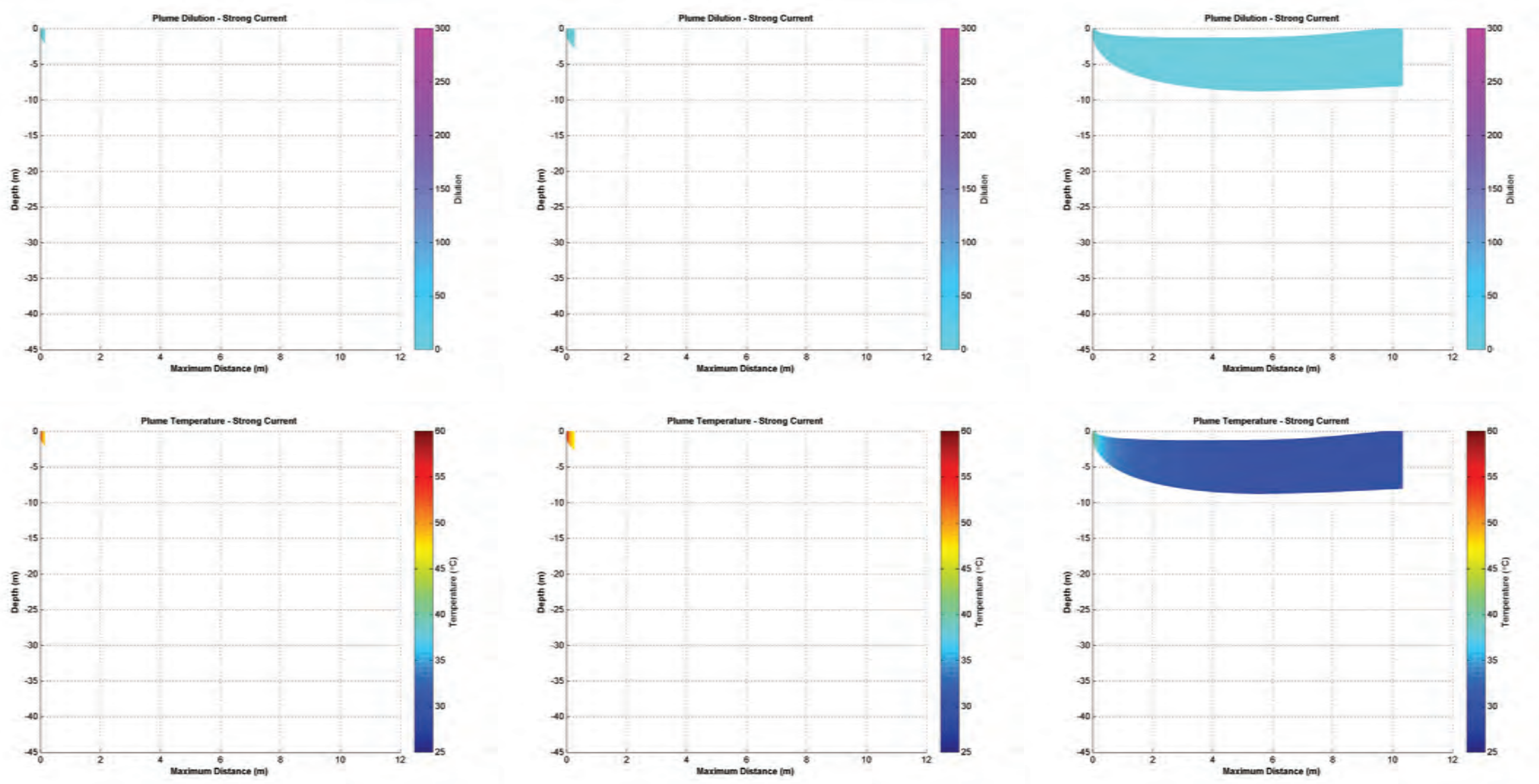



**Figure 3.42 Near-field average dilution and temperature results for constant strong summer currents with discharge flow rates of 64,800 $m^3/d$ (Case C4; left column), 82,800 $m^3/d$ (Case C7; middle column) and 165,600 $m^3/d$ (Case C1; right column) at a discharge depth of 0 m.**

### 3.1.3.4.3 Transitional

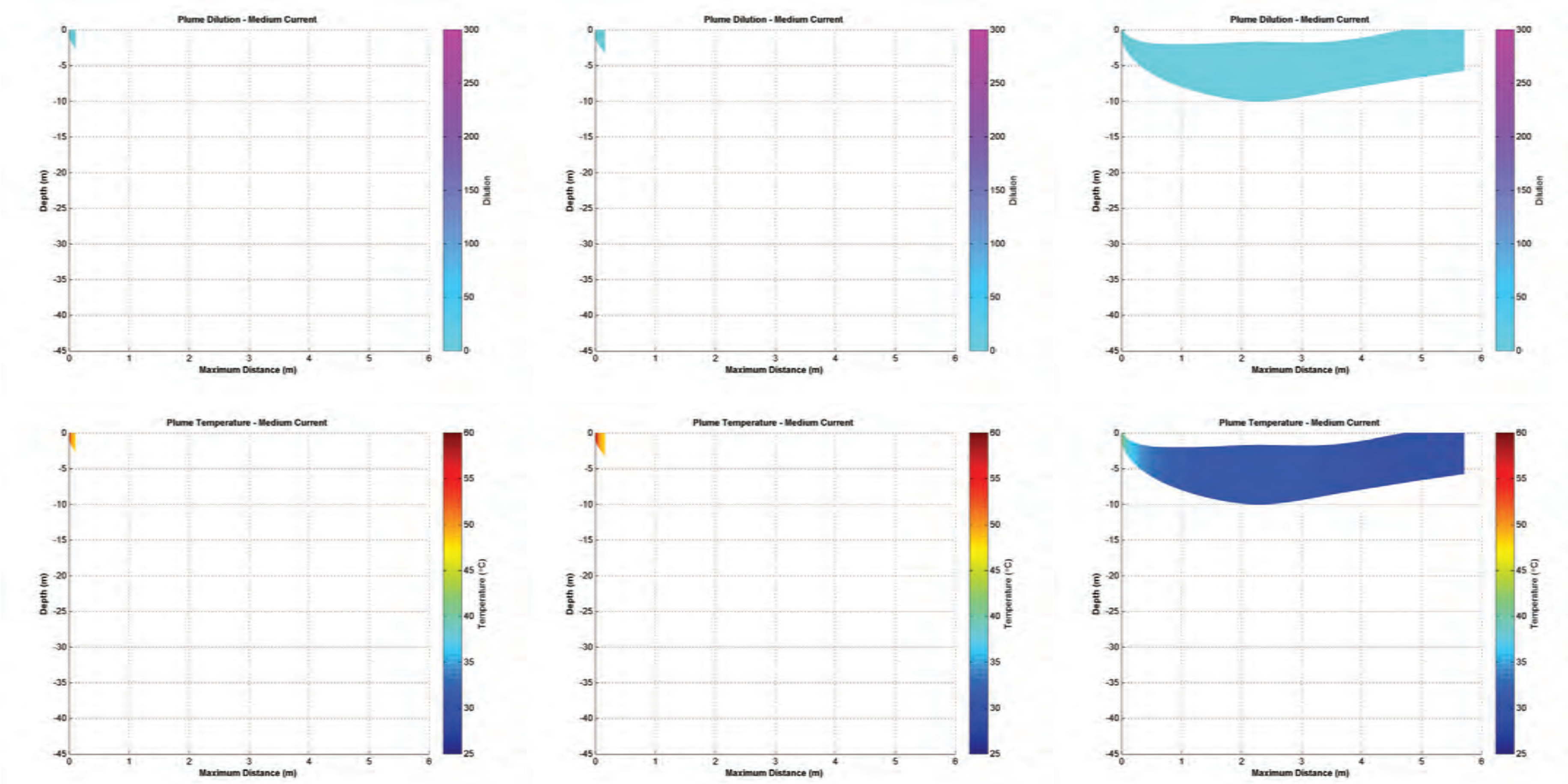



**Figure 3.43 Near-field average dilution and temperature results for constant medium transitional currents with discharge flow rates of 64,800 m$^3$/d (Case C4; left column), 82,800 m$^3$/d (Case C7; middle column) and 165,600 m$^3$/d (Case C1; right column) at a discharge depth of 0 m.**

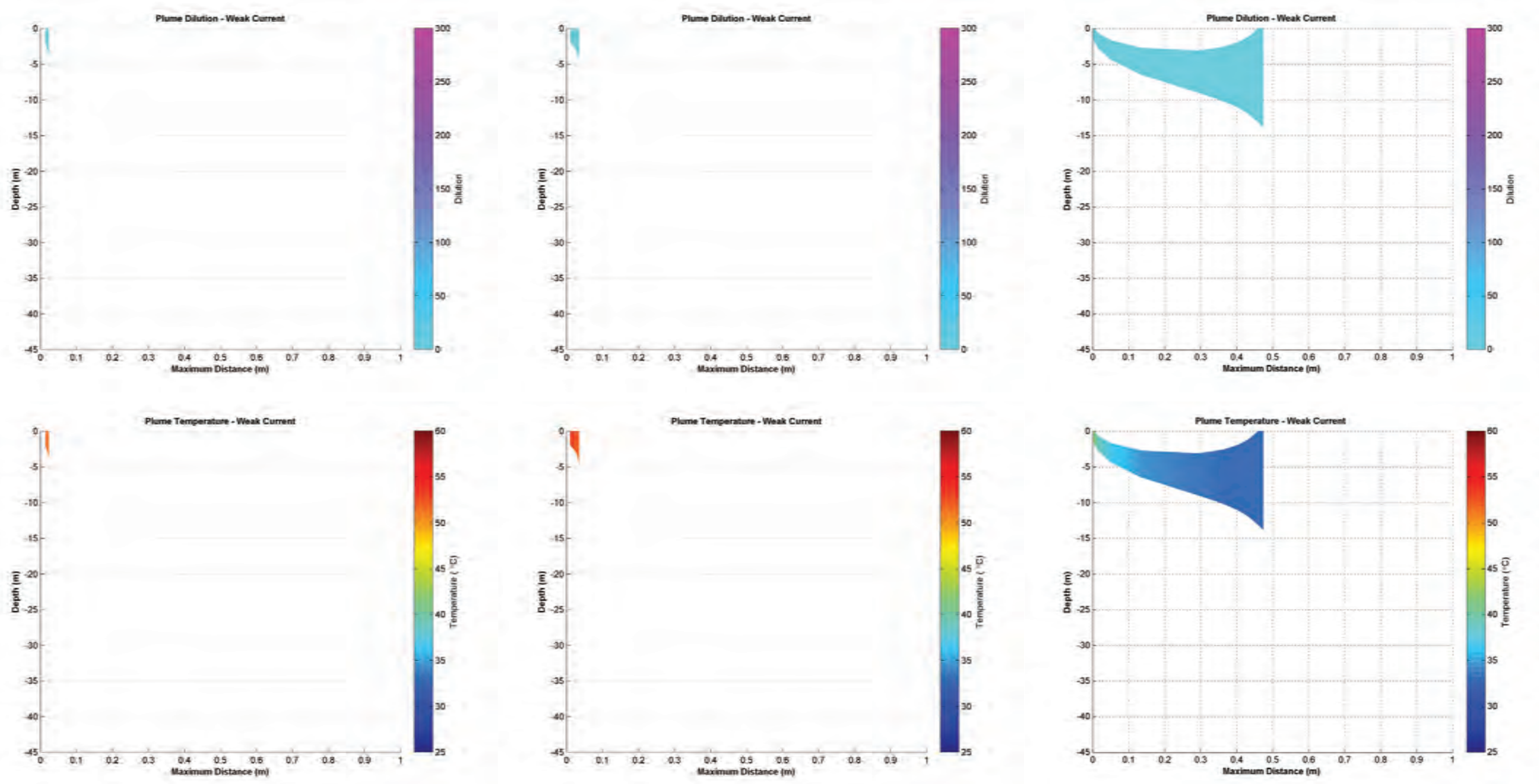



Figure 3.44 Near-field average dilution and temperature results for constant weak transitional currents with discharge flow rates of 64,800 m³/d (Case C4; left column), 82,800 m³/d (Case C7; middle column) and 165,600 m³/d (Case C1; right column) at a discharge depth of 0 m.

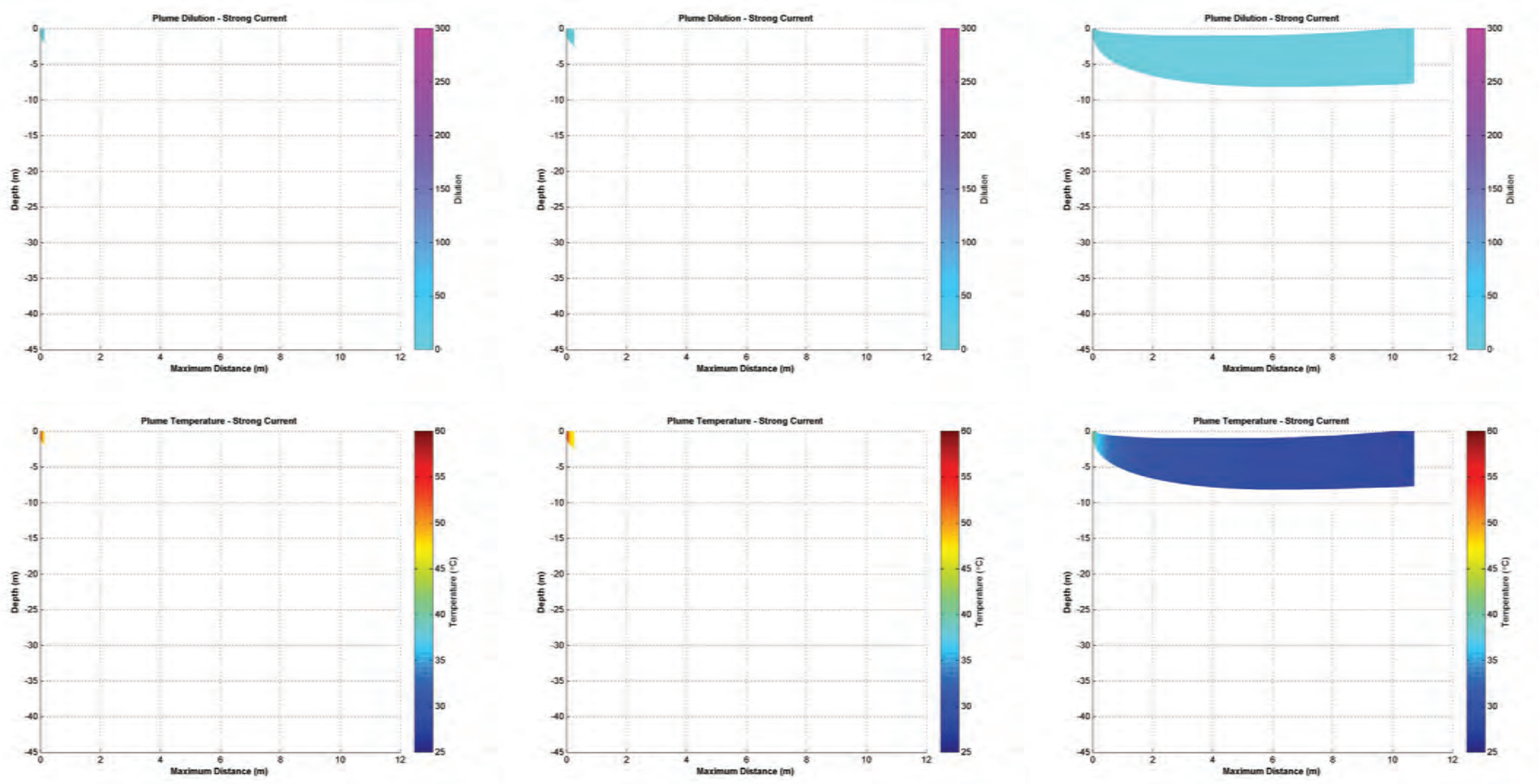



Figure 3.45 Near-field average dilution and temperature results for constant strong transitional currents with discharge flow rates of 64,800 $m^3/d$ (Case C4; left column), 82,800 $m^3/d$ (Case C7; middle column) and 165,600 $m^3/d$ (Case C1; right column) at a discharge depth of 0 m.

### 3.1.3.4.4 Winter

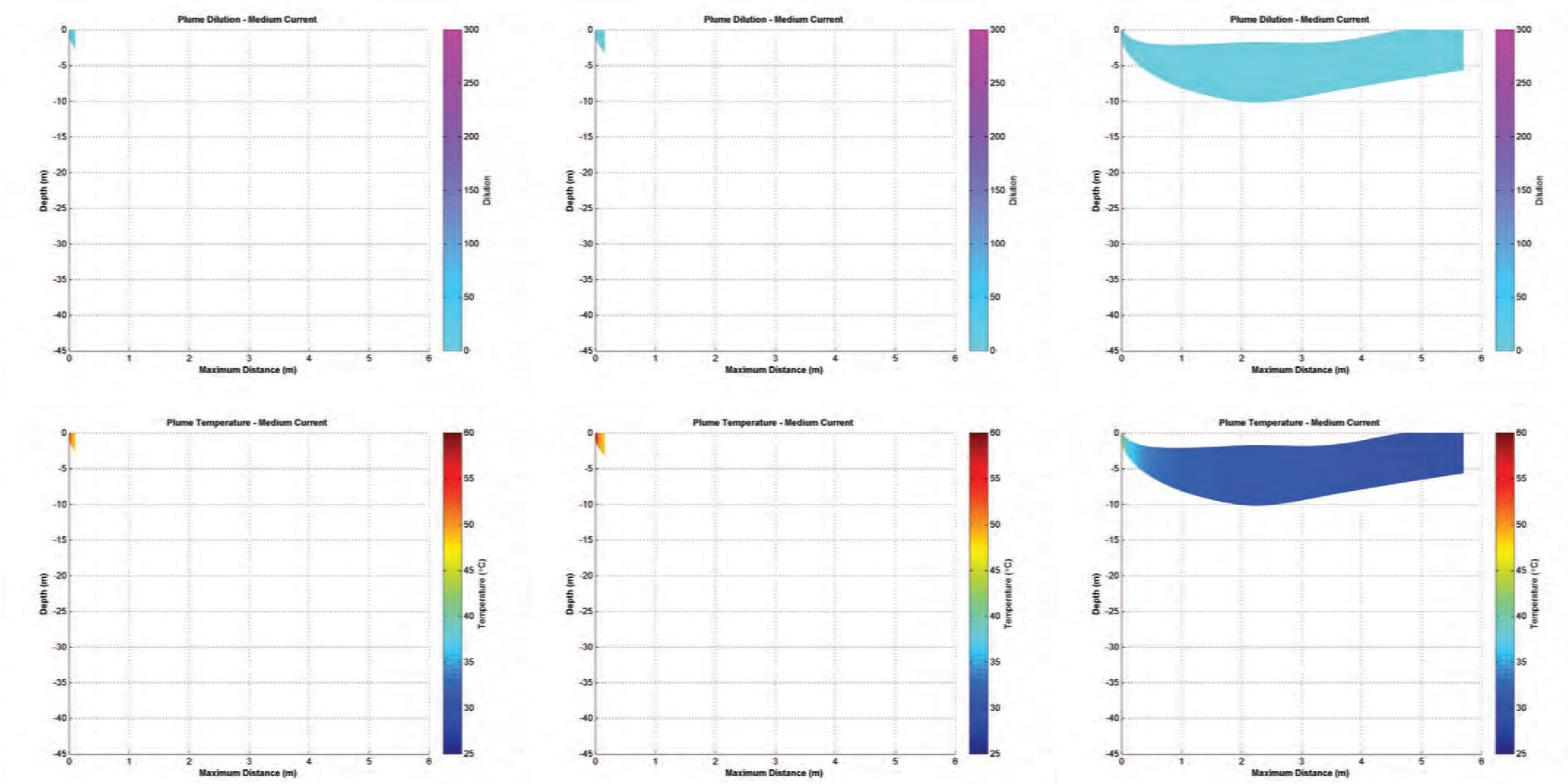



**Figure 3.46 Near-field average dilution and temperature results for constant medium winter currents with discharge flow rates of 64,800 $m^3$/d (Case C4; left column), 82,800 $m^3$/d (Case C7; middle column) and 165,600 $m^3$/d (Case C1; right column) at a discharge depth of 0 m.**

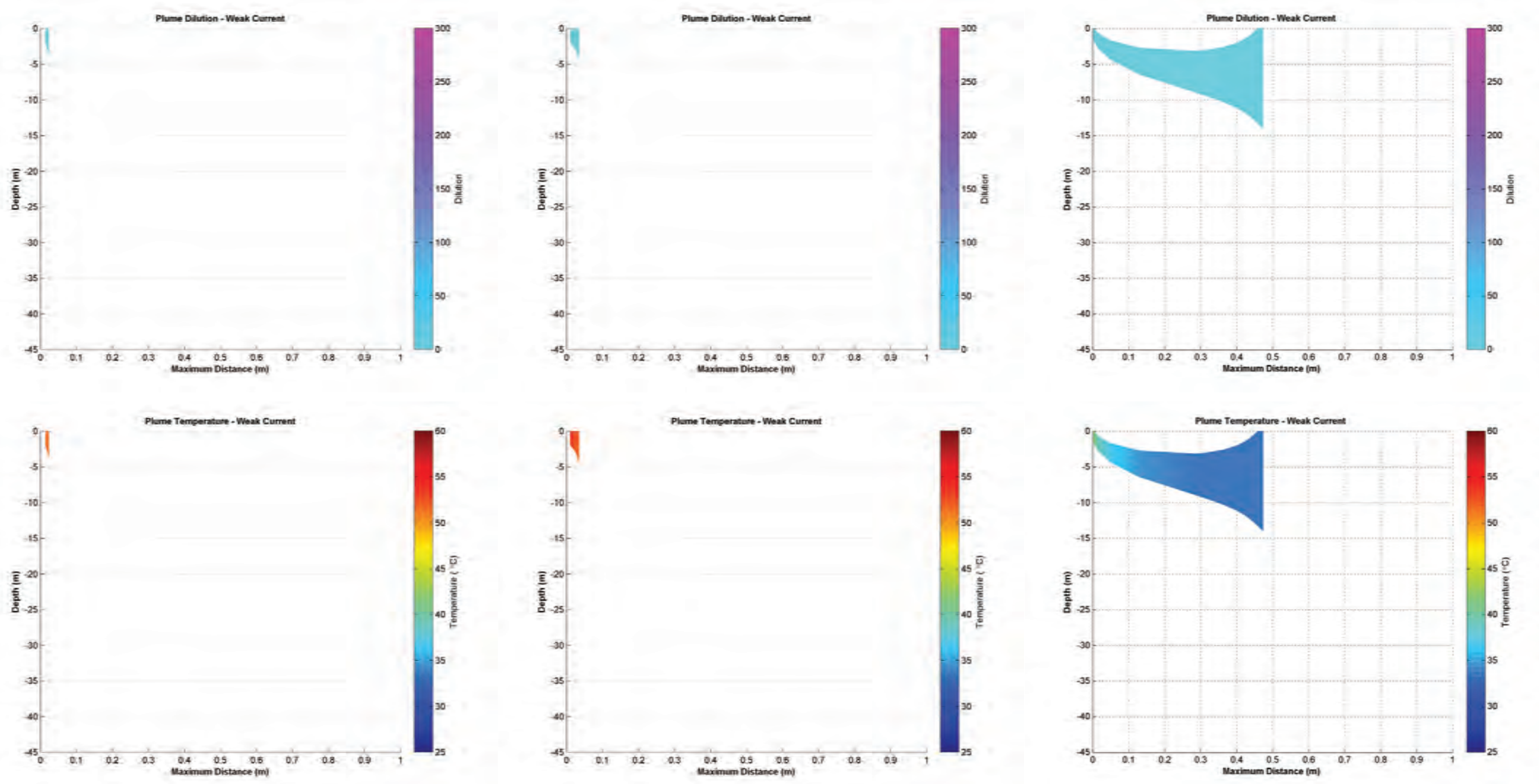



**Figure 3.47 Near-field average dilution and temperature results for constant weak winter currents with discharge flow rates of 64,800 m³/d (Case C4; left column), 82,800 m³/d (Case C7; middle column) and 165,600 m³/d (Case C1; right column) at a discharge depth of 0 m.**

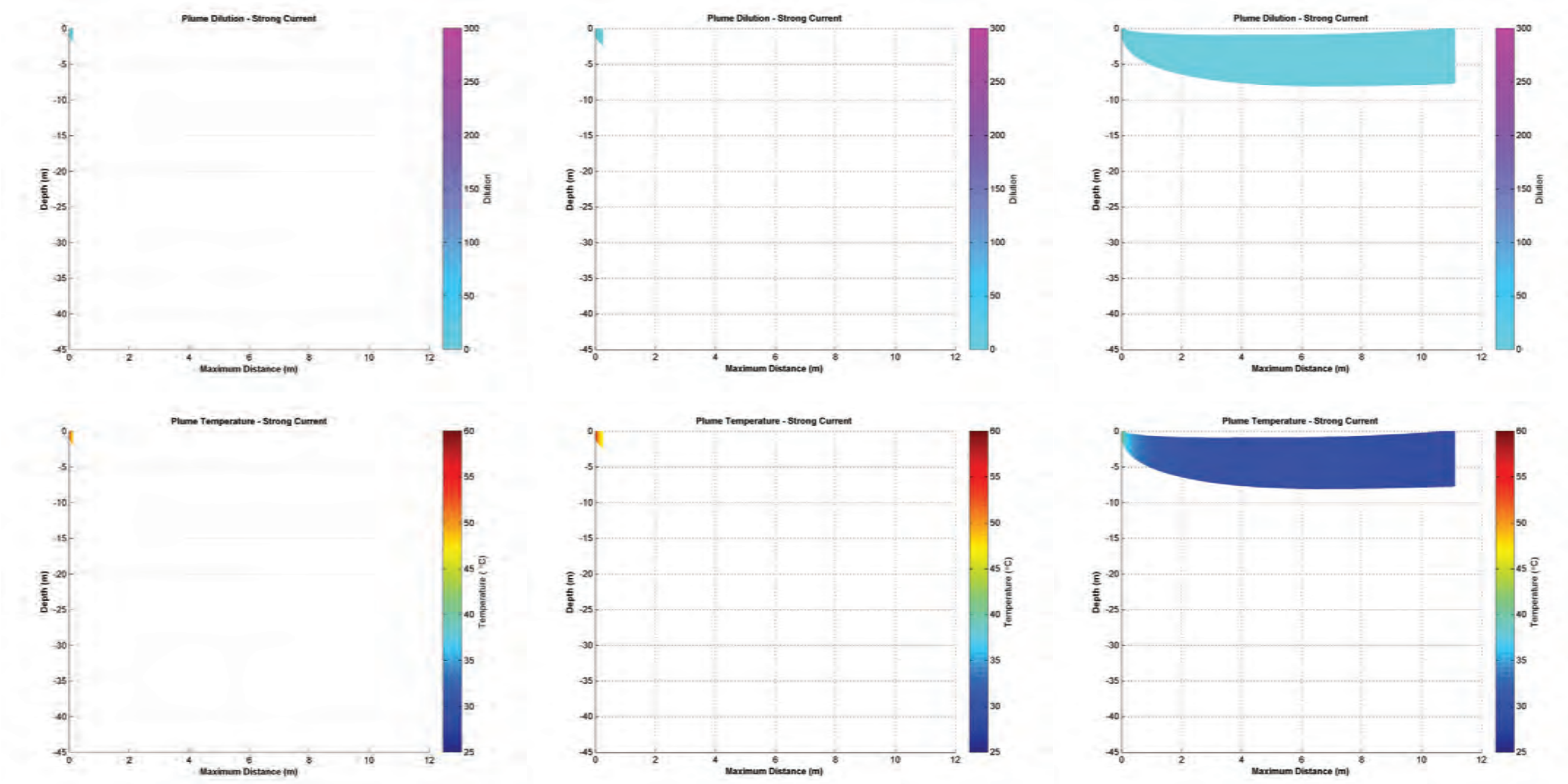



**Figure 3.48 Near-field average dilution and temperature results for constant strong winter currents with discharge flow rates of 64,800 m³/d (Case C4; left column), 82,800 m³/d (Case C7; middle column) and 165,600 m³/d (Case C1; right column) at a discharge depth of 0 m.**

### 3.1.3.5 Discharge Depth of 10 m with Varying Flow Rates

#### 3.1.3.5.1 Annualised

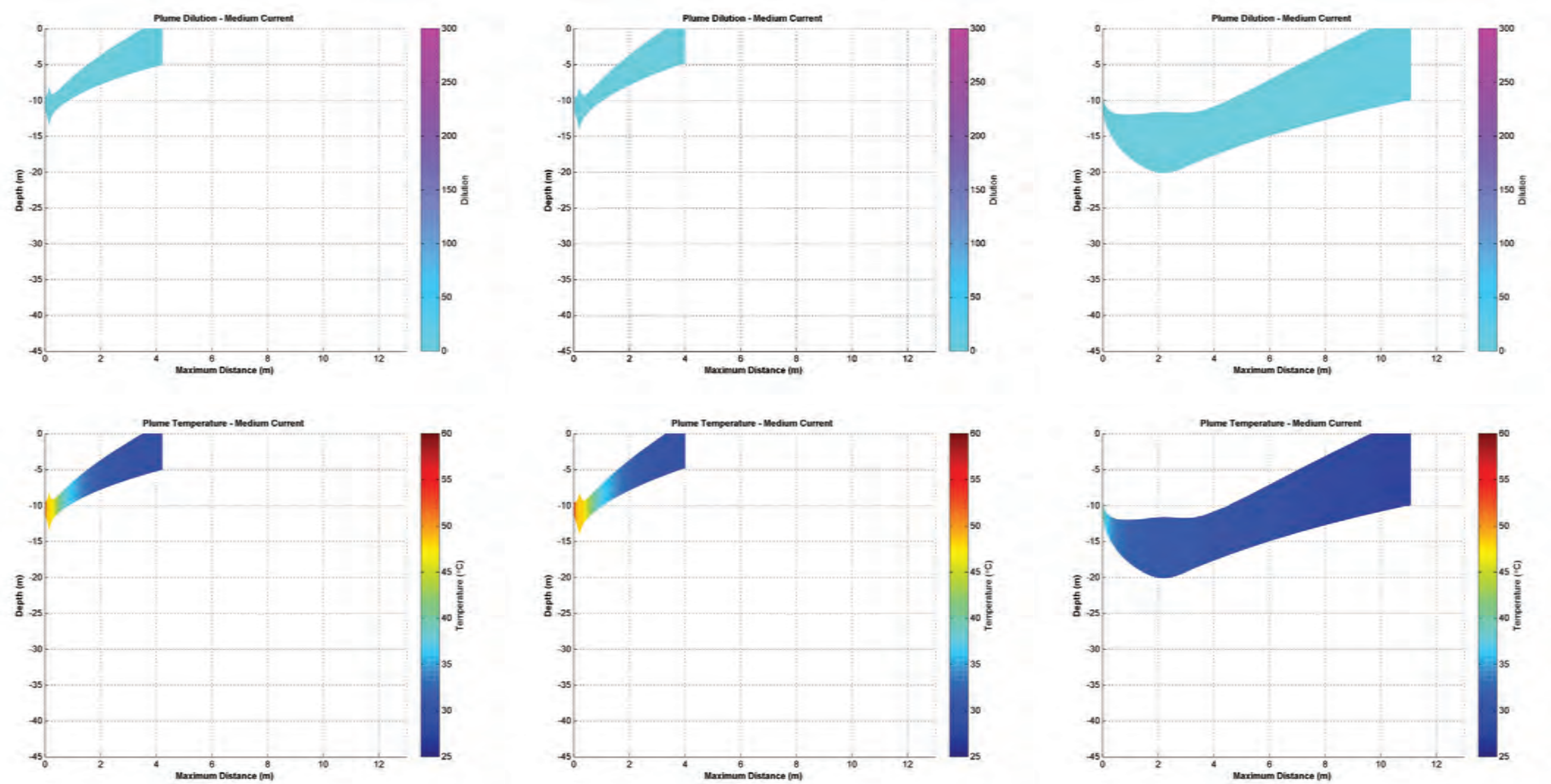



Figure 3.49 Near-field average dilution and temperature results for constant medium annualised currents with discharge flow rates of 64,800 $m^3$/d (Case C5; left column), 82,800 $m^3$/d (Case C8; middle column) and 165,600 $m^3$/d (Case C2; right column) at a discharge depth of 10 m.

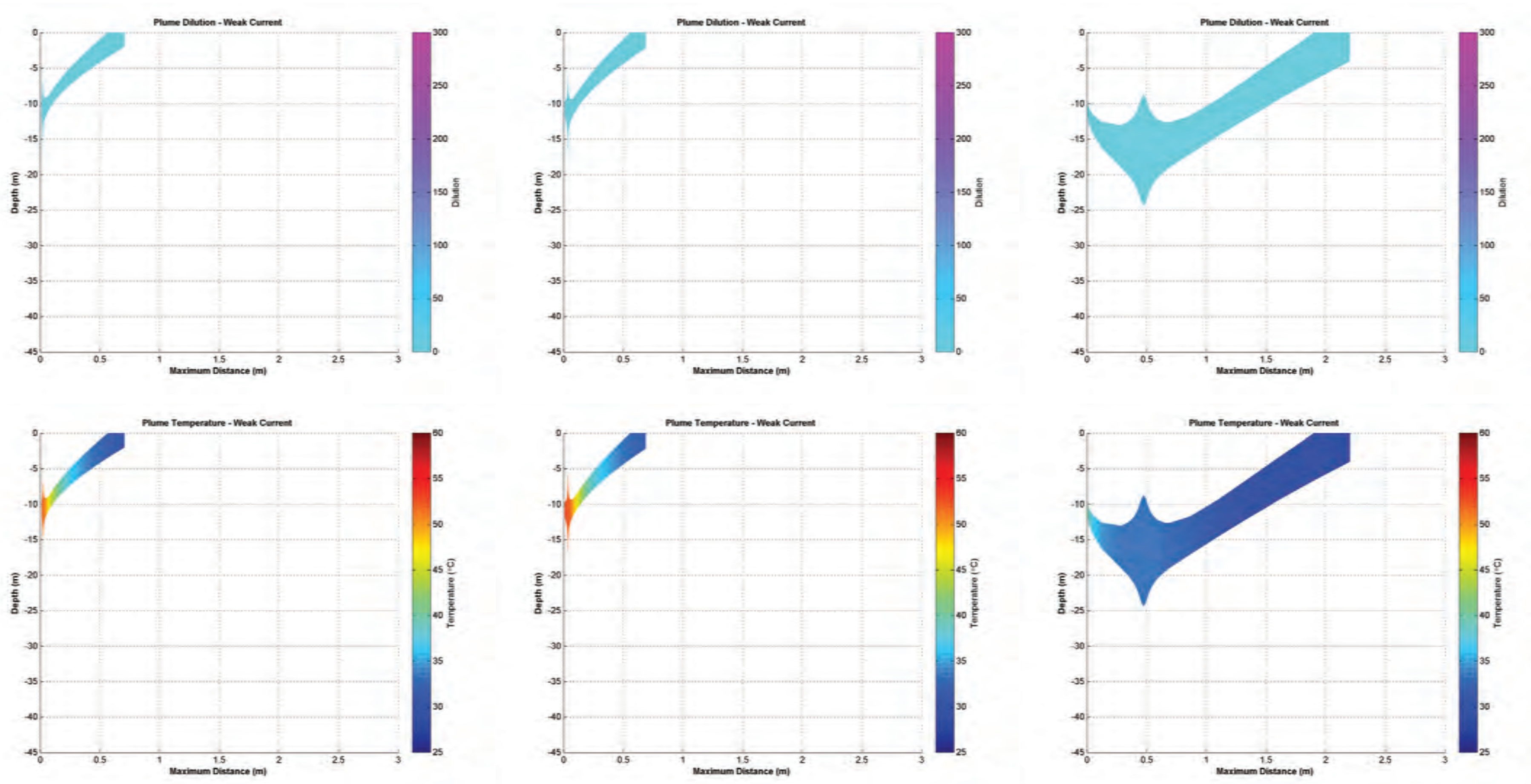



**Figure 3.50** **Near-field average dilution and temperature results for constant weak annualised currents with discharge flow rates of 64,800 $m^3/d$ (Case C5; left column), 82,800 $m^3/d$ (Case C8; middle column) and 165,600 $m^3/d$ (Case C2; right column) at a discharge depth of 10 m.**

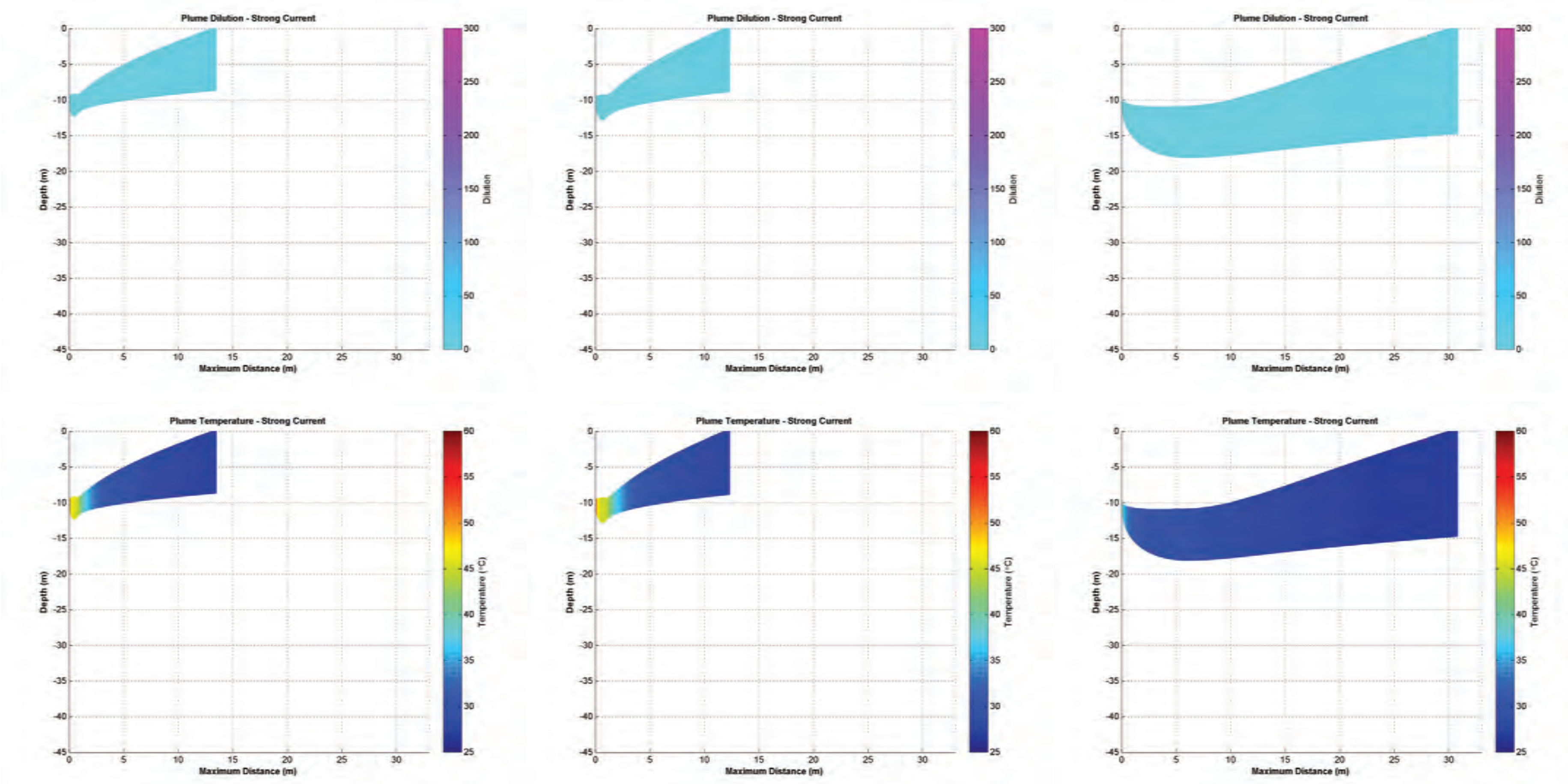



**Figure 3.51 Near-field average dilution and temperature results for constant strong annualised currents with discharge flow rates of 64,800 $m^3/d$ (Case C5; left column), 82,800 $m^3/d$ (Case C8; middle column) and 165,600 $m^3/d$ (Case C2; right column) at a discharge depth of 10 m.**

### 3.1.3.5.2 Summer

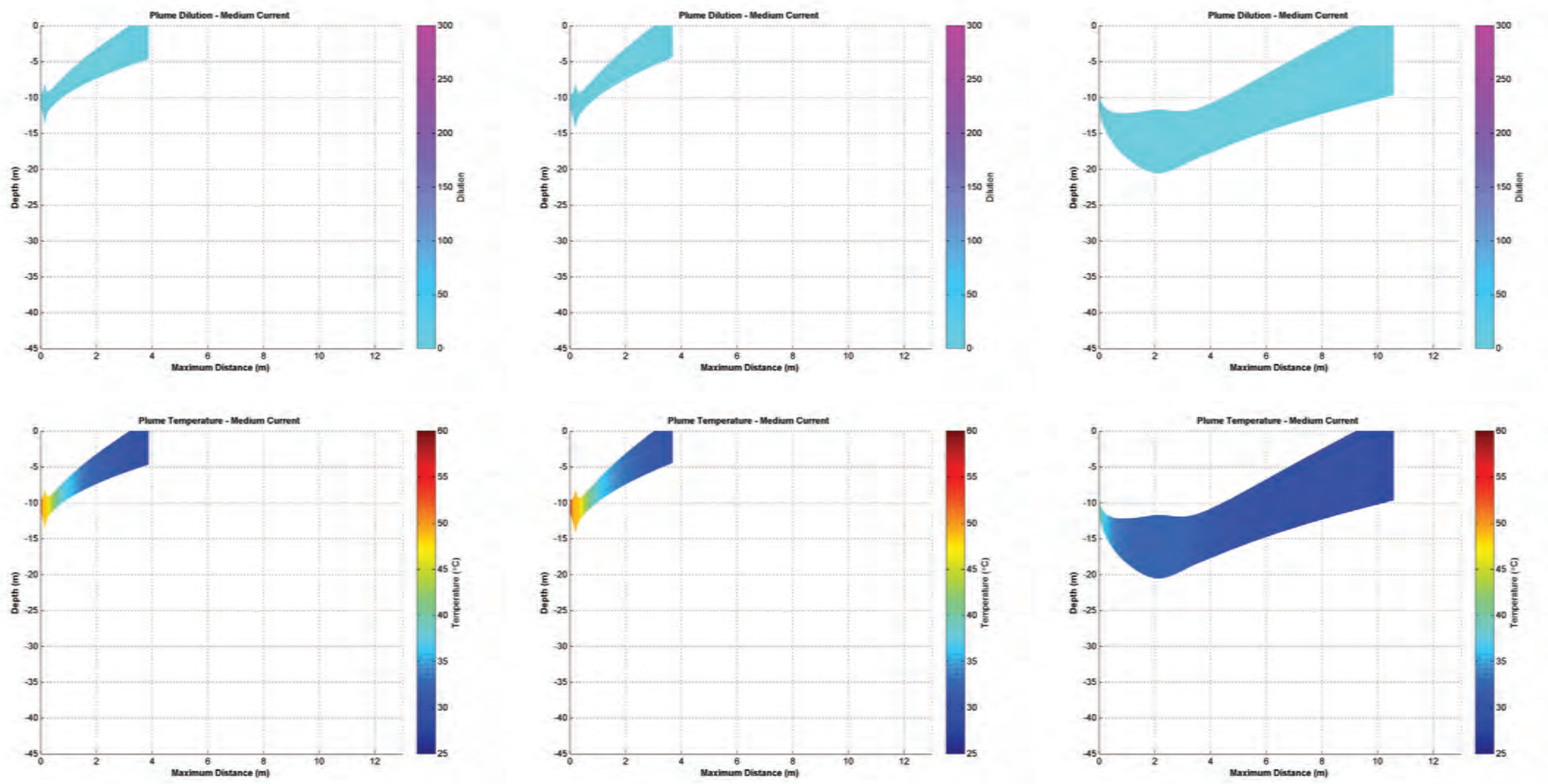



Figure 3.52 Near-field average dilution and temperature results for constant medium summer currents with discharge flow rates of 64,800 $m^3/d$ (Case C5; left column), 82,800 $m^3/d$ (Case C8; middle column) and 165,600 $m^3/d$ (Case C2; right column) at a discharge depth of 10 m.

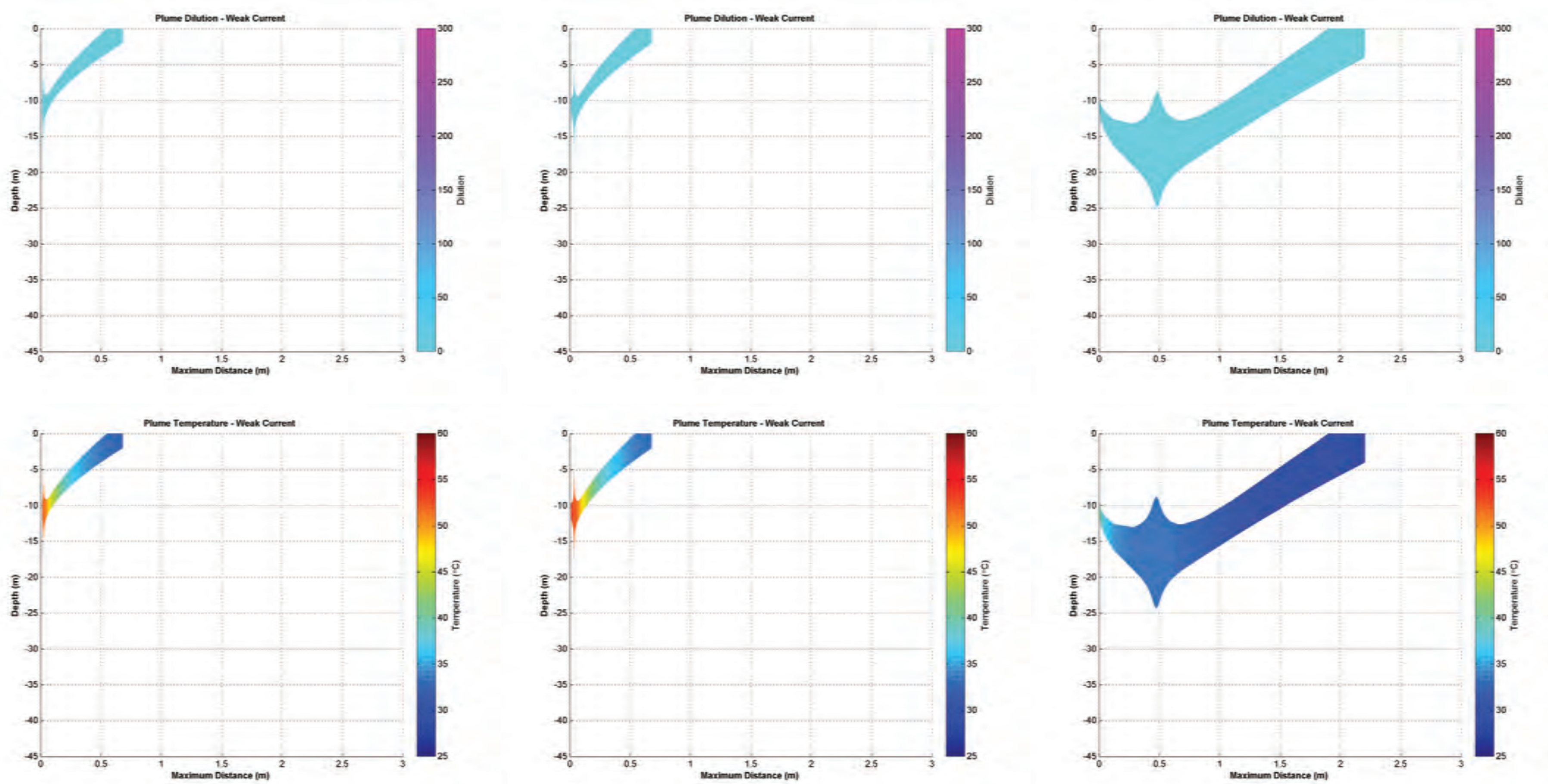



Figure 3.53 Near-field average dilution and temperature results for constant weak summer currents with discharge flow rates of 64,800 $m^3/d$ (Case C5; left column), 82,800 $m^3/d$ (Case C8; middle column) and 165,600 $m^3/d$ (Case C2; right column) at a discharge depth of 10 m.

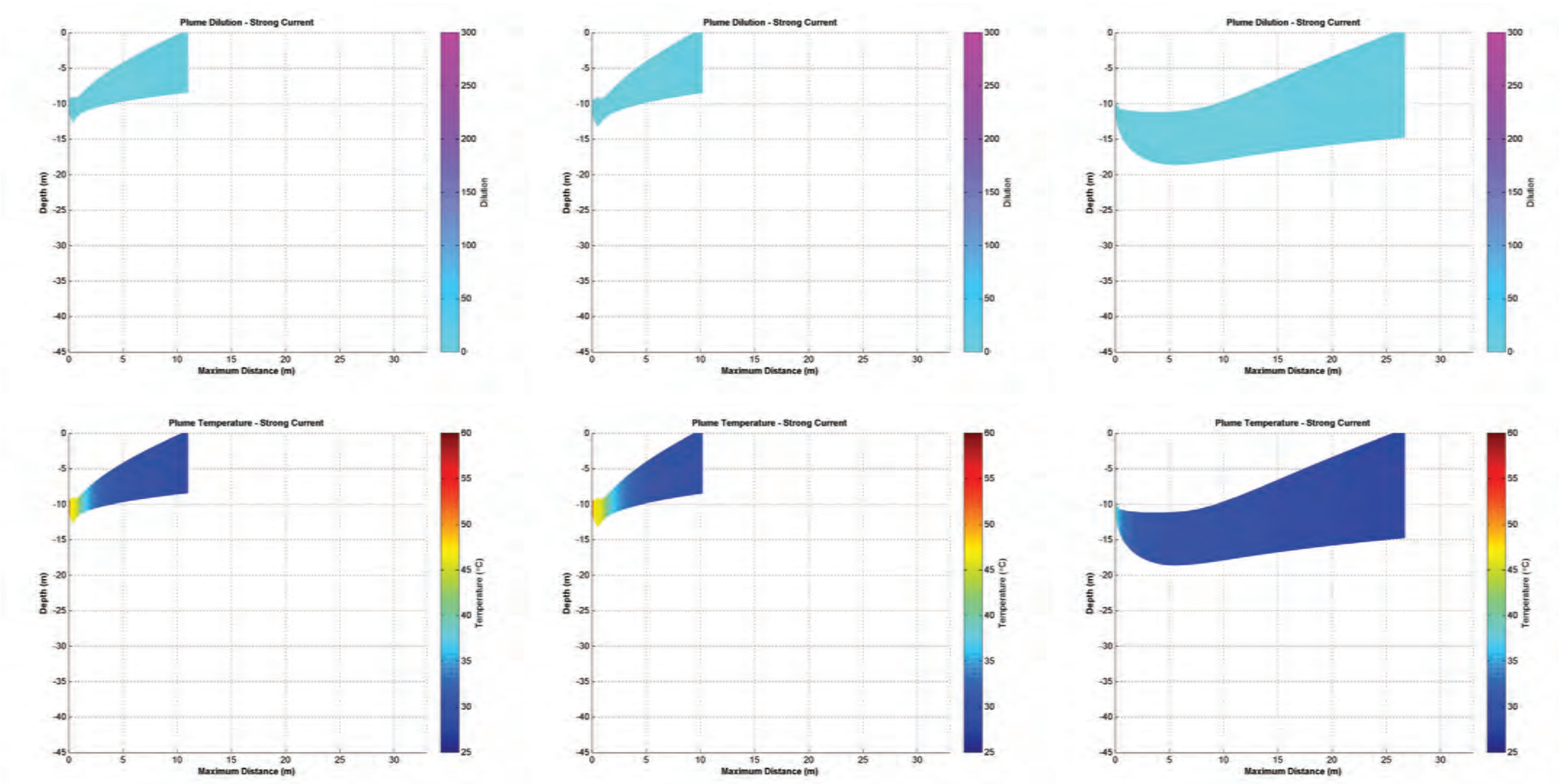



**Figure 3.54 Near-field average dilution and temperature results for constant strong summer currents with discharge flow rates of 64,800 $m^3/d$ (Case C5; left column), 82,800 $m^3/d$ (Case C8; middle column) and 165,600 $m^3/d$ (Case C2; right column) at a discharge depth of 10 m.**

### 3.1.3.5.3 Transitional

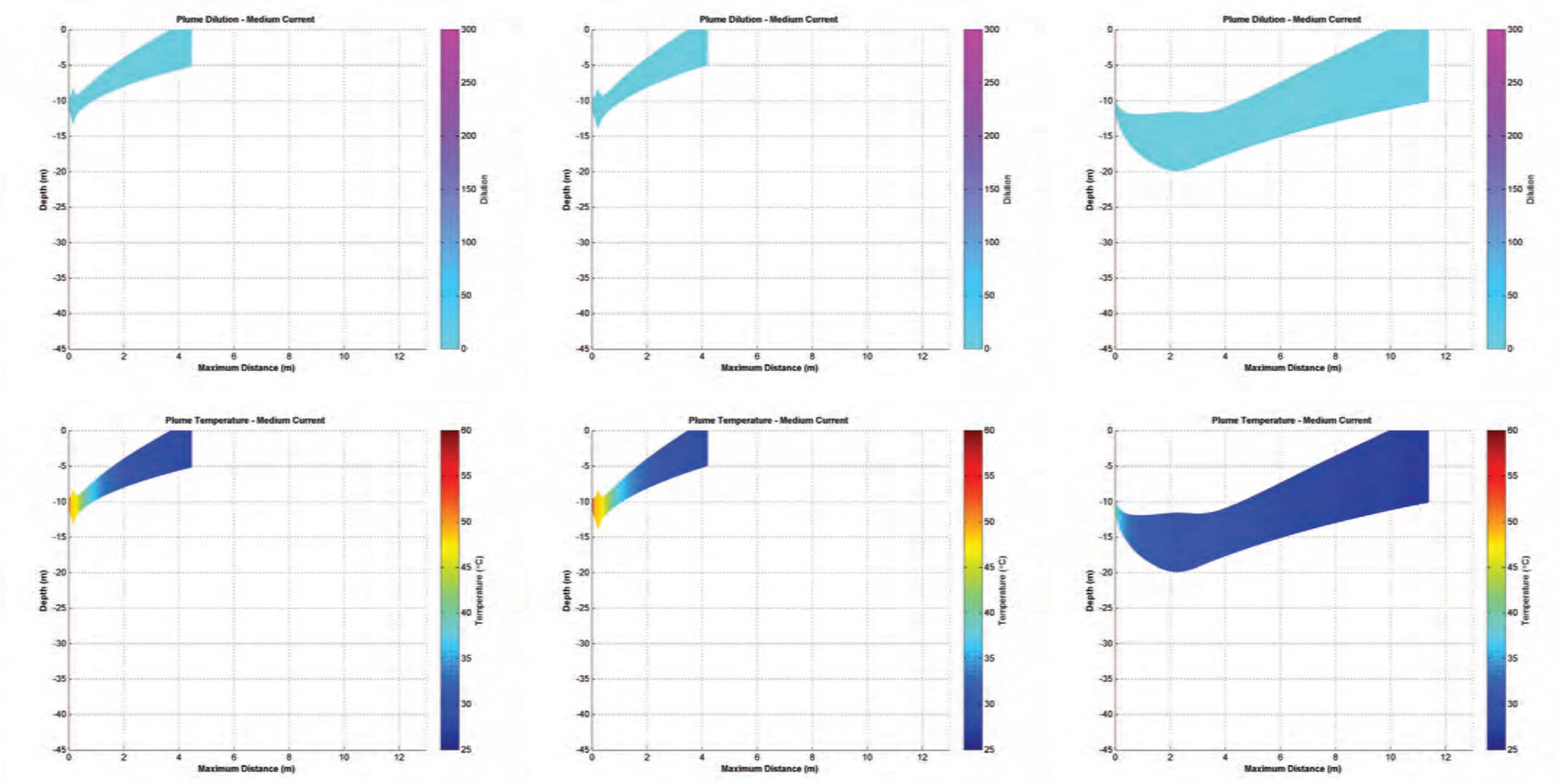



**Figure 3.55 Near-field average dilution and temperature results for constant medium transitional currents with discharge flow rates of 64,800 $m^3/d$ (Case C5; left column), 82,800 $m^3/d$ (Case C8; middle column) and 165,600 $m^3/d$ (Case C2; right column) at a discharge depth of 10 m.**

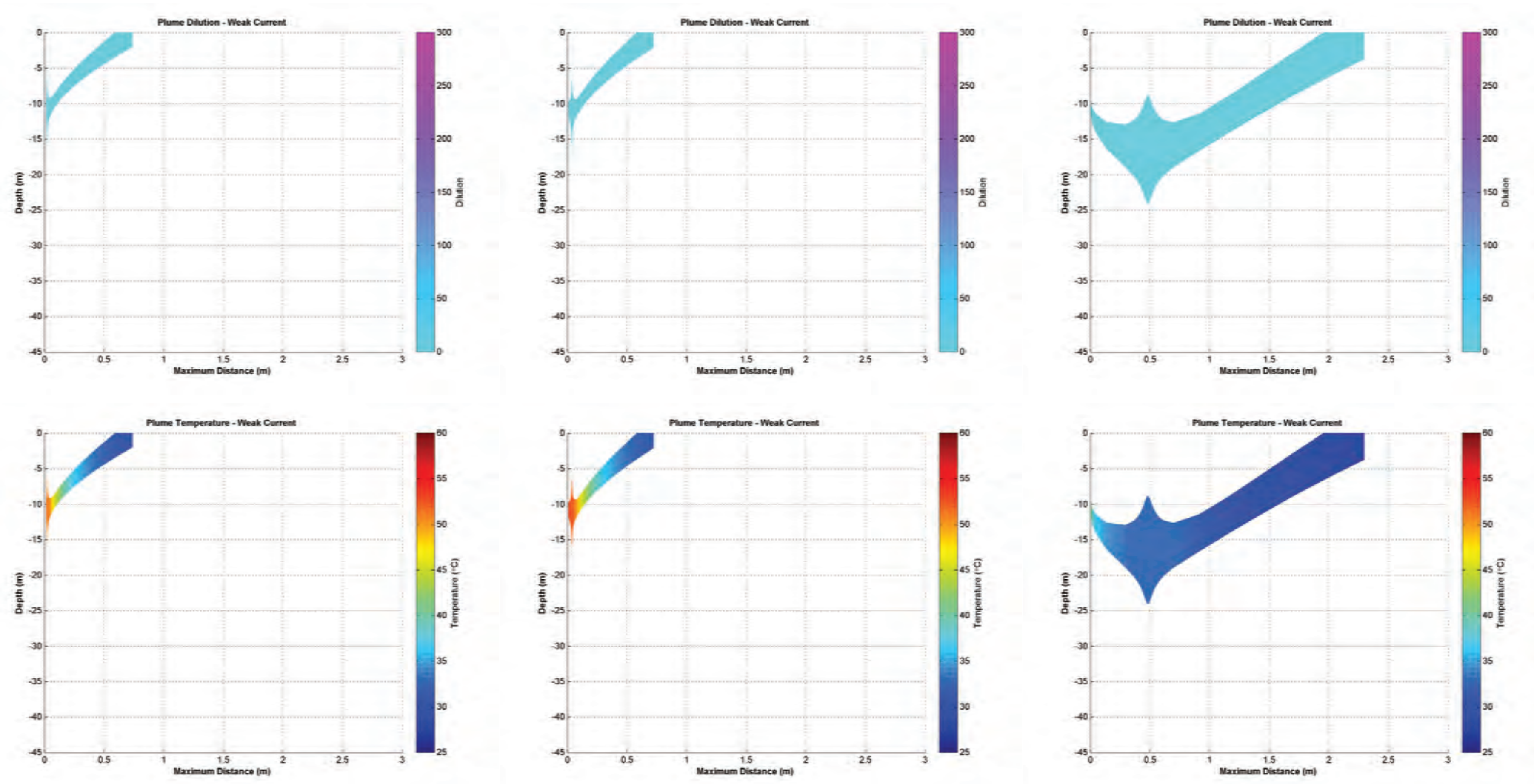



Figure 3.56 Near-field average dilution and temperature results for constant weak transitional currents with discharge flow rates of 64,800 $m^3/d$ (Case C5; left column), 82,800 $m^3/d$ (Case C8; middle column) and 165,600 $m^3/d$ (Case C2; right column) at a discharge depth of 10 m.

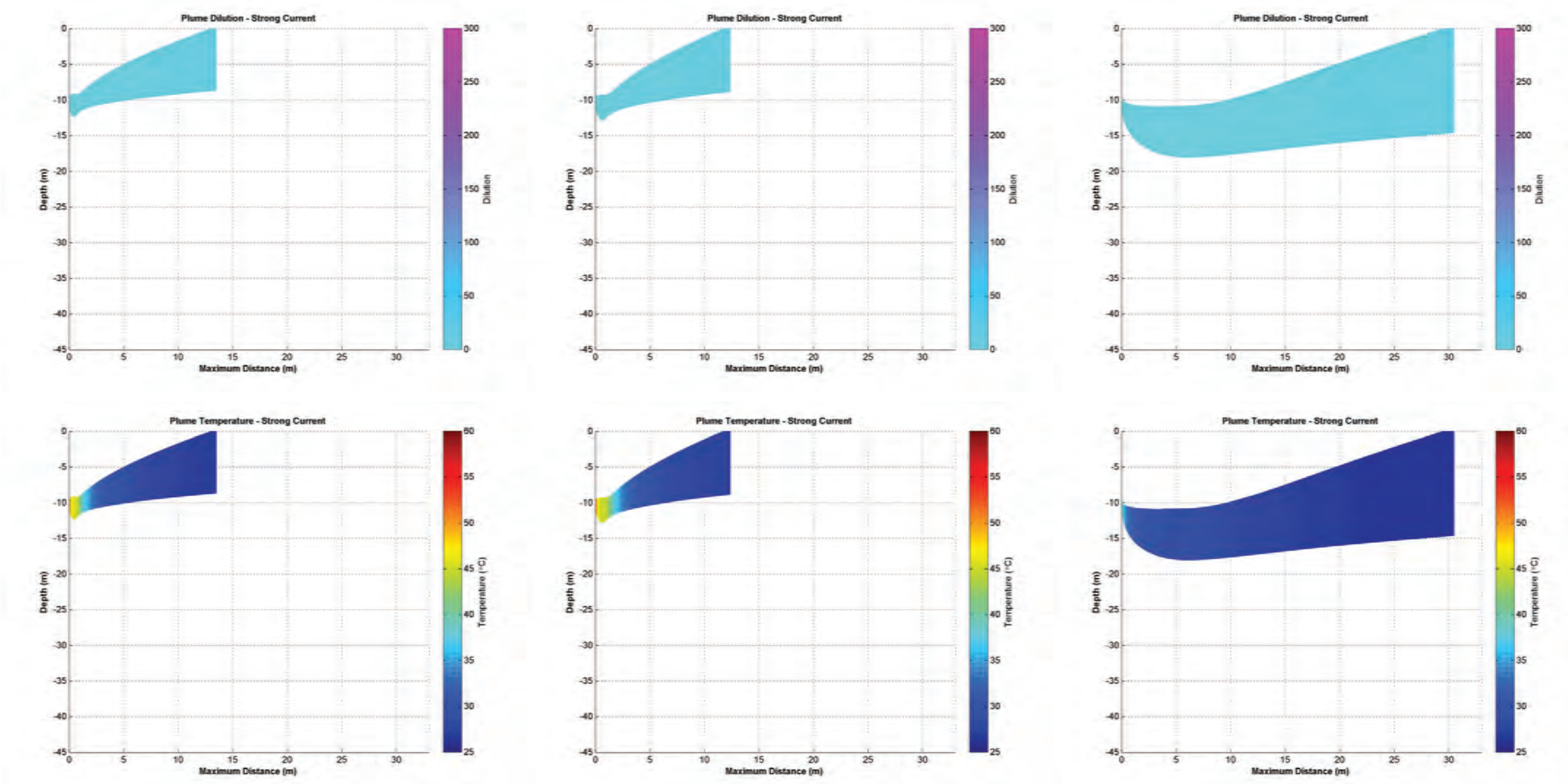



Figure 3.57 Near-field average dilution and temperature results for constant strong transitional currents with discharge flow rates of 64,800 $m^3/d$ (Case C5; left column), 82,800 $m^3/d$ (Case C8; middle column) and 165,600 $m^3/d$ (Case C2; right column) at a discharge depth of 10 m.

### 3.1.3.5.4 Winter

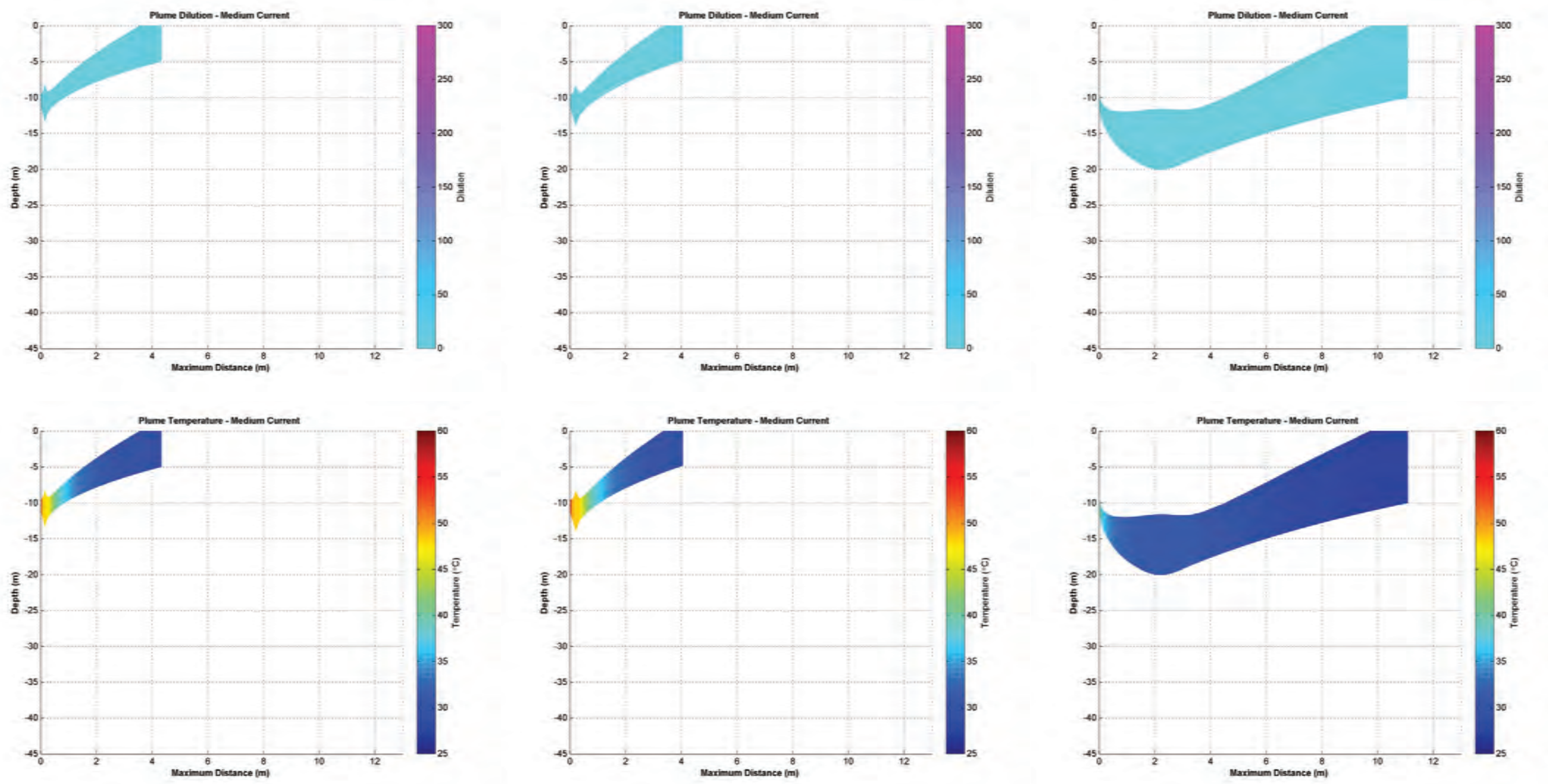



**Figure 3.58 Near-field average dilution and temperature results for constant medium winter currents with discharge flow rates of 64,800 $m^3/d$ (Case C5; left column), 82,800 $m^3/d$ (Case C8; middle column) and 165,600 $m^3/d$ (Case C2; right column) at a discharge depth of 10 m.**

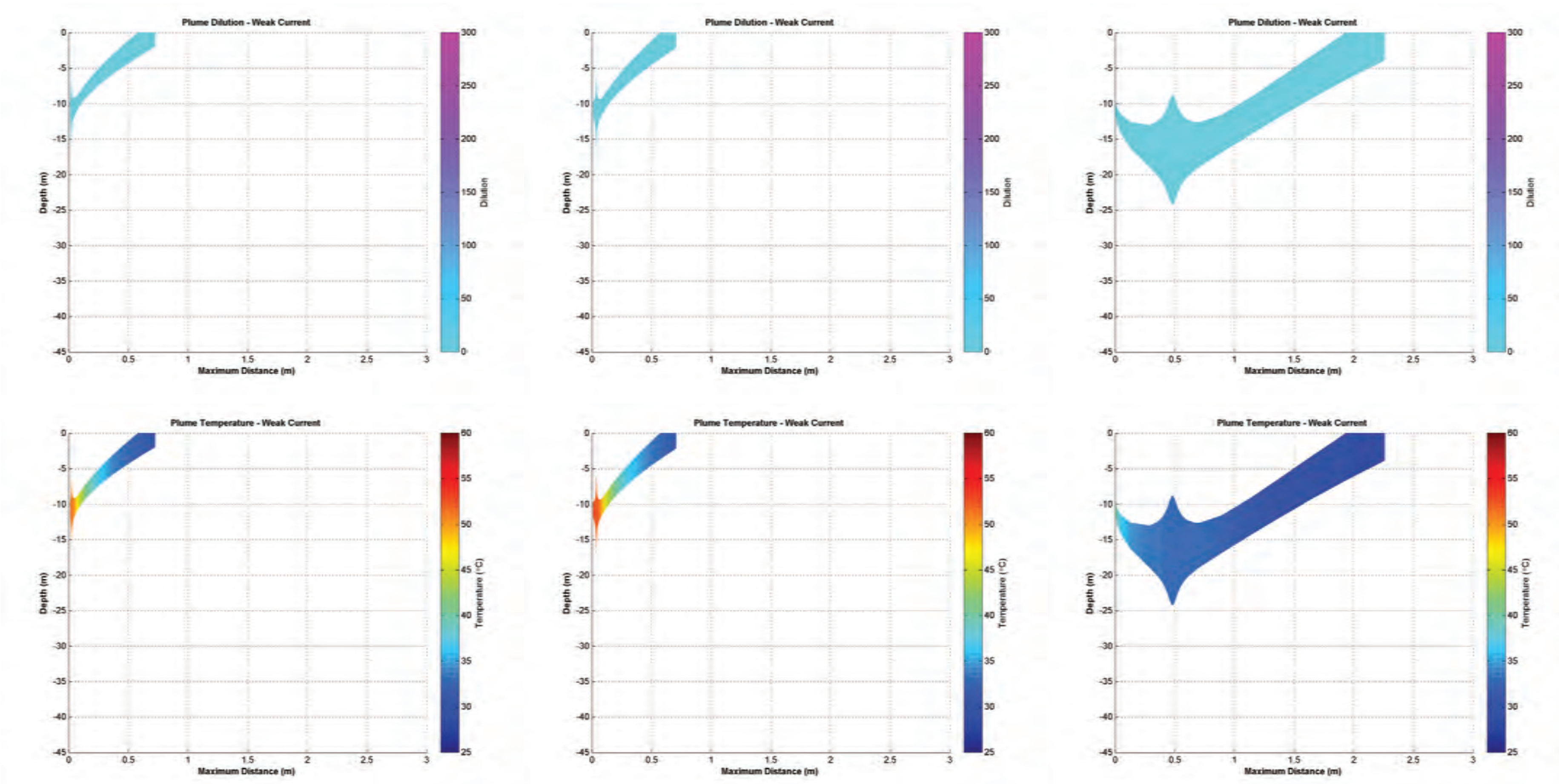



**Figure 3.59 Near-field average dilution and temperature results for constant weak winter currents with discharge flow rates of 64,800 $m^3$/d (Case C5; left column), 82,800 $m^3$/d (Case C8; middle column) and 165,600 $m^3$/d (Case C2; right column) at a discharge depth of 10 m.**

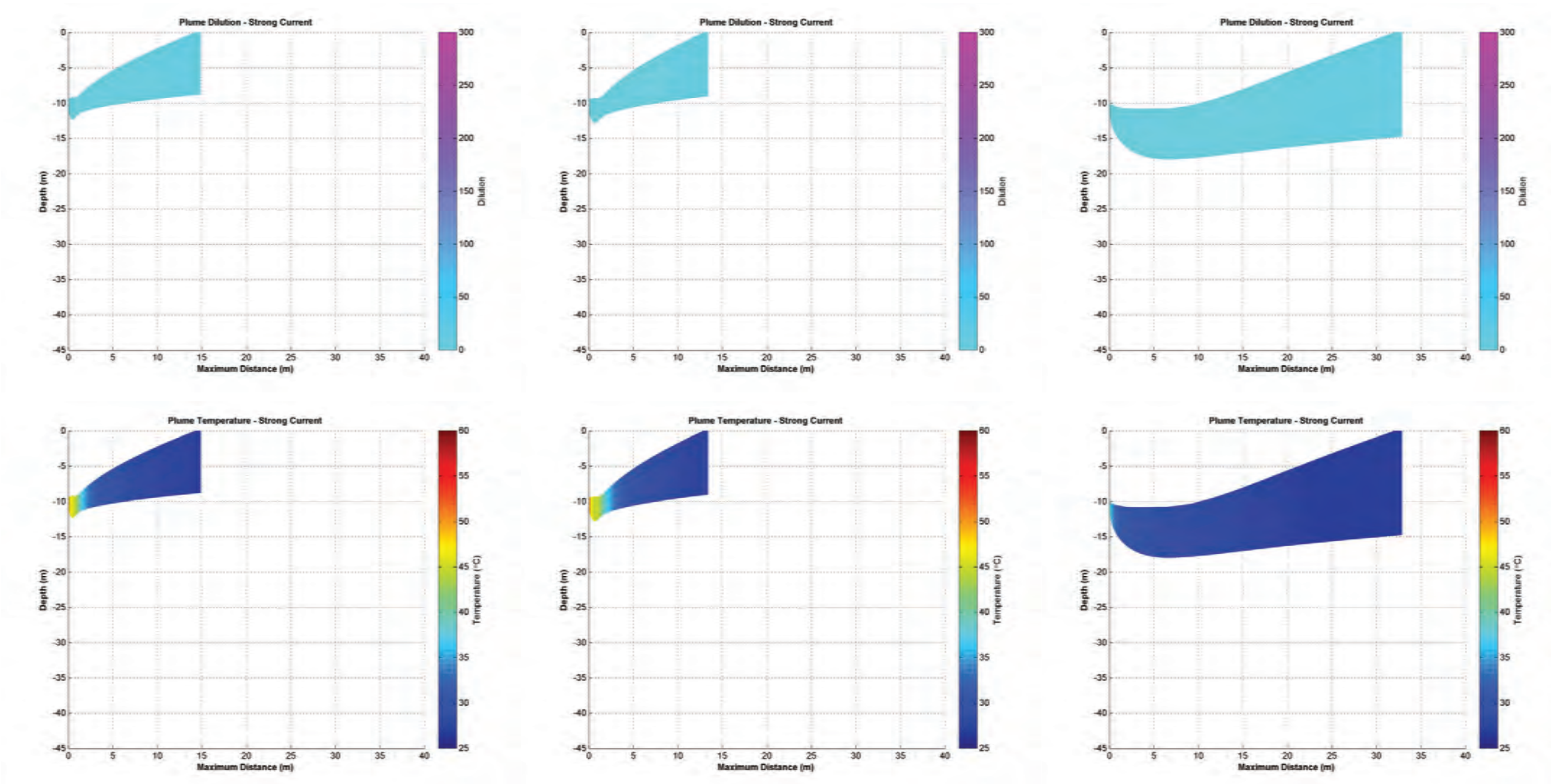



**Figure 3.60 Near-field average dilution and temperature results for constant strong winter currents with discharge flow rates of 64,800 m³/d (Case C5; left column), 82,800 m³/d (Case C8; middle column) and 165,600 m³/d (Case C2; right column) at a discharge depth of 10 m.**

### 3.1.3.6 Discharge Depth of 30 m with Varying Flow Rates

#### 3.1.3.6.1 Annualised

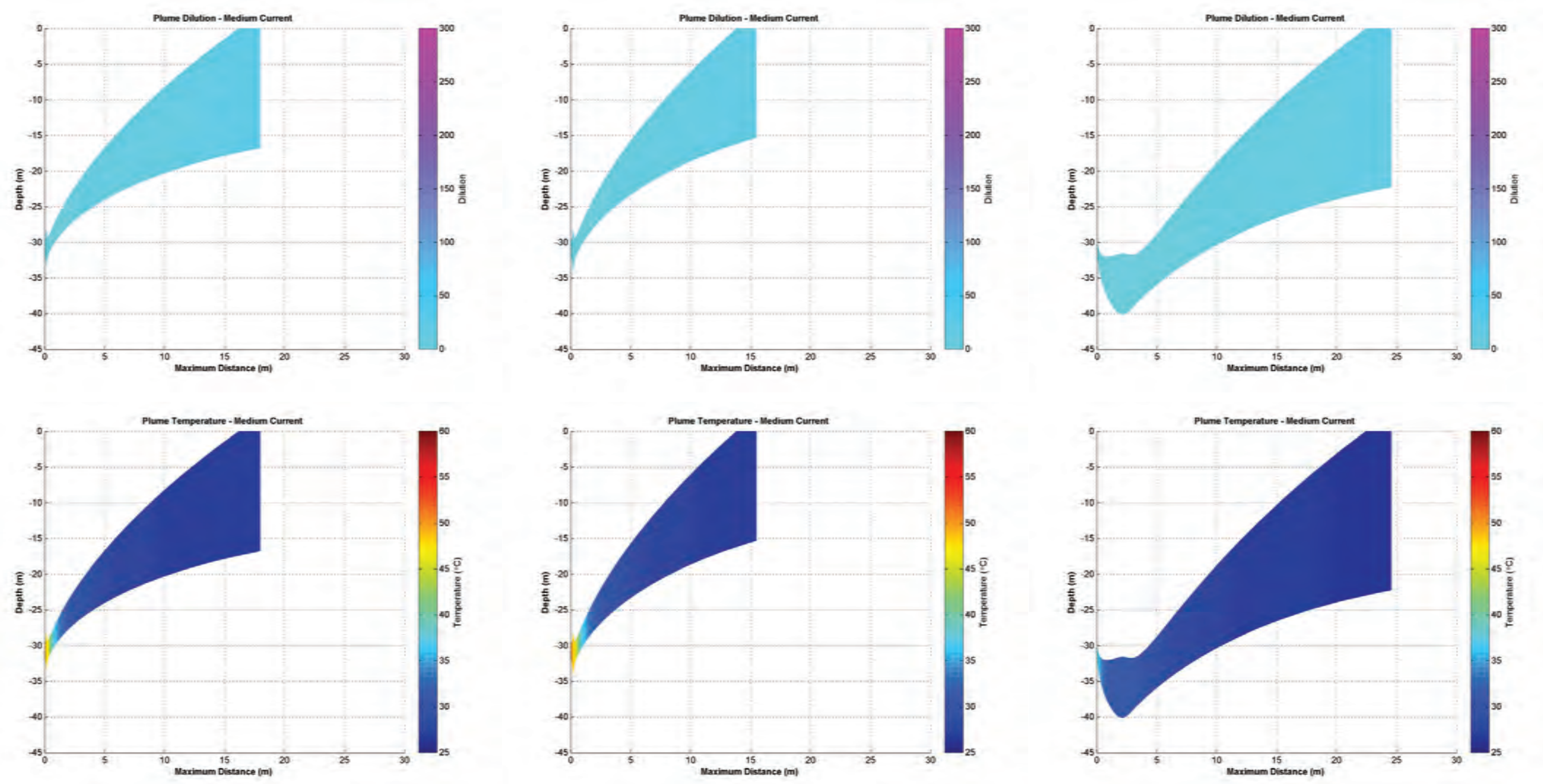



Figure 3.61 Near-field average dilution and temperature results for constant medium annualised currents with discharge flow rates of 64,800 $m^3$/d (Case C6; left column), 82,800 $m^3$/d (Case C9; middle column) and 165,600 $m^3$/d (Case C3; right column) at a discharge depth of 30 m.

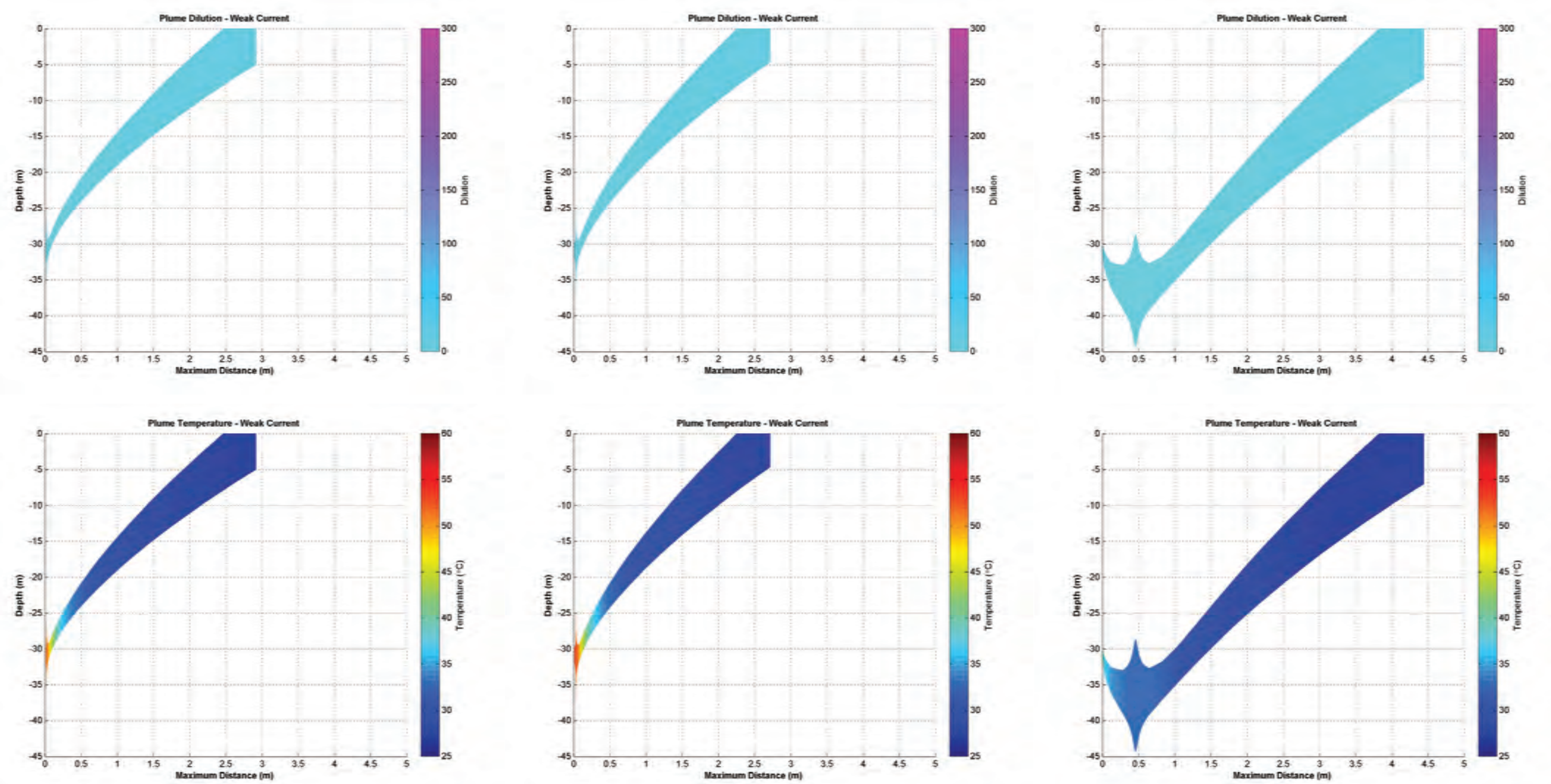



**Figure 3.62 Near-field average dilution and temperature results for constant weak annualised currents with discharge flow rates of 64,800 $m^3/d$ (Case C6; left column), 82,800 $m^3/d$ (Case C9; middle column) and 165,600 $m^3/d$ (Case C3; right column) at a discharge depth of 30 m.**

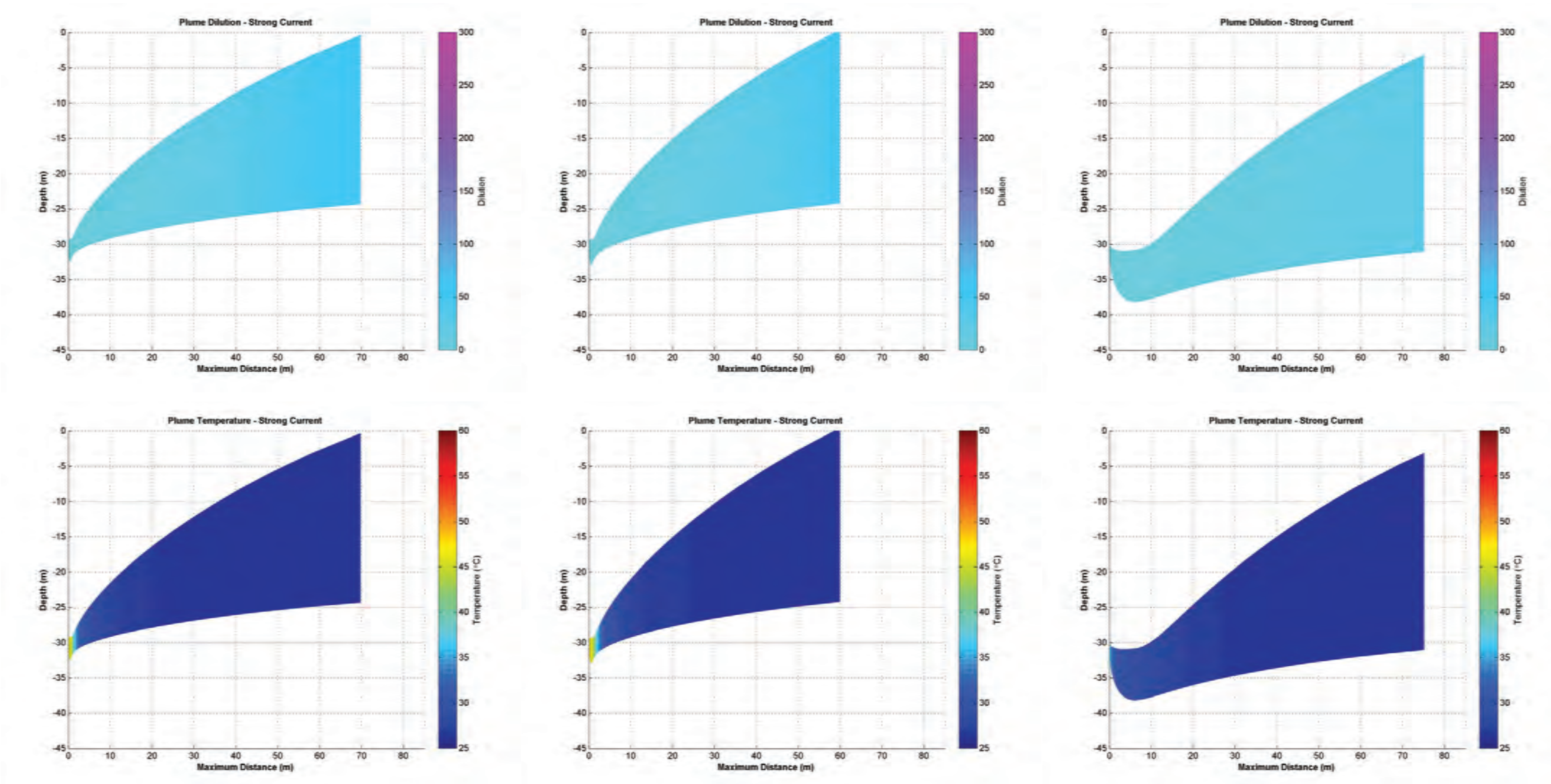



**Figure 3.63 Near-field average dilution and temperature results for constant strong annualised currents with discharge flow rates of 64,800 $m^3$/d (Case C6; left column), 82,800 $m^3$/d (Case C9; middle column) and 165,600 $m^3$/d (Case C3; right column) at a discharge depth of 30 m.**

### 3.1.3.6.2 Summer

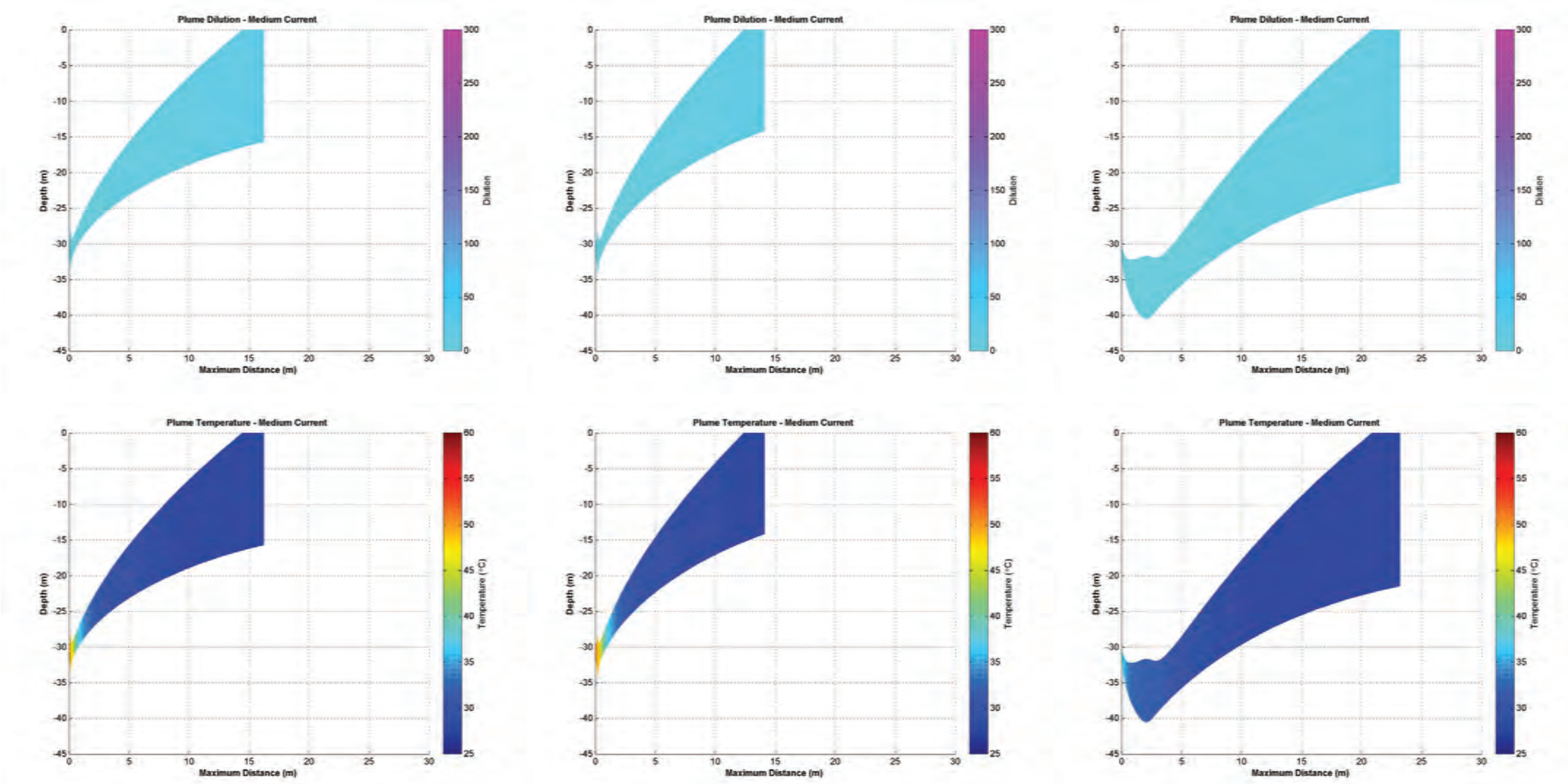



Figure 3.64 Near-field average dilution and temperature results for constant medium summer currents with discharge flow rates of 64,800 m³/d (Case C6; left column), 82,800 m³/d (Case C9; middle column) and 165,600 m³/d (Case C3; right column) at a discharge depth of 30 m.

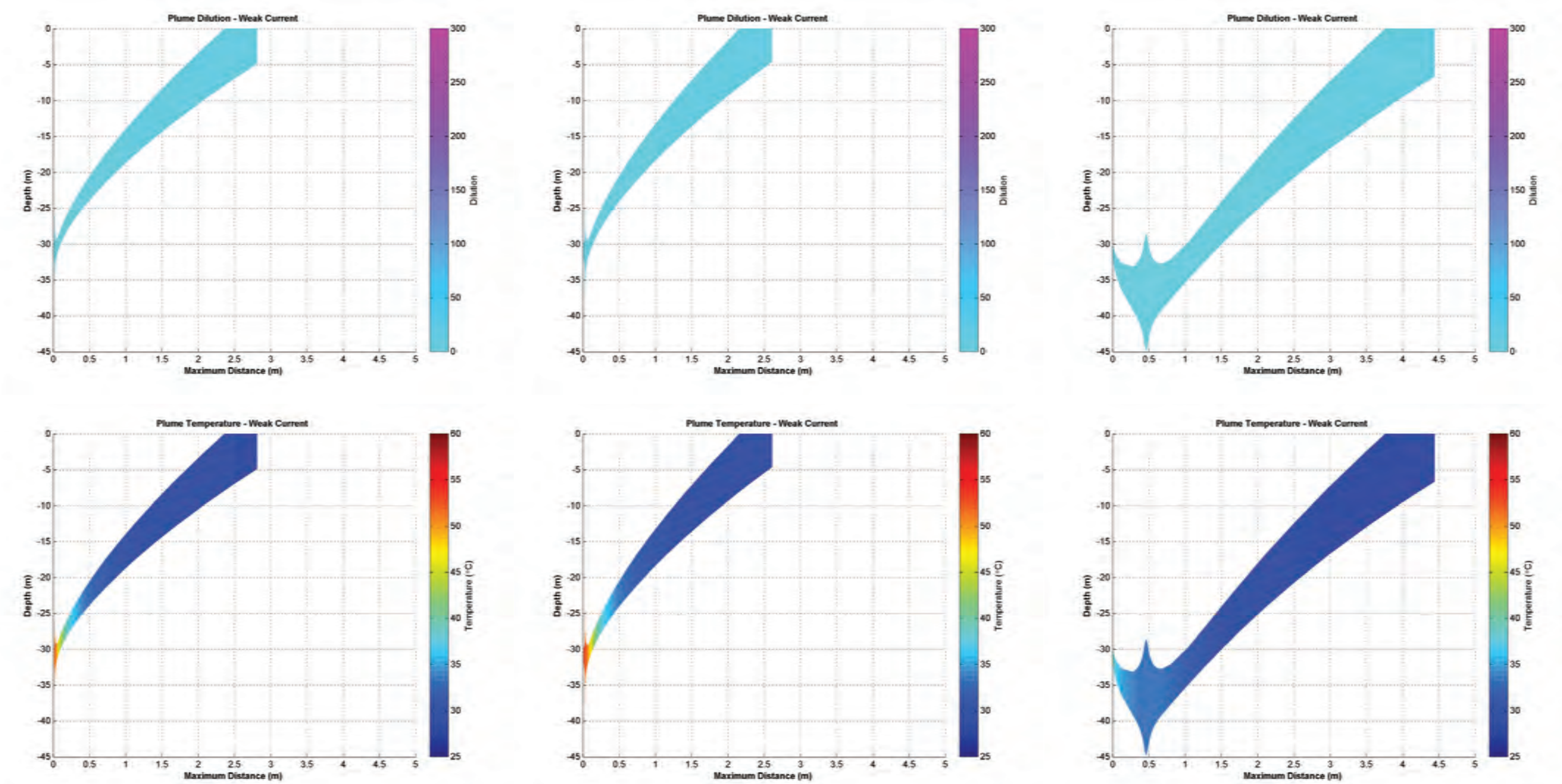



Figure 3.65 Near-field average dilution and temperature results for constant weak summer currents with discharge flow rates of 64,800 $m^3/d$ (Case C6; left column), 82,800 $m^3/d$ (Case C9; middle column) and 165,600 $m^3/d$ (Case C3; right column) at a discharge depth of 30 m.

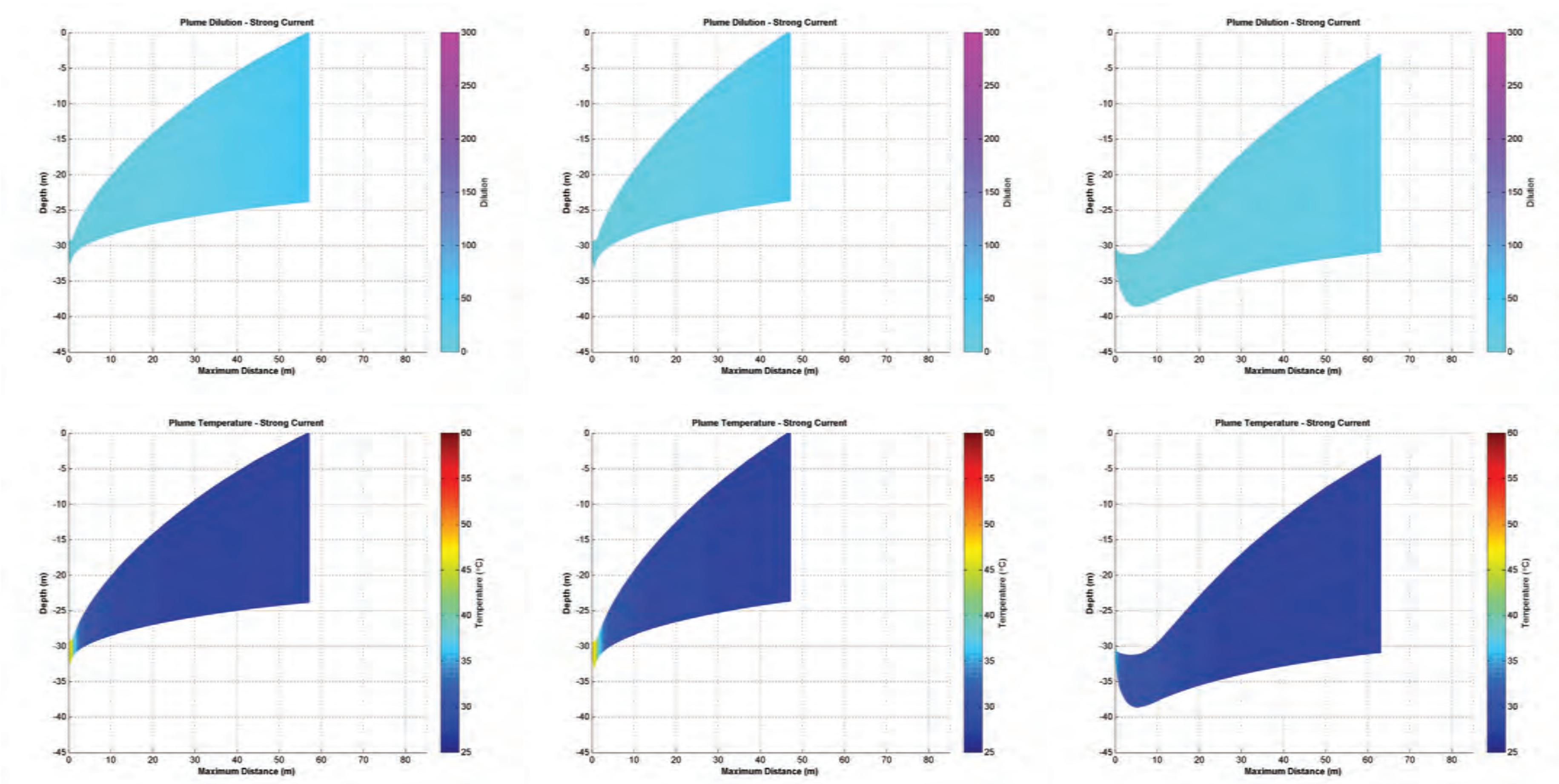



**Figure 3.66 Near-field average dilution and temperature results for constant strong summer currents with discharge flow rates of 64,800 $m^3/d$ (Case C6; left column), 82,800 $m^3/d$ (Case C9; middle column) and 165,600 $m^3/d$ (Case C3; right column) at a discharge depth of 30 m.**

#### 3.1.3.6.3 Transitional

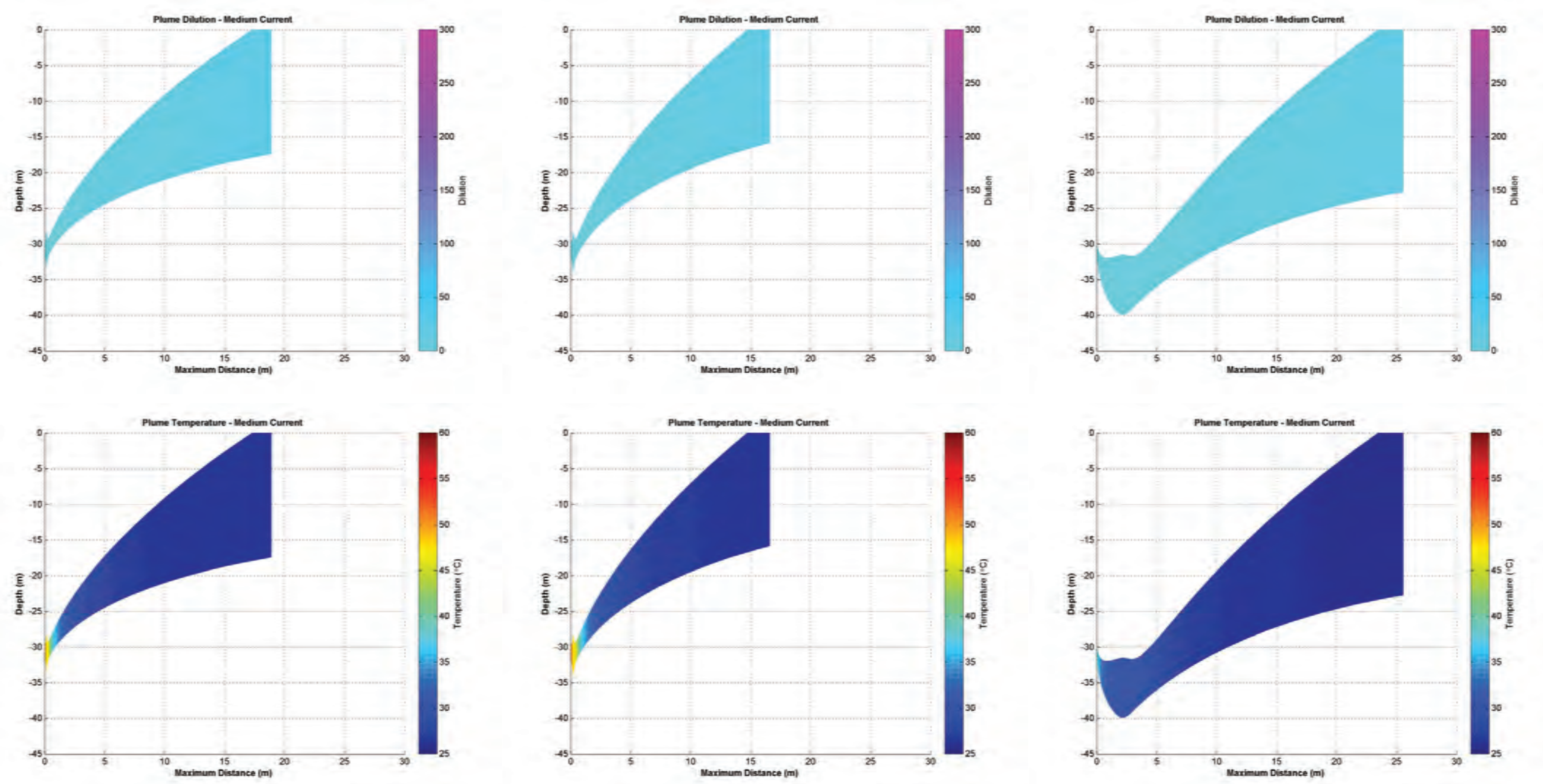



**Figure 3.67 Near-field average dilution and temperature results for constant medium transitional currents with discharge flow rates of 64,800 m³/d (Case C6; left column), 82,800 m³/d (Case C9; middle column) and 165,600 m³/d (Case C3; right column) at a discharge depth of 30 m.**

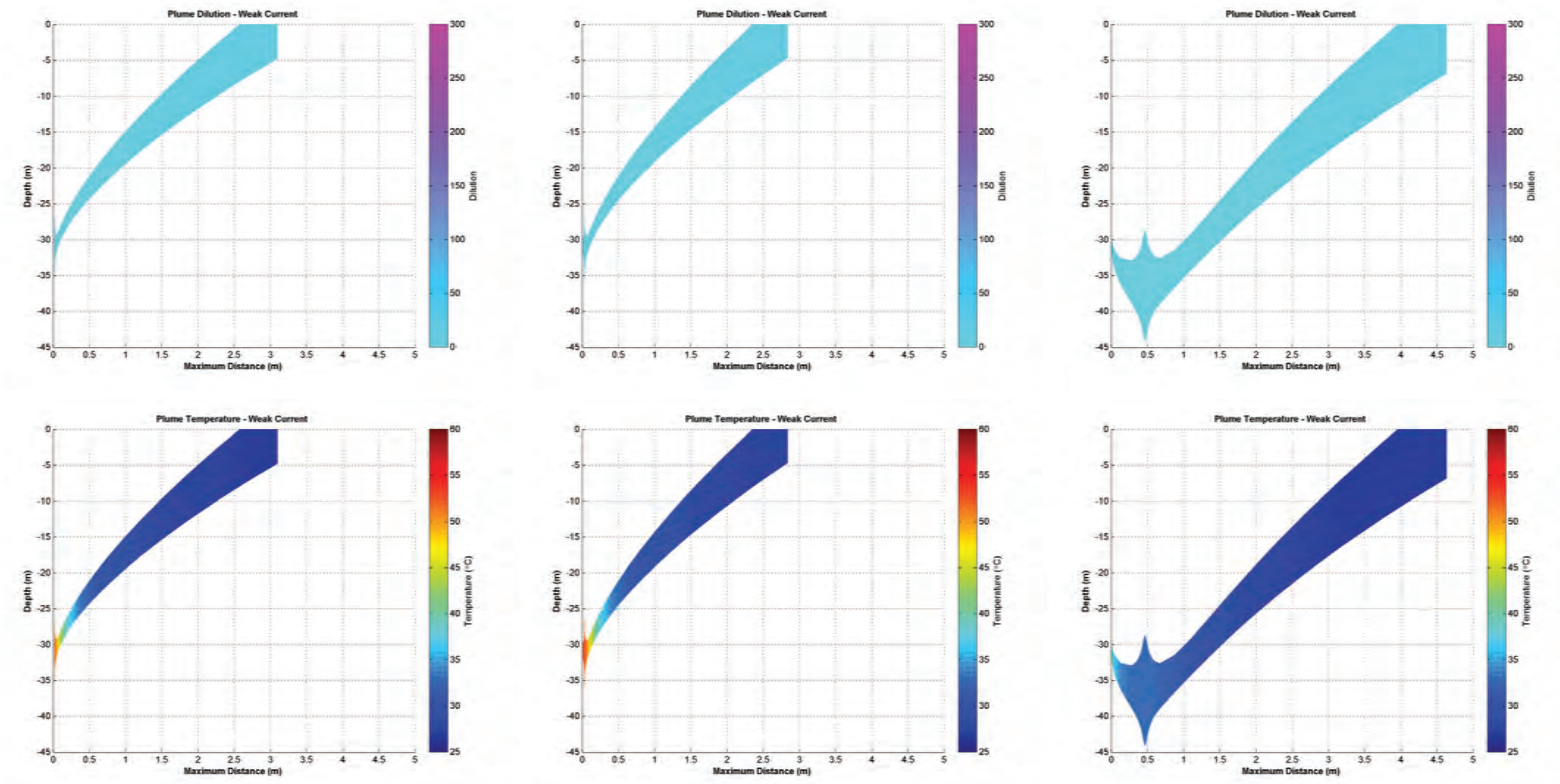



Figure 3.68 Near-field average dilution and temperature results for constant weak transitional currents with discharge flow rates of 64,800 $m^3/d$ (Case C6; left column), 82,800 $m^3/d$ (Case C9; middle column) and 165,600 $m^3/d$ (Case C3; right column) at a discharge depth of 30 m.

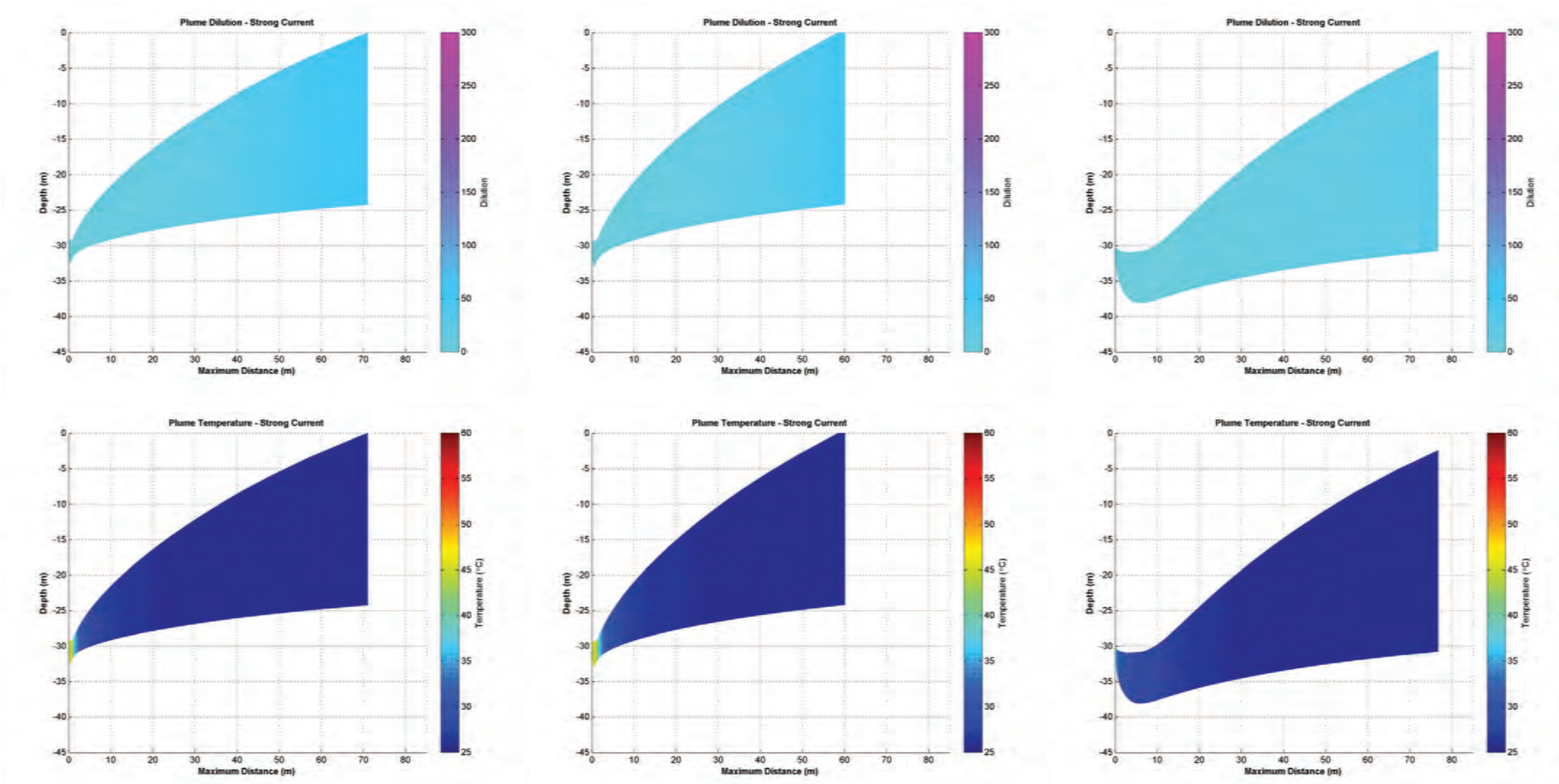



**Figure 3.69 Near-field average dilution and temperature results for constant strong transitional currents with discharge flow rates of 64,800 $m^3/d$ (Case C6; left column), 82,800 $m^3/d$ (Case C9; middle column) and 165,600 $m^3/d$ (Case C3; right column) at a discharge depth of 30 m.**

### 3.1.3.6.4 Winter

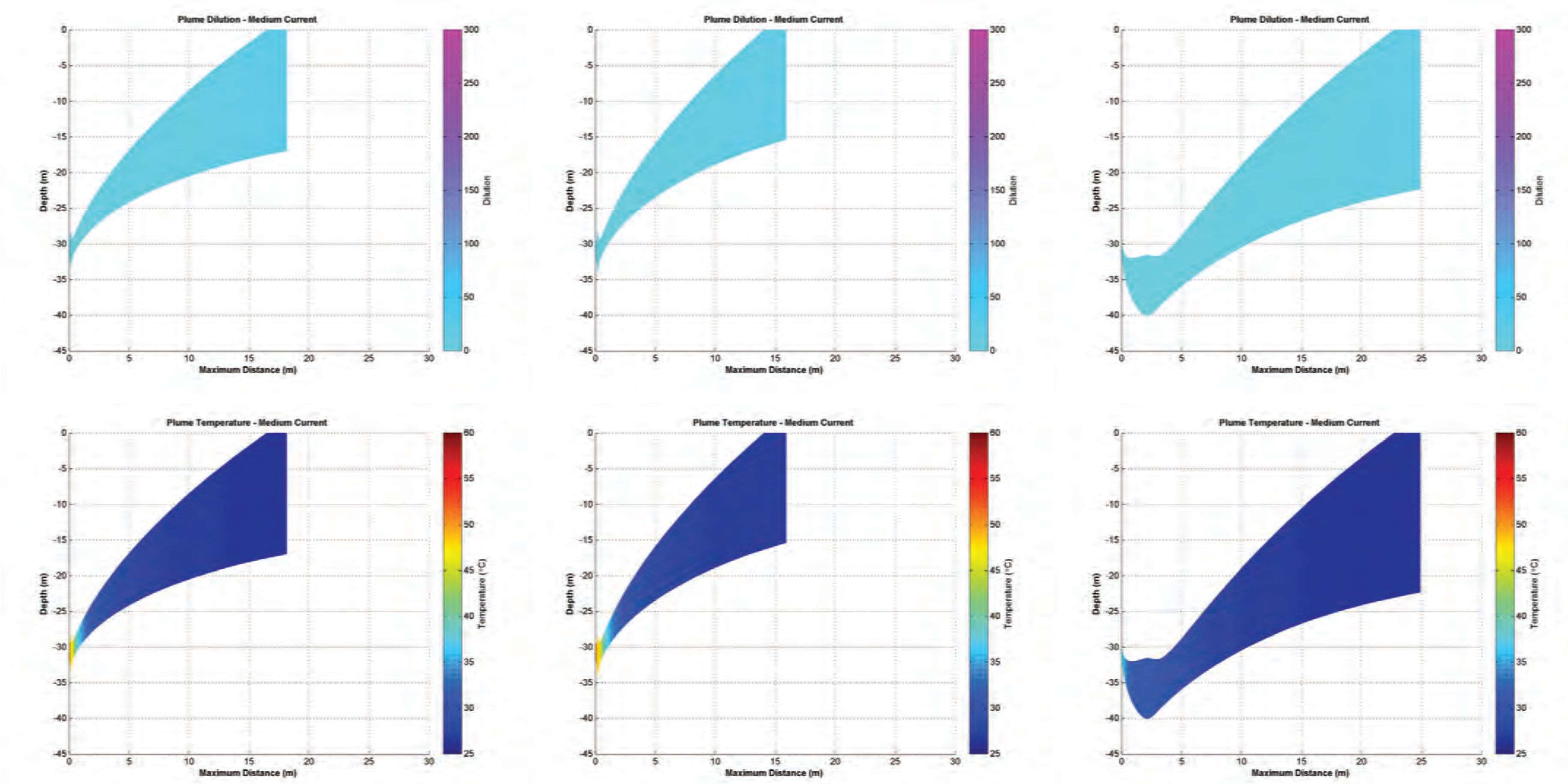



**Figure 3.70 Near-field average dilution and temperature results for constant medium winter currents with discharge flow rates of 64,800 $m^3$/d (Case C6; left column), 82,800 $m^3$/d (Case C9; middle column) and 165,600 $m^3$/d (Case C3; right column) at a discharge depth of 30 m.**

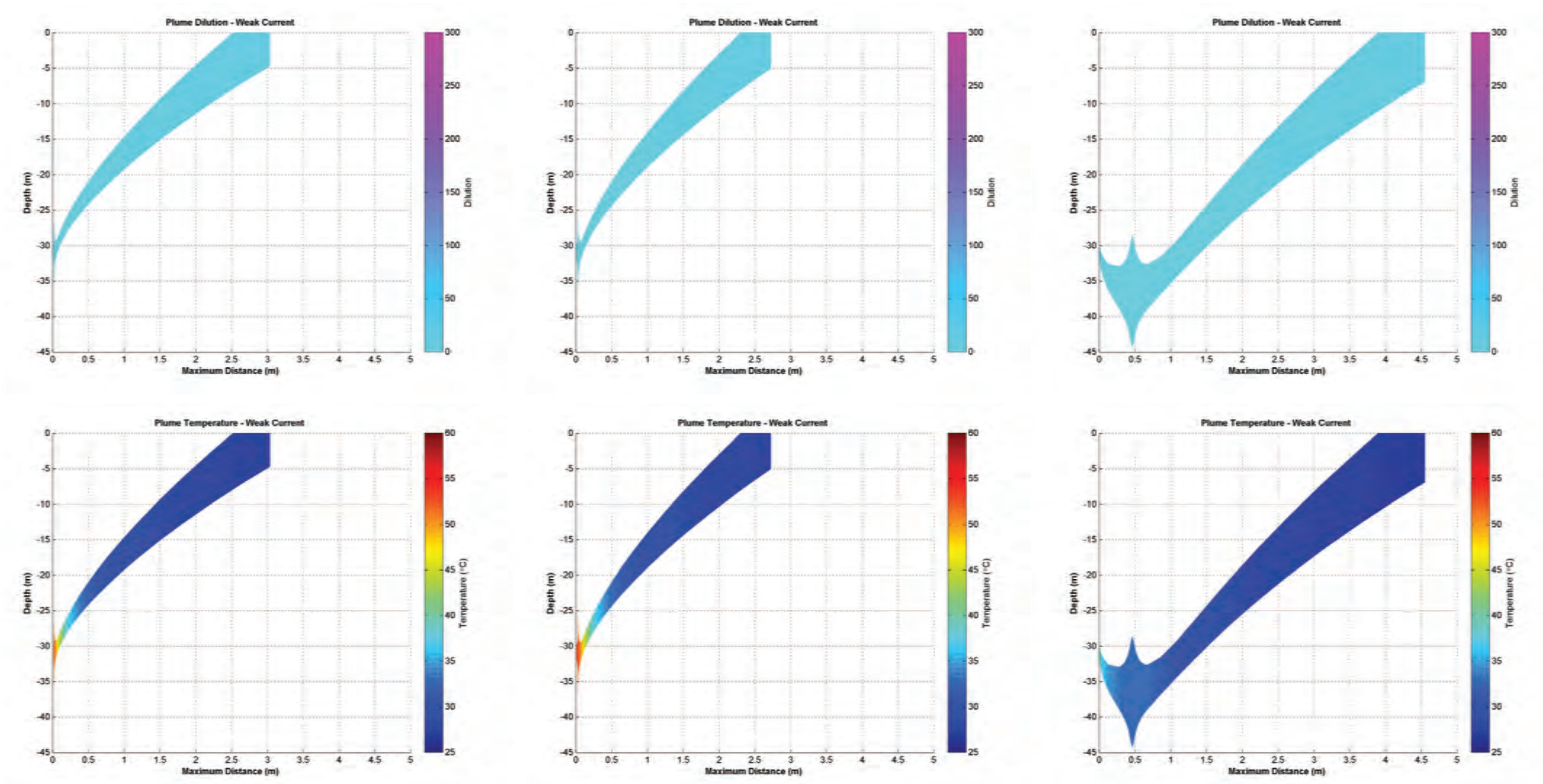



**Figure 3.71 Near-field average dilution and temperature results for constant weak winter currents with discharge flow rates of 64,800 $m^3/d$ (Case C6; left column), 82,800 $m^3/d$ (Case C9; middle column) and 165,600 $m^3/d$ (Case C3; right column) at a discharge depth of 30 m.**

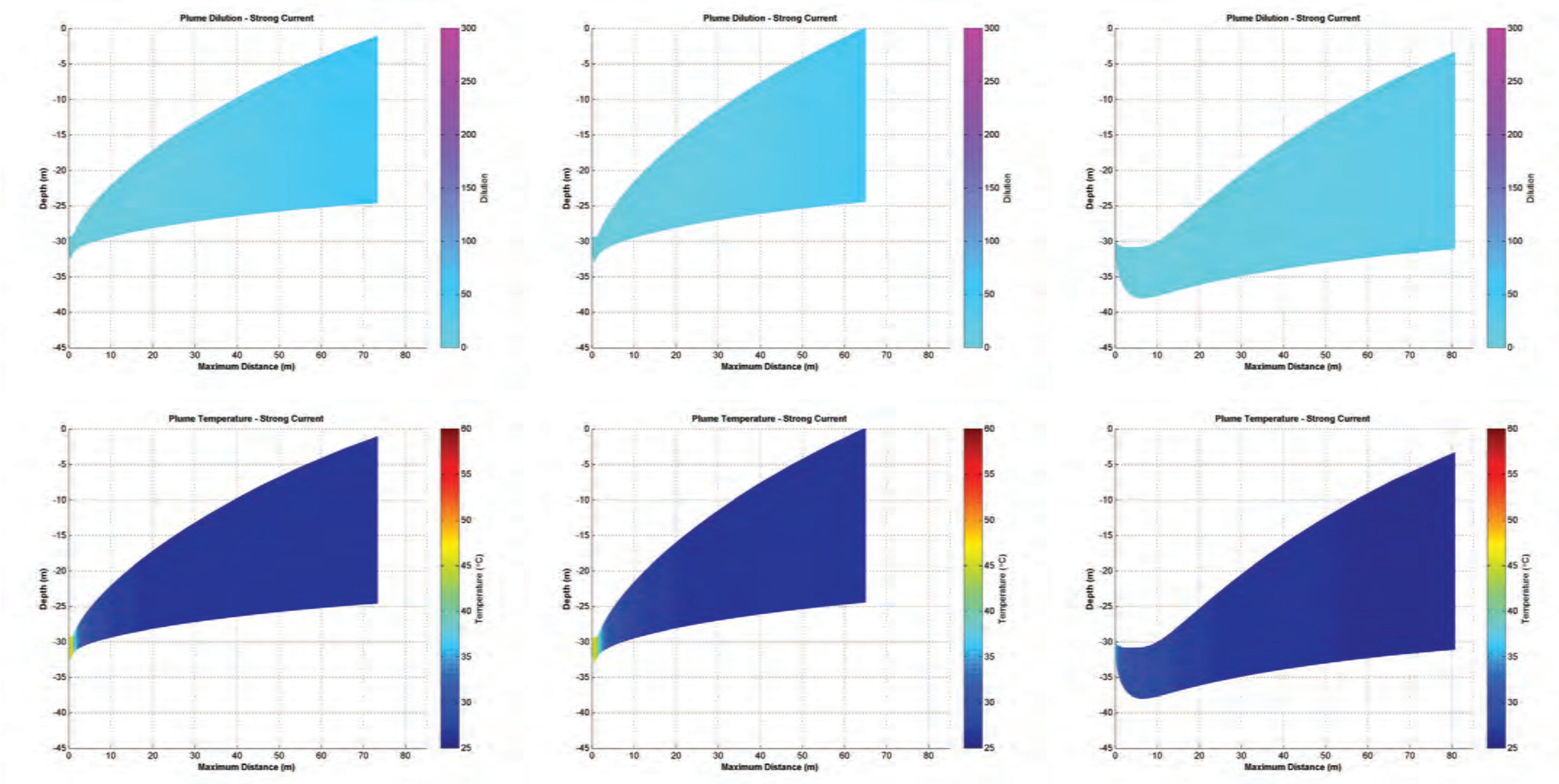



**Figure 3.72 Near-field average dilution and temperature results for constant strong winter currents with discharge flow rates of 64,800 m$^3$/d (Case C6; left column), 82,800 m$^3$/d (Case C9; middle column) and 165,600 m$^3$/d (Case C3; right column) at a discharge depth of 30 m.**

## 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 Interpretation of Percentile Dilution Contours

For each of the modelled discharge cases, the results for all simulations were combined and a statistical analysis performed to produce percentile contours of dilution. In the following sections, outcomes based on 95$^{th}$ and 99$^{th}$ percentile dilution contours are presented.

Calculation of 95$^{th}$ and 99$^{th}$ percentile statistics is a common approach to assessing the impact of dispersing plumes and captures the variability in outcomes, for all but the most ephemeral of forcing conditions, in the data set under consideration. Impact assessment criteria for water quality are often defined using similar statistical indicators.

Note that the percentile figures do not represent the location of a plume at any point in time; they are a statistical and spatial summary of the percentage of time that particular dilution values occur across all replicate simulations and time steps. For example, if the 95$^{th}$ percentile minimum dilution at a particular location in the model domain is predicted as a value of 100, this means that for 95% of the time the dilution level will be higher than 100 and for only 5% of the time the dilution level will be lower than 100. A comparison of the plume extents shown in Figure 3.73 with those shown in Sections 3.2.4 and 3.2.5 demonstrates the significant difference between an instantaneous snapshot and a cumulative estimate of coverage over several days and many individual simulations.

Dilution contours are calculated from the ratios of dispersing contaminant concentrations in the receiving waters to the initial concentration of the contaminant in the discharge. Note that this assumes the background concentration of the constituent in the receiving waters is zero and there is no significant biodegradation of the discharged constituent over the short duration of the dispersion process.

Table 3.46 summarises the initial concentrations of chlorine, as specified, and the equivalent dispersed concentrations required to yield particular dilution levels (1:100, 1:200 and 1:400). These concentrations may be useful to consider when interpreting the contour plots of percentile dilutions.

**Table 3.46 Initial concentrations of chlorine and equivalent concentrations at example dilution levels.**

| Chlorine Parameter | Chlorine Concentration (mg/L) |
|---|---|
| Initial concentration in discharge | 1,000.0 |
| Initial concentration in receiving waters | 0.0 |
| Concentration at 1:100 dilution | 10.0 |
| Concentration at 1:200 dilution | 5.0 |
| Concentration at 1:400 dilution | 1.5 |

### 3.2.3 General Observations

Figure 3.73 shows example time series snapshots of predicted dilutions during a single simulation at 3-hour intervals from 18:00 on 25th October 2013 to 10:00 on 26th October 2013. This simulation – selected merely to be representative of typical conditions – considers the Case C1 flow rate of 165,600 m$^3$/d at 0 m BMSL. 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.

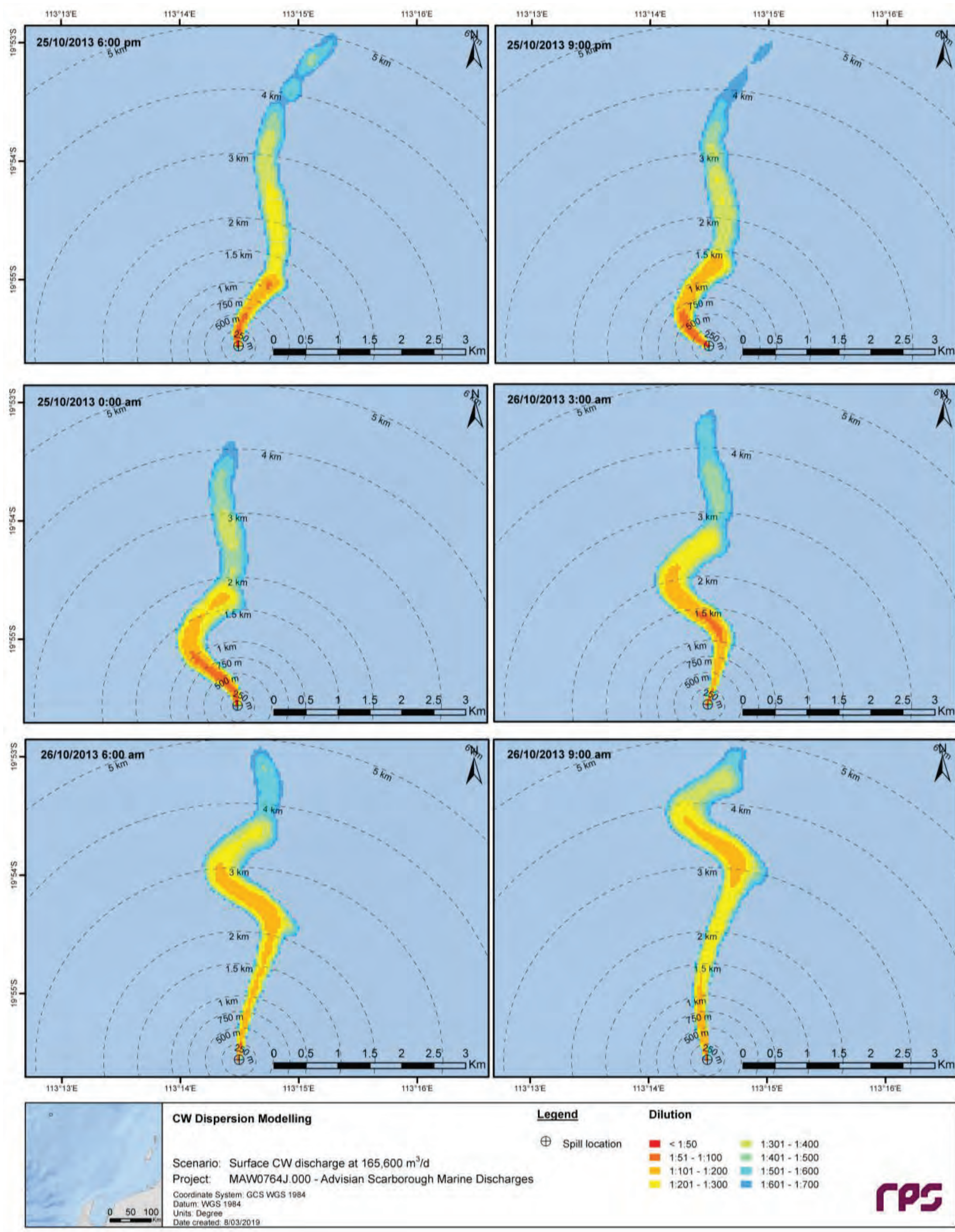



**Figure 3.73 Snapshots of predicted dilution levels, at 3-hour intervals from 18:00 on 25th October 2013 to 09:00 on 26th October 2013, for Case C1 (0 m depth discharge at 165,600 m$^3$/d flow rate).**

### 3.2.4 Seasonal Analysis

The model outputs over the ten-year hindcast period (2006-2015) were combined and analysed on a seasonal basis (summer, transitional and winter). This approach assists with identifying the potential exposure to surrounding sensitive receptors whilst considering inter-annual variability in ocean current conditions.

Table 3.47 to Table 3.50 summarise the minimum dilution achieved at specific radial distances from the discharge location for each season and percentile.

Table 3.51 to Table 3.54 provide summaries of the maximum distances from the discharge location to achieve 1:200 dilution for each season and percentile. The results indicate that the release of effluent under all seasonal conditions results in rapid dispersion within the ambient environment. For Cases C1 and C3, dilution to reach threshold concentration is achieved for chlorine within an area of influence ranging from 588 m to 639 m and 623 m to 771 m, respectively, at the 95$^{th}$ percentile across all seasons (Table 3.51 and Table 3.52). For Cases C4 and C6, the maximum spatial extents of the relevant dilution contour vary from 140 m to 182 m and 169 m to 212 m, respectively, at the 95$^{th}$ percentile across all seasons (Table 3.53 and Table 3.54). The greatest spatial extents are observed in winter.

Table 3.55 to Table 3.58 provide summaries of the total area of coverage for the 1:200 dilution contour for each season and percentile. For Cases C1 and C3, the area of exposure defined by the relevant dilution contour is predicted to reach maximums of 0.34 km$^2$ to 0.53 km$^2$ and 0.39 km$^2$ to 0.70 km$^2$, respectively, at the 95$^{th}$ percentile (Table 3.55 and Table 3.56). For Cases C4 and C6, the corresponding maximum areas of exposure vary from 0.04 km$^2$ to 0.05 km$^2$ and 0.05 km$^2$ to 0.08 km$^2$, respectively, at the 95$^{th}$ percentile (Table 3.57 and Table 3.58).

Table 3.59 to Table 3.62 provide summaries of the maximum depths from the discharge location to achieve 1:200 dilution for each season and percentile. Maximum depths are predicted as 8 m (summer and winter), 38 m (winter), 6 m (all seasons) and 38 m (summer) for Cases C1, C3, C4 and C6, respectively.

Table 3.63 to Table 3.66 provide summaries of the maximum distances from the discharge location to achieve a 3 °C plume-ambient temperature differential for each season and percentile. For all cases, the requirement is forecast to be met within 115 m at the 99$^{th}$ percentile across all seasons. In many cases, the requirement is forecast to be met within the scale of the model grid resolution (40 m).

For Cases C1, C3, C4 and C6, Figure 3.74 to Figure 3.97 show the aggregated spatial extents of the minimum dilutions for each season and percentile. 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.

For the cases where the temperature requirement is not met within the scale of the model grid resolution, Figure 3.98 to Figure 3.104 show the aggregated spatial extents of the maximum plume-ambient temperature differential for each season and percentile.

**Table 3.47 Minimum dilution achieved at specific radial distances from the CW discharge location in each season for Case C1 (0 m depth discharge at 165,600 m$^3$/d flow rate).**

| Percentile | Season | Minimum dilution (1:x) achieved at specific radial distances from discharge location | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0.02 km | 0.05 km | 0.10 km | 0.20 km | 0.30 km | 0.40 km | 0.50 km | 0.60 km | 0.70 km | 0.80 km | 0.90 km | 1.00 km | 1.10 km | 1.20 km | 1.30 km | 1.40 km | 1.50 km | 1.60 km | 1.70 km | 1.80 km | 1.90 km | 2.00 km |
| 95th | Summer | 1:35.0 | 1:36.0 | 1:41.3 | 1:76.0 | 1:107.1 | 1:132.7 | 1:151.4 | 1:176.0 | 1:205.8 | 1:233.6 | 1:261.6 | 1:287.6 | 1:303.5 | 1:365.1 | 1:391.1 | 1:442.6 | 1:489.0 | 1:542.9 | 1:588.7 | 1:651.8 | 1:671.0 | 1:692.1 |
| | Transitional | 1:36.8 | 1:34.0 | 1:49.5 | 1:72.9 | 1:106.5 | 1:128.7 | 1:148.8 | 1:182.7 | 1:209.1 | 1:232.9 | 1:262.4 | 1:293.7 | 1:326.9 | 1:344.4 | 1:388.6 | 1:418.2 | 1:437.6 | 1:476.6 | 1:521.2 | 1:548.7 | 1:585.7 | 1:617.3 |
| | Winter | 1:28.7 | 1:26.4 | 1:35.0 | 1:68.8 | 1:102.2 | 1:123.1 | 1:151.8 | 1:181.2 | 1:209.1 | 1:237.3 | 1:260.7 | 1:304.9 | 1:329.9 | 1:363.9 | 1:397.4 | 1:418.3 | 1:460.4 | 1:469.2 | 1:512.8 | 1:560.0 | 1:580.9 | 1:609.5 |
| 99th | Summer | 1:17.0 | 1:18.9 | 1:19.1 | 1:38.6 | 1:63.9 | 1:75.2 | 1:91.1 | 1:104.8 | 1:116.5 | 1:130.2 | 1:136.2 | 1:147.7 | 1:163.1 | 1:165.9 | 1:186.4 | 1:196.2 | 1:204.9 | 1:230.3 | 1:244.1 | 1:250.5 | 1:261.8 | 1:268.6 |
| | Transitional | 1:19.4 | 1:17.2 | 1:18.6 | 1:31.6 | 1:49.6 | 1:68.6 | 1:89.8 | 1:109.7 | 1:132.1 | 1:151.3 | 1:160.1 | 1:179.2 | 1:186.4 | 1:196.1 | 1:214.7 | 1:233.0 | 1:235.9 | 1:252.3 | 1:267.0 | 1:275.4 | 1:288.9 | 1:307.6 |
| | Winter | 1:14.3 | 1:11.6 | 1:17.0 | 1:32.7 | 1:49.5 | 1:61.0 | 1:71.1 | 1:74.3 | 1:81.7 | 1:94.8 | 1:98.4 | 1:106.3 | 1:126.6 | 1:136.2 | 1:147.0 | 1:149.1 | 1:161.2 | 1:165.4 | 1:170.8 | 1:176.6 | 1:212.8 | 1:237.8 |

**Table 3.48 Minimum dilution achieved at specific radial distances from the CW discharge location in each season for Case C3 (30 m depth discharge at 165,600 m$^3$/d flow rate).**

| Percentile | Season | Minimum dilution (1:x) achieved at specific radial distances from discharge location | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0.02 km | 0.05 km | 0.10 km | 0.20 km | 0.30 km | 0.40 km | 0.50 km | 0.60 km | 0.70 km | 0.80 km | 0.90 km | 1.00 km | 1.10 km | 1.20 km | 1.30 km | 1.40 km | 1.50 km | 1.60 km | 1.70 km | 1.80 km | 1.90 km | 2.00 km |
| 95th | Summer | 1:29.9 | 1:18.0 | 1:30.8 | 1:64.2 | 1:98.8 | 1:122.8 | 1:157.8 | 1:177.0 | 1:204.2 | 1:224.0 | 1:256.3 | 1:302.6 | 1:320.4 | 1:342.1 | 1:387.8 | 1:412.1 | 1:426.9 | 1:446.3 | 1:506.0 | 1:510.9 | 1:548.7 | 1:671.9 |
| | Transitional | 1:33.2 | 1:23.9 | 1:35.6 | 1:66.7 | 1:99.2 | 1:120.0 | 1:136.7 | 1:156.3 | 1:177.5 | 1:196.3 | 1:217.3 | 1:231.7 | 1:244.4 | 1:260.0 | 1:283.8 | 1:292.9 | 1:316.9 | 1:330.2 | 1:337.8 | 1:363.3 | 1:394.3 | 1:408.2 |
| | Winter | 1:24.5 | 1:18.8 | 1:29.7 | 1:58.9 | 1:82.6 | 1:125.0 | 1:140.7 | 1:166.1 | 1:174.6 | 1:202.1 | 1:208.5 | 1:235.7 | 1:271.3 | 1:363.9 | 1:423.2 | 1:458.8 | 1:539.1 | 1:669.4 | 1:758.1 | 1:875.3 | 1:1,055.4 | 1:1,144.4 |
| 99th | Summer | 1:9.7 | 1:13.6 | 1:15.1 | 1:32.0 | 1:50.0 | 1:61.7 | 1:70.1 | 1:84.7 | 1:86.5 | 1:100.3 | 1:100.9 | 1:107.8 | 1:112.1 | 1:124.3 | 1:129.1 | 1:141.4 | 1:154.8 | 1:165.5 | 1:174.5 | 1:181.6 | 1:195.5 | 1:206.0 |
| | Transitional | 1:18.5 | 1:12.8 | 1:16.1 | 1:31.8 | 1:51.8 | 1:72.1 | 1:83.3 | 1:98.7 | 1:104.1 | 1:112.3 | 1:115.5 | 1:122.4 | 1:132.2 | 1:147.0 | 1:163.3 | 1:182.0 | 1:186.9 | 1:186.0 | 1:187.4 | 1:193.9 | 1:211.4 | 1:231.7 |
| | Winter | 1:13.0 | 1:9.6 | 1:16.0 | 1:28.8 | 1:41.0 | 1:49.8 | 1:56.7 | 1:69.3 | 1:79.3 | 1:94.1 | 1:93.2 | 1:98.8 | 1:118.5 | 1:130.8 | 1:140.5 | 1:163.3 | 1:171.6 | 1:178.2 | 1:191.8 | 1:192.7 | 1:214.8 | 1:224.2 |

**Table 3.49 Minimum dilution achieved at specific radial distances from the CW discharge location in each season for Case C4 (0 m depth discharge at 64,800 m$^3$/d flow rate).**

| Percentile | Season | Minimum dilution (1:x) achieved at specific radial distances from discharge location | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0.02 km | 0.05 km | 0.10 km | 0.20 km | 0.30 km | 0.40 km | 0.50 km | 0.60 km | 0.70 km | 0.80 km | 0.90 km | 1.00 km | 1.10 km | 1.20 km | 1.30 km | 1.40 km | 1.50 km | 1.60 km | 1.70 km | 1.80 km | 1.90 km | 2.00 km |
| 95th | Summer | 1:89.5 | 1:92.5 | 1:105.4 | 1:194.0 | 1:273.7 | 1:339.0 | 1:387.0 | 1:449.9 | 1:526.1 | 1:596.9 | 1:668.6 | 1:735.0 | 1:775.7 | 1:933.1 | 1:999.5 | 1:1,131.0 | 1:1,249.7 | 1:1,387.4 | 1:1,504.5 | 1:1,665.8 | 1:1,714.7 | 1:1,768.7 |
| | Transitional | 1:94.0 | 1:87.0 | 1:90.3 | 1:186.4 | 1:272.3 | 1:328.8 | 1:380.3 | 1:467.0 | 1:534.3 | 1:595.2 | 1:670.6 | 1:750.6 | 1:835.5 | 1:880.1 | 1:993.1 | 1:1,068.6 | 1:1,118.4 | 1:1,217.9 | 1:1,331.9 | 1:1,402.1 | 1:1,496.7 | 1:1,577.6 |
| | Winter | 1:67.4 | 1:73.3 | 1:89.5 | 1:175.7 | 1:261.2 | 1:314.6 | 1:387.9 | 1:463.2 | 1:534.3 | 1:606.3 | 1:666.1 | 1:779.1 | 1:843.1 | 1:929.9 | 1:1,015.6 | 1:1,069.1 | 1:1,176.5 | 1:1,199.0 | 1:1,310.6 | 1:1,431.2 | 1:1,484.6 | 1:1,557.7 |
| 99th | Summer | 1:43.5 | 1:48.2 | 1:48.8 | 1:98.7 | 1:163.2 | 1:192.1 | 1:232.8 | 1:267.8 | 1:297.8 | 1:332.7 | 1:348.0 | 1:377.5 | 1:416.9 | 1:424.0 | 1:476.4 | 1:501.4 | 1:523.6 | 1:588.5 | 1:623.9 | 1:640.1 | 1:669.0 | 1:686.4 |
| | Transitional | 1:49.7 | 1:44.0 | 1:47.6 | 1:80.8 | 1:126.6 | 1:175.4 | 1:229.4 | 1:280.4 | 1:337.6 | 1:386.8 | 1:409.2 | 1:457.9 | 1:476.2 | 1:501.0 | 1:548.6 | 1:595.4 | 1:602.9 | 1:644.8 | 1:682.4 | 1:703.9 | 1:738.3 | 1:786.2 |
| | Winter | 1:29.6 | 1:36.5 | 1:43.2 | 1:83.5 | 1:126.6 | 1:156.0 | 1:181.7 | 1:189.8 | 1:208.7 | 1:242.3 | 1:251.6 | 1:271.7 | 1:313.4 | 1:348.0 | 1:375.7 | 1:381.1 | 1:411.8 | 1:422.6 | 1:436.4 | 1:451.4 | 1:543.8 | 1:607.8 |

**Table 3.50 Minimum dilution achieved at specific radial distances from the CW discharge location in each season for Case C6 (30 m depth discharge at 64,800 m$^3$/d flow rate).**

| Percentile | Season | Minimum dilution (1:x) achieved at specific radial distances from discharge location | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0.02 km | 0.05 km | 0.10 km | 0.20 km | 0.30 km | 0.40 km | 0.50 km | 0.60 km | 0.70 km | 0.80 km | 0.90 km | 1.00 km | 1.10 km | 1.20 km | 1.30 km | 1.40 km | 1.50 km | 1.60 km | 1.70 km | 1.80 km | 1.90 km | 2.00 km |
| 95th | Summer | 1:44.7 | 1:72.6 | 1:99.7 | 1:156.6 | 1:256.5 | 1:321.2 | 1:400.4 | 1:450.5 | 1:537.7 | 1:617.3 | 1:655.1 | 1:773.2 | 1:818.7 | 1:874.3 | 1:991.1 | 1:1,053.1 | 1:1,091.1 | 1:1,140.7 | 1:1,293.1 | 1:1,305.7 | 1:1,402.3 | 1:1,717.2 |
| | Transitional | 1:61.2 | 1:89.4 | 1:111.0 | 1:162.2 | 1:252.6 | 1:306.6 | 1:350.9 | 1:407.4 | 1:458.9 | 1:507.0 | 1:561.3 | 1:595.5 | 1:630.0 | 1:680.7 | 1:741.7 | 1:772.3 | 1:856.5 | 1:856.6 | 1:892.2 | 1:1,001.1 | 1:1,064.3 | 1:1,056.5 |
| | Winter | 1:50.7 | 1:62.7 | 1:76.5 | 1:151.7 | 1:208.6 | 1:281.5 | 1:359.8 | 1:424.6 | 1:446.2 | 1:516.6 | 1:532.9 | 1:602.4 | 1:693.4 | 1:930.0 | 1:1,081.5 | 1:1,172.4 | 1:1,377.7 | 1:1,710.7 | 1:1,835.9 | 1:2,197.7 | 1:2,411.9 | 1:2,611.3 |
| 99th | Summer | 1:24.6 | 1:34.7 | 1:37.9 | 1:81.2 | 1:121.0 | 1:150.2 | 1:175.3 | 1:209.6 | 1:216.6 | 1:256.2 | 1:257.8 | 1:275.6 | 1:286.6 | 1:317.6 | 1:329.9 | 1:361.4 | 1:395.6 | 1:423.0 | 1:445.9 | 1:464.2 | 1:499.6 | 1:526.4 |
| | Transitional | 1:29.5 | 1:40.6 | 1:60.3 | 1:92.6 | 1:132.9 | 1:179.8 | 1:207.3 | 1:230.8 | 1:251.6 | 1:270.1 | 1:285.6 | 1:312.6 | 1:315.5 | 1:319.8 | 1:376.2 | 1:423.1 | 1:465.4 | 1:453.9 | 1:455.8 | 1:445.5 | 1:503.0 | 1:548.3 |
| | Winter | 1:24.4 | 1:33.2 | 1:40.8 | 1:73.6 | 1:104.9 | 1:130.7 | 1:141.9 | 1:181.2 | 1:195.2 | 1:240.5 | 1:238.2 | 1:252.7 | 1:302.7 | 1:331.3 | 1:395.0 | 1:417.4 | 1:438.6 | 1:455.4 | 1:504.9 | 1:492.5 | 1:548.8 | 1:572.9 |

**Table 3.51 Maximum distance from the CW discharge location to achieve 1:200 dilution in each season for Case C1 (0 m depth discharge at 165,600 m³/d flow rate).**

| Percentile | Season | Maximum distance (m) from discharge location to achieve given dilution |
|---|---|---|
| 95th | Summer | 639 |
| | Transitional | 588 |
| | Winter | 636 |
| 99th | Summer | 1,354 |
| | Transitional | 1,175 |
| | Winter | 1,789 |
| 100th | Summer | 3,572 |
| | Transitional | 3,741 |
| | Winter | 4,705 |

**Table 3.52 Maximum distance from the CW discharge location to achieve 1:200 dilution in each season for Case C3 (30 m depth discharge at 165,600 m³/d flow rate).**

| Percentile | Season | Maximum distance (m) from discharge location to achieve given dilution |
|---|---|---|
| 95th | Summer | 623 |
| | Transitional | 757 |
| | Winter | 771 |
| 99th | Summer | 1,896 |
| | Transitional | 1,758 |
| | Winter | 2,470 |
| 100th | Summer | 5,857 |
| | Transitional | 6,391 |
| | Winter | 5,549 |

**Table 3.53 Maximum distance from the CW discharge location to achieve 1:200 dilution in each season for Case C4 (0 m depth discharge at 64,800 m$^3$/d flow rate).**

| Percentile | Season | Maximum distance (m) from discharge location to achieve given dilution |
|---|---|---|
| 95$^{th}$ | Summer | 140 |
| | Transitional | 152 |
| | Winter | 182 |
| 99$^{th}$ | Summer | 351 |
| | Transitional | 393 |
| | Winter | 621 |
| 100$^{th}$ | Summer | 1,723 |
| | Transitional | 1,579 |
| | Winter | 2,272 |

**Table 3.54 Maximum distance from the CW discharge location to achieve 1:200 dilution in each season for Case C6 (30 m depth discharge at 64,800 m$^3$/d flow rate).**

| Percentile | Season | Maximum distance (m) from discharge location to achieve given dilution |
|---|---|---|
| 95$^{th}$ | Summer | 188 |
| | Transitional | 169 |
| | Winter | 212 |
| 99$^{th}$ | Summer | 519 |
| | Transitional | 413 |
| | Winter | 631 |
| 100$^{th}$ | Summer | 3,258 |
| | Transitional | 3,258 |
| | Winter | 3,566 |

**Table 3.55 Total area of coverage for 1:200 dilution in each season for Case C1 (0 m depth discharge at 165,600 m$^3$/d flow rate).**

| Percentile | Season | Total area (km$^2$) of coverage for given dilution |
|---|---|---|
| 95$^{th}$ | Summer | 0.353 |
| | Transitional | 0.343 |
| | Winter | 0.528 |
| 99$^{th}$ | Summer | 2.016 |
| | Transitional | 2.086 |
| | Winter | 4.409 |
| 100$^{th}$ | Summer | 10.966 |
| | Transitional | 9.992 |
| | Winter | 20.163 |

**Table 3.56 Total area of coverage for 1:200 dilution in each season for Case C3 (30 m depth discharge at 165,600 m$^3$/d flow rate).**

| Percentile | Season | Total area (km$^2$) of coverage for given dilution |
|---|---|---|
| 95$^{th}$ | Summer | 0.441 |
| | Transitional | 0.385 |
| | Winter | 0.701 |
| 99$^{th}$ | Summer | 4.625 |
| | Transitional | 3.768 |
| | Winter | 5.482 |
| 100$^{th}$ | Summer | 33.376 |
| | Transitional | 29.964 |
| | Winter | 30.908 |

**Table 3.57 Total area of coverage for 1:200 dilution in each season for Case C4 (0 m depth discharge at 64,800 m$^3$/d flow rate).**

| Percentile | Season | Total area (km$^2$) of coverage for given dilution |
|---|---|---|
| 95$^{th}$ | Summer | 0.039 |
| | Transitional | 0.035 |
| | Winter | 0.053 |
| 99$^{th}$ | Summer | 0.189 |
| | Transitional | 0.215 |
| | Winter | 0.374 |
| 100$^{th}$ | Summer | 1.425 |
| | Transitional | 1.164 |
| | Winter | 3.334 |

**Table 3.58 Total area of coverage for 1:200 dilution in each season for Case C6 (30 m depth discharge at 64,800 m$^3$/d flow rate).**

| Percentile | Season | Total area (km$^2$) of coverage for given dilution |
|---|---|---|
| 95$^{th}$ | Summer | 0.061 |
| | Transitional | 0.045 |
| | Winter | 0.075 |
| 99$^{th}$ | Summer | 0.465 |
| | Transitional | 0.242 |
| | Winter | 0.550 |
| 100$^{th}$ | Summer | 5.286 |
| | Transitional | 2.948 |
| | Winter | 5.635 |

**Table 3.59 Maximum depth from the CW discharge location to achieve 1:200 dilution in each season for Case C1 (0 m depth discharge at 165,600 $m^3$/d flow rate).**

| Season | Maximum depth (m) from discharge location to achieve given dilution |
|---|---|
| Summer | 8 |
| Transitional | 6 |
| Winter | 8 |

**Table 3.60 Maximum depth from the CW discharge location to achieve 1:200 dilution in each season for Case C3 (30 m depth discharge at 165,600 $m^3$/d flow rate).**

| Season | Maximum depth (m) from discharge location to achieve given dilution |
|---|---|
| Summer | 36 |
| Transitional | 36 |
| Winter | 38 |

**Table 3.61 Maximum depth from the CW discharge location to achieve 1:200 dilution in each season for Case C4 (0 m depth discharge at 64,800 $m^3$/d flow rate).**

| Season | Maximum depth (m) from discharge location to achieve given dilution |
|---|---|
| Summer | 6 |
| Transitional | 6 |
| Winter | 6 |

**Table 3.62 Maximum depth from the CW discharge location to achieve 1:200 dilution in each season for Case C6 (30 m depth discharge at 64,800 $m^3$/d flow rate).**

| Season | Maximum depth (m) from discharge location to achieve given dilution |
|---|---|
| Summer | 38 |
| Transitional | 36 |
| Winter | 36 |

**Table 3.63 Maximum distance from the CW discharge location to achieve 3 °C plume-ambient ΔT in each season for Case C1 (0 m depth discharge at 165,600 $m^3$/d flow rate).**

| Percentile | Season | Maximum distance (m) from discharge location to achieve given ΔT |
|---|---|---|
| 95th | Summer | <40 |
| | Transitional | <40 |
| | Winter | <40 |
| 99th | Summer | <40 |
| | Transitional | <40 |
| | Winter | 90 |
| 100th | Summer | 115 |
| | Transitional | 145 |
| | Winter | 285 |

**Table 3.64 Maximum distance from the CW discharge location to achieve 3 °C plume-ambient ΔT in each season for Case C3 (30 m depth discharge at 165,600 $m^3$/d flow rate).**

| Percentile | Season | Maximum distance (m) from discharge location to achieve given ΔT |
|---|---|---|
| 95th | Summer | <40 |
| | Transitional | <40 |
| | Winter | <40 |
| 99th | Summer | 115 |
| | Transitional | 115 |
| | Winter | 115 |
| 100th | Summer | 350 |
| | Transitional | 380 |
| | Winter | 345 |

**Table 3.65 Maximum distance from the CW discharge location to achieve 3 °C plume-ambient ΔT in each season for Case C4 (0 m depth discharge at 64,800 $m^3$/d flow rate).**

| Percentile | Season | Maximum distance (m) from discharge location to achieve given ΔT |
|---|---|---|
| 95th | Summer | <40 |
| | Transitional | <40 |
| | Winter | <40 |
| 99th | Summer | <40 |
| | Transitional | <40 |
| | Winter | <40 |
| 100th | Summer | 90 |
| | Transitional | 90 |
| | Winter | 145 |

**Table 3.66 Maximum distance from the CW discharge location to achieve 3 °C plume-ambient ΔT in each season for Case C6 (30 m depth discharge at 64,800 $m^3$/d flow rate).**

| Percentile | Season | Maximum distance (m) from discharge location to achieve given ΔT |
|---|---|---|
| 95th | Summer | <40 |
| | Transitional | <40 |
| | Winter | <40 |
| 99th | Summer | 90 |
| | Transitional | 90 |
| | Winter | 90 |
| 100th | Summer | 145 |
| | Transitional | 175 |
| | Winter | 145 |

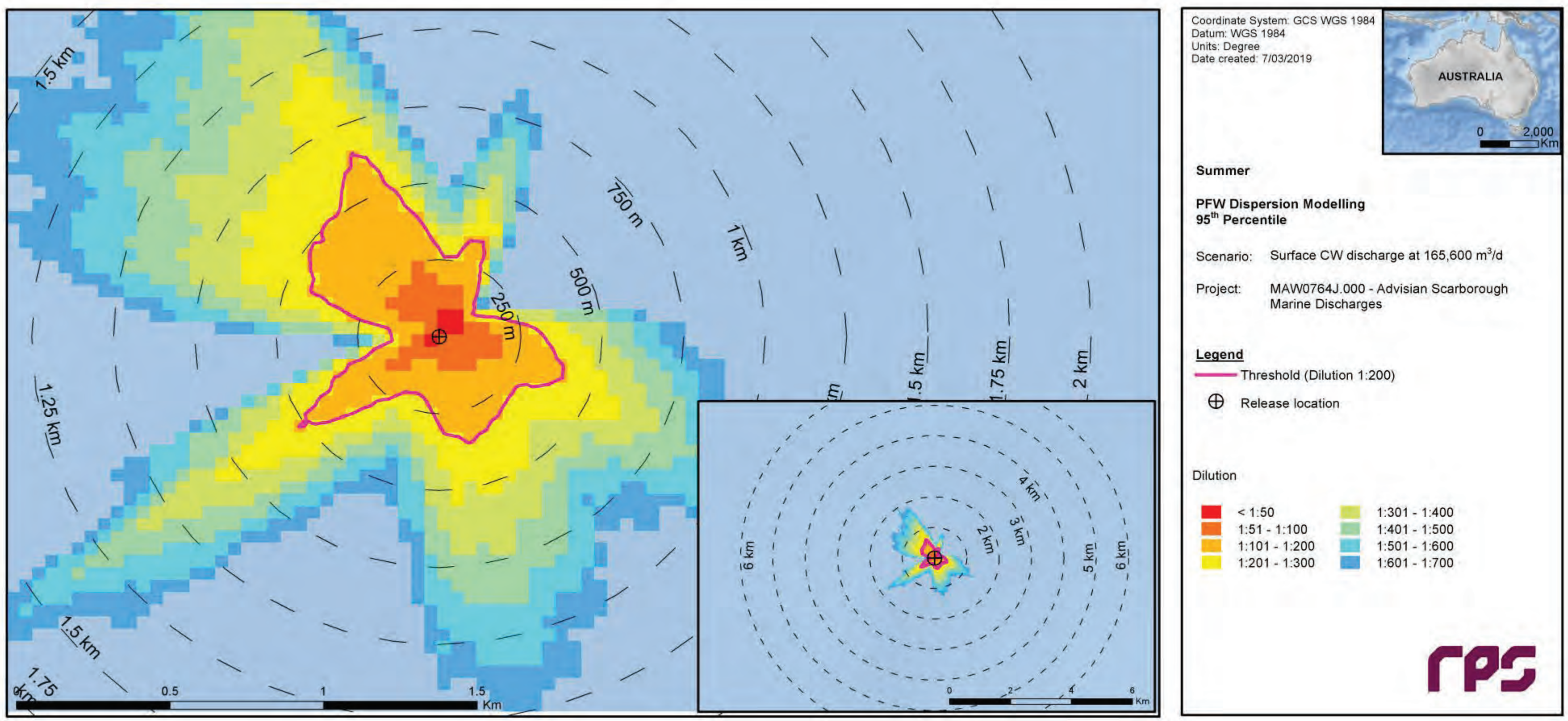



**Figure 3.74 Predicted minimum dilutions at the 95th percentile under summer conditions for Case C1 (0 m depth discharge at 165,600 m$^3$/d flow rate).**

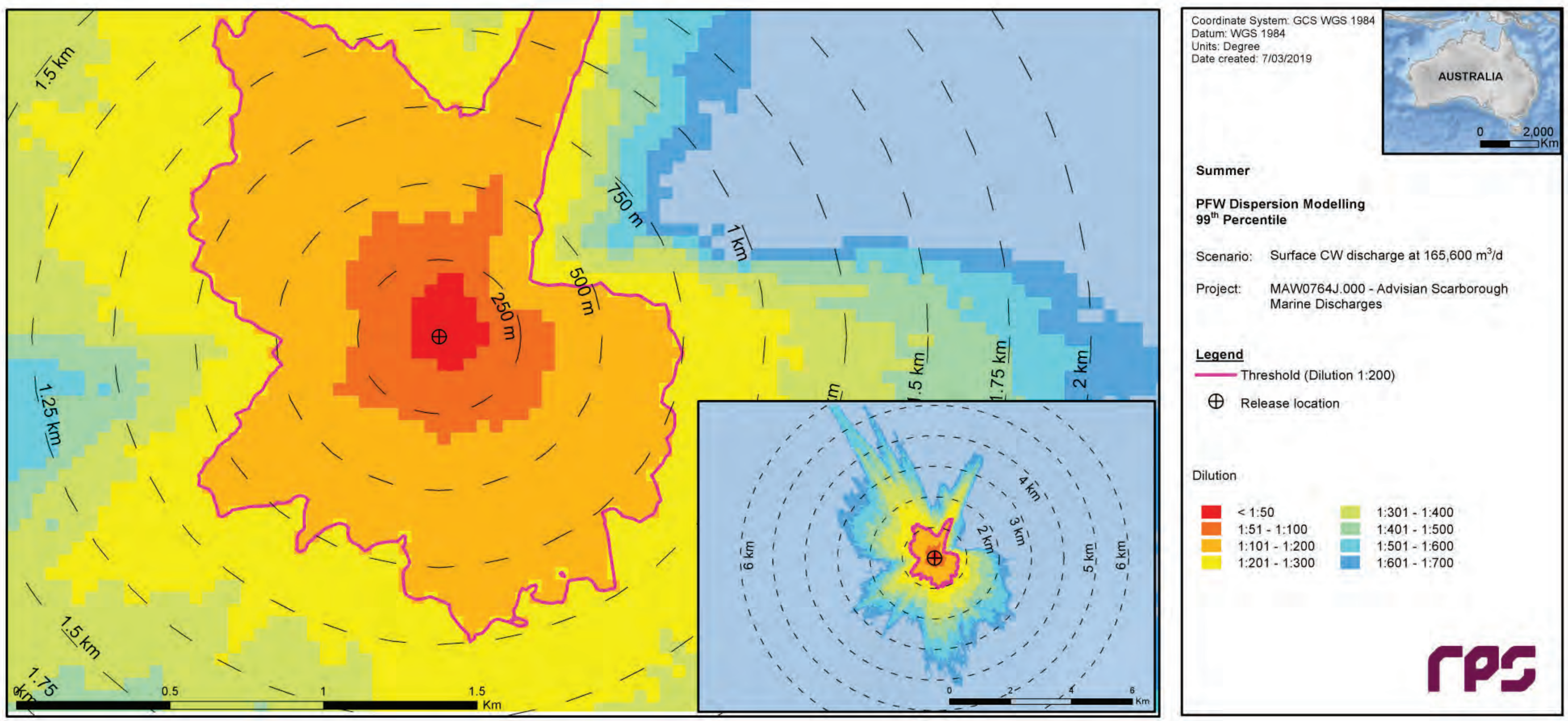



**Figure 3.75 Predicted minimum dilutions at the 99th percentile under summer conditions for Case C1 (0 m depth discharge at 165,600 $m^3$/d flow rate).**

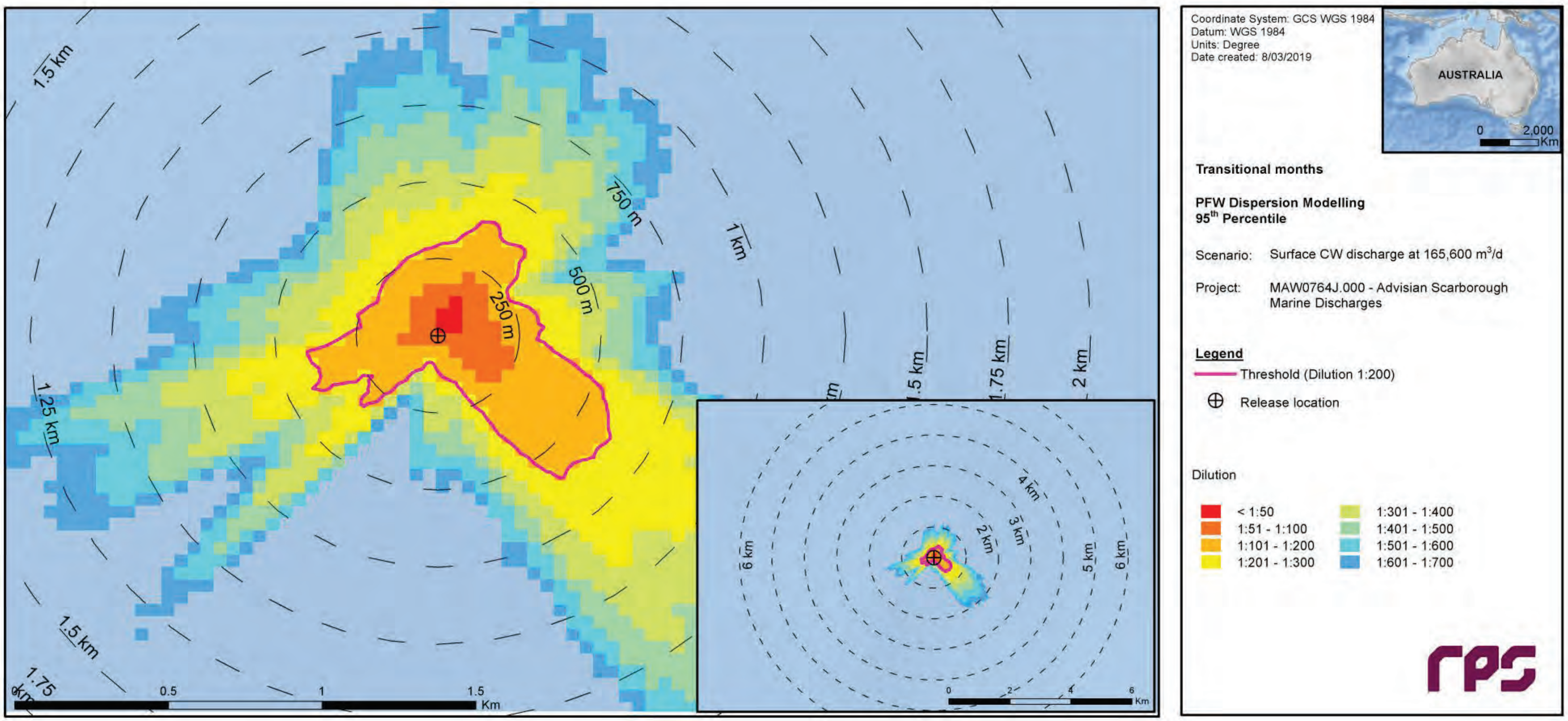



**Figure 3.76 Predicted minimum dilutions at the 95th percentile under transitional conditions for Case C1 (0 m depth discharge at 165,600 m$^3$/d flow rate).**

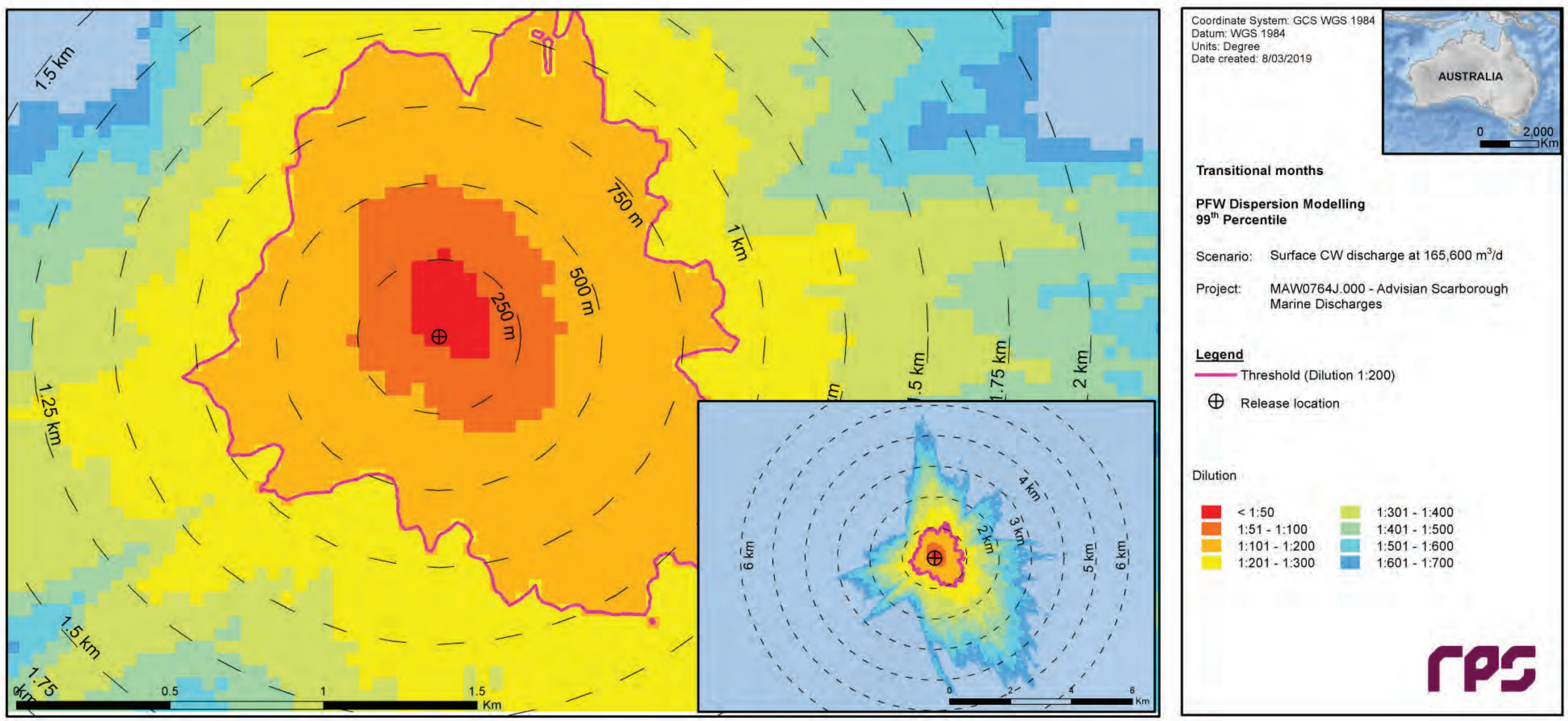



**Figure 3.77 Predicted minimum dilutions at the 99th percentile under transitional conditions for Case C1 (0 m depth discharge at 165,600 m$^3$/d flow rate).**

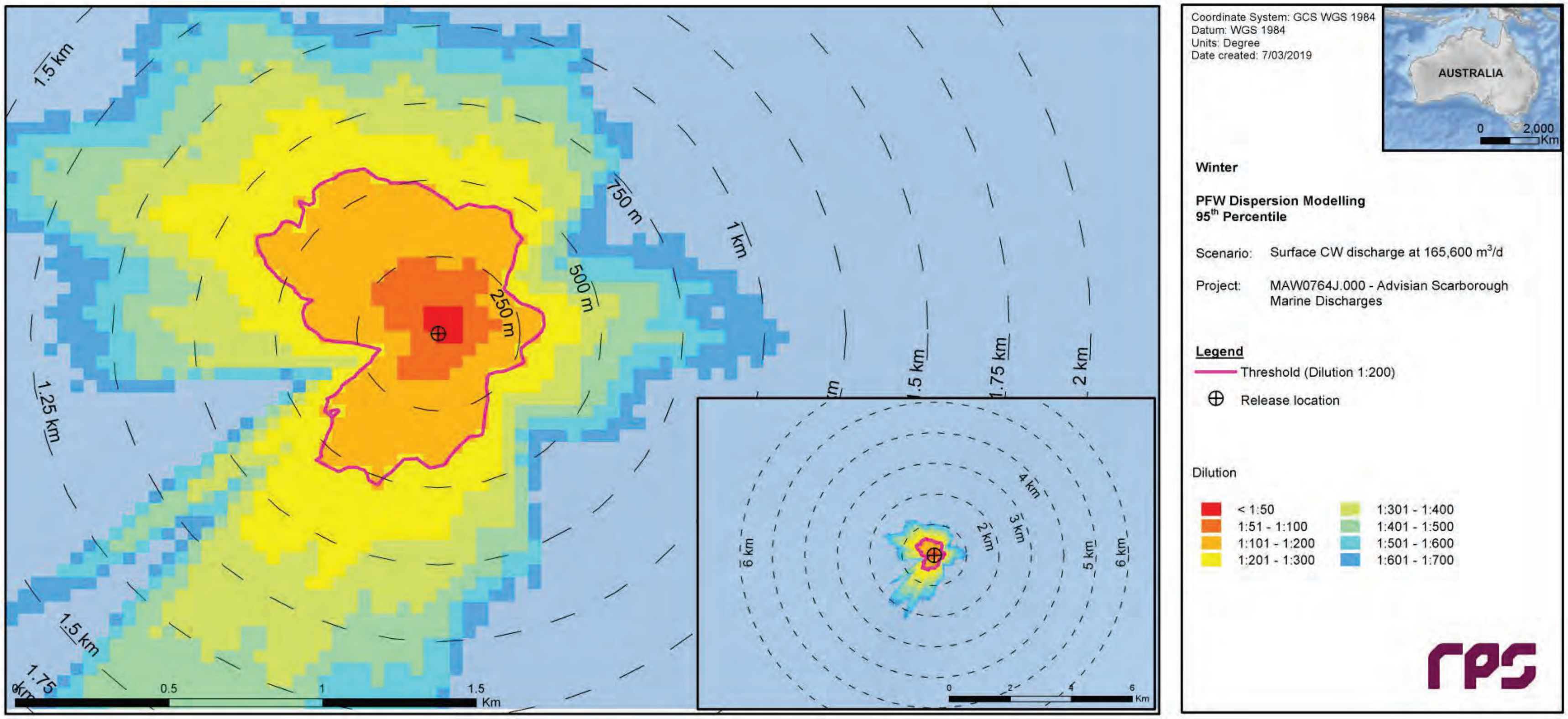



**Figure 3.78 Predicted minimum dilutions at the 95th percentile under winter conditions for Case C1 (0 m depth discharge at 165,600 $m^3$/d flow rate).**

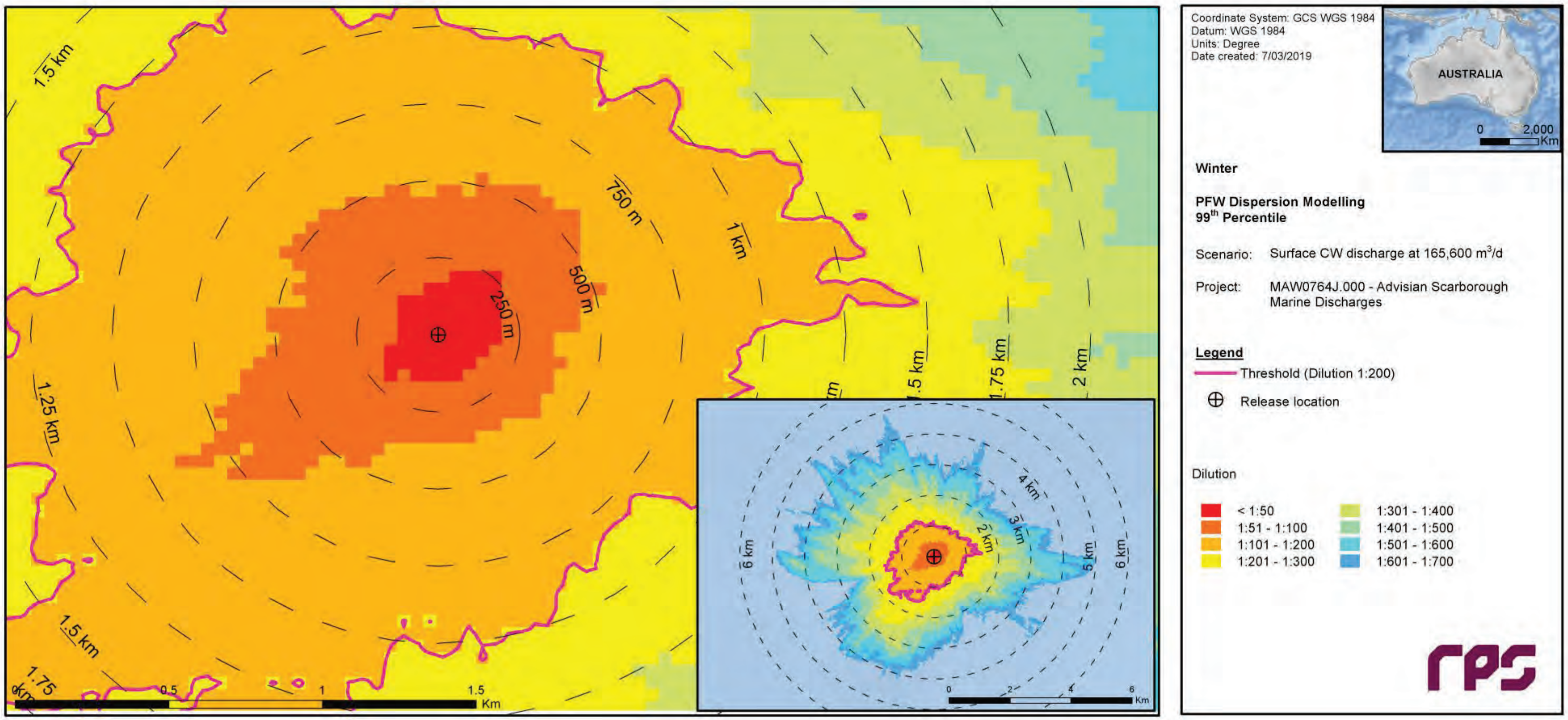



**Figure 3.79 Predicted minimum dilutions at the 99th percentile under winter conditions for Case C1 (0 m depth discharge at 165,600 m³/d flow rate).**

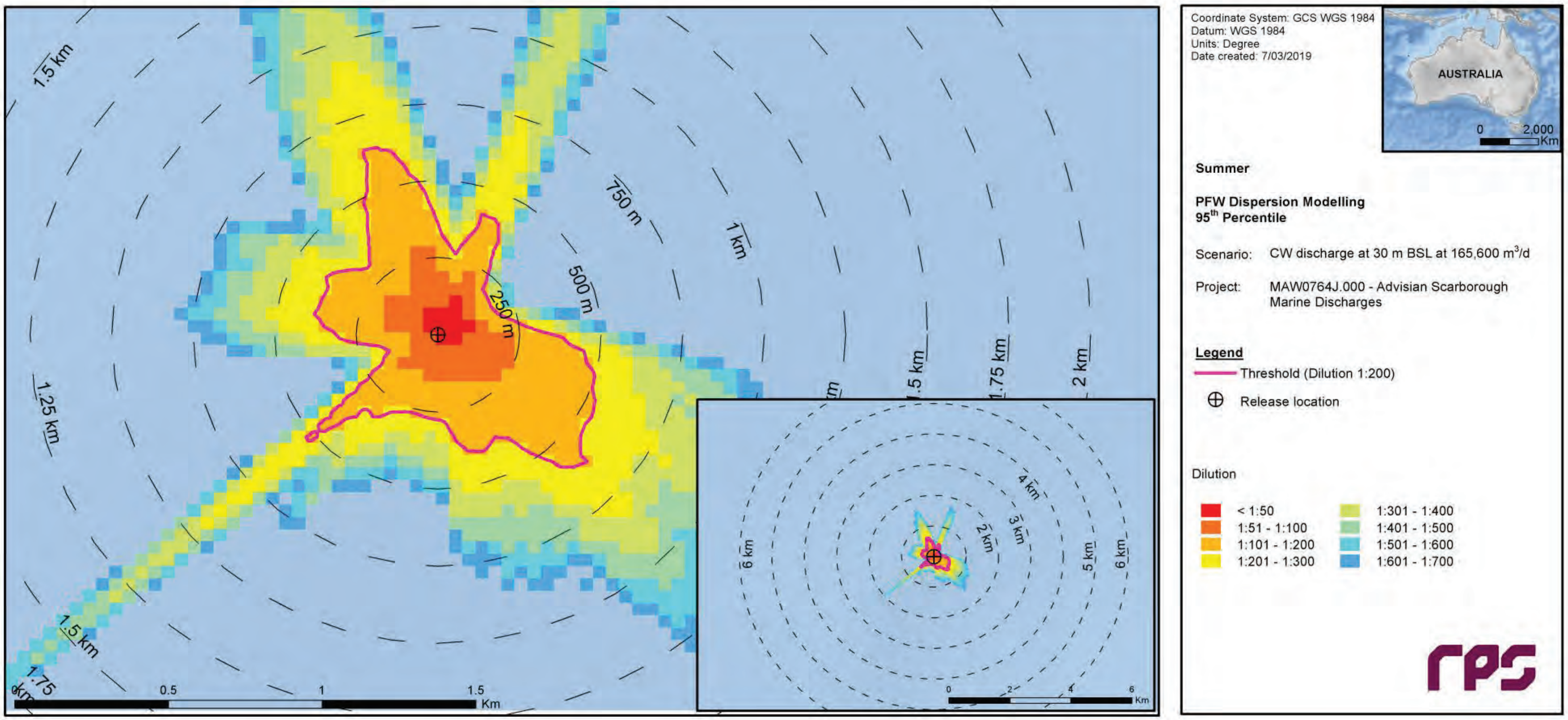



**Figure 3.80 Predicted minimum dilutions at the 95th percentile under summer conditions for Case C3 (30 m depth discharge at 165,600 m$^3$/d flow rate).**

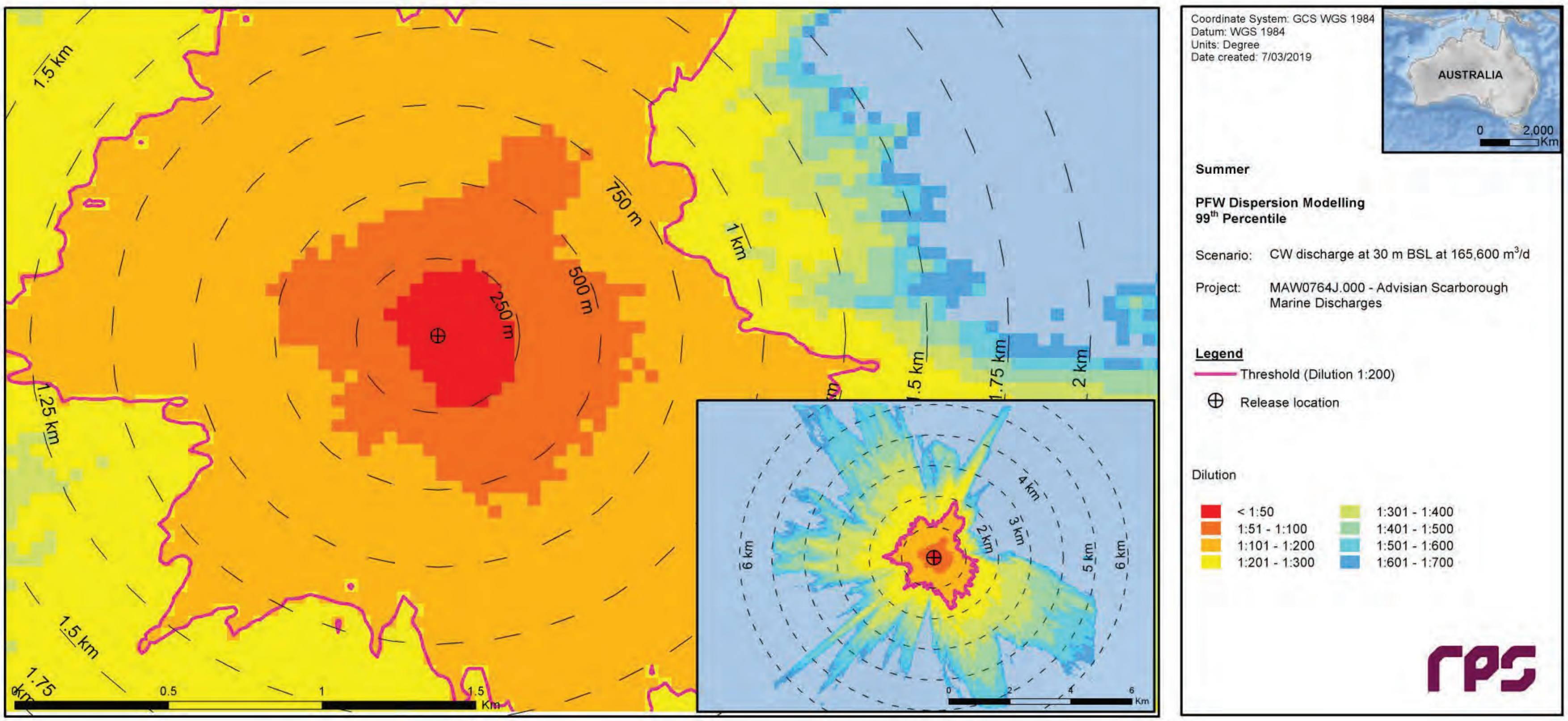



**Figure 3.81 Predicted minimum dilutions at the 99th percentile under summer conditions for Case C3 (30 m depth discharge at 165,600 $m^3/d$ flow rate).**

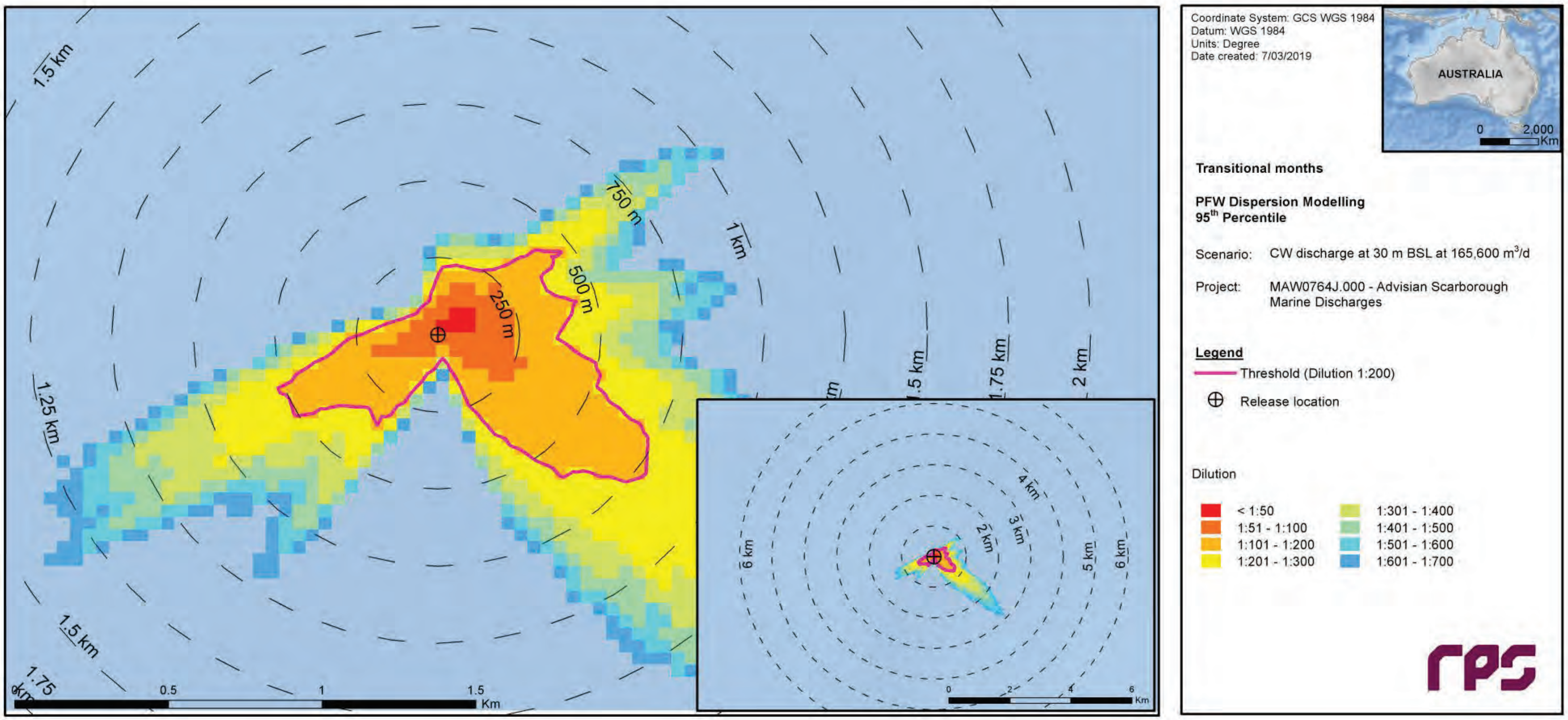



**Figure 3.82 Predicted minimum dilutions at the 95th percentile under transitional conditions for Case C3 (30 m depth discharge at 165,600 m³/d flow rate).**

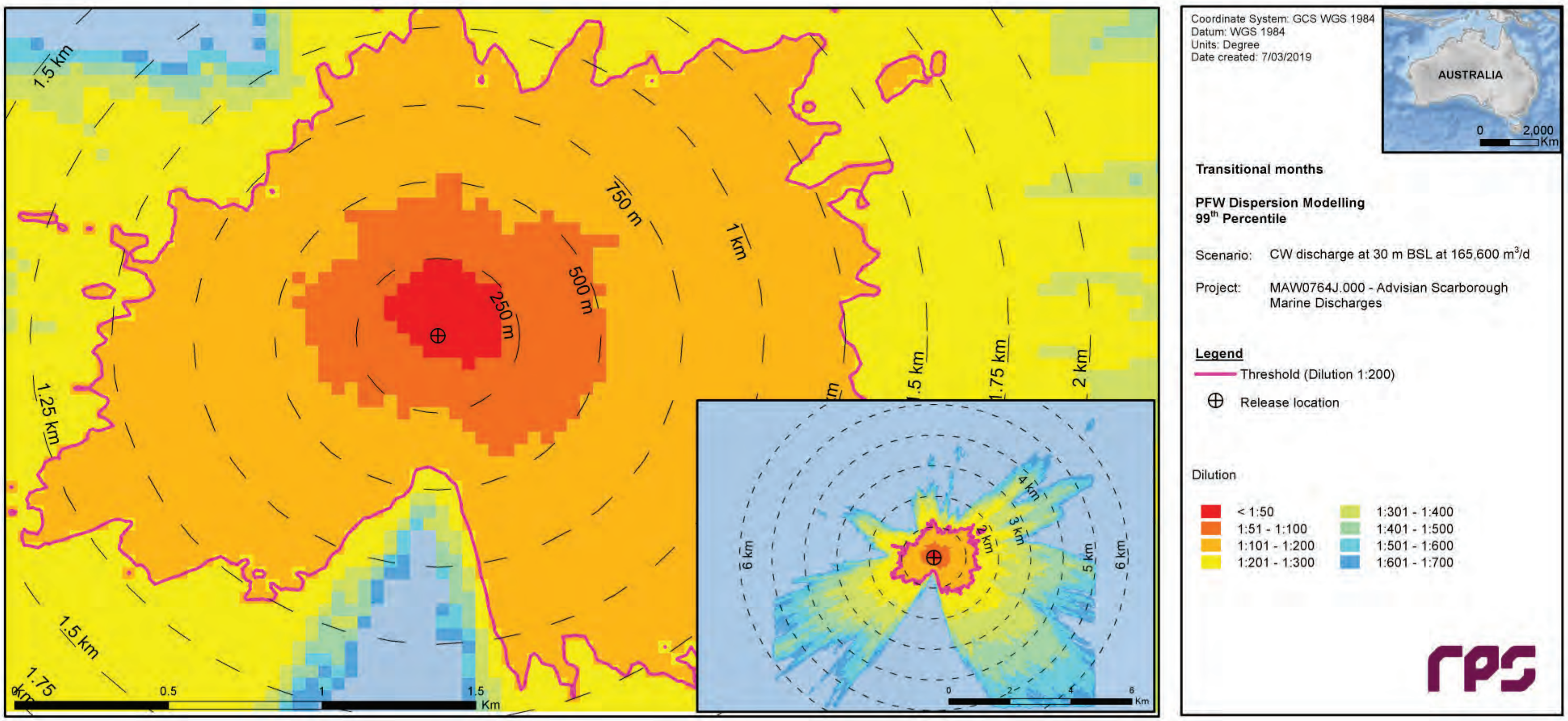



**Figure 3.83 Predicted minimum dilutions at the 99th percentile under transitional conditions for Case C3 (30 m depth discharge at 165,600 $m^3$/d flow rate).**

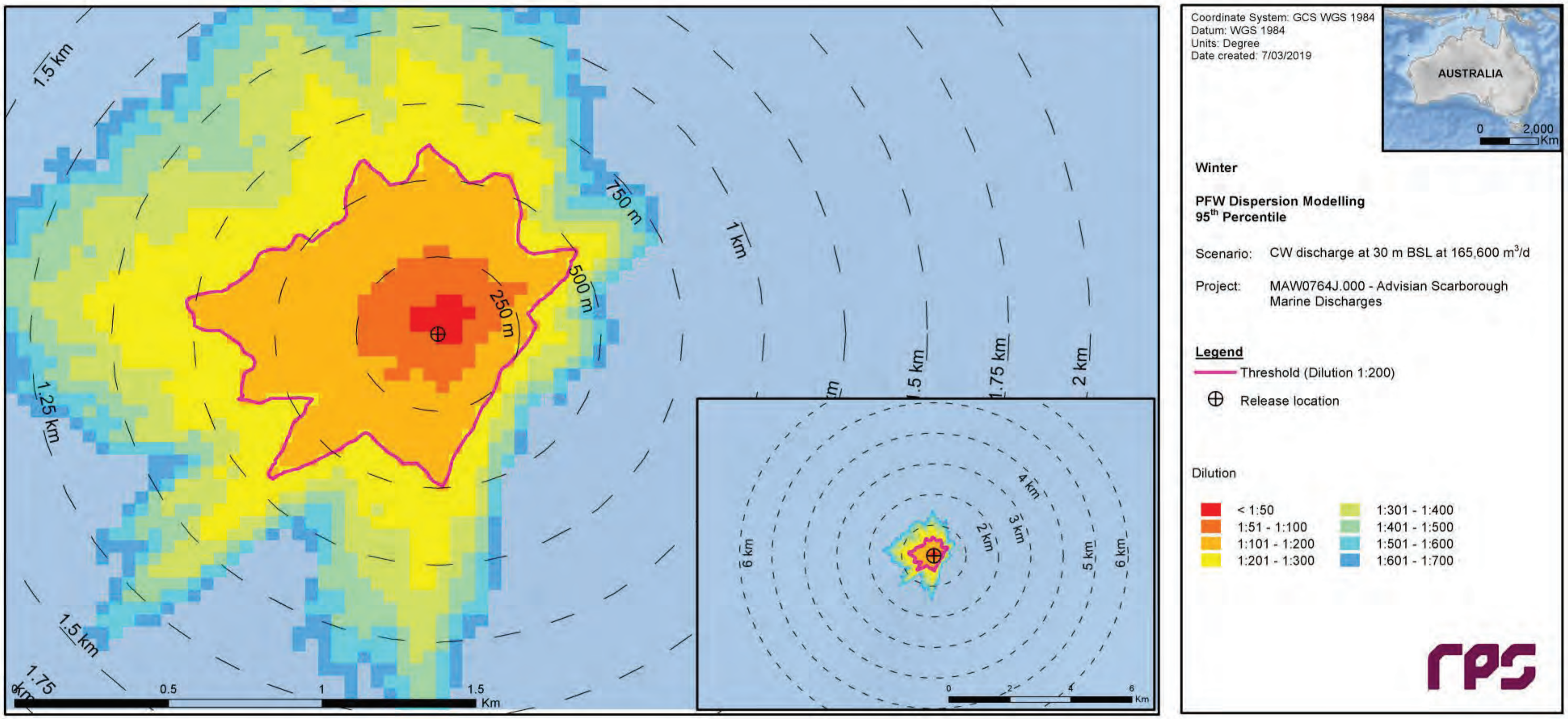



**Figure 3.84 Predicted minimum dilutions at the 95th percentile under winter conditions for Case C3 (30 m depth discharge at 165,600 m$^3$/d flow rate).**

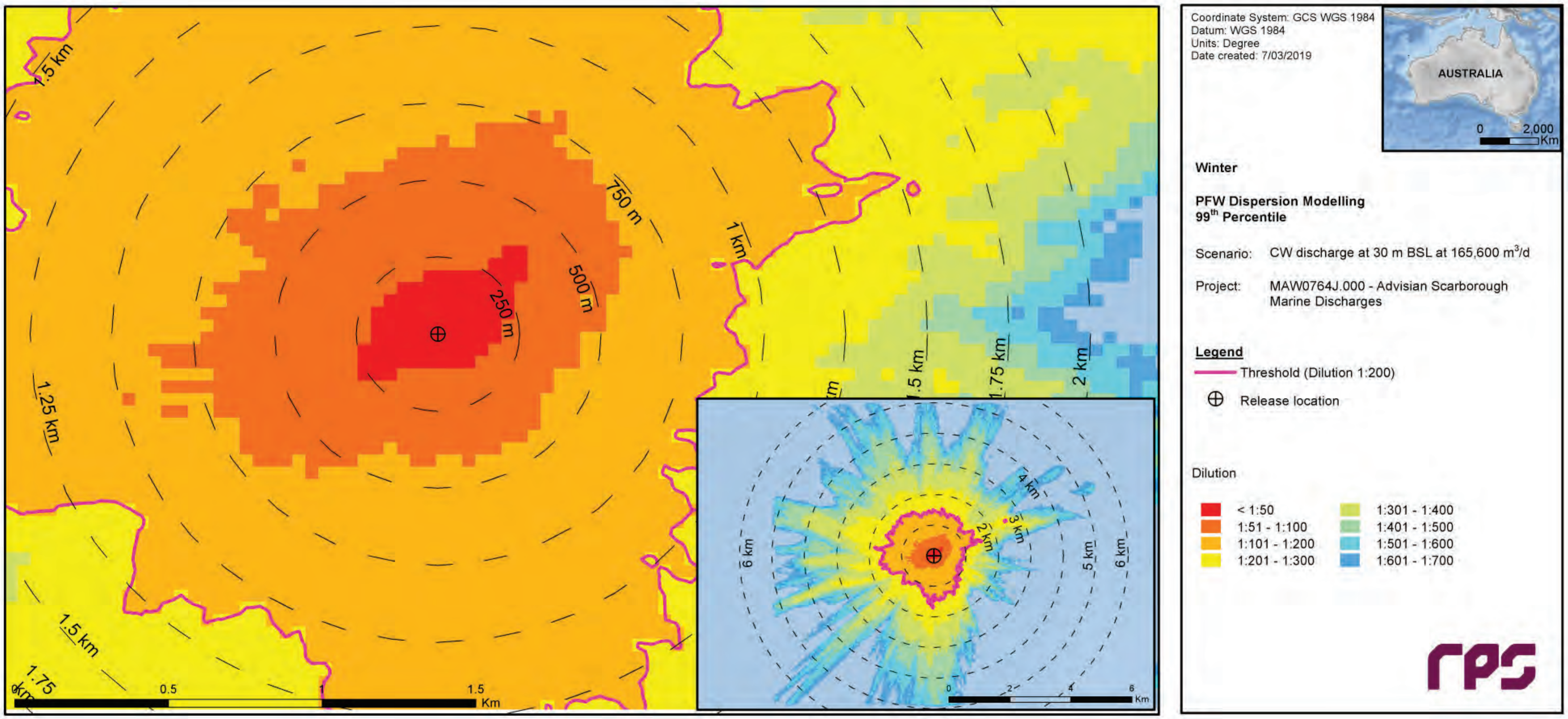



**Figure 3.85 Predicted minimum dilutions at the 99th percentile under winter conditions for Case C3 (30 m depth discharge at 165,600 m³/d flow rate).**

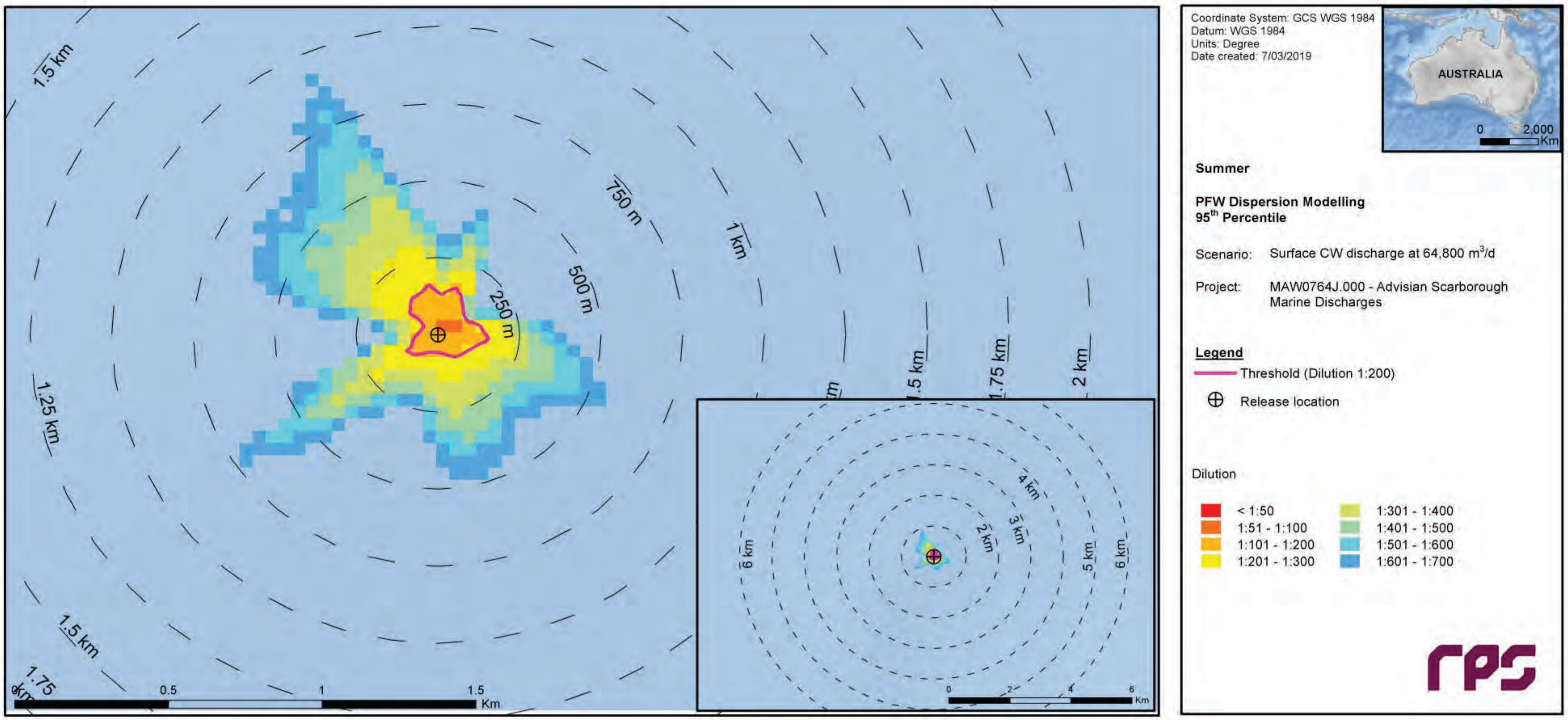



**Figure 3.86 Predicted minimum dilutions at the 95th percentile under summer conditions for Case C4 (0 m depth discharge at 64,800 $m^3$/d flow rate).**

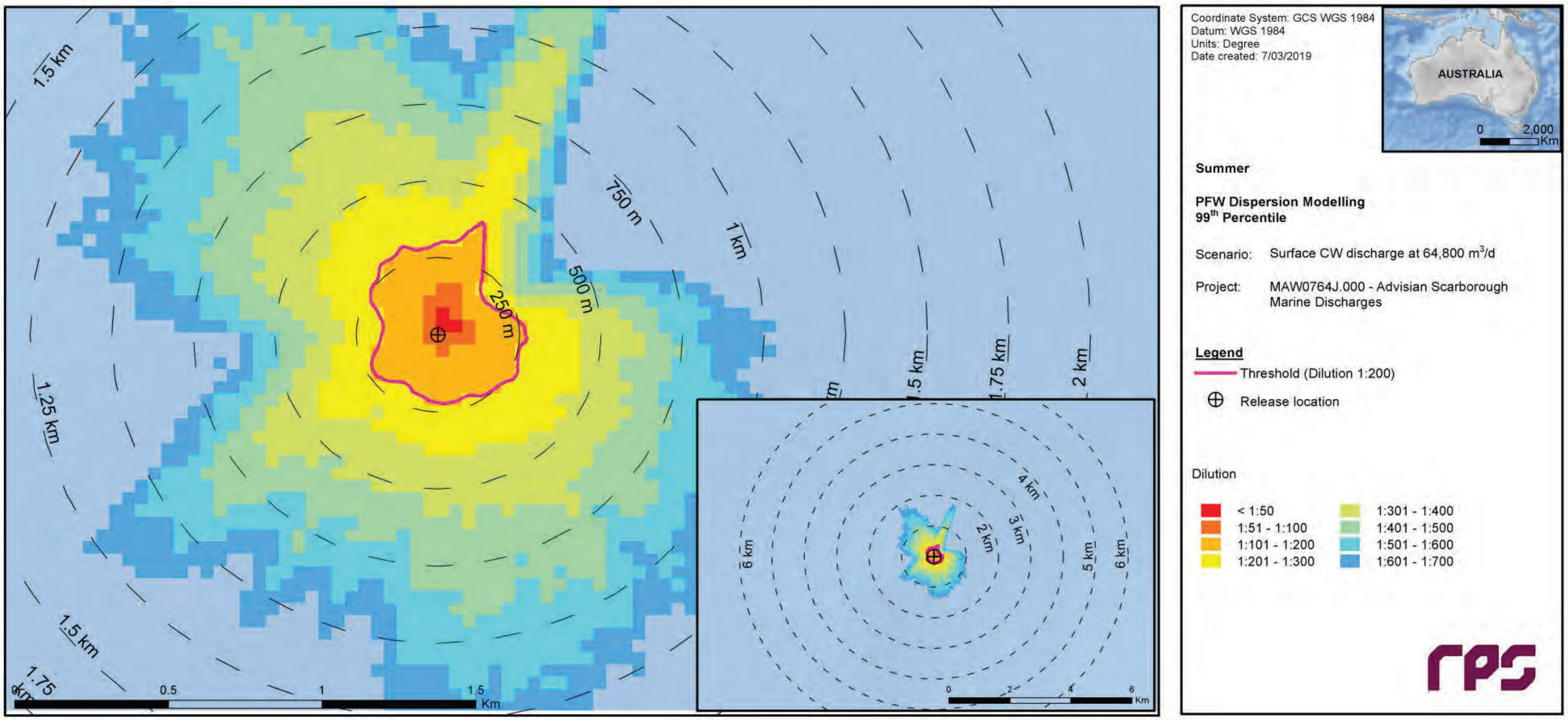



**Figure 3.87 Predicted minimum dilutions at the 99th percentile under summer conditions for Case C4 (0 m depth discharge at 64,800 $m^3$/d flow rate).**

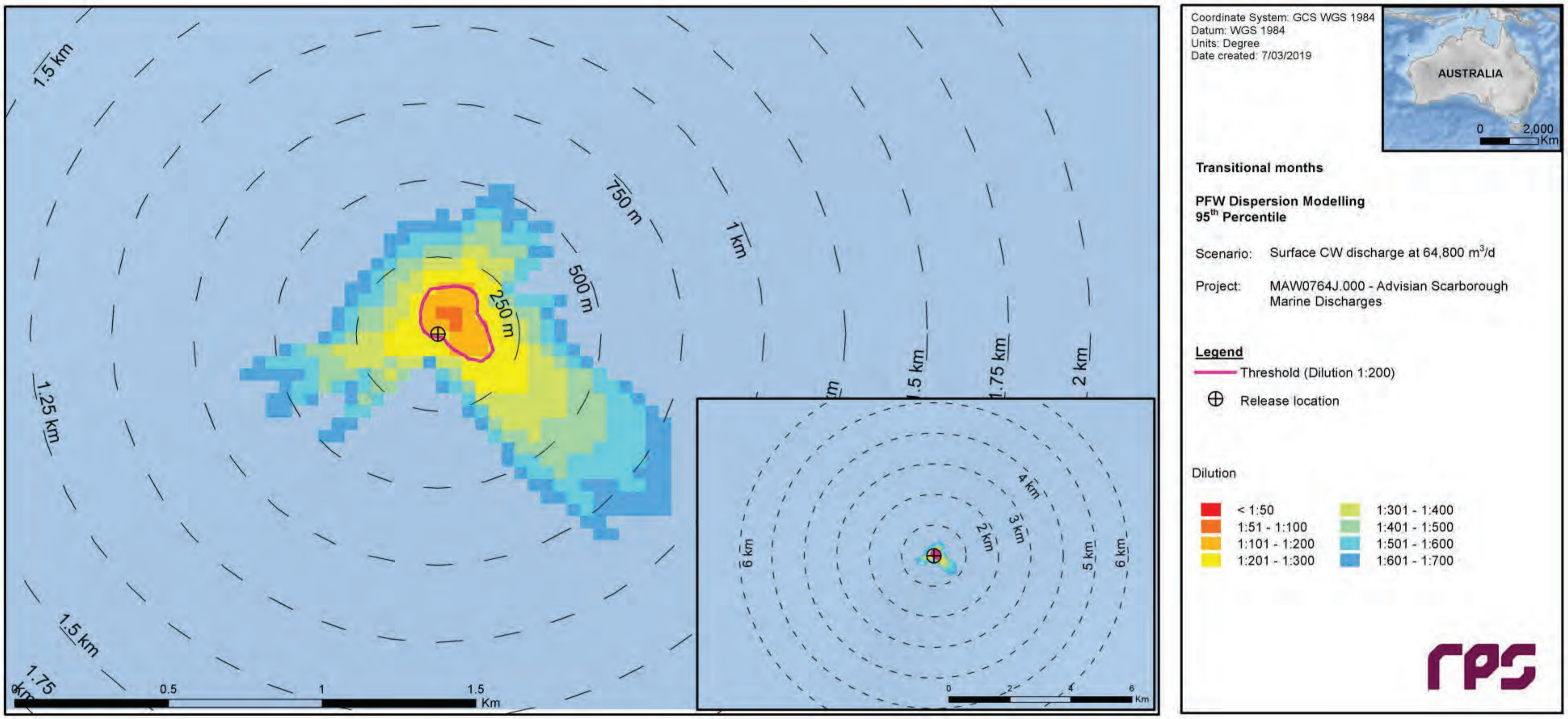



**Figure 3.88 Predicted minimum dilutions at the 95th percentile under transitional conditions for Case C4 (0 m depth discharge at 64,800 $m^3$/d flow rate).**

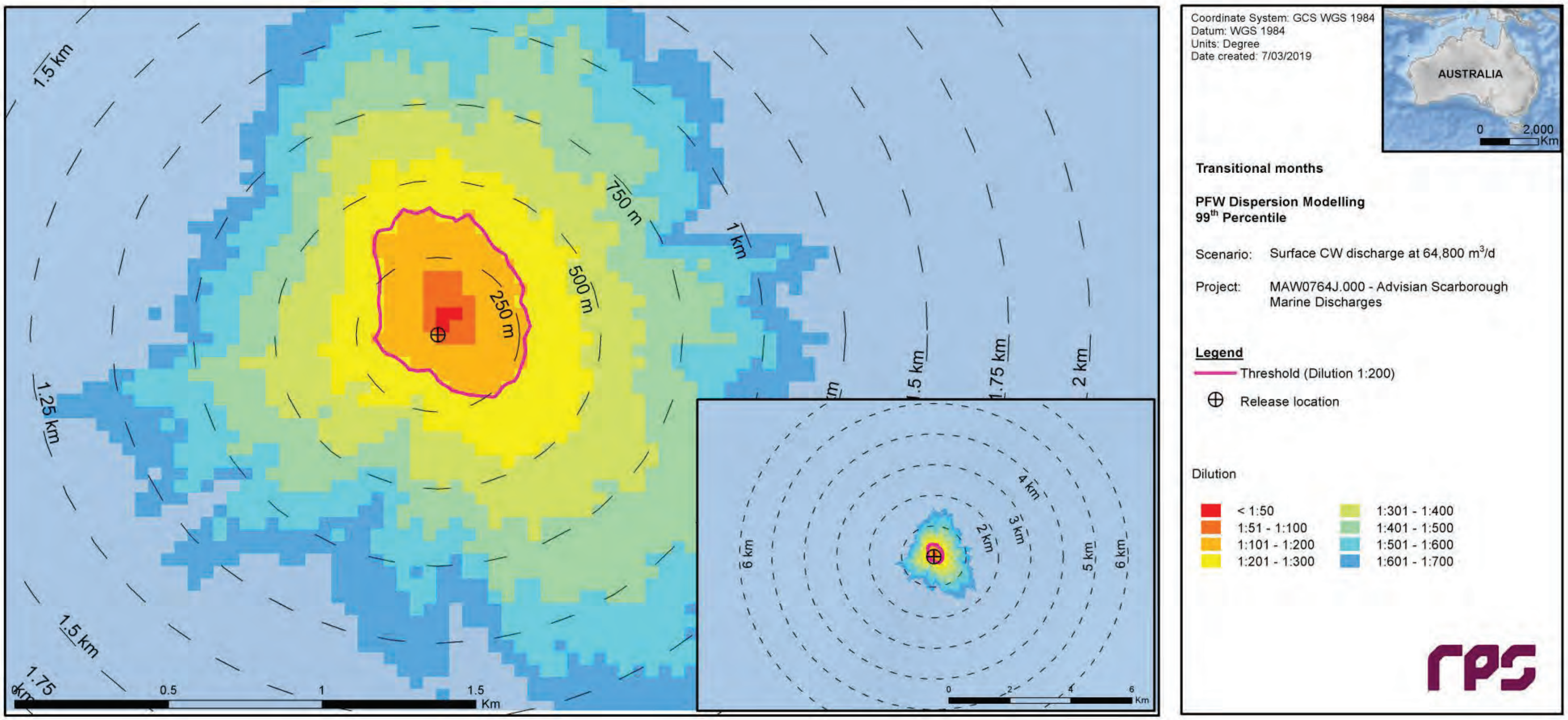



**Figure 3.89 Predicted minimum dilutions at the 99th percentile under transitional conditions for Case C4 (0 m depth discharge at 64,800 m$^3$/d flow rate).**

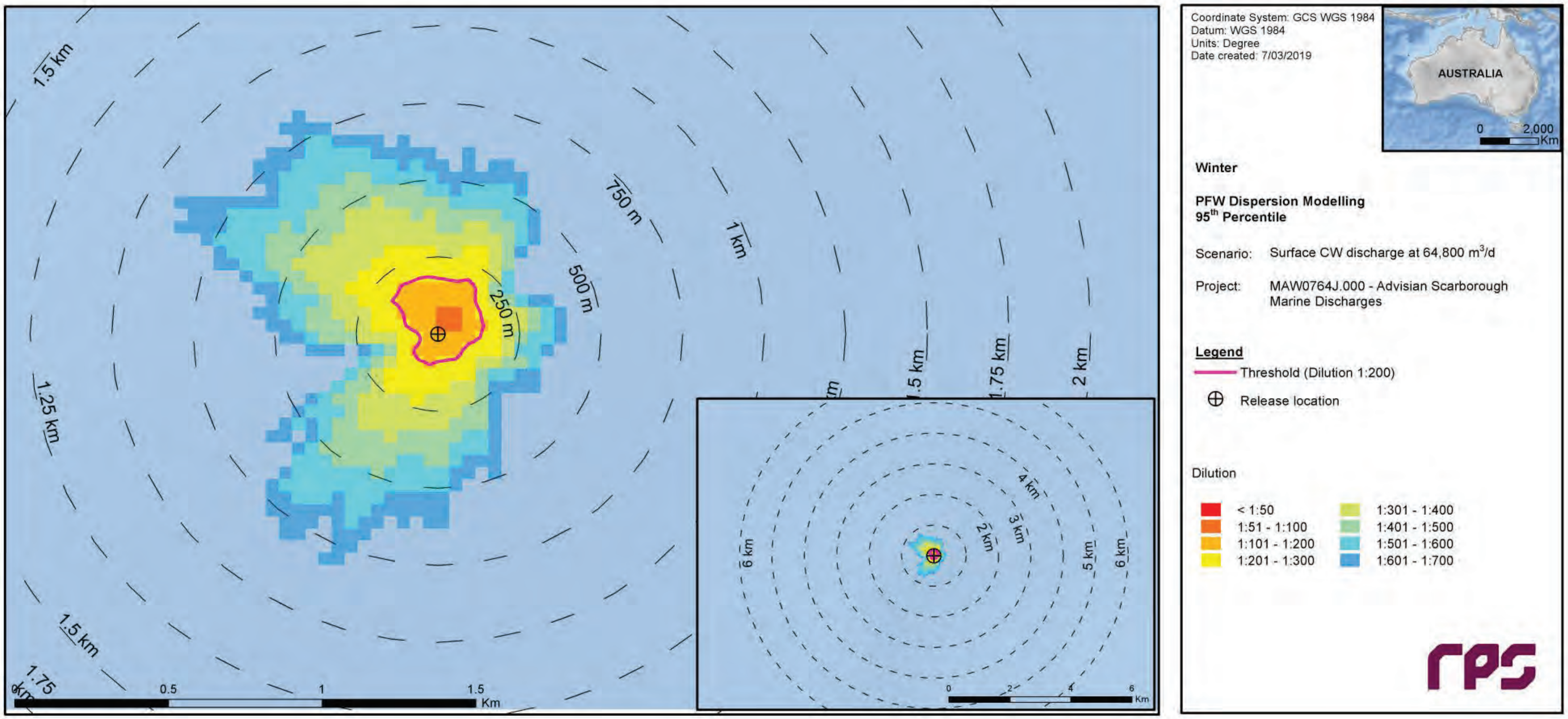



**Figure 3.90 Predicted minimum dilutions at the 95th percentile under winter conditions for Case C4 (0 m depth discharge at 64,800 $m^3$/d flow rate).**

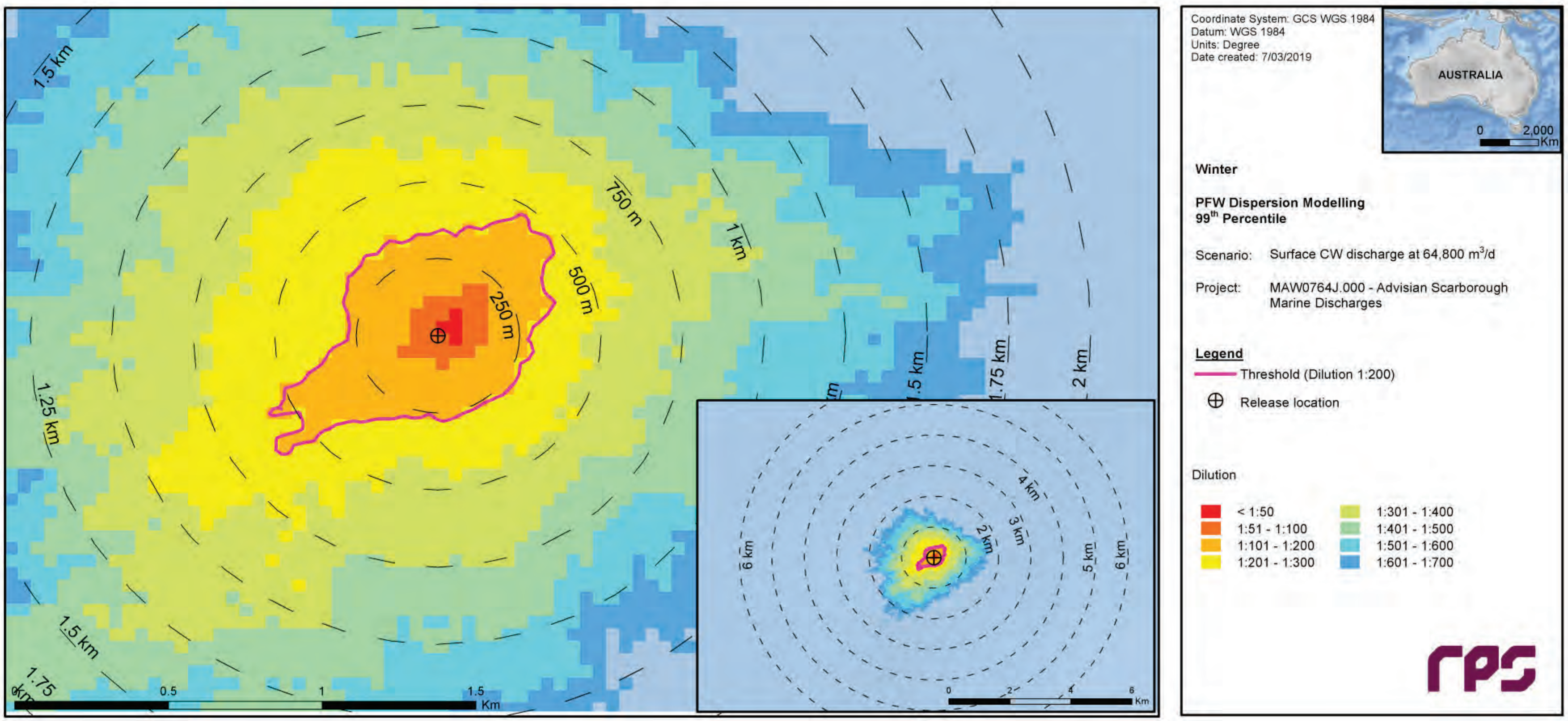



**Figure 3.91 Predicted minimum dilutions at the 99th percentile under winter conditions for Case C4 (0 m depth discharge at 64,800 $m^3$/d flow rate).**

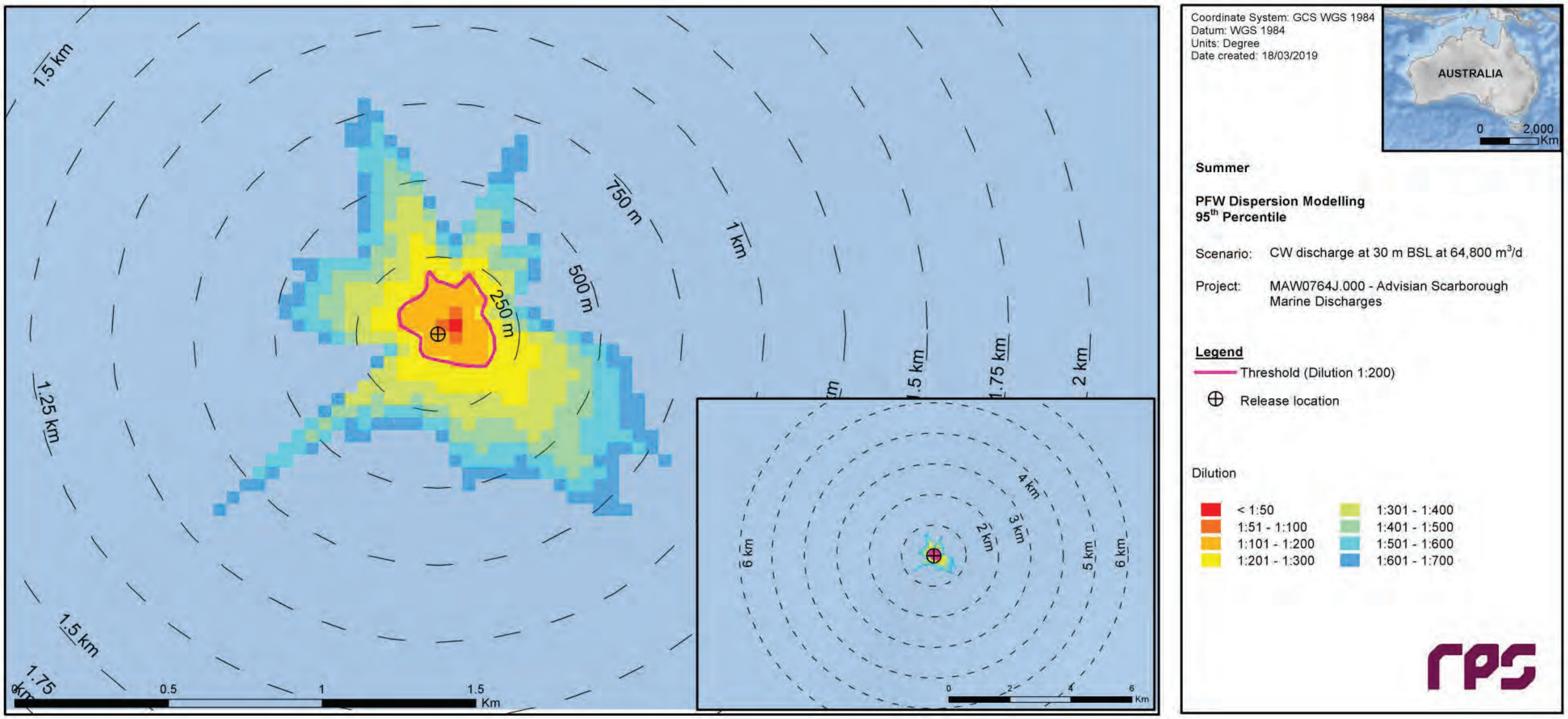



**Figure 3.92 Predicted minimum dilutions at the 95th percentile under summer conditions for Case C6 (30 m depth discharge at 64,800 m³/d flow rate).**

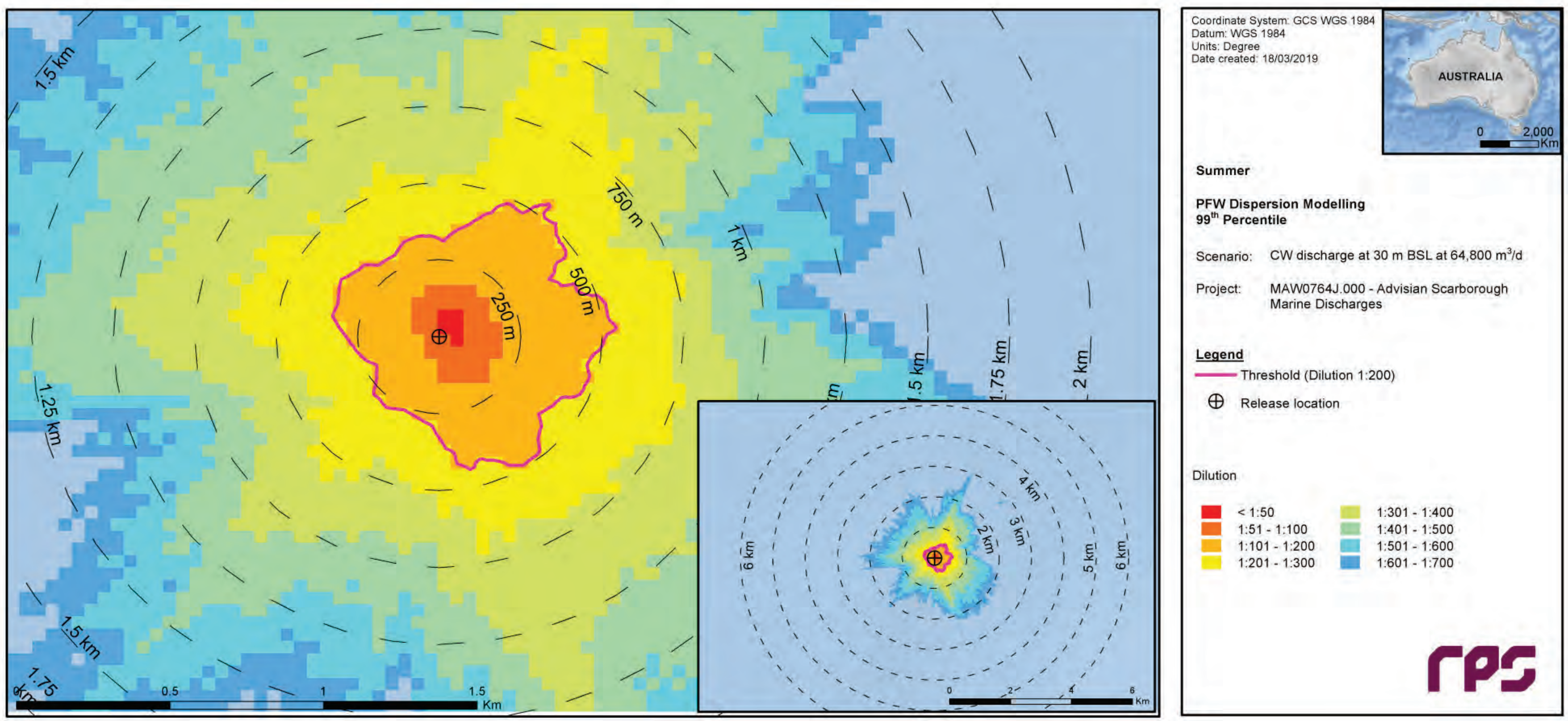



**Figure 3.93 Predicted minimum dilutions at the 99th percentile under summer conditions for Case C6 (30 m depth discharge at 64,800 m$^3$/d flow rate).**

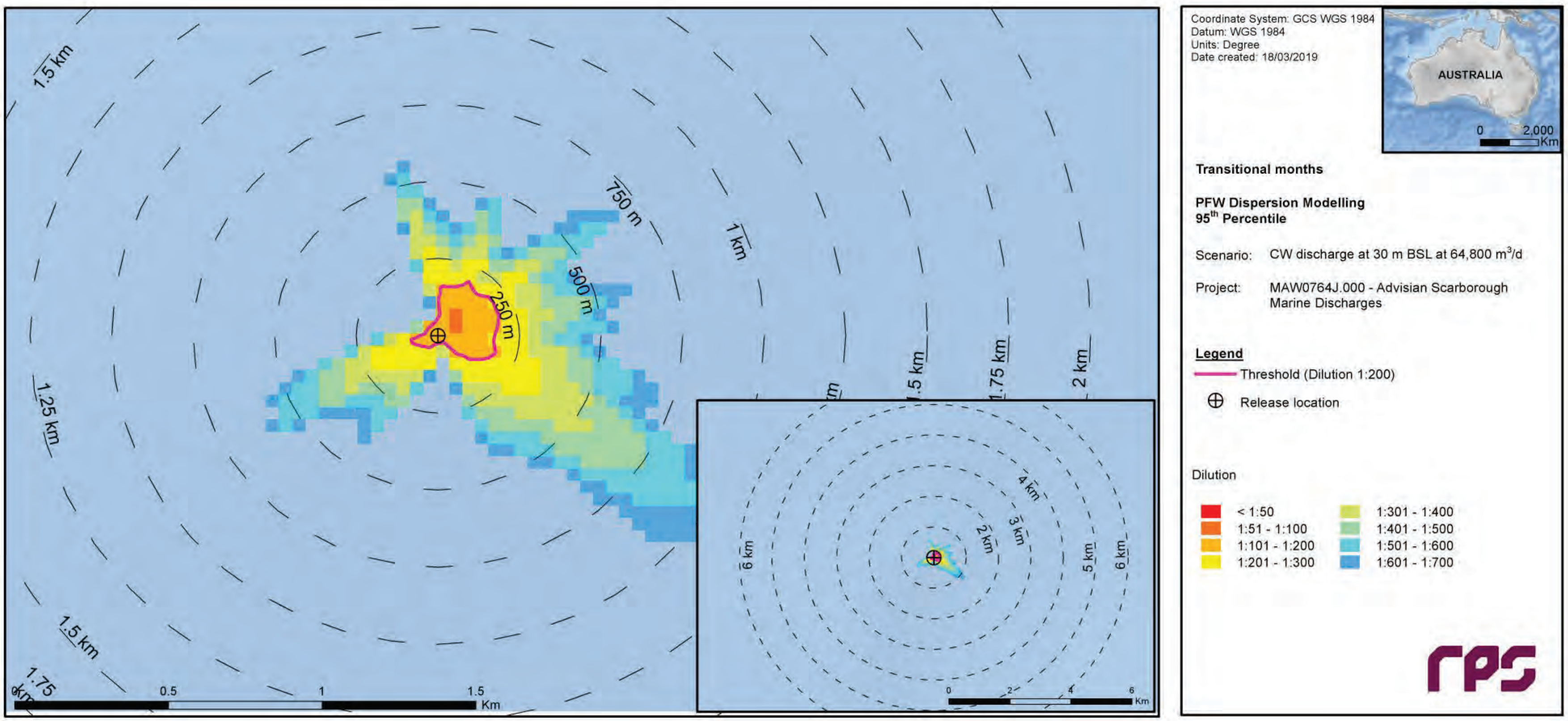



**Figure 3.94 Predicted minimum dilutions at the 95th percentile under transitional conditions for Case C6 (30 m depth discharge at 64,800 $m^3$/d flow rate).**

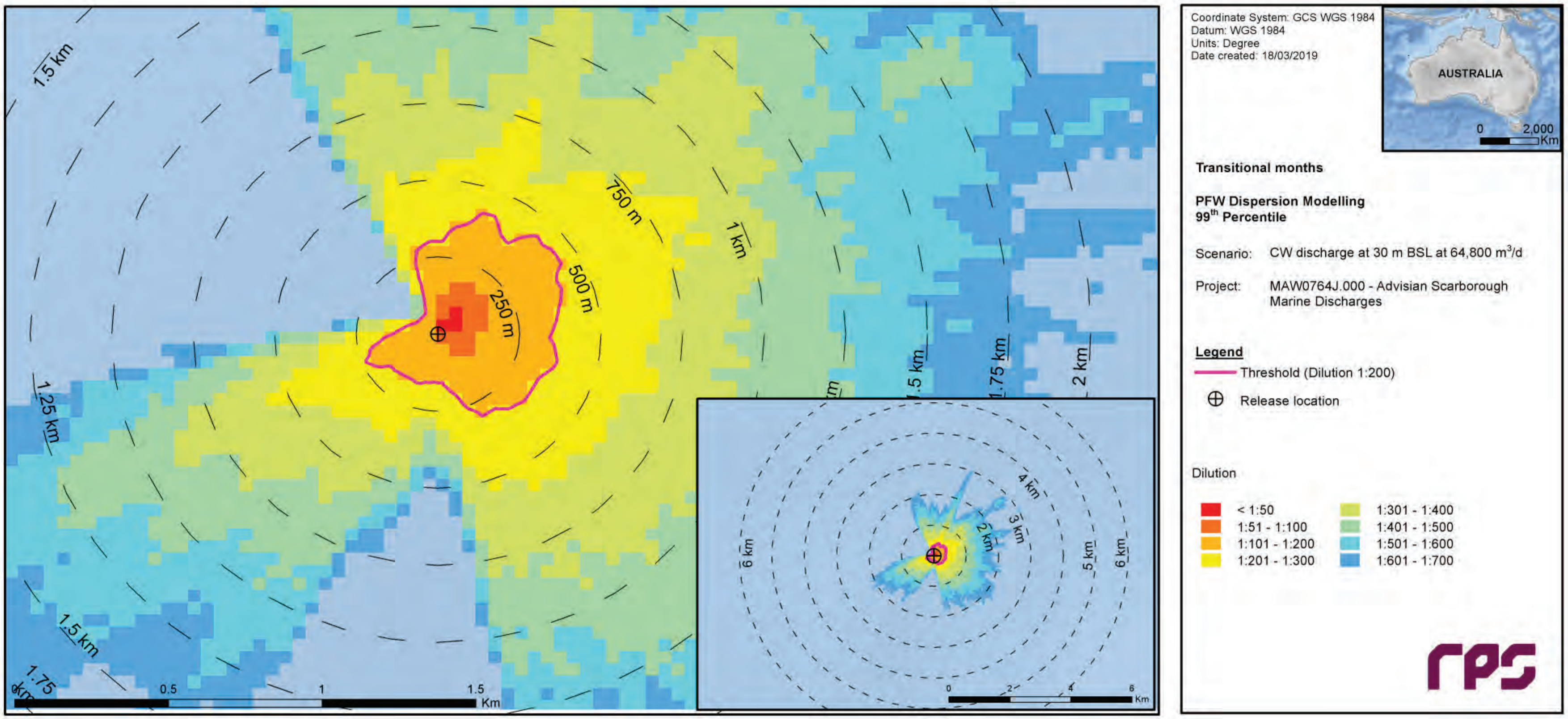



**Figure 3.95 Predicted minimum dilutions at the 99th percentile under transitional conditions for Case C6 (30 m depth discharge at 64,800 m$^3$/d flow rate).**

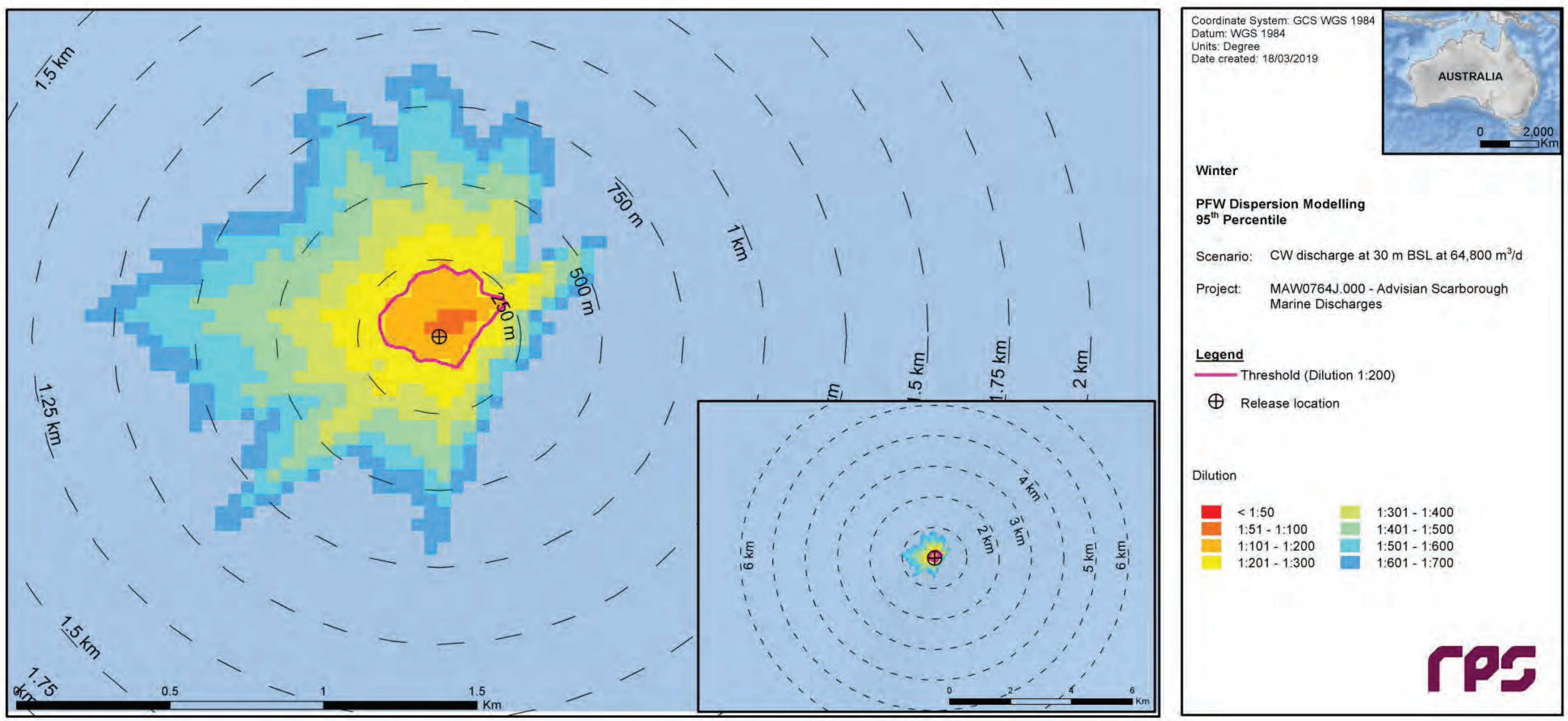



**Figure 3.96 Predicted minimum dilutions at the 95th percentile under winter conditions for Case C6 (30 m depth discharge at 64,800 $m^3$/d flow rate).**

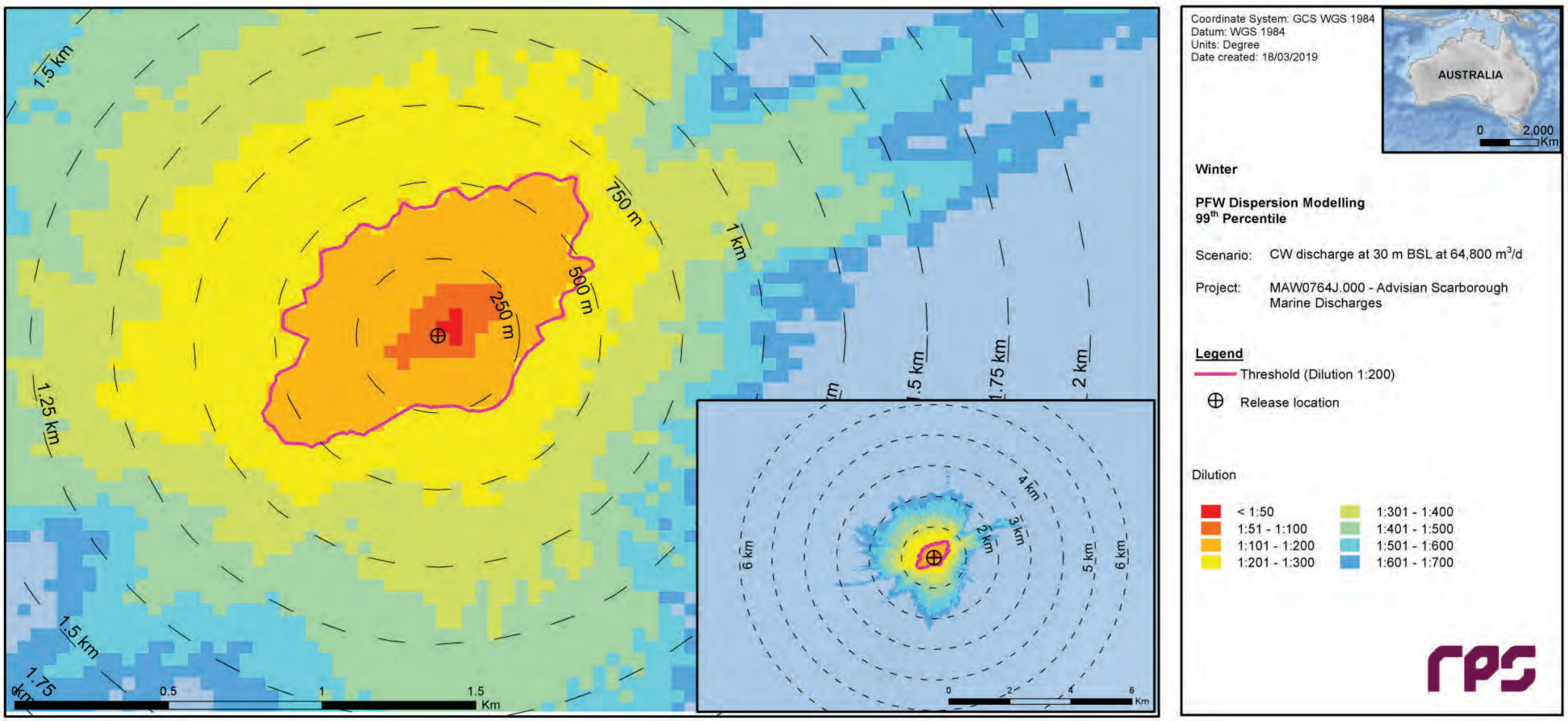



**Figure 3.97 Predicted minimum dilutions at the 99th percentile under winter conditions for Case C6 (30 m depth discharge at 64,800 $m^3$/d flow rate).**

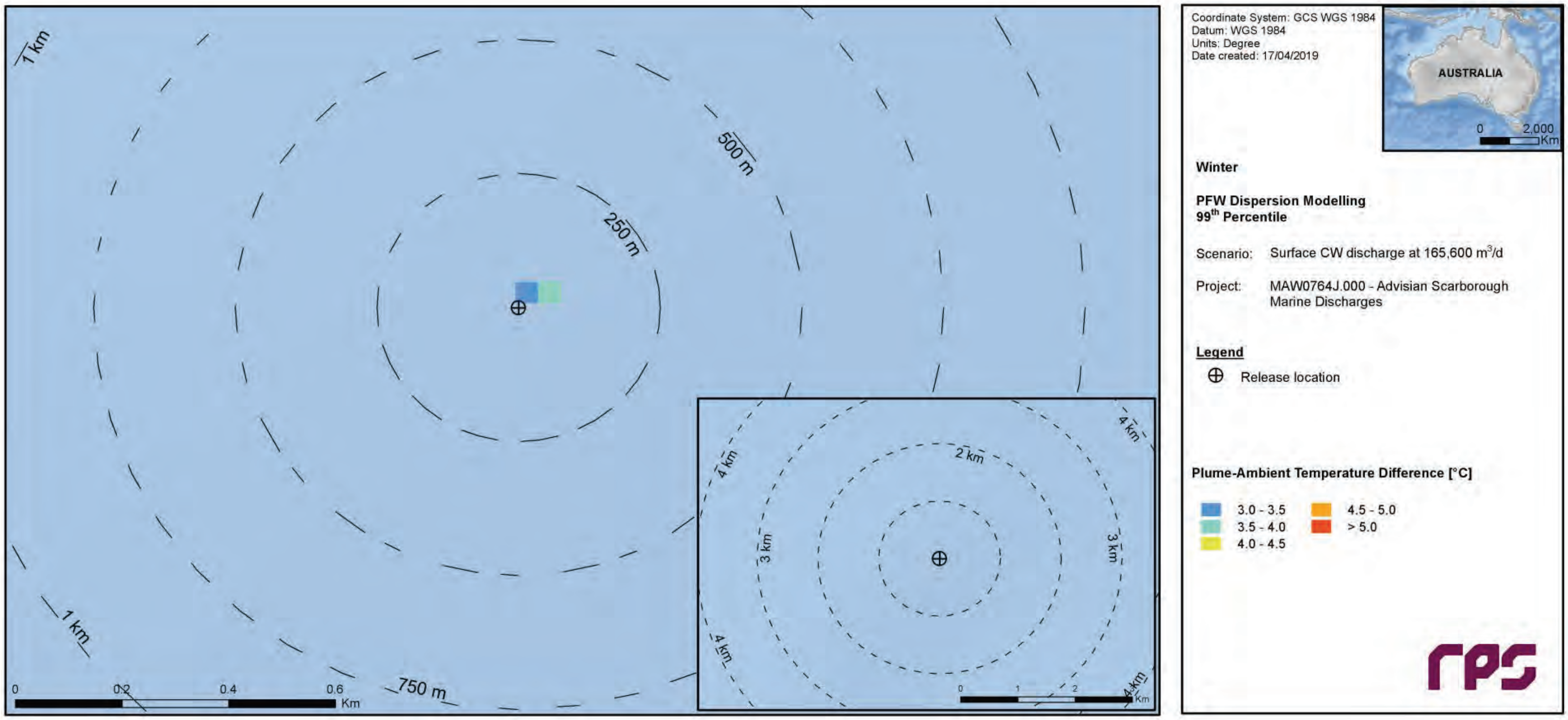



**Figure 3.98 Predicted maximum plume-ambient ΔT at the 99th percentile under winter conditions for Case C1 (0 m depth discharge at 165,600 m$^3$/d flow rate).**

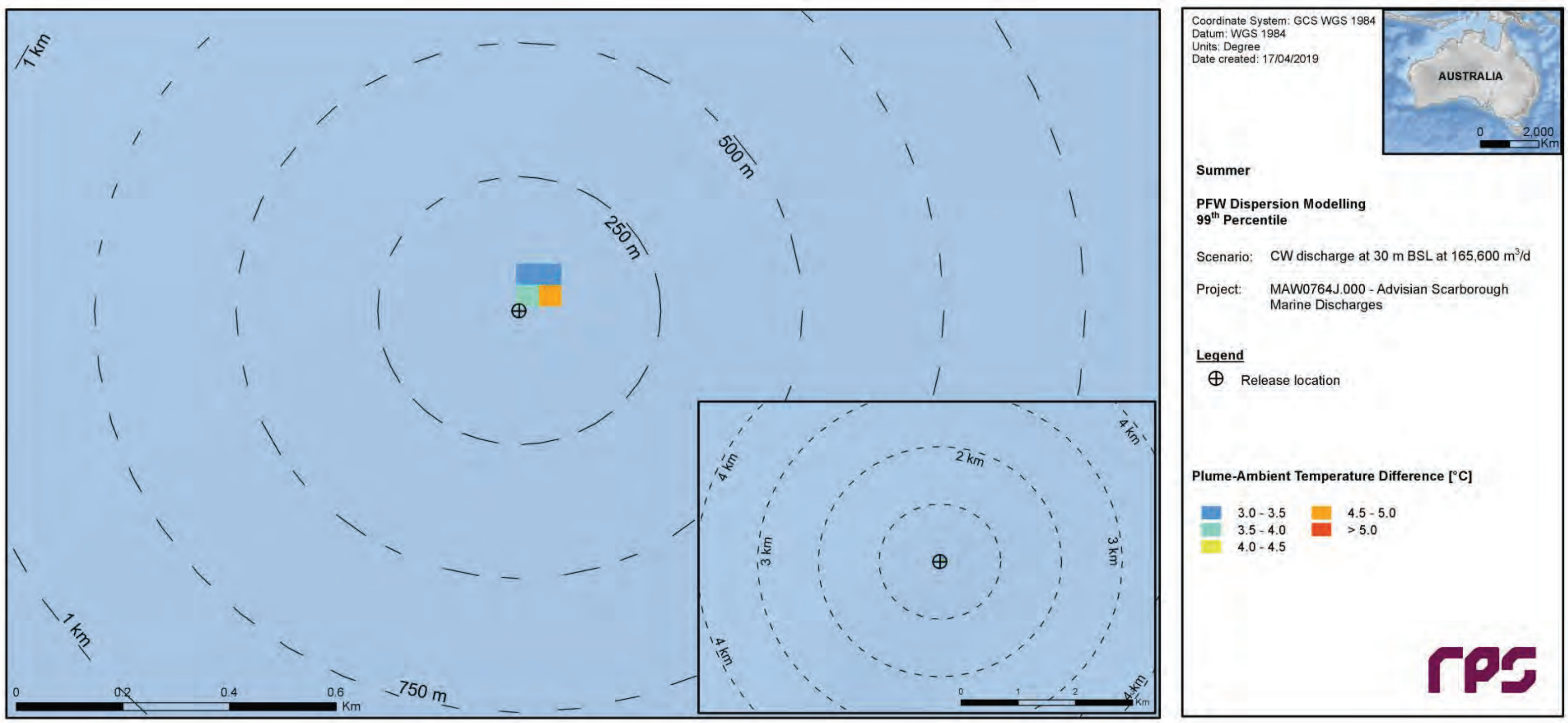



**Figure 3.99 Predicted maximum plume-ambient ΔT at the 99th percentile under summer conditions for Case C3 (30 m depth discharge at 165,600 $m^3/d$ flow rate).**

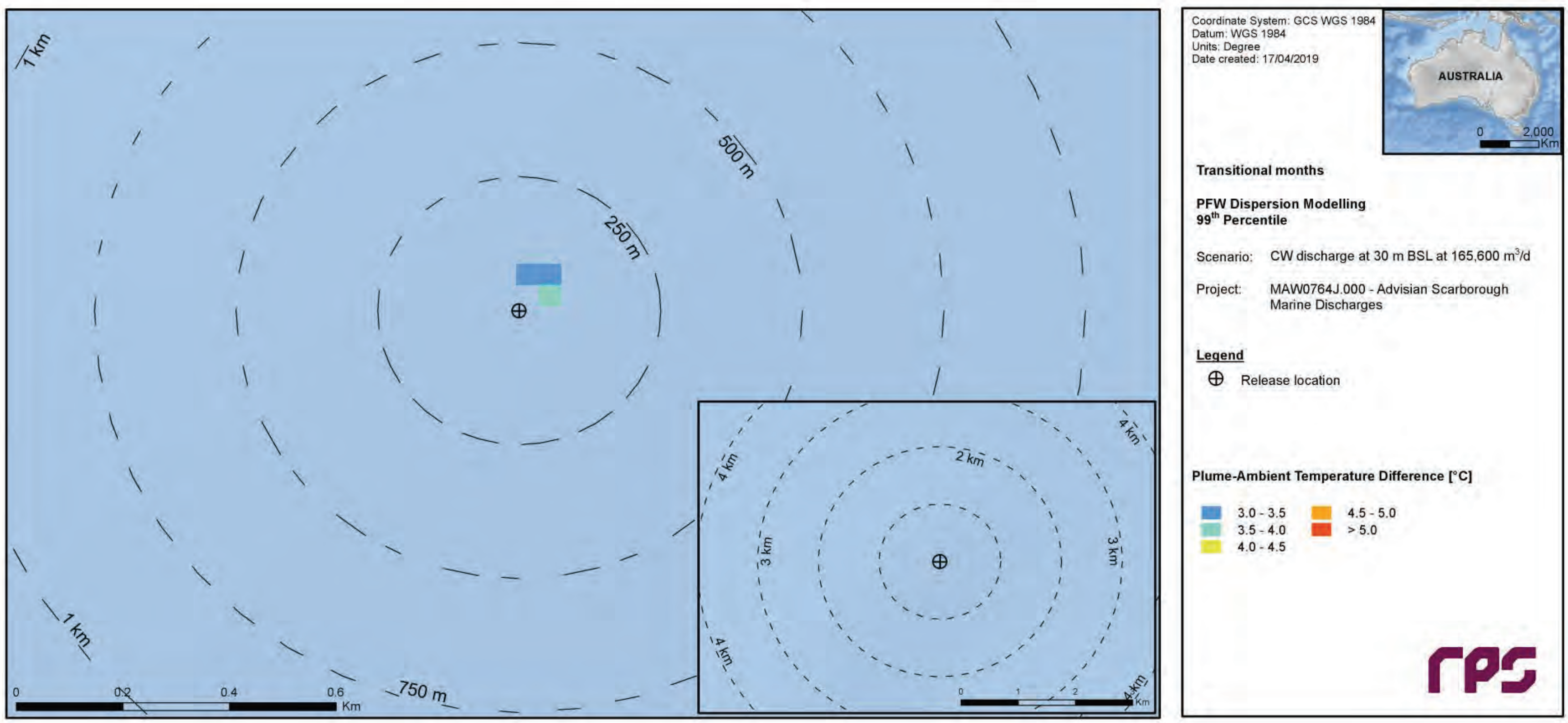



**Figure 3.100 Predicted maximum plume-ambient ΔT at the 99th percentile under transitional conditions for Case C3 (30 m depth discharge at 165,600 $m^3/d$ flow rate).**

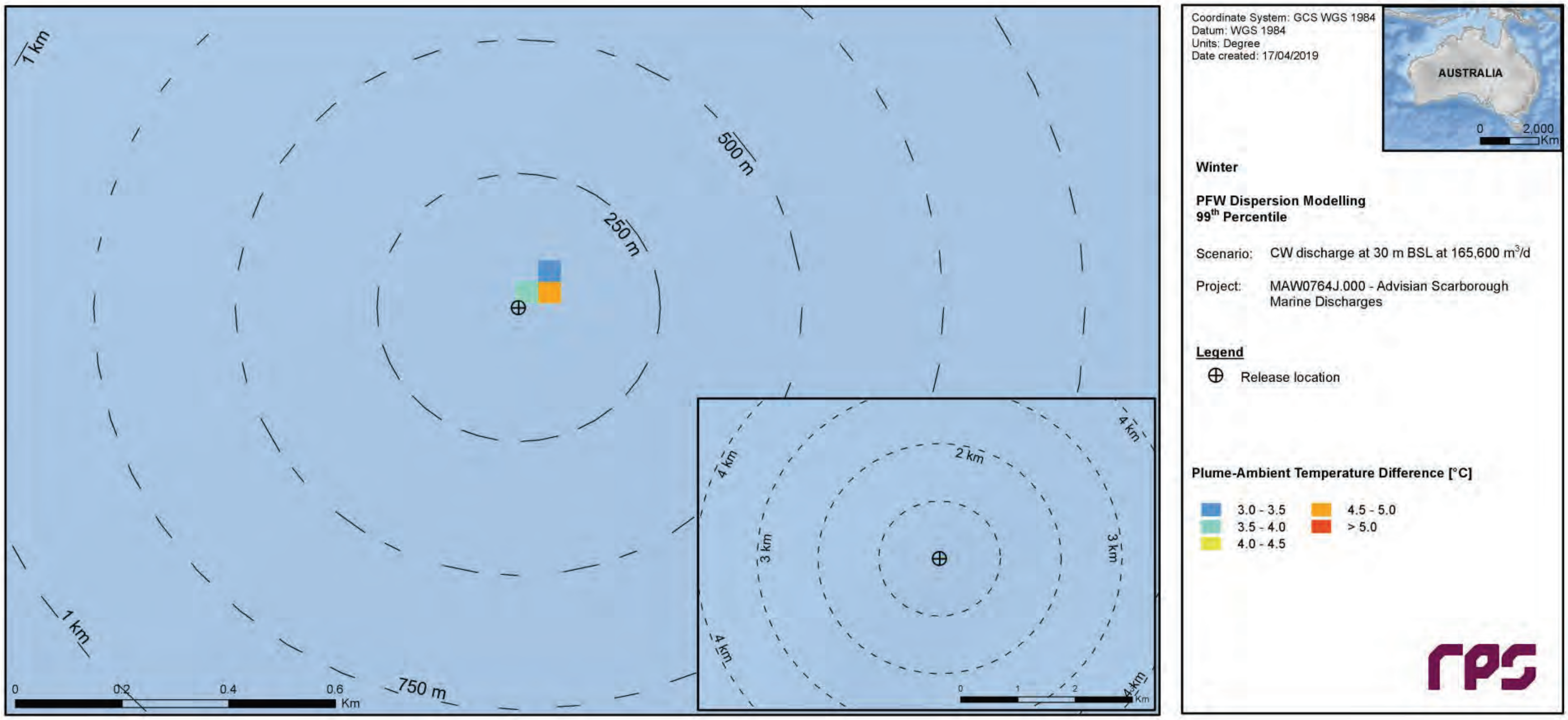



**Figure 3.101 Predicted maximum plume-ambient ΔT at the 99th percentile under winter conditions for Case C3 (30 m depth discharge at 165,600 $m^3/d$ flow rate).**

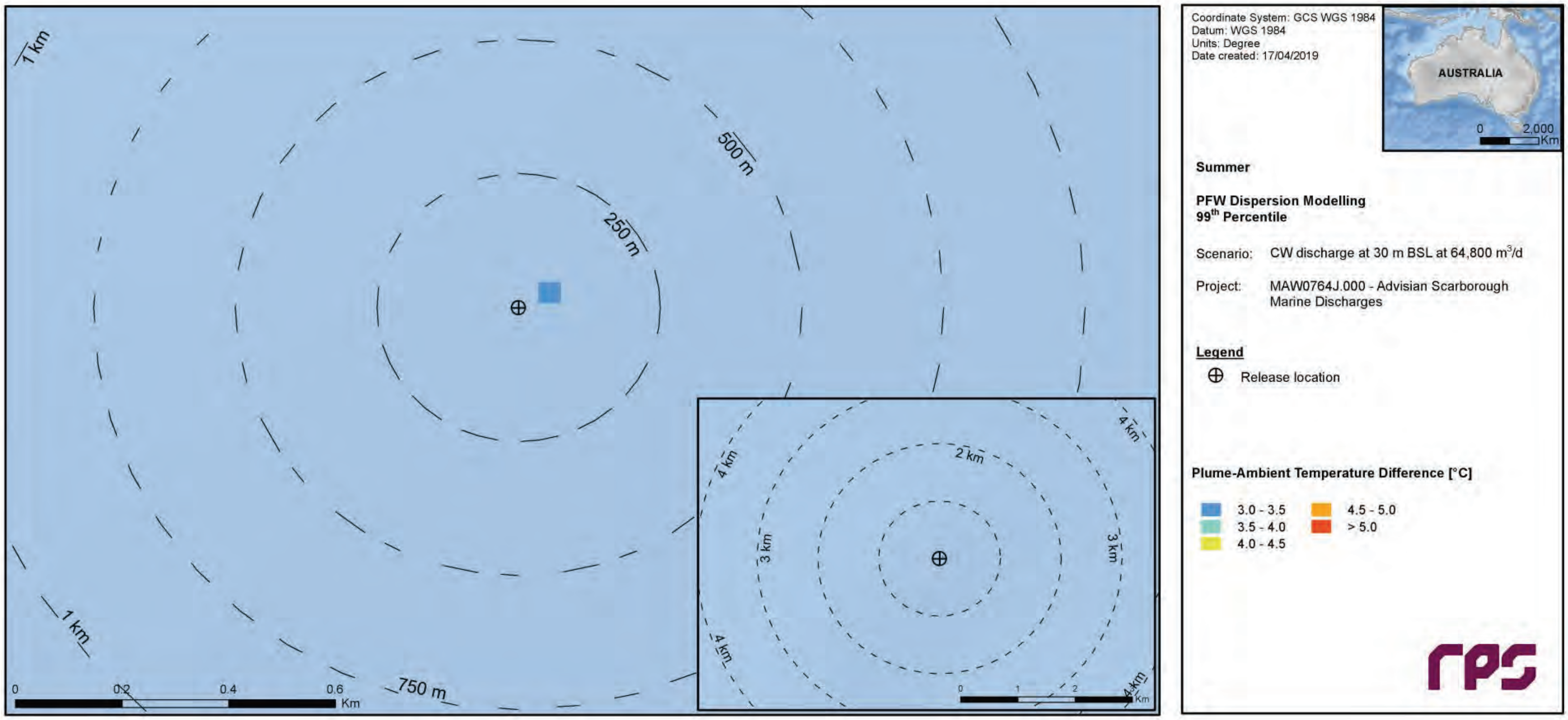



**Figure 3.102** **Predicted maximum plume-ambient ΔT at the 99th percentile under summer conditions for Case C6 (30 m depth discharge at 64,800 $m^3/d$ flow rate).**

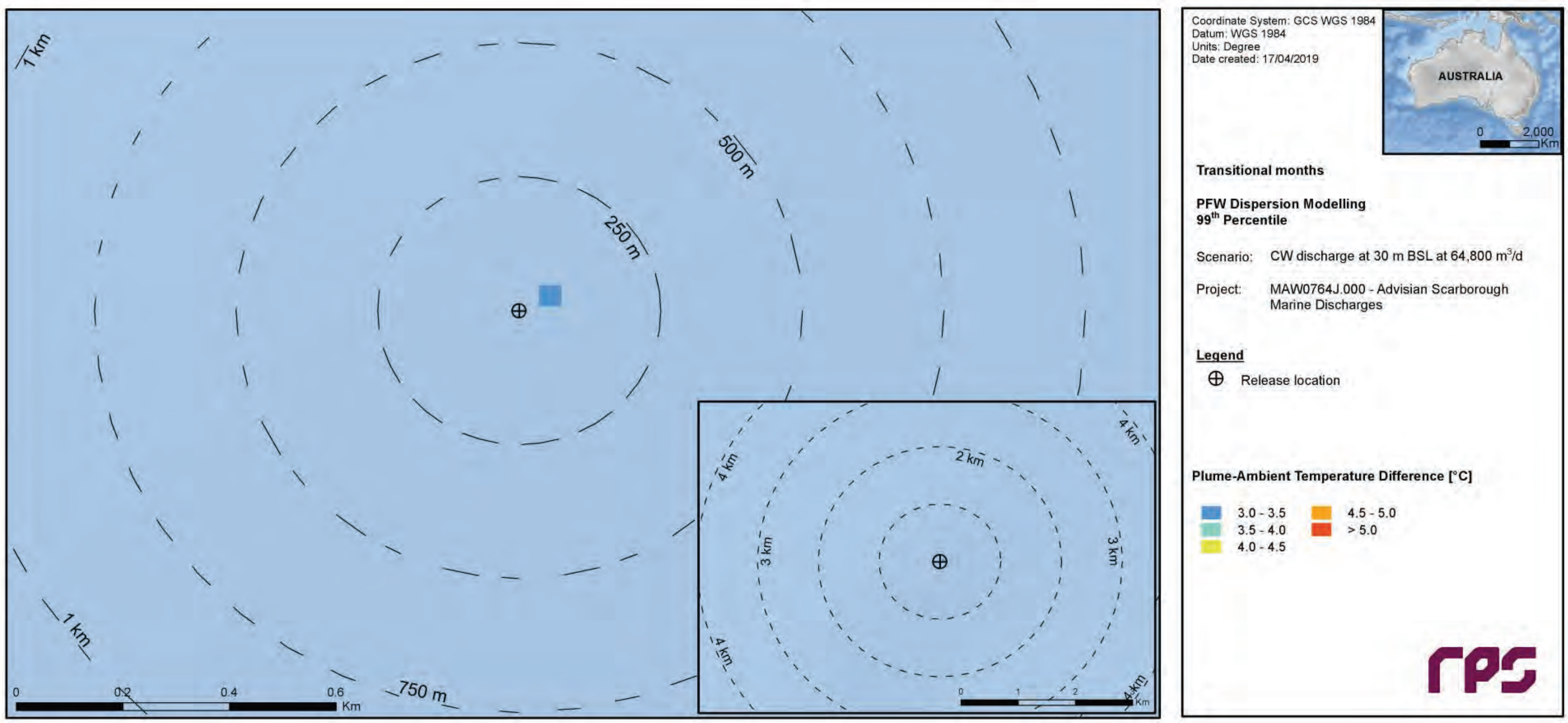



**Figure 3.103 Predicted maximum plume-ambient ΔT at the 99th percentile under transitional conditions for Case C6 (30 m depth discharge at 64,800 $m^3/d$ flow rate).**

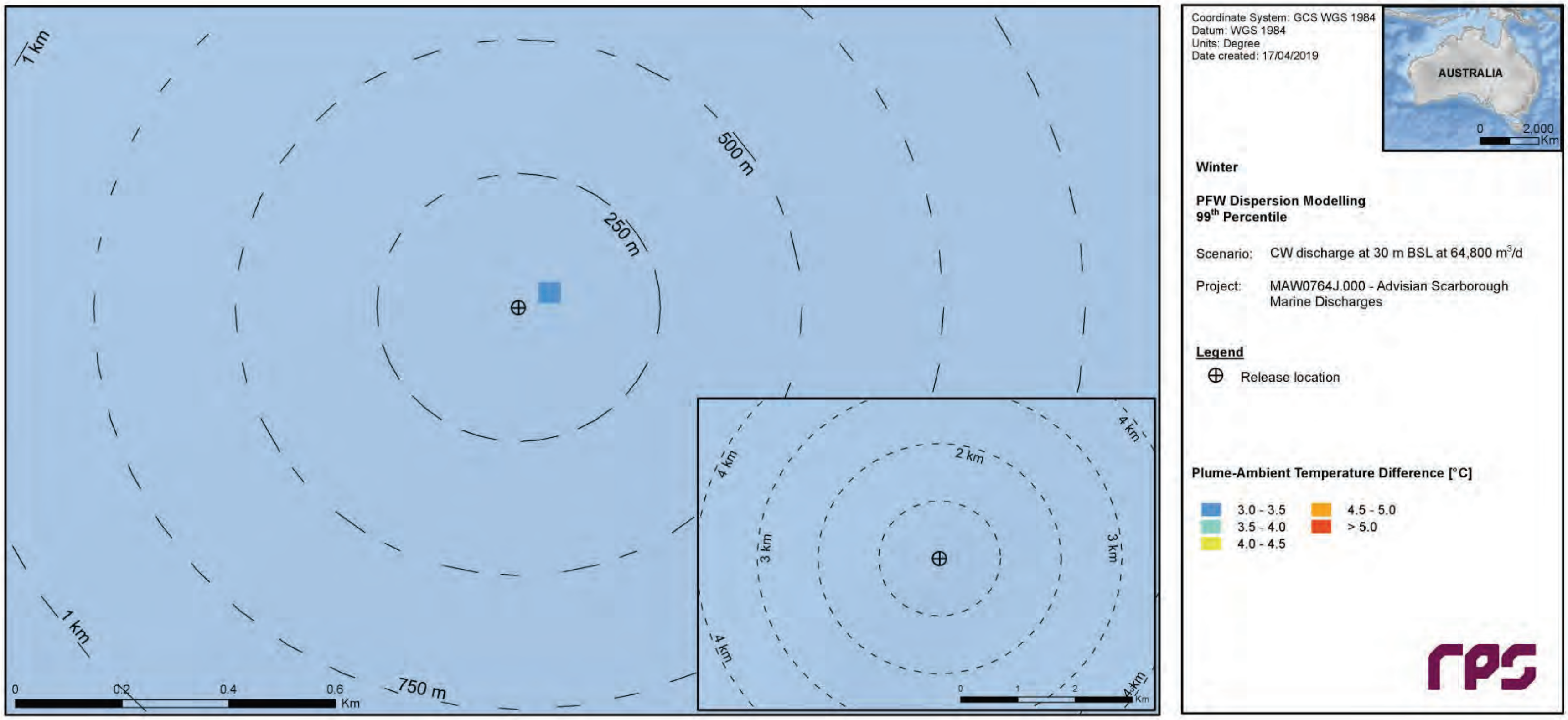



**Figure 3.104 Predicted maximum plume-ambient ΔT at the 99th percentile under winter conditions for Case C6 (30 m depth discharge at 64,800 m$^3$/d flow rate).**

### 3.2.5 Annualised Analysis

The model outputs for each season (summer, transitional and winter) over the ten-year hindcast period (2006-2015) were combined and analysed on an annualised basis.

Table 3.67 to Table 3.70 summarise the minimum dilution achieved at specific radial distances from the discharge location for each percentile over the annual period.

Table 3.71 to Table 3.74 provide summaries of the annualised maximum distances from the discharge location to achieve 1:200 dilution for each percentile. The results indicate that the release of effluent under all seasonal conditions results in rapid dispersion within the ambient environment. Dilution to reach threshold concentration is achieved for chlorine within a maximum area of influence of 1.79 km (Case C1), 2.47 km (Case C3), 0.62 km (Case C4) and 0.63 km (Case C6) at the 99$^{th}$ percentile, this being the maximum spatial extent of the relevant dilution contour from the discharge location in any season.

Table 3.75 to Table 3.78 provide summaries of the total area of coverage for the 1:200 dilution contour for each percentile. The area of exposure defined by the relevant dilution contour is predicted to reach maximum values of 4.59 km$^2$ (Case C1), 6.56 km$^2$ (Case C3), 0.40 km$^2$ (Case C4) and 0.68 km$^2$ (Case C6) at the 99$^{th}$ percentile in any season.

Table 3.79 to Table 3.82 provide summaries of the annualised maximum distances from the discharge location to achieve a 3 °C plume-ambient temperature differential for each percentile. For all cases, the requirement is forecast to be met within 115 m at the 99$^{th}$ percentile. In many cases, the requirement is forecast to be met within the scale of the model grid resolution (40 m).

For Cases C1, C3, C4 and C6, Figure 3.105 to Figure 3.112 show the aggregated spatial extents of the minimum dilutions for each percentile. 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.

For the cases where the temperature requirement is not met within the scale of the model grid resolution, Figure 3.113 to Figure 3.115 show the aggregated spatial extents of the maximum plume-ambient temperature differential for each percentile.

**Table 3.67 Annualised minimum dilution achieved at specific radial distances from the CW discharge location for Case C1 (0 m depth discharge at 165,600 m$^3$/d flow rate).**

| Percentile | Season | Minimum dilution (1:x) achieved at specific radial distances from discharge location | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0.02 km | 0.05 km | 0.10 km | 0.20 km | 0.30 km | 0.40 km | 0.50 km | 0.60 km | 0.70 km | 0.80 km | 0.90 km | 1.00 km | 1.10 km | 1.20 km | 1.30 km | 1.40 km | 1.50 km | 1.60 km | 1.70 km | 1.80 km | 1.90 km | 2.00 km |
| 95th | Annual | 1:28.7 | 1:26.4 | 1:35.0 | 1:68.8 | 1:102.2 | 1:123.1 | 1:148.8 | 1:176.0 | 1:205.8 | 1:232.9 | 1:260.7 | 1:287.6 | 1:326.9 | 1:344.4 | 1:388.6 | 1:418.2 | 1:437.6 | 1:469.2 | 1:512.8 | 1:548.7 | 1:580.9 | 1:609.5 |
| 99th | Annual | 1:14.3 | 1:11.6 | 1:17.0 | 1:31.6 | 1:49.5 | 1:61.0 | 1:71.1 | 1:74.3 | 1:81.7 | 1:94.8 | 1:98.4 | 1:106.3 | 1:126.6 | 1:136.2 | 1:147.0 | 1:149.1 | 1:161.2 | 1:165.4 | 1:244.1 | 1:176.6 | 1:212.8 | 1:237.8 |

**Table 3.68 Annualised minimum dilution achieved at specific radial distances from the CW discharge location for Case C3 (30 m depth discharge at 165,600 m$^3$/d flow rate).**

| Percentile | Season | Minimum dilution (1:x) achieved at specific radial distances from discharge location | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0.02 km | 0.05 km | 0.10 km | 0.20 km | 0.30 km | 0.40 km | 0.50 km | 0.60 km | 0.70 km | 0.80 km | 0.90 km | 1.00 km | 1.10 km | 1.20 km | 1.30 km | 1.40 km | 1.50 km | 1.60 km | 1.70 km | 1.80 km | 1.90 km | 2.00 km |
| 95th | Annual | 1:24.5 | 1:18.0 | 1:29.7 | 1:58.9 | 1:82.6 | 1:120.0 | 1:136.7 | 1:156.3 | 1:174.6 | 1:196.3 | 1:208.5 | 1:231.7 | 1:244.4 | 1:260.0 | 1:283.8 | 1:292.9 | 1:316.9 | 1:330.2 | 1:337.8 | 1:363.3 | 1:394.3 | 1:408.2 |
| 99th | Annual | 1:9.7 | 1:9.6 | 1:15.1 | 1:28.8 | 1:41.0 | 1:49.8 | 1:56.7 | 1:69.3 | 1:69.3 | 1:94.1 | 1:93.2 | 1:98.8 | 1:112.1 | 1:124.3 | 1:124.3 | 1:141.4 | 1:154.8 | 1:165.5 | 1:174.5 | 1:181.6 | 1:195.5 | 1:206.0 |

**Table 3.69 Annualised minimum dilution achieved at specific radial distances from the CW discharge location for Case C4 (0 m depth discharge at 64,800 m$^3$/d flow rate).**

| Percentile | Season | Minimum dilution (1:x) achieved at specific radial distances from discharge location | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0.02 km | 0.05 km | 0.10 km | 0.20 km | 0.30 km | 0.40 km | 0.50 km | 0.60 km | 0.70 km | 0.80 km | 0.90 km | 1.00 km | 1.10 km | 1.20 km | 1.30 km | 1.40 km | 1.50 km | 1.60 km | 1.70 km | 1.80 km | 1.90 km | 2.00 km |
| 95th | Annual | 1:67.4 | 1:73.3 | 1:89.5 | 1:175.7 | 1:261.2 | 1:314.6 | 1:380.3 | 1:449.9 | 1:526.1 | 1:595.2 | 1:666.1 | 1:735.0 | 1:775.7 | 1:880.1 | 1:993.1 | 1:1,068.6 | 1:1,118.4 | 1:1,199.0 | 1:1,310.6 | 1:1,402.1 | 1:1,484.6 | 1:1,577.6 |
| 99th | Annual | 1:29.6 | 1:36.5 | 1:43.2 | 1:80.8 | 1:126.6 | 1:156.0 | 1:181.7 | 1:189.8 | 1:208.7 | 1:242.3 | 1:251.6 | 1:271.7 | 1:313.4 | 1:348.0 | 1:375.7 | 1:381.1 | 1:411.8 | 1:422.6 | 1:436.4 | 1:451.4 | 1:543.8 | 1:607.8 |

**Table 3.70 Annualised minimum dilution achieved at specific radial distances from the CW discharge location for Case C6 (30 m depth discharge at 64,800 m$^3$/d flow rate).**

| Percentile | Season | Minimum dilution (1:x) achieved at specific radial distances from discharge location | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0.02 km | 0.05 km | 0.10 km | 0.20 km | 0.30 km | 0.40 km | 0.50 km | 0.60 km | 0.70 km | 0.80 km | 0.90 km | 1.00 km | 1.10 km | 1.20 km | 1.30 km | 1.40 km | 1.50 km | 1.60 km | 1.70 km | 1.80 km | 1.90 km | 2.00 km |
| 95th | Annual | 1:44.7 | 1:62.7 | 1:76.5 | 1:151.7 | 1:208.6 | 1:281.5 | 1:350.9 | 1:407.4 | 1:446.2 | 1:507.0 | 1:532.9 | 1:595.5 | 1:630.0 | 1:680.7 | 1:741.7 | 1:772.3 | 1:856.5 | 1:856.6 | 1:8,92.2 | 1:1,001.1 | 1:1,064.3 | 1:1,056.5 |
| 99th | Annual | 1:24.4 | 1:33.2 | 1:37.9 | 1:73.6 | 1:104.9 | 1:130.7 | 1:141.9 | 1:181.2 | 1:195.2 | 1:240.5 | 1:238.2 | 1:252.7 | 1:302.7 | 1:317.6 | 1:329.9 | 1:361.4 | 1:395.6 | 1:423.0 | 1:445.9 | 1:445.5 | 1:499.6 | 1:526.4 |

**Table 3.71 Annualised maximum distance from the CW discharge location to achieve 1:200 dilution for Case C1 (0 m depth discharge at 165,600 $m^3$/d flow rate).**

| Percentile | Season | Maximum distance (m) from discharge location to achieve given dilution |
|---|---|---|
| 95th | Annual | 639 |
| 99th | | 1,789 |
| 100th | | 4,705 |

**Table 3.72 Annualised maximum distance from the CW discharge location to achieve 1:200 dilution for Case C3 (30 m depth discharge at 165,600 $m^3$/d flow rate).**

| Percentile | Season | Maximum distance (m) from discharge location to achieve given dilution |
|---|---|---|
| 95th | Annual | 771 |
| 99th | | 2,470 |
| 100th | | 6,391 |

**Table 3.73 Annualised maximum distance from the CW discharge location to achieve 1:200 dilution for Case C4 (0 m depth discharge at 64,800 $m^3$/d flow rate).**

| Percentile | Season | Maximum distance (m) from discharge location to achieve given dilution |
|---|---|---|
| 95th | Annual | 182 |
| 99th | | 621 |
| 100th | | 2,272 |

**Table 3.74 Annualised maximum distance from the CW discharge location to achieve 1:200 dilution for Case C6 (30 m depth discharge at 64,800 $m^3$/d flow rate).**

| Percentile | Season | Maximum distance (m) from discharge location to achieve given dilution |
|---|---|---|
| 95th | Annual | 212 |
| 99th | | 631 |
| 100th | | 3,566 |

**Table 3.75 Annualised total area of coverage for 1:200 dilution for Case C1 (0 m depth discharge at 165,600 m³/d flow rate).**

| Percentile | Season | Total area (km²) of coverage for given dilution |
|---|---|---|
| 95th | Annual | 0.680 |
| 99th | | 4.591 |
| 100th | | 22.347 |

**Table 3.76 Annualised total area of coverage for 1:200 dilution for Case C3 (30 m depth discharge at 165,600 m³/d flow rate).**

| Percentile | Season | Total area (km²) of coverage for given dilution |
|---|---|---|
| 95th | Annual | 0.897 |
| 99th | | 6.557 |
| 100th | | 45.284 |

**Table 3.77 Annualised total area of coverage for 1:200 dilution for Case C4 (0 m depth discharge at 64,800 m³/d flow rate).**

| Percentile | Season | Total area (km²) of coverage for given dilution |
|---|---|---|
| 95th | Annual | 0.059 |
| 99th | | 0.397 |
| 100th | | 3.556 |

**Table 3.78 Annualised total area of coverage for 1:200 dilution for Case C6 (30 m depth discharge at 64,800 m³/d flow rate).**

| Percentile | Season | Total area (km²) of coverage for given dilution |
|---|---|---|
| 95th | Annual | 0.090 |
| 99th | | 0.680 |
| 100th | | 7.597 |

**Table 3.79 Annualised maximum distance from the CW discharge location to achieve 3 °C plume-ambient ΔT for Case C1 (0 m depth discharge at 165,600 $m^3$/d flow rate).**

| Percentile | Season | Maximum distance (m) from discharge location to achieve given ΔT |
|---|---|---|
| 95th | Annual | <40 |
| 99th | | 90 |
| 100th | | 285 |

**Table 3.80 Annualised maximum distance from the CW discharge location to achieve 3 °C plume-ambient ΔT for Case C3 (30 m depth discharge at 165,600 $m^3$/d flow rate).**

| Percentile | Season | Maximum distance (m) from discharge location to achieve given ΔT |
|---|---|---|
| 95th | Annual | <40 |
| 99th | | 115 |
| 100th | | 380 |

**Table 3.81 Annualised maximum distance from the CW discharge location to achieve 3 °C plume-ambient ΔT for Case C4 (0 m depth discharge at 64,800 $m^3$/d flow rate).**

| Percentile | Season | Maximum distance (m) from discharge location to achieve given ΔT |
|---|---|---|
| 95th | Annual | <40 |
| 99th | | <40 |
| 100th | | 145 |

**Table 3.82 Annualised maximum distance from the CW discharge location to achieve 3 °C plume-ambient ΔT for Case C6 (30 m depth discharge at 64,800 $m^3$/d flow rate).**

| Percentile | Season | Maximum distance (m) from discharge location to achieve given ΔT |
|---|---|---|
| 95th | Annual | <40 |
| 99th | | 90 |
| 100th | | 175 |

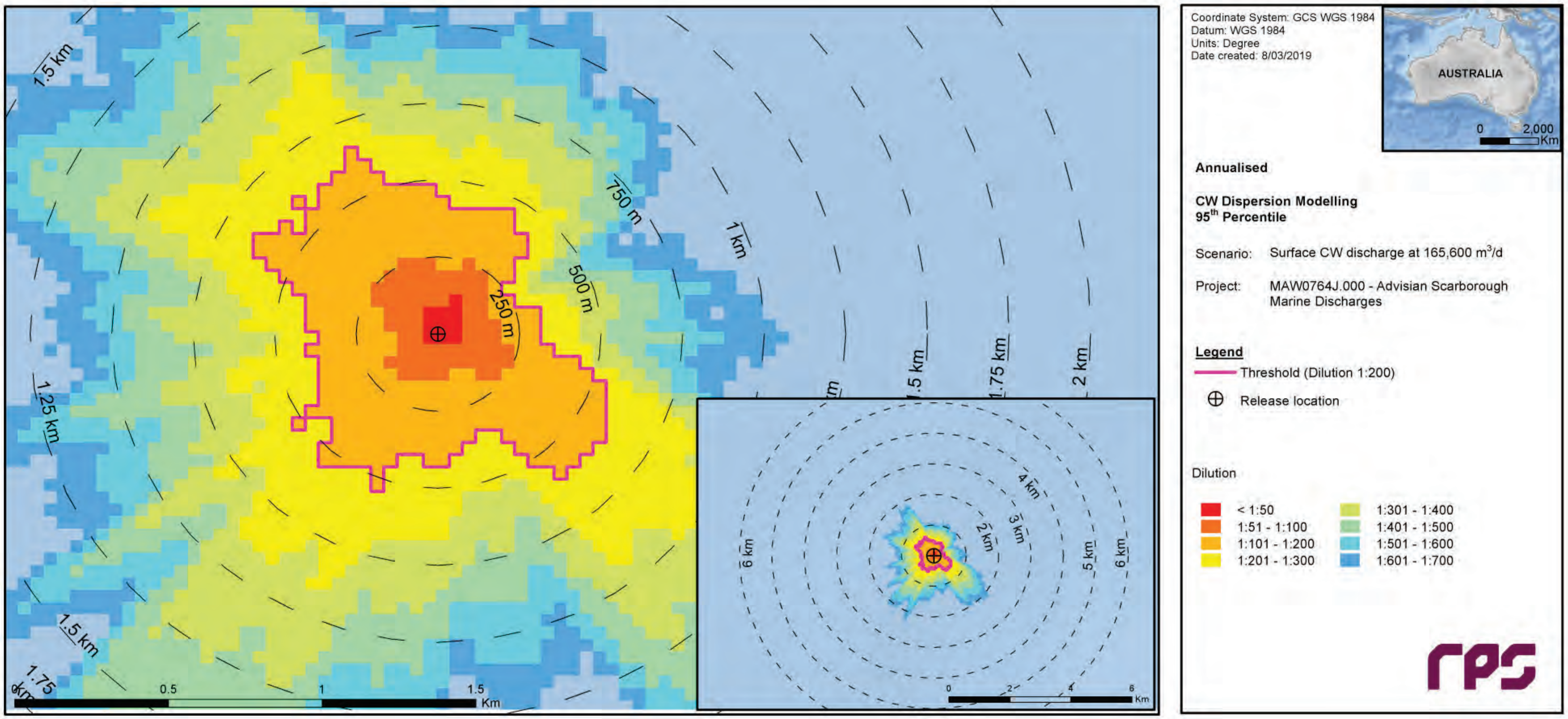



**Figure 3.105 Predicted annualised minimum dilutions at the 95th percentile for Case C1 (0 m depth discharge at 165,600 m$^3$/d flow rate).**

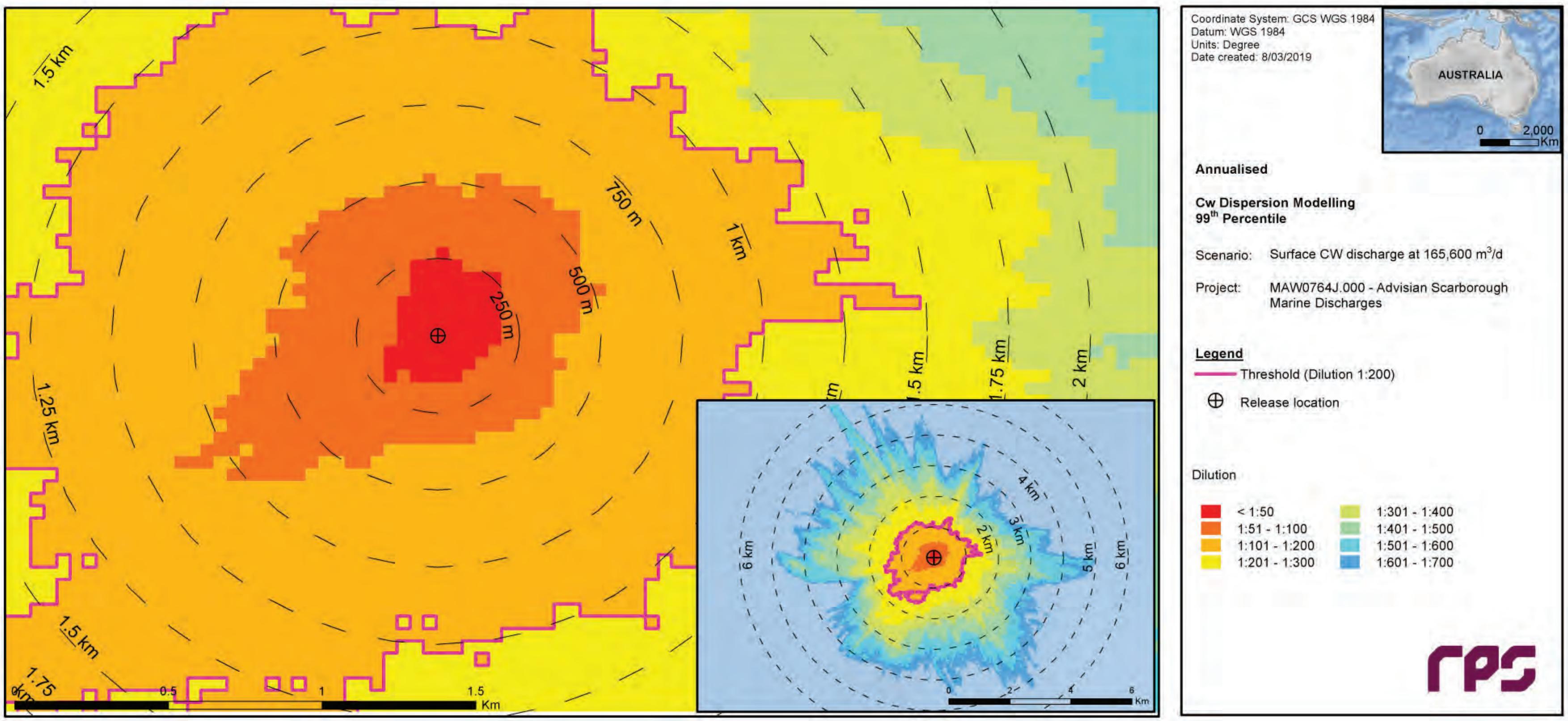



**Figure 3.106 Predicted annualised minimum dilutions at the 99th percentile for Case C1 (0 m depth discharge at 165,600 m$^3$/d flow rate).**

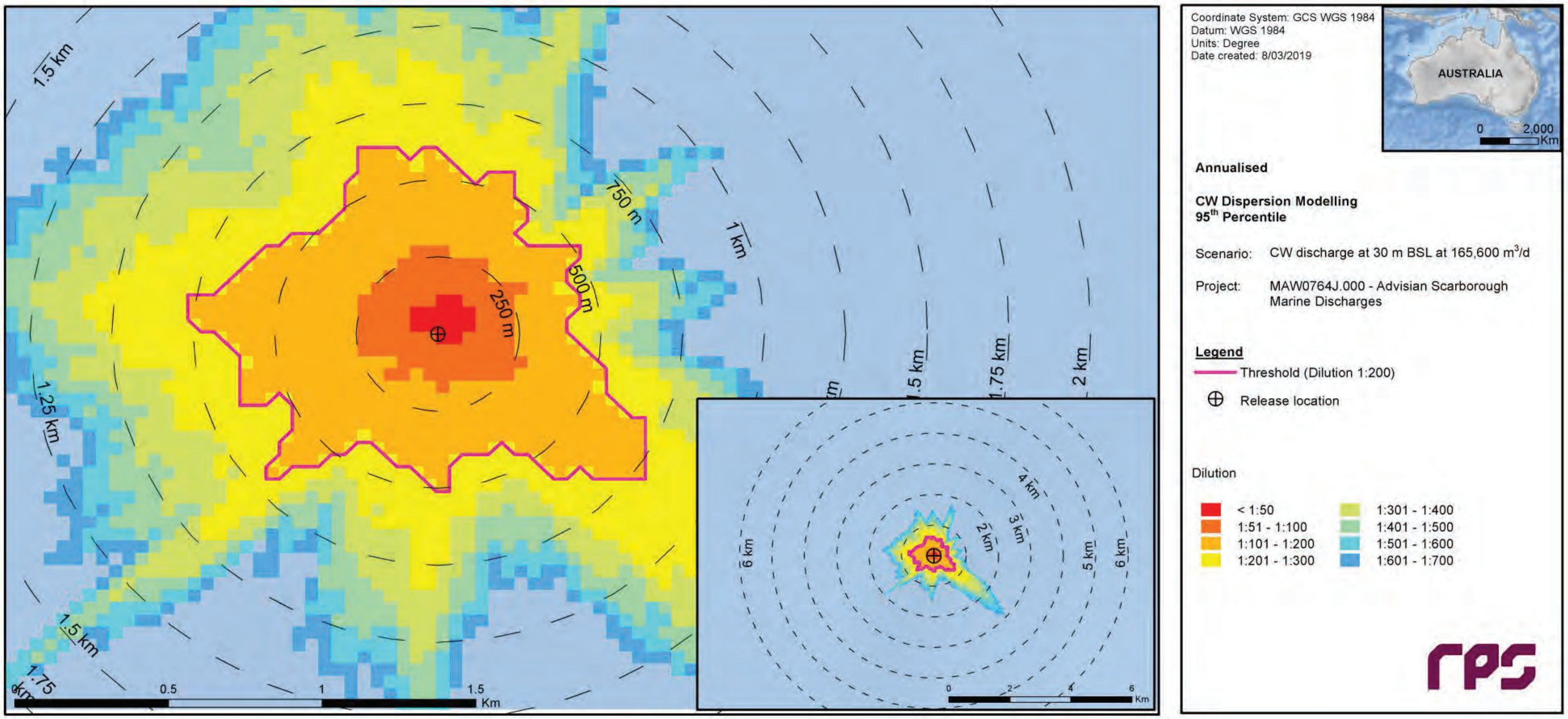



**Figure 3.107 Predicted annualised minimum dilutions at the 95th percentile for Case C3 (30 m depth discharge at 165,600 m$^3$/d flow rate).**

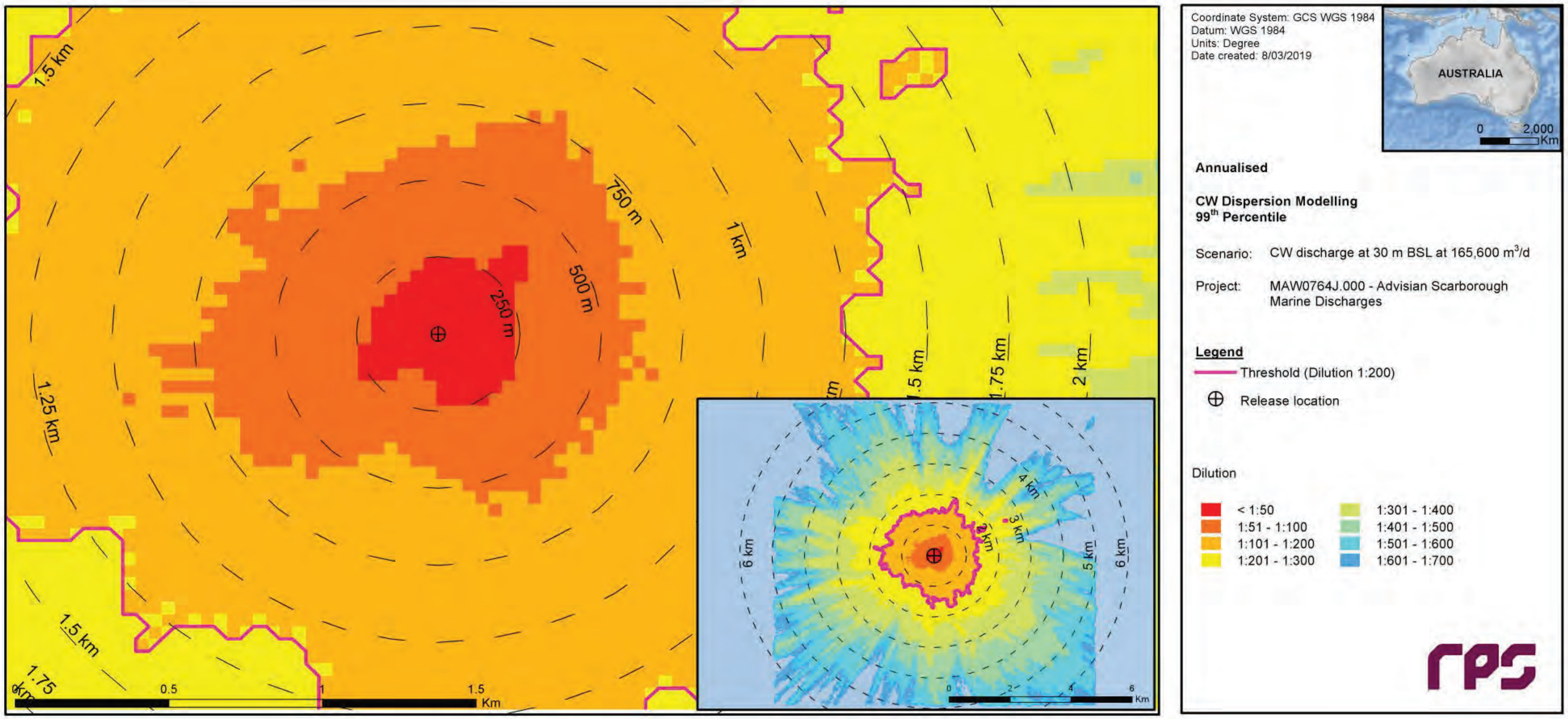



**Figure 3.108 Predicted annualised minimum dilutions at the 99th percentile for Case C3 (30 m depth discharge at 165,600 m³/d flow rate).**

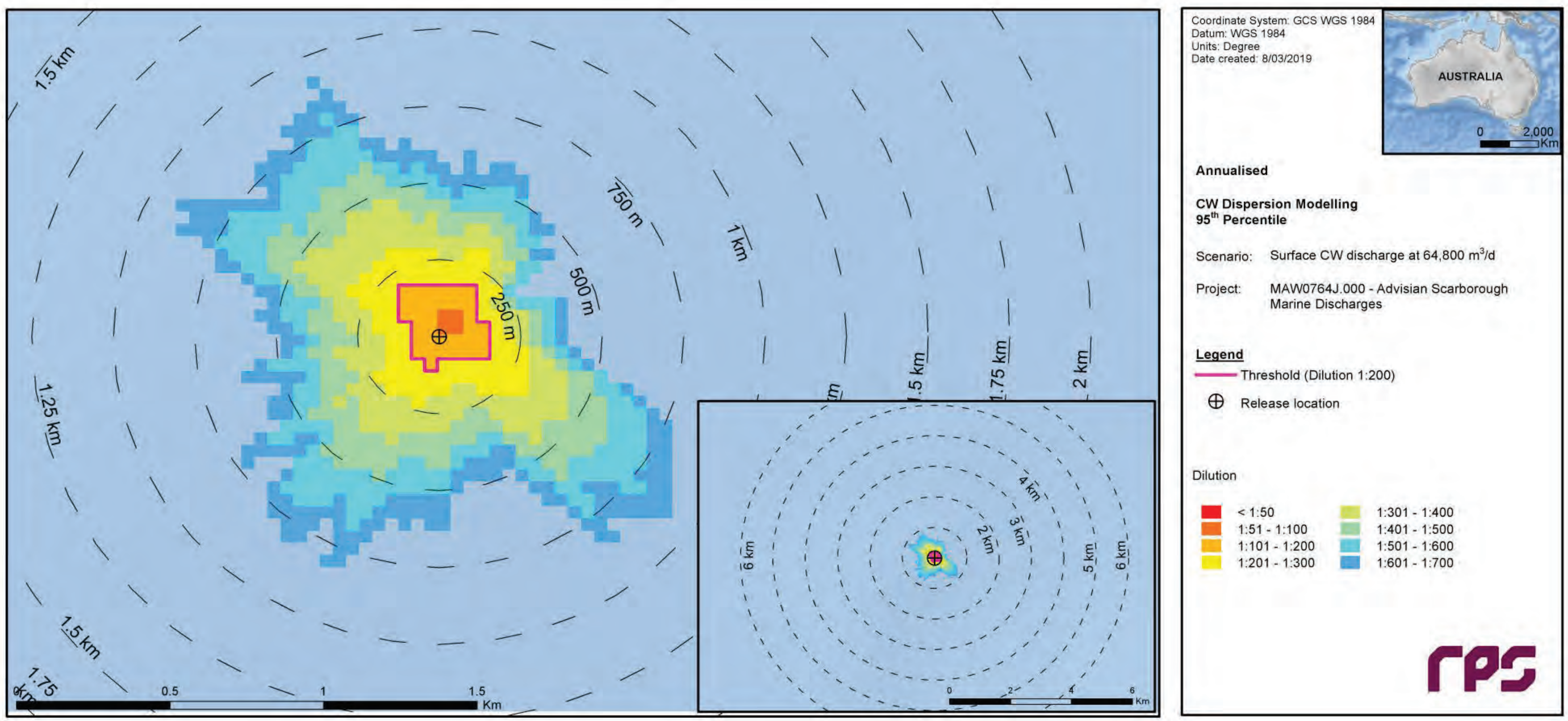



**Figure 3.109 Predicted annualised minimum dilutions at the 95th percentile for Case C4 (0 m depth discharge at 64,800 $m^3$/d flow rate).**

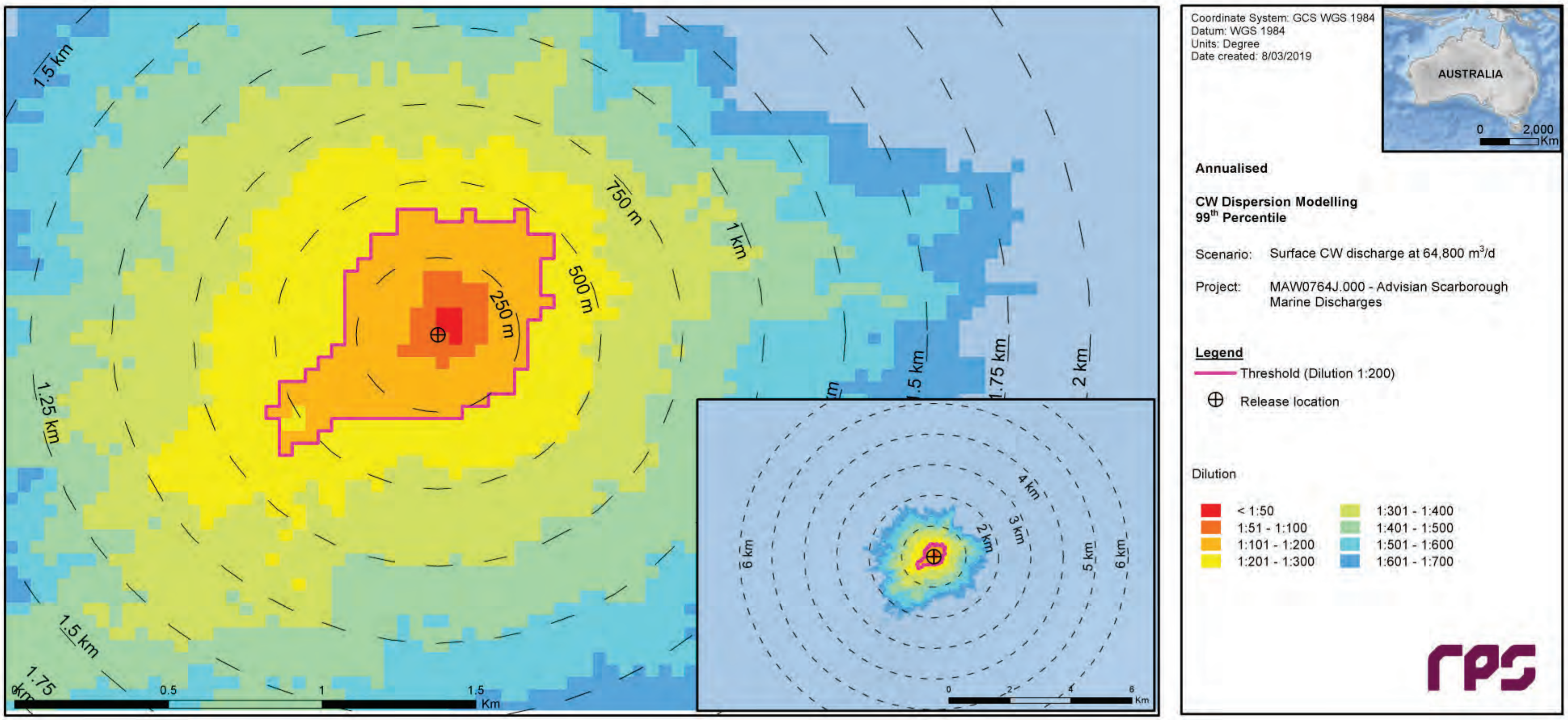



Figure 3.110 Predicted annualised minimum dilutions at the 99th percentile for Case C4 (0 m depth discharge at 64,800 $m^3$/d flow rate).

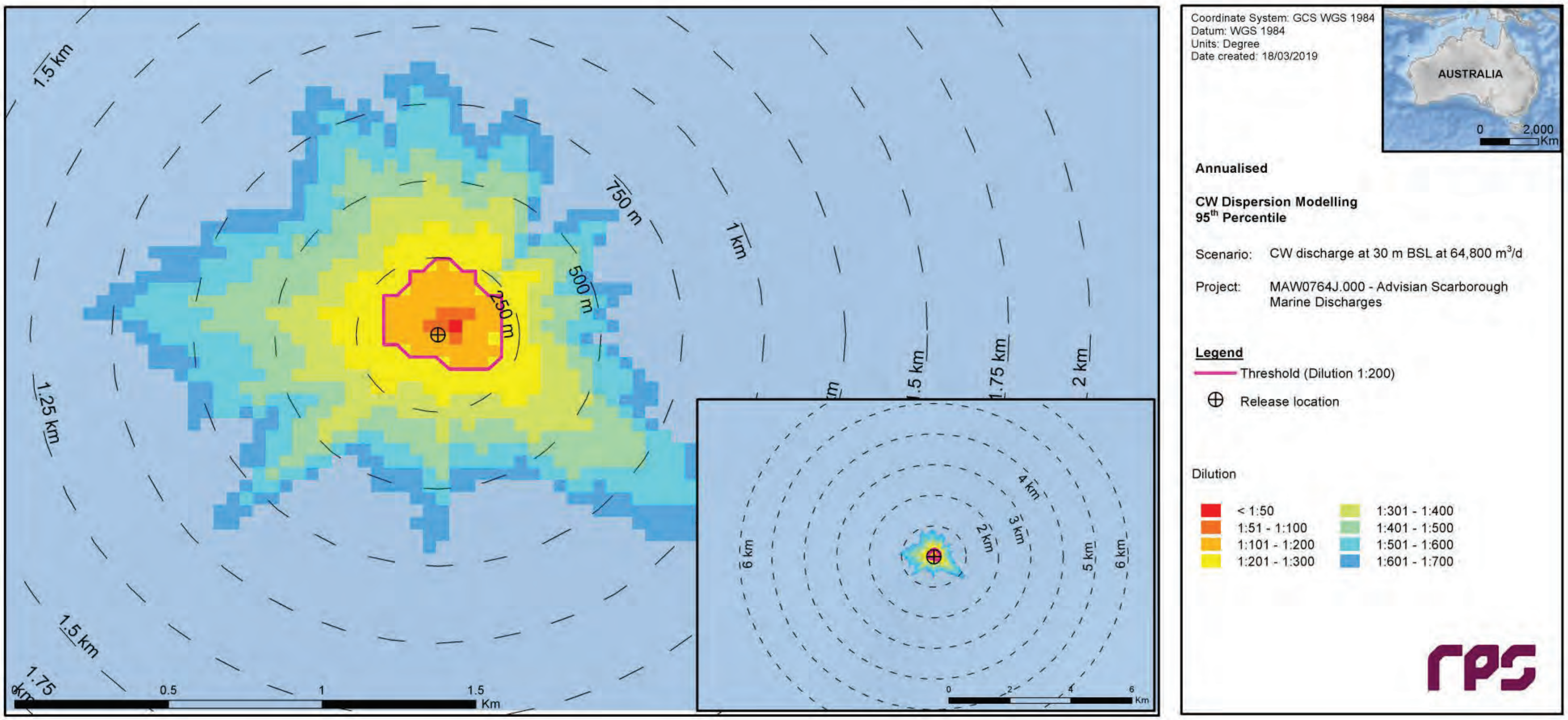



**Figure 3.111 Predicted annualised minimum dilutions at the 95th percentile for Case C6 (30 m depth discharge at 64,800 m$^3$/d flow rate).**

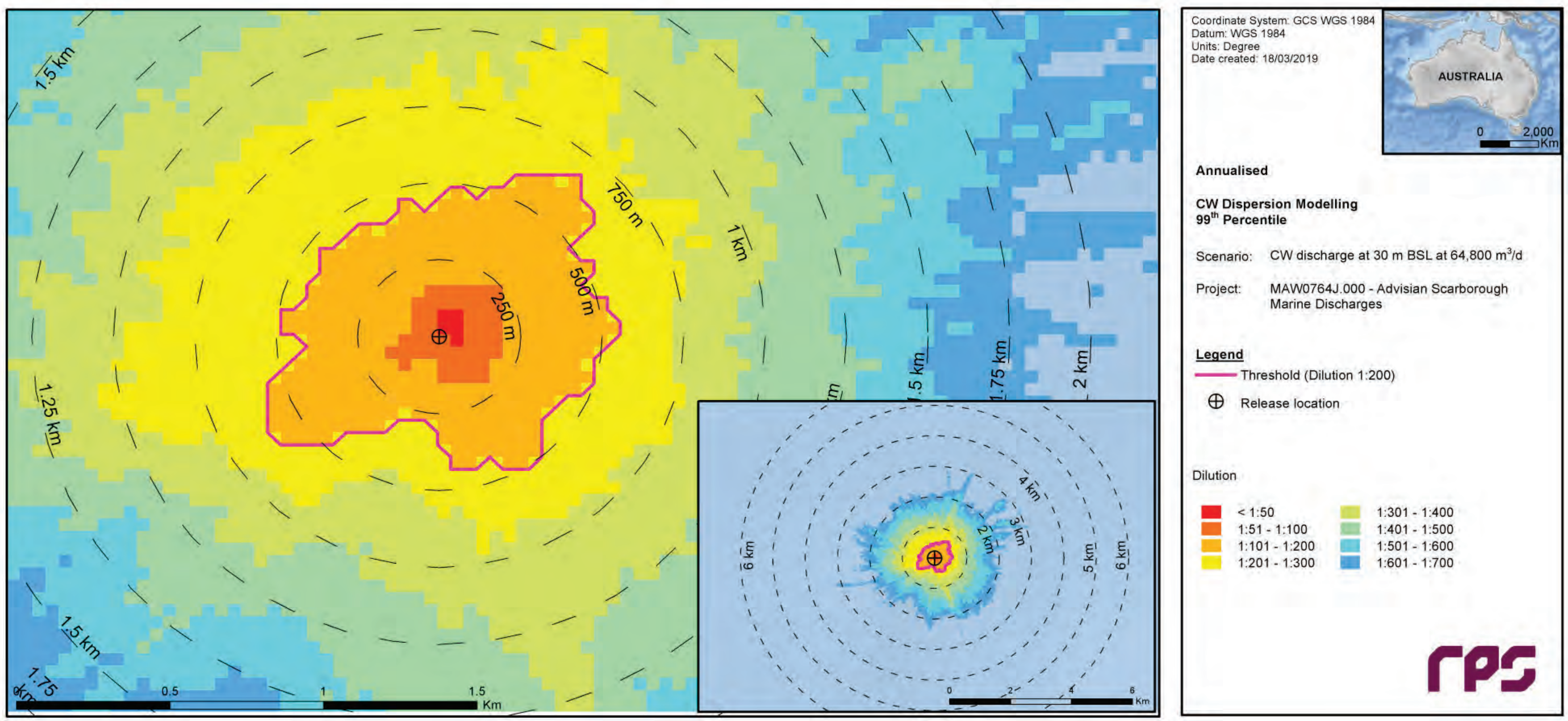



**Figure 3.112 Predicted annualised minimum dilutions at the 99th percentile for Case C6 (30 m depth discharge at 64,800 $m^3/d$ flow rate).**

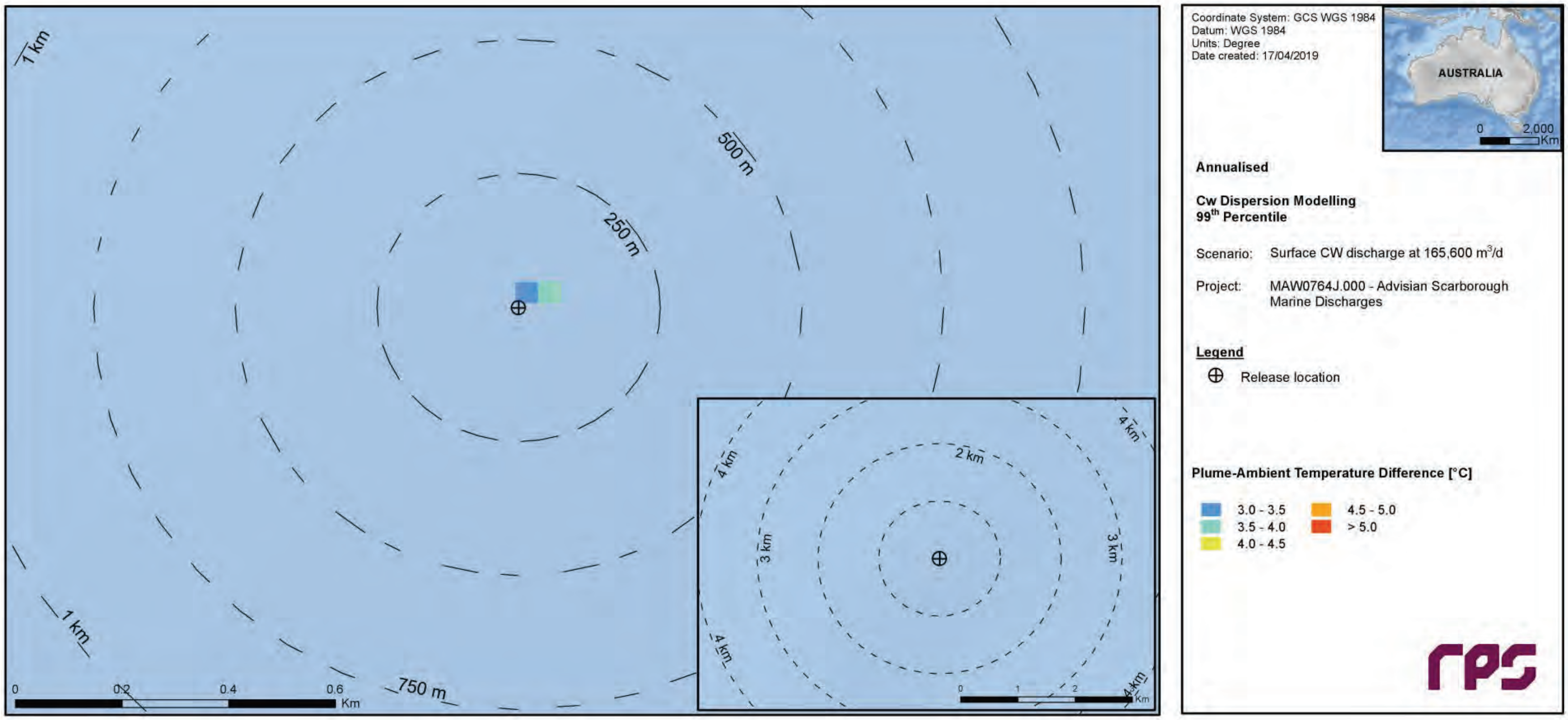



**Figure 3.113** Predicted annualised maximum plume-ambient ΔT at the 99th percentile for Case C1 (0 m depth discharge at 165,600 $m^3$/d flow rate).

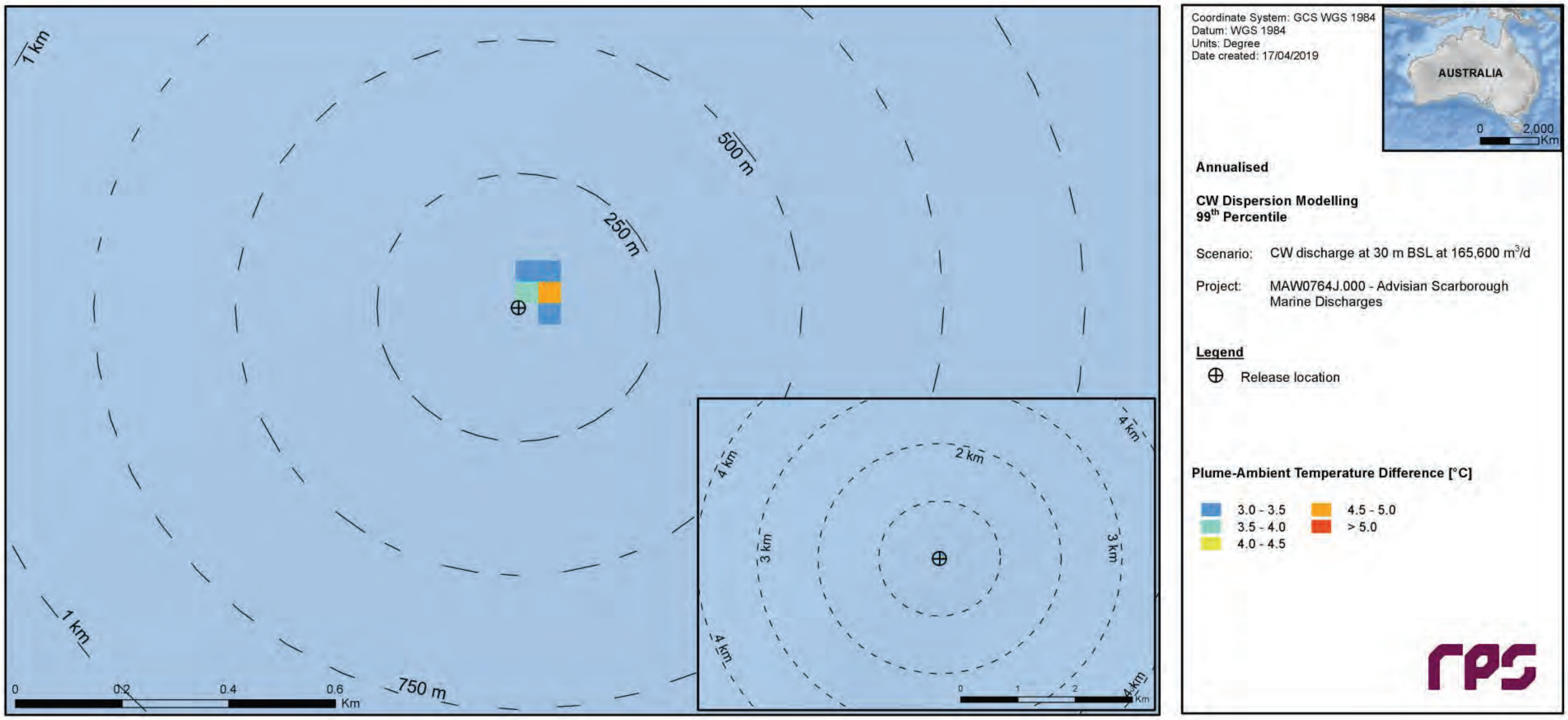



Figure 3.114 Predicted annualised maximum plume-ambient ΔT at the 99th percentile for Case C3 (30 m depth discharge at 165,600 m$^3$/d flow rate).

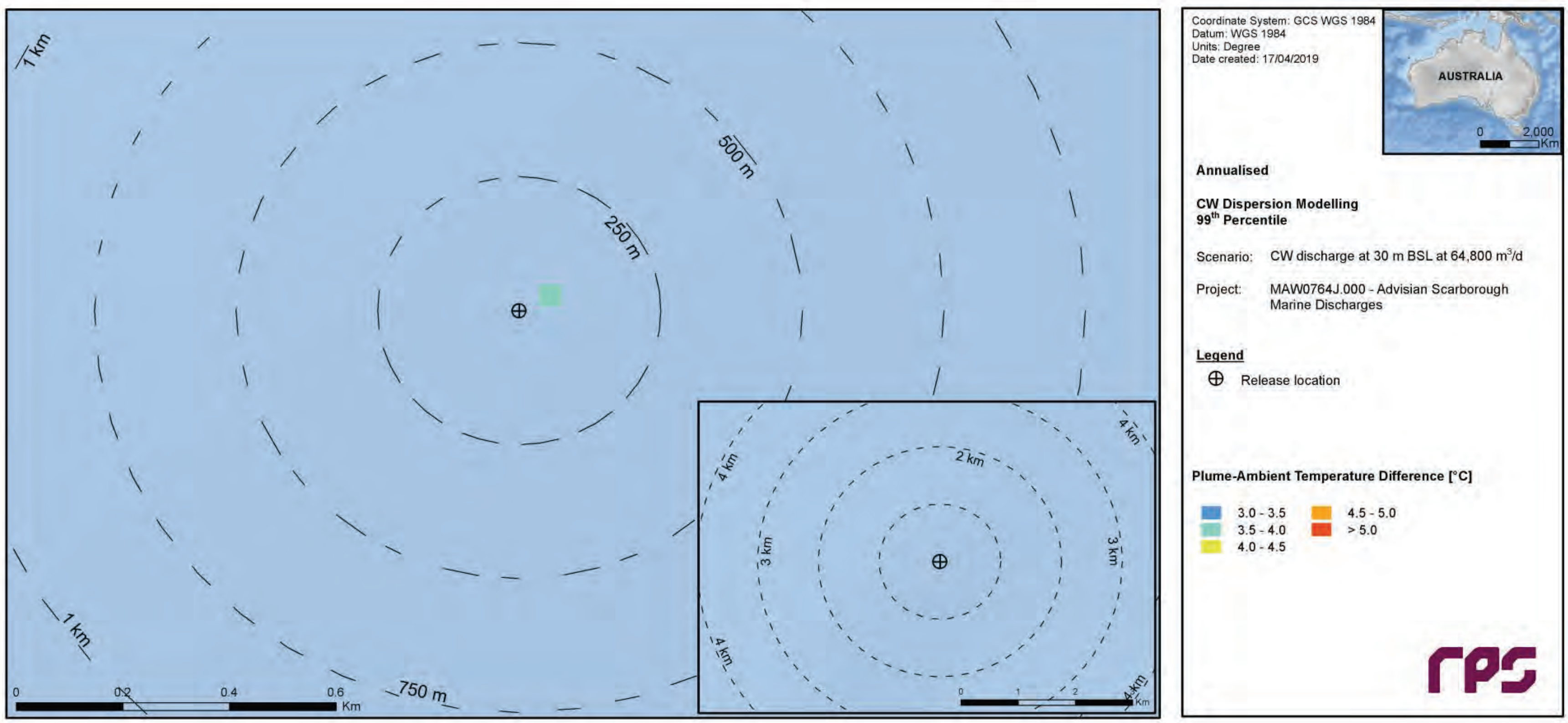



**Figure 3.115 Predicted annualised maximum plume-ambient ΔT at the 99th percentile for Case C6 (30 m depth discharge at 64,800 m³/d flow rate).**

# 4 CONCLUSIONS

The main findings of the study are as follows:

## Near-Field Modelling

- 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 0 m (Cases C1, C4 and C7), 10 m (Cases C2, C5 and C8) and 30 m (Cases C3, C6 and C9) below the water surface. The surface discharges are shown to increase the extent of the turbulent mixing zone. Following this initial mixing, the positively-buoyant plumes are predicted to rise in the water column.
- For Cases C1, C4 and C7 (0 m depth discharge), the plume is predicted to plunge up to 14 m below the sea surface, with the highest flow rate yielding the greatest plunge depth due to the vertical orientation of the discharges. For the discharges at depths of 10 m and 30 m, the plumes are predicted to plunge up to 25 m and 43 m below the sea surface, respectively, with the highest flow rate yielding the greatest plunge depths.
- Increased ambient current strengths are shown to increase the horizontal distance travelled by the plume from the discharge point.
- For a discharge at a 165,600 $m^3/d$ flow rate, the maximum horizontal distance travelled by the plume under annualised average current speeds is predicted for a discharge at 30 m depth as 75.0 m. The dilution level for this case is predicted as 1:52.
- For a discharge at a 64,800 $m^3/d$ flow rate, the maximum horizontal distance travelled by the plume under annualised average current speeds is predicted for a discharge at 30 m depth as 69.7 m. The dilution level for this case is predicted as 1:77.
- For a discharge at an 82,800 $m^3/d$ flow rate, the maximum horizontal distance travelled by the plume under annualised average current speeds is predicted for a discharge at 30 m depth as 59.8 m. The dilution level for this case is predicted as 1:59.
- For a discharge at 0 m depth, the maximum horizontal distance travelled by the plume under annualised average current speeds is predicted for a 165,600 $m^3/d$ flow rate discharge as 5.7 m. The dilution level for this case is predicted as 1:6.
- For a discharge at 10 m depth, the maximum horizontal distance travelled by the plume under annualised average current speeds is predicted for a 165,600 $m^3/d$ flow rate discharge as 11.1 m. The dilution level for this case is predicted as 1:17.
- For a discharge at 30 m depth, the maximum horizontal distance travelled by the plume under annualised average current speeds is predicted for a 165,600 $m^3/d$ flow rate discharge as 24.5 m. The dilution level for this case is predicted as 1:52.
- For each combination of discharge flow rate and depth, 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 surface (or trapping depth, at which the predictions of dispersion are halted due to the plume reaching equilibrium with the ambient receiving water) closer to the discharge point, which slows the rate of dilution.

- The predictions of dilution 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 each combination of discharge flow rate and depth indicate that the chlorine constituent of the CW discharge is not expected to reach the required levels of dilution in the near field mixing zone.
- The temperature differential between the plume and the ambient water meets the required criterion in all conditions for Cases C2, C3, C6 and C9, and in the stronger-current simulations for Cases C1, C5 and C8. For Cases C4 and C7, however, compliance with the temperature differential criterion is not achieved.
- Some failures to reach the required threshold concentration and temperature are attributable to the plume rapidly breaking the surface.

## Far-Field Modelling

- For Cases C1 and C3, dilution to reach threshold concentration is achieved for chlorine within an area of influence extending up to 1.79 km and 2.47 km, respectively, at the 99$^{th}$ percentile. For Cases C4 and C6, the maximum spatial extents of the relevant dilution contour are up to 0.62 km and 0.63 km, respectively, at the 99$^{th}$ percentile.
- For Cases C1 and C3, the areas of exposure defined by the relevant dilution contour are predicted to reach maximums of 4.59 km$^2$ and 6.56 km$^2$, respectively, at the 99$^{th}$ percentile. For Cases C4 and C6, the corresponding maximum areas of exposure are up to 0.40 km$^2$ and 0.68 km$^2$, respectively, at the 99$^{th}$ percentile.
- Maximum depths reached by. the discharges are predicted as 8 m, 38 m, 6 m and 38 m for Cases C1, C3, C4 and C6, respectively.
- Because the 3 °C plume-ambient temperature differential requirement is forecast to be met within a distance of 115 m at the 99$^{th}$ percentile in any case, the limiting factor for the plume's area of influence will be defined by its chlorine constituent rather than its temperature.

## Key Observations

- Due to the similarity in typical magnitude of the hindcast currents throughout the depth range of discharges under consideration, predicted outcomes are broadly similar.
- The greater variability in surface-layer currents may promote the highest levels of mixing and dilution.
- Because the discharge will be initially positively buoyant, it will rise in the water column and may resurface in the vicinity of the discharge point prior to acclimation with ambient receiving water conditions. This outcome is particularly likely for the surface discharge.
- Outcomes show that below-threshold chlorine concentrations are achieved closer to the discharge point for a flow rate of 64,800 m$^3$/d than for a higher flow rate of 165,600 m$^3$/d. This is attributable to the fact that initial peak chlorine concentrations in the water column are lower in the former case, which reduces the average concentrations likely to be recorded in each model grid cell during episodes of recirculation and pooling.

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# Appendix G

## Scarborough Gas Development Produced Water Discharge Modelling Study

# WOODSIDE SCARBOROUGH PROJECT – PRODUCED WATER DISCHARGE MODELLING

## Report

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# EXECUTIVE SUMMARY

RPS was commissioned by Advisian Pty Ltd (Advisian), on behalf of Woodside Energy Ltd (Woodside), to undertake a marine dispersion modelling study of proposed water discharges from the Scarborough Project's Floating Production Unit (FPU).

The Scarborough gas resource, located in Commonwealth waters approximately 375 km off the Burrup Peninsula, forms part of the Greater Scarborough gas fields, comprising the Scarborough, North Scarborough, Thebe and Jupiter gas fields.

As Operator of the Greater Scarborough gas fields, Woodside is proposing to develop the gas resource through new offshore facilities. These will be connected to the mainland through an approximately 430 km trunkline.

The Scarborough Project will involve the processing of hydrocarbons which will result in the production of produced water (PW).

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 the Total Petroleum Hydrocarbons (TPH) in the produced water (PW) discharge. This will indicate whether concentrations of this contaminant are still likely to be above stated 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 PW 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 TPH in the PW stream from the FPU, dispersion modelling was carried out for a flow rate of 95 $m^3/d$ at three discharge depths: 0 m, 10 m and 30 m below the water surface.

The potential area that may be influenced by the PW 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). An annualised aggregation of outcomes was also assembled.

The main findings of the study are as follows:

## Near-Field Modelling

- 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 0 m, 10 m and 30 m below the water surface (Cases P1, P2 and P3, respectively). The surface discharges are shown to increase the extent of the turbulent mixing zone. Following this initial mixing, the near neutrally-buoyant plumes are predicted to travel laterally in the water column.
- For Case P1, the plume is predicted to plunge up to 4.4 m below the sea surface. For Cases P2 and P3, the plumes are predicted to remain at approximately the discharge depth: up to 11 m below the surface for Case P2 and up to 31 m below the surface for Case P3.
- Increased ambient current strengths are shown to increase the horizontal distance travelled by the plume from the discharge point.

- For a discharge at a 95 $m^3/d$ flow rate, the maximum horizontal distance travelled by the plume under annualised average current speeds is predicted for a discharge at 0 m depth as 255 m. The dilution level for this case is predicted as 1:1,519.
- The maximum diameter of the plume at the end of the near-field zone was predicted as 3.7 m for Case P1, 1.8 m for Case P2 and 1.7 m for Case P3. Increases in current speed serve to restrict the diameter of the plume.
- For each discharge depth, 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 (at which the predictions of dispersion are halted due to the plume reaching equilibrium with the ambient receiving water) closer to the discharge point, which slows the rate of dilution.
- The average dilution levels of the plume upon reaching the trapping depth under average current speeds are predicted to be 1:1,519 for Case P1, 1:88 for Case P2 and 1:43 for Case P3. Additionally, the minimum dilution levels of the plume (i.e. dilution of the plume centreline) upon encountering the trapping depth under average current speeds are predicted to be 1:390 for Case P1, 1:22 for Case P2 and 1:11 for Case P3.
- The predictions of dilution 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 Case P1, P2 and P3 discharges indicate that the TPH constituent of the PW discharge is not expected to reach the required levels of dilution in the near field mixing zone.

## Far-Field Modelling

- For Case P1, dilution to reach threshold concentration is achieved for TPH within an area of influence extending up to 543 m at the 99$^{th}$ percentile. For Case P3, the maximum spatial extents of the relevant dilution contour are up to 810 m at the 99$^{th}$ percentile.
- For Case P1, the area of exposure defined by the relevant dilution contour is predicted to reach a maximum of 0.48 $km^2$ at the 99$^{th}$ percentile. For Case P3, the corresponding maximum area of exposure is up to 0.70 $km^2$ at the 99$^{th}$ percentile.
- Maximum depths reached by the discharges are predicted as 5 m and 33 m for Cases P1 and P3, respectively.

## Key Observations

- Due to the similarity in typical magnitude of the hindcast currents throughout the depth range of discharges under consideration, predicted outcomes are broadly similar.
- The greater variability in surface-layer currents will promote the highest levels of mixing and dilution.
- Because the discharge will be initially negatively buoyant, it will sink in the water column and even a surface discharge is unlikely to resurface in the vicinity of the discharge point prior to acclimation with ambient receiving water conditions.

# 1 INTRODUCTION

## 1.1 Background

RPS was commissioned by Advisian Pty Ltd (Advisian), on behalf of Woodside Energy Ltd (Woodside), to undertake a marine dispersion modelling study of proposed water discharges from the Scarborough Project's Floating Production Unit (FPU).

The Scarborough gas resource, located in Commonwealth waters approximately 375 km off the Burrup Peninsula, forms part of the Greater Scarborough gas fields, comprising the Scarborough, North Scarborough, Thebe and Jupiter gas fields.

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The Scarborough Project will involve the processing of hydrocarbons which will result in the production of produced water (PW).

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 the Total Petroleum Hydrocarbons (TPH) in the produced water (PW) discharge. This will indicate whether concentrations of this contaminant are still likely to be above stated 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 PW 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 TPH in the PW stream from the FPU (location shown in Table 1.1), dispersion modelling was carried out for a flow rate of 95 $m^3$/d at three discharge depths: 0 m, 10 m and 30 m below the water surface.

The potential area that may be influenced by the PW 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). An annualised aggregation of outcomes was also assembled.

All PW discharge characteristics used as input to the modelling are specified in the Model Input Form for this study (Advisian, 2018).

**Table 1.1 Location of the proposed FPU used as the release site for the PW dispersion modelling assessment.**

| Release Site | Latitude (°S) | Longitude (°E) | Water Depth (m) |
|---|---|---|---|
| FPU | 19° 53' 54.715" | 113° 14' 19.561" | 930 |

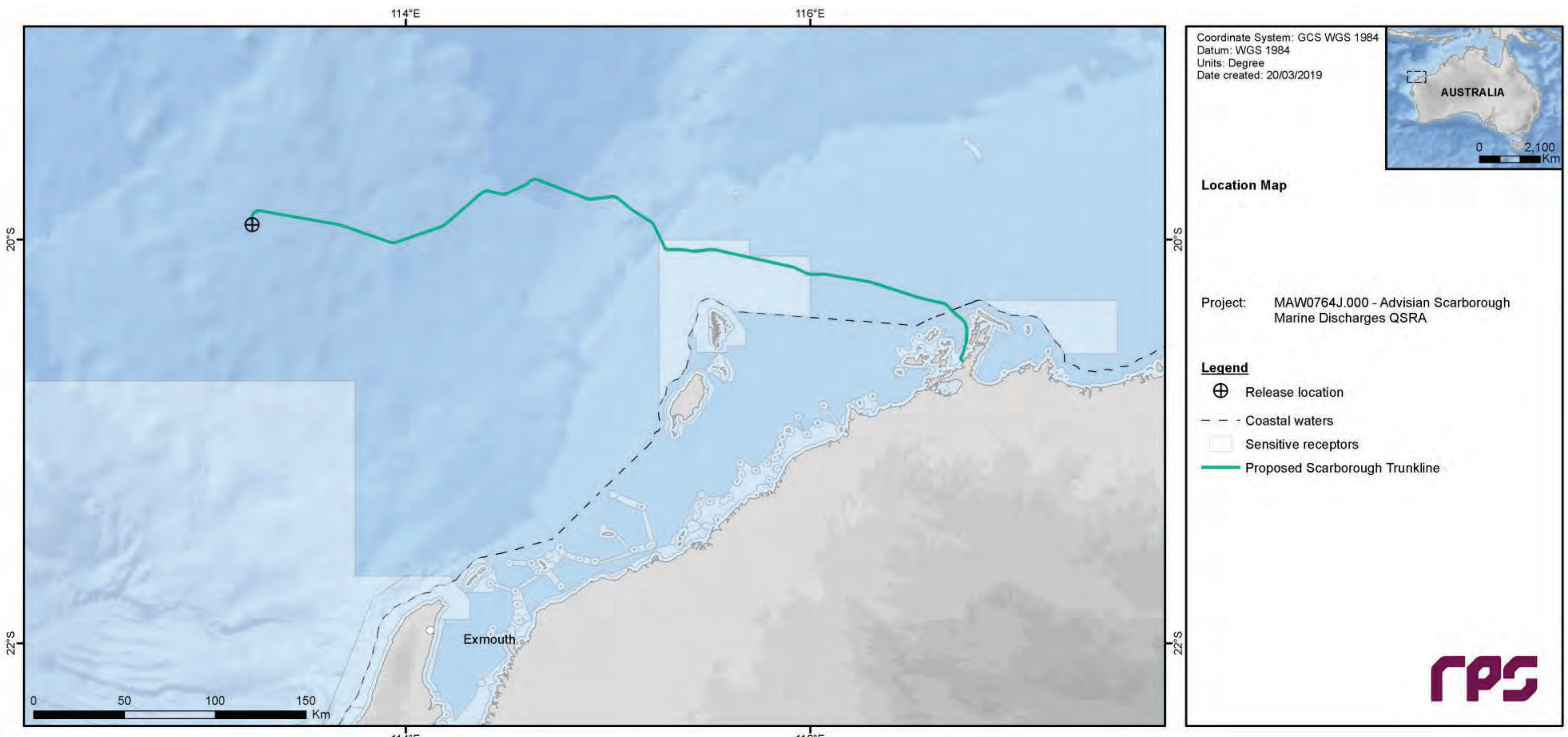



**Figure 1.1 Location of the proposed Scarborough pipeline and FPU on the North West Shelf of Australia.**

## 1.2 Modelling Scope

The physical mixing of the PW 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:

- Collation of a suitable three-dimensional, spatially-varying current data set surrounding the FPU location for a ten-year (2006-2015) 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 metocean data collected in the Scarborough Project area.
- 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.
- Collation of seasonally-varying vertical water density profiles at the FPU location for use as input to the dispersion models.
- 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).
- 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.
- 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.
- 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 PW 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 PW 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 FPU location.

### 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.

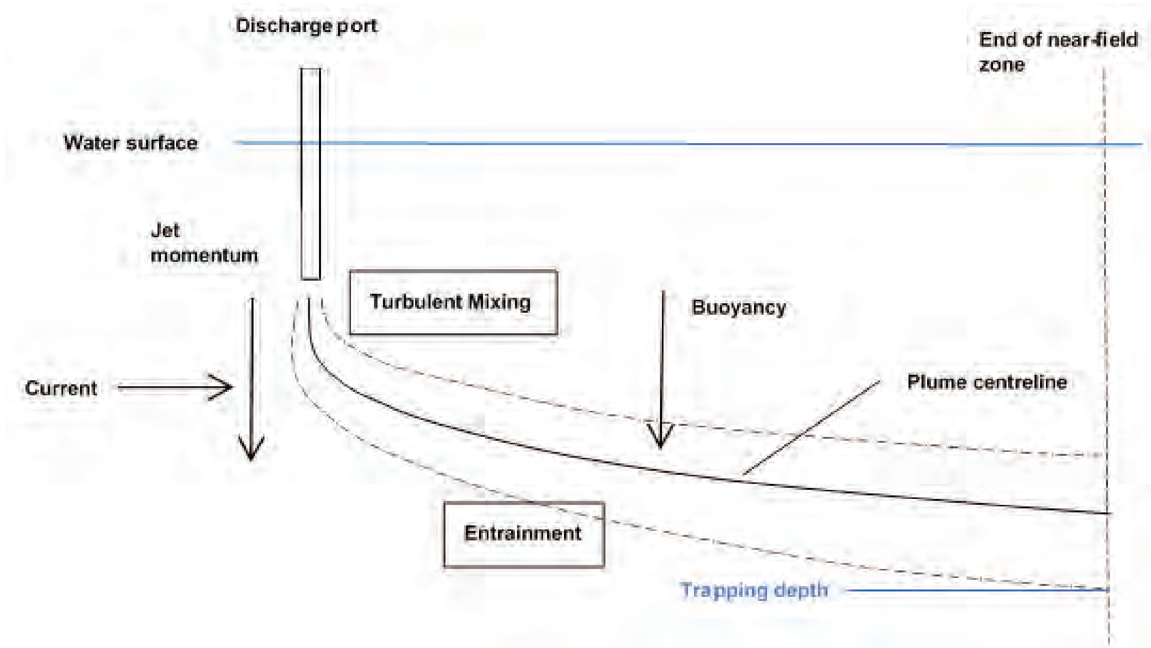



**Figure 2.1 Conceptual diagram showing the general behaviour of negatively buoyant discharge.**

### 2.1.3 Setup of Near-Field Model

#### 2.1.3.1 Discharge Characteristics

The PW discharge characteristics for Cases P1 to P3 are summarised in Table 2.1. Cases P1, P2 and P3 were assumed to occur at depths of 0 m below mean sea level (BMSL), 10 m BMSL and 30 m BMSL, respectively. The flow was assumed to occur through a single outlet of 0.2 m diameter at a rate of 95 $m^3$/d and have a salinity and temperature of 40.5 parts per thousand (ppt) and 40 °C, respectively.

Concentrations of the constituent of interest (TPH) within the discharges are described in Table 2.2, along with the required dilution factor to reach the defined threshold concentration (Advisian, 2018).

**Table 2.1 Summary of PW discharge characteristics.**

| Parameter | Case P1 | Case P2 | Case P3 |
|---|---|---|---|
| Flow rate ($m^3$/d) | | 95 | |
| Outlet pipe internal diameter (m) [in] | | 0.2 [7.9] | |
| Outlet pipe orientation | | Vertical (downwards) | |
| Depth of pipe below sea surface (m) | 0 | 10 | 30 |
| Discharge salinity (ppt) | | 40.5 | |
| Discharge temperature (°C) | | 40 | |

**Table 2.2 Constituent of interest within the PW discharges and criteria for analysis of exposure.**

| Constituent | Source Concentration (mg/L) | Threshold Concentration (mg/L) | Required Dilution Factor |
|---|---|---|---|
| Total Petroleum Hydrocarbons (TPH) | 29 | 0.07 | 414.3 |

### 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 PW plume. These inputs are described in the following sections.

#### 2.1.3.2.1 Ambient Temperature and Salinity

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, NOAA) and its co-located World Data Center for Oceanography (Levitus *et al.*, 2013).

Table 2.3 shows the average seasonal water temperature and salinity levels at varying depths from 0 m to 50 m. This data can be considered representative of seasonal conditions at the FPU location.

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 (34.7-34.8 practical salinity unit, PSU), irrespective of season or depth.

**Table 2.3 Average temperature and salinity levels adjacent to the proposed FPU location.**

| Season | Depth (m) | Temperature (°C) | Salinity (PSU) |
|---|---|---|---|
| Summer | 0 | 27.8 | 34.7 |
| | 20 | 27.3 | 34.8 |
| | 50 | 26.2 | 34.8 |
| Transitional | 0 | 26.0 | 34.7 |
| | 20 | 25.7 | 34.7 |
| | 50 | 25.1 | 34.7 |
| Winter | 0 | 26.4 | 34.7 |
| | 20 | 26.3 | 34.7 |
| | 50 | 26.2 | 34.7 |
| Annualised | 0 | 26.6 | 34.7 |
| | 20 | 26.3 | 34.7 |
| | 50 | 25.8 | 34.7 |

#### 2.1.3.2.2 Ambient Current

Ocean current data was sourced from a 10-year hindcast data set of combined large-scale ocean (BRAN) and tidal currents. The data was statistically analysed to determine the 5$^{th}$, 50$^{th}$ and 95$^{th}$ percentile current speeds. These statistical current speeds can be considered representative of seasonal conditions at the FPU location.

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:

- 5$^{th}$ percentile current speed: weak currents, low dilution and slow advection.
- 50$^{th}$ percentile (median) current speed: average currents, moderate dilution and advection.
- 95$^{th}$ percentile current speed: strong currents, high dilution and rapid advection to nearby areas.

The 5$^{th}$, 50$^{th}$ and 95$^{th}$ percentile values are referenced as weak, medium and strong current speeds, respectively.

**Table 2.4 Adopted ambient current conditions adjacent to the proposed FPU location.**

| 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 | 2.5 | 0.041 | 0.158 | 0.326 |
| | 22.7 | 0.049 | 0.154 | 0.312 |
| | 56.7 | 0.044 | 0.138 | 0.267 |
| Transitional | 2.5 | 0.045 | 0.177 | 0.375 |
| | 22.7 | 0.045 | 0.173 | 0.369 |
| | 56.7 | 0.043 | 0.157 | 0.322 |
| Winter | 2.5 | 0.044 | 0.172 | 0.395 |
| | 22.7 | 0.043 | 0.166 | 0.375 |
| | 56.7 | 0.039 | 0.156 | 0.341 |
| Annualised | 2.5 | 0.043 | 0.170 | 0.374 |
| | 22.7 | 0.045 | 0.164 | 0.361 |
| | 56.7 | 0.042 | 0.151 | 0.320 |

## 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 (25) 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.

Two PW discharge scenarios were modelled as a continuous discharge using 25 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). The PW discharge characteristics for the selected cases (P1 and P3) are summarised in Table 2.5. These cases were chosen to cover the full range of proposed discharge depths.

**Table 2.5 Summary of far-field PW discharge modelling assumptions.**

| Parameter | Case P1 | Case P3 |
|---|---|---|
| Hindcast modelling period | 2006-2015 | |
| Seasons | Summer (December to February)<br>Transitional (March and September to November)<br>Winter (April to August)<br>Annual | |
| Flow rate ($m^3$/d) | 95 | |
| Discharge depth (m) | 0 | 30 |
| Discharge salinity (ppt) | 40.5 | |
| Discharge temperature (°C) | 40 | |
| Number of simulations | 75 (25 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 PW 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 5 m x 5 m to track the movement and fate of the discharge plume. The extent of the grid region measured approximately 5 km (longitude or x-axis) by 5 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 Background

The area of interest for this study is typified by strong tidal flows over the shallower regions, particularly along the inshore region of the North West Shelf and among the island groups stretching from the Dampier Archipelago to the North West Cape. 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 slicks 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 pollutants can be variably affected by combinations of tidal, wind-induced and density-induced drift currents. Depending on their local influence, it is critical 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 of pollutants. As measured current data is not available for simultaneous periods over a network of locations covering the wide area of this study, 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 mesoscale ocean models, with estimates of the tidal currents generated by an RPS model set up for the study area.

### 2.2.5.2 Mesoscale Circulation Model

Representation of the drift currents that affect the area were available from the output of the BRAN (Bluelink ReANalysis; Oke *et al.*, 2008, 2009; Schiller *et al.*, 2008) ocean model, which is sponsored by the Australian Government through the Commonwealth Bureau of Meteorology (BoM), Royal Australian Navy, and Commonwealth Scientific and Industrial Research Organisation (CSIRO). BRAN is a data-assimilative, three-dimensional ocean model that has been run as a hindcast for many periods and is now used for ocean forecasting (Schiller *et al.*, 2008).

The BRAN predictions for drift currents are produced at a horizontal spatial resolution of approximately 0.1° over the region, at a frequency of once per day, averaged over the 24-hour period. Hence, the BRAN model data provides estimates of mesoscale circulation with horizontal resolution suitable to resolve eddies of a few tens of kilometres' diameter, as well as connecting stream currents of similar spatial scale. Drift currents that are represented over the inner shelf waters in the BRAN data are principally attributable to wind induced drift.

There are several versions of the BRAN database available. The latest BRAN simulation spans the period of January 1994 to August 2016. From this database, time series of current speed and direction were extracted for all points in the model domain for the years 2006-2015 (inclusive). The data was assumed to be a suitably representative sample of the current conditions over the study area for future years.

Figure 2.2 shows the seasonal distribution of current speeds and directions for the BRAN data point closest to the FPU location. Note that the convention for defining current direction is the direction towards which the current flows.

The data shows that current speeds and directions vary between seasons. In general, during transitional months (March and September to November) currents have the strongest average speed (0.22 m/s with a maximum of 0.56 m/s) and tend to flow south-east. During winter (April to August), current flow conditions are more variable, with lower average speed (0.21 m/s with a maximum of 0.53 m/s). During summer (December to February), the current flow occurs in a predominantly south/south-westerly direction with the lowest average speed (0.20 m/s with a maximum of 0.46 m/s).

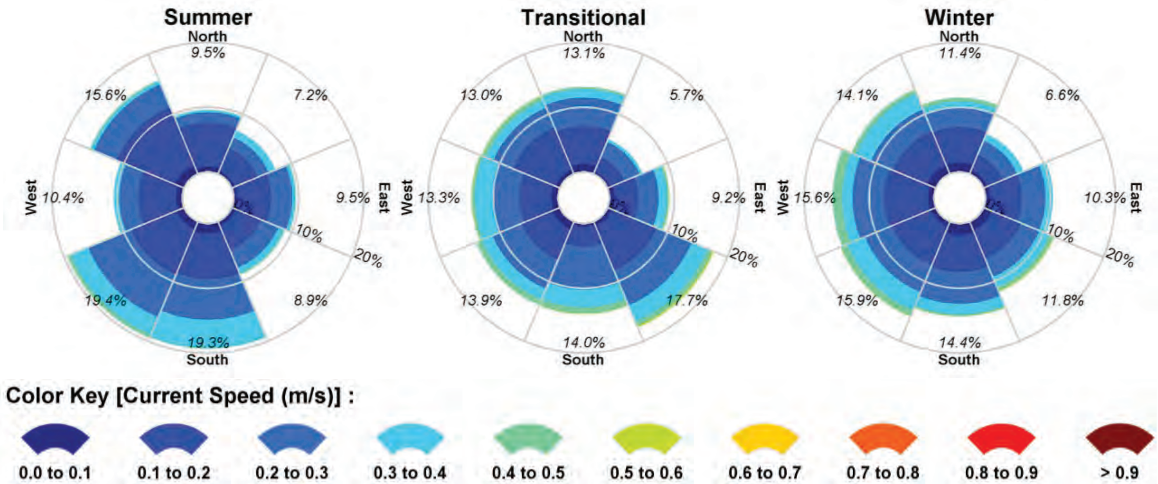



**Figure 2.2 Seasonal current distribution (2006-2015, inclusive) derived from the BRAN database near to the proposed FPU location. The colour key shows the current magnitude, the compass direction provides the direction towards which the current is flowing, and the size of the wedge gives the percentage of the record.**

### 2.2.5.3 Tidal Circulation Model

As the BRAN 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, 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).

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 2.3).

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 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.

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.

For the purpose of verification of the tidal 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 40 tidal stations within the HYDROMAP model domain, ten were used for comparison.

Water level time series for these locations are shown in Figure 2.4 for a one-month period (January 2005). 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.

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 2.5. 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.

Figure 2.6 shows the seasonal distribution of current speeds and directions for the HYDROMAP data point closest to the FPU location. Note that the convention for defining current direction is the direction towards which the current flows.

The current data indicates cyclical tidal flow directions along a northeast-southwest axis, with maximum speeds of around 0.09 m/s.

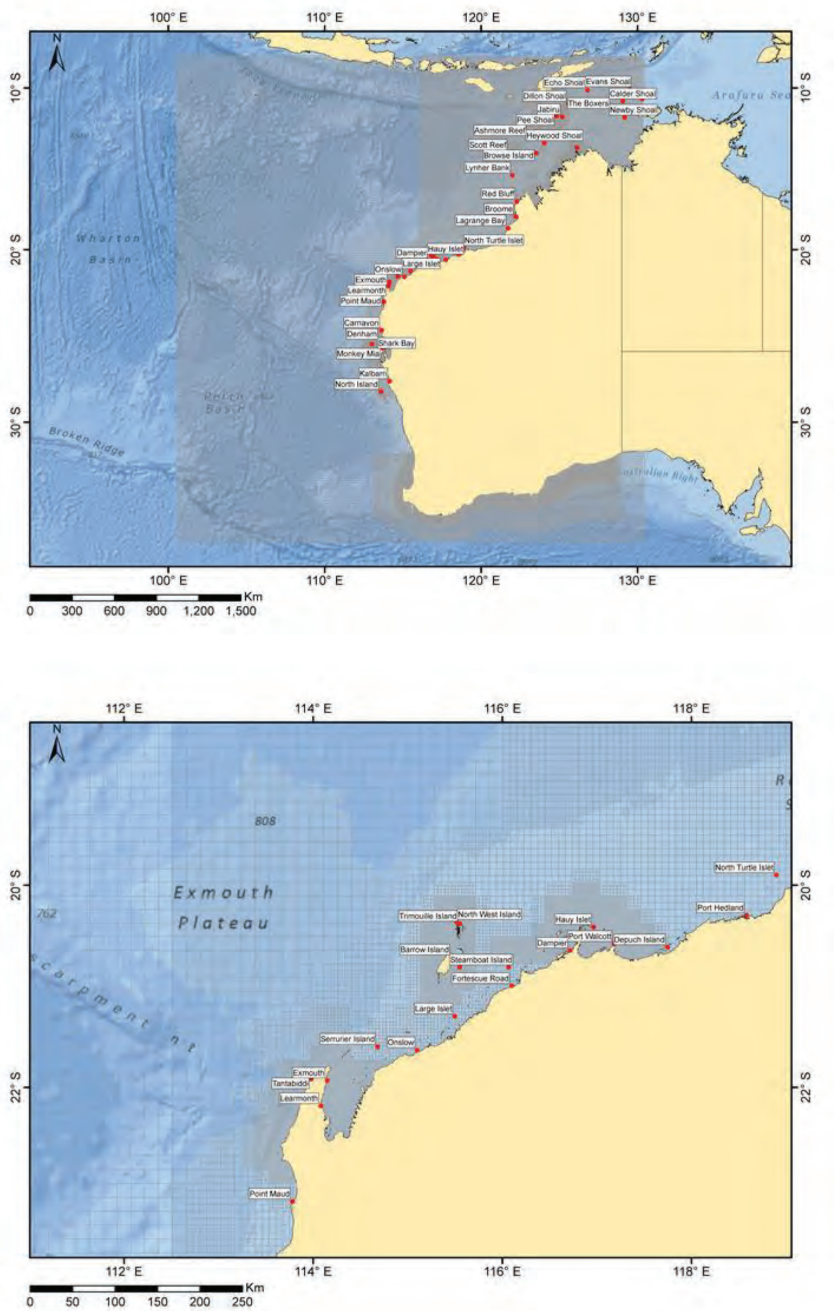



**Figure 2.3** **Hydrodynamic model grid (grey wire mesh) used to generate the tidal currents, showing locations available for tidal comparisons (red labelled dots). The top panel shows the full domain in context with the continental land mass, while the bottom panel shows a zoomed subset near the discharge locations. Higher-resolution areas are indicated by the denser mesh zones.**

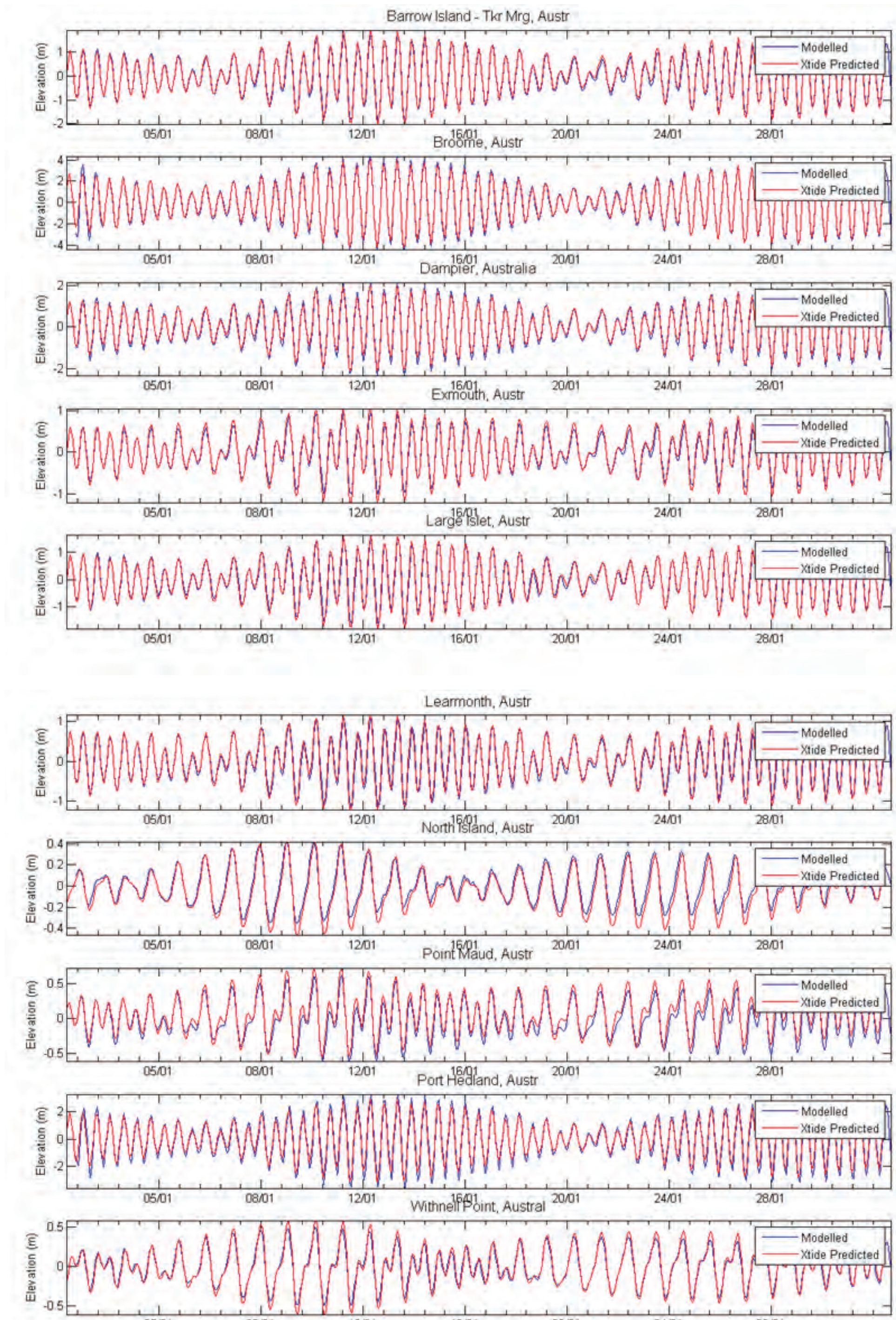
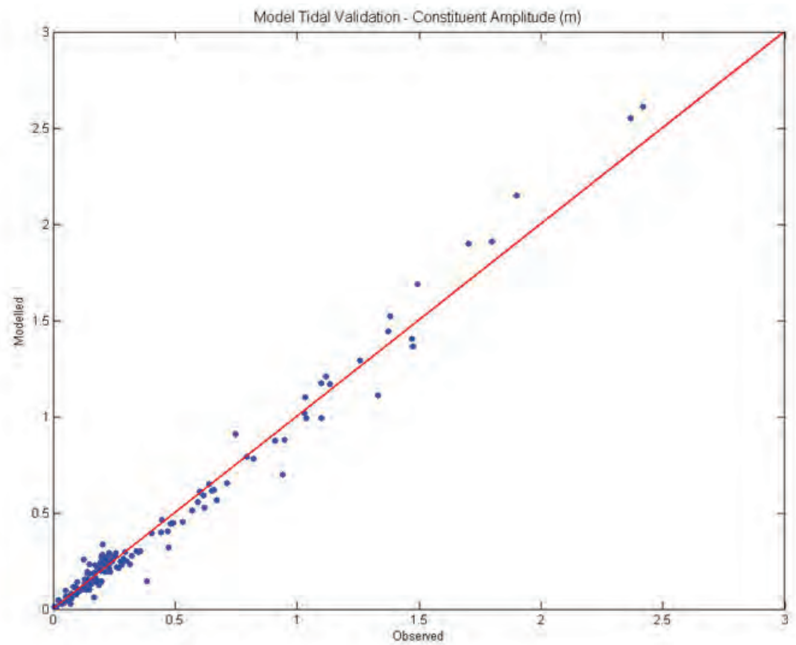



**Figure 2.4 Comparisons between the predicted (blue line) and observed (red line) surface elevation variations at ten locations in the tidal model domain for January 2005.**



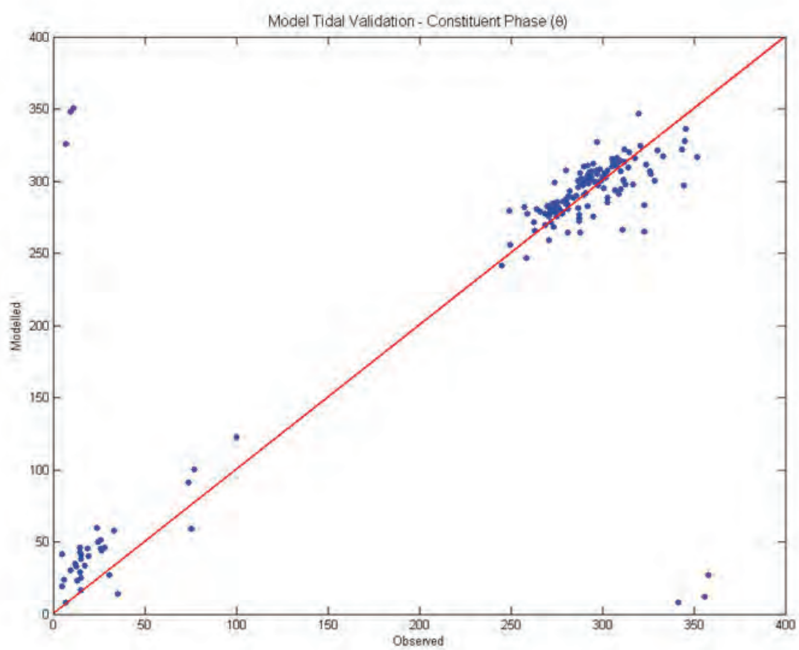




**Figure 2.5 Comparisons between modelled and observed tidal constituent amplitudes (top) and phases (bottom) at all stations in the HYDROMAP model domain. The red line indicates a 1:1 correlation between the modelled and observed data.**

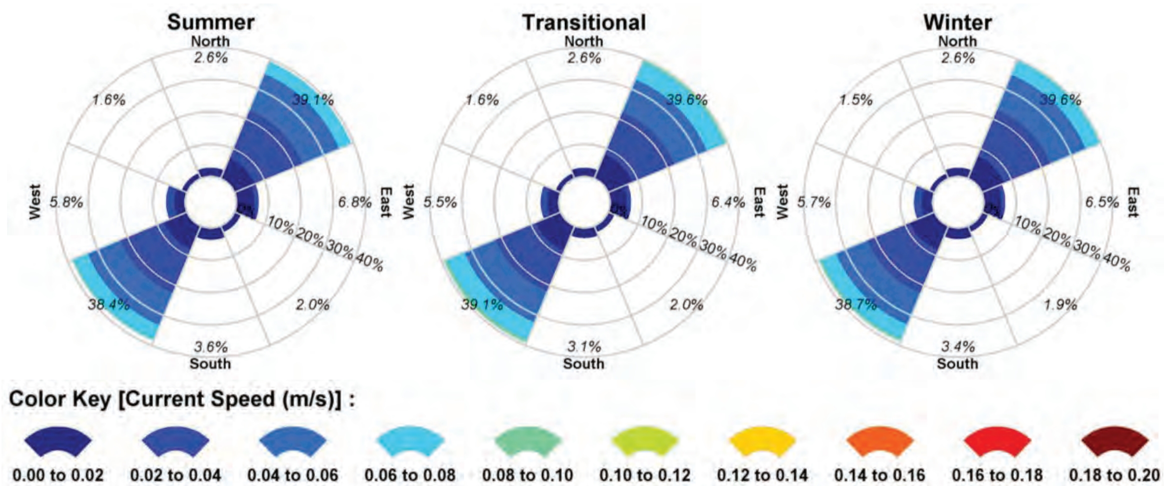



**Figure 2.6** **Seasonal current distribution (2006-2015, inclusive) derived from the HYDROMAP database near to the proposed FPU location. The colour key shows the current magnitude, the compass direction provides the direction towards which the current is flowing, and the size of the wedge gives the percentage of the record.**

# 3 MODELLING RESULTS

## 3.1 Near-Field Modelling

### 3.1.1 Overview

In the following sections, information for each of the modelled discharge cases is presented first in a table summarising the predicted plume characteristics in the near-field mixing zone under varying current speeds, and then in further tables summarising the concentrations of TPH at the end of the near-field mixing zone, the concentration threshold, and the amount of dilution for each season and for the annual period. 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 3.12 (note the differing x-axis and y-axis aspect ratios) show the change in average dilution and temperature of the plume under varying discharge depths (0 m, 10 m and 30 m), seasonal conditions (summer, transitional, winter and annual) 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).

In each figure, the plots have been arranged to demonstrate the variation in predicted outcomes for the same discharge at different depths under identical current conditions.

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 0 m, 10 m and 30 m below the water surface (Cases P1, P2 and P3, respectively). The surface discharges are shown to increase the extent of the turbulent mixing zone. Following this initial mixing, the near neutrally-buoyant plumes are predicted to travel laterally in the water column. For Case P1, the plume is predicted to plunge between 0.1 m and 4.4 m below the sea surface depending on season. For Cases P2 and P3, the plumes are predicted to remain at approximately the discharge depth: 9-11 m below the surface for Case P2 and 29-31 m below the surface for Case P3, depending on season. Increased ambient current strengths are shown to increase the horizontal distance travelled by the plume from the discharge point.

Table 3.1, Table 3.6 and Table 3.11 show the predicted plume characteristics for the varying discharge depths, seasonal conditions and current speeds. High annualised currents push the plume to maximum horizontal distances of 866 m and 123 m for the Case P1 and Case P3 discharges, respectively.

The diameter of the plume at the end of the near-field zone ranged from 0.4 m to 3.7 m for Case P1, 0.5 m to 1.8 m for Case P2 and 0.6 m to 1.7 m for Case P3. Increases in current speed serve to restrict the diameter of the plume.

For most combinations of season and discharge depth, 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, Table 3.6 and Table 3.11). The average dilution levels of the plume upon reaching the trapping depth under medium and strong currents are predicted to be 1:1,519 and 1:3,616 for Case P1, 1:88 and 1:140 for Case P2, and 1:43 and 1:181 for Case P3, 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 1:390 and 1:929 for Case P1, 1:22 and 1:36 for Case P2, and 1:11 and 1:46 for Case P3. 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 Case P1 (Section 3.1.2; Table 3.2 to Table 3.5), Case P2 (Section 3.1.2.2; Table 3.7 to Table 3.10) and Case P3 (Section 3.1.2.3; Table 3.12 to Table 3.15) discharges indicate that the TPH constituent of the PW discharge is not expected to reach the required levels of dilution in the near field mixing zone.

## 3.1.2 Results – Tables

### 3.1.2.1 Discharge Case P1: Flow Rate of 95 $m^3$/day at 0 m Depth (Surface)

**Table 3.1 Predicted plume characteristics at the end of the near-field mixing zone for the 0 m depth (surface) discharge for each season and current speed.**

| Season | Surface Current Speed (m/s) | Plume Diameter (m) at Depth [m] | Plume Temperature (°C) | Plume-Ambient Temperature Difference (°C) | Plume Dilution (1:x) | | Maximum Horizontal Distance (m) |
|---|---|---|---|---|---|---|---|
| | | | | | Minimum | Average | |
| Summer | Weak (0.04) | 3.5 [2.7] | 27.83 | 0.03 | 91 | 351 | 16.8 |
| | Medium (0.16) | 3.4 [2.6] | 27.81 | 0.01 | 339 | 1,321 | 124.1 |
| | Strong (0.33) | 3.5 [2.6] | 27.80 | 0.00 | 725 | 2,821 | 376.9 |
| Transitional | Weak (0.05) | 0.3 [0.2] | 32.84 | 6.84 | 1 | 2 | 0.9 |
| | Medium (0.18) | 0.4 [0.2] | 26.91 | 0.91 | 4 | 15 | 4.2 |
| | Strong (0.38) | 0.3 [0.2] | 26.47 | 0.47 | 7 | 30 | 7.9 |
| Winter | Weak (0.04) | 0.4 [0.2] | 31.03 | 4.63 | 1 | 3 | 0.4 |
| | Medium (0.17) | 3.6 [2.6] | 26.41 | 0.01 | 412 | 1,601 | 325.7 |
| | Strong (0.40) | 0.4 [0.2] | 26.74 | 0.34 | 10 | 40 | 11.8 |
| Annual | Weak (0.04) | 0.4 [0.2] | 29.83 | 3.23 | 1 | 4 | 0.8 |
| | Medium (0.17) | 3.5 [2.6] | 26.61 | 0.01 | 390 | 1,519 | 255.0 |
| | Strong (0.37) | 3.7 [2.6] | 26.60 | 0.00 | 929 | 3,613 | 866.3 |

**Table 3.2 Concentration of TPH at the end of the near-field stage, and the required concentration threshold 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 351, 1,321 and 2,821, respectively. Dilution rates highlighted in red indicate that suitable dilution is not achieved during the near-field stage.**

| Contaminant | Source Concentration (mg/L) | End of Near-Field Concentration (mg/L) | | | Threshold Concentration (mg/L) | Required Dilution Factor |
|---|---|---|---|---|---|---|
| | | 5th %ile | 50th %ile | 95th %ile | | |
| | | 351x Dilution | 1,321x Dilution | 2,821x Dilution | | |
| TPH | 29 | $8.3*10^{-2}$ | $2.2*10^{-2}$ | $1.0*10^{-2}$ | 0.07 | 414.3 |

**Table 3.3 Concentration of TPH at the end of the near-field stage, and the required concentration threshold 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 2, 15 and 30, respectively. Dilution rates highlighted in red indicate that suitable dilution is not achieved during the near-field stage.**

| Contaminant | Source Concentration (mg/L) | End of Near-Field Concentration (mg/L) | | | Threshold Concentration (mg/L) | Required Dilution Factor |
|---|---|---|---|---|---|---|
| | | 5th %ile | 50th %ile | 95th %ile | | |
| | | 2x Dilution | 15x Dilution | 30x Dilution | | |
| TPH | 29 | 14.5 | 1.9 | $9.7 \times 10^{-1}$ | 0.07 | 414.3 |

**Table 3.4 Concentration of TPH at the end of the near-field stage, and the required concentration threshold 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 3, 1,601 and 40, respectively. Dilution rates highlighted in red indicate that suitable dilution is not achieved during the near-field stage.**

| Contaminant | Source Concentration (mg/L) | End of Near-Field Concentration (mg/L) | | | Threshold Concentration (mg/L) | Required Dilution Factor |
|---|---|---|---|---|---|---|
| | | 5th %ile | 50th %ile | 95th %ile | | |
| | | 3x Dilution | 1,601x Dilution | 40x Dilution | | |
| TPH | 29 | 9.7 | $1.8 \times 10^{-2}$ | $7.2 \times 10^{-1}$ | 0.07 | 414.3 |

**Table 3.5 Concentration of TPH at the end of the near-field stage, and the required concentration threshold and number of dilutions for the annual period. Note from Table 3.1 that dilutions at the 5th, 50th and 95th percentile current speeds were 4, 1,519 and 3,613, respectively. Dilution rates highlighted in red indicate that suitable dilution is not achieved during the near-field stage.**

| Contaminant | Source Concentration (mg/L) | End of Near-Field Concentration (mg/L) | | | Threshold Concentration (mg/L) | Required Dilution Factor |
|---|---|---|---|---|---|---|
| | | 5th %ile | 50th %ile | 95th %ile | | |
| | | 4x Dilution | 1,519x Dilution | 3,613x Dilution | | |
| TPH | 29 | 7.3 | $1.9 \times 10^{-2}$ | $8.0 \times 10^{-3}$ | 0.07 | 414.3 |

#### 3.1.2.2 Discharge Case P2: Flow Rate of 95 m$^3$/day at 10 m Depth

**Table 3.6 Predicted plume characteristics at the end of the near-field mixing zone for the 10 m depth discharge for each season and current speed.**

| Season | Surface Current Speed (m/s) | Plume Diameter (m) at Depth [m] | Plume Temperature (°C) | Plume-Ambient Temperature Difference (°C) | Plume Dilution (1:x) | | Maximum Horizontal Distance (m) |
|---|---|---|---|---|---|---|---|
| | | | | | Minimum | Average | |
| Summer | Weak (0.04) | 1.8 [11.3] | 27.73 | 0.14 | 25 | 99 | 7.5 |
| | Medium (0.16) | 1.2 [10.8] | 27.69 | 0.09 | 42 | 163 | 28.4 |
| | Strong (0.33) | 1.0 [10.5] | 27.67 | 0.06 | 56 | 220 | 58.1 |
| Transitional | Weak (0.05) | 1.0 [9.5] | 26.28 | 0.43 | 8 | 32 | 4.2 |
| | Medium (0.18) | 0.7 [9.9] | 26.07 | 0.23 | 16 | 61 | 27.2 |
| | Strong (0.38) | 0.7 [10.0] | 25.93 | 0.10 | 36 | 141 | 83.2 |
| Winter | Weak (0.04) | 0.7 [9.8] | 27.36 | 0.12 | 3 | 12 | 1.8 |
| | Medium (0.17) | 0.8 [10.3] | 26.41 | 0.18 | 19 | 76 | 41.3 |
| | Strong (0.40) | 0.7 [10.2] | 26.34 | 0.11 | 32 | 127 | 67.1 |
| Annual | Weak (0.04) | 0.5 [10.0] | 28.17 | 1.74 | 2 | 8 | 1.3 |
| | Medium (0.17) | 0.9 [10.4] | 26.58 | 0.16 | 22 | 88 | 35.5 |
| | Strong (0.37) | 0.7 [10.2] | 26.52 | 0.09 | 36 | 140 | 67.3 |

**Table 3.7 Concentration of TPH at the end of the near-field stage, and the required concentration threshold and number of dilutions for the summer season. Note from Table 3.6 that dilutions at the 5th, 50th and 95th percentile current speeds were 99, 163 and 220, respectively. Dilution rates highlighted in red indicate that suitable dilution is not achieved during the near-field stage.**

| Contaminant | Source Concentration (mg/L) | End of Near-Field Concentration (mg/L) | | | Threshold Concentration (mg/L) | Required Dilution Factor |
|---|---|---|---|---|---|---|
| | | 5th %ile | 50th %ile | 95th %ile | | |
| | | 99x Dilution | 163x Dilution | 220x Dilution | | |
| TPH | 29 | $2.9*10^{-1}$ | $1.8*10^{-1}$ | $1.3*10^{-1}$ | 0.07 | 414.3 |

Table 3.8 Concentration of TPH at the end of the near-field stage, and the required concentration threshold and number of dilutions for the transitional season. Note from Table 3.6 that dilutions at the 5th, 50th and 95th percentile current speeds were 32, 61 and 141, respectively. Dilution rates highlighted in red indicate that suitable dilution is not achieved during the near-field stage.

| Contaminant | Source Concentration (mg/L) | End of Near-Field Concentration (mg/L) | | | Threshold Concentration (mg/L) | Required Dilution Factor |
|---|---|---|---|---|---|---|
| | | 5th %ile | 50th %ile | 95th %ile | | |
| | | 32x Dilution | 61x Dilution | 141x Dilution | | |
| TPH | 29 | $9.1*10^{-1}$ | $4.8*10^{-1}$ | $2.1*10^{-1}$ | 0.07 | 414.3 |

Table 3.9 Concentration of TPH at the end of the near-field stage, and the required concentration threshold and number of dilutions for the winter season. Note from Table 3.6 that dilutions at the 5th, 50th and 95th percentile current speeds were 12, 76 and 127, respectively. Dilution rates highlighted in red indicate that suitable dilution is not achieved during the near-field stage.

| Contaminant | Source Concentration (mg/L) | End of Near-Field Concentration (mg/L) | | | Threshold Concentration (mg/L) | Required Dilution Factor |
|---|---|---|---|---|---|---|
| | | 5th %ile | 50th %ile | 95th %ile | | |
| | | 12x Dilution | 76x Dilution | 127x Dilution | | |
| TPH | 29 | 2.4 | $3.8*10^{-1}$ | $2.3*10^{-1}$ | 0.07 | 414.3 |

Table 3.10 Concentration of TPH at the end of the near-field stage, and the required concentration threshold and number of dilutions for the annual period. Note from Table 3.6 that dilutions at the 5th, 50th and 95th percentile current speeds were 8, 88 and 140, respectively. Dilution rates highlighted in red indicate that suitable dilution is not achieved during the near-field stage.

| Contaminant | Source Concentration (mg/L) | End of Near-Field Concentration (mg/L) | | | Threshold Concentration (mg/L) | Required Dilution Factor |
|---|---|---|---|---|---|---|
| | | 5th %ile | 50th %ile | 95th %ile | | |
| | | 8x Dilution | 88x Dilution | 140x Dilution | | |
| TPH | 29 | 3.6 | $3.3*10^{-1}$ | $2.1*10^{-1}$ | 0.07 | 414.3 |

### 3.1.2.3 Discharge Case P3: Flow Rate of 95 m³/day at 30 m Depth

**Table 3.11 Predicted plume characteristics at the end of the near-field mixing zone for the 30 m depth discharge for each season and current speed.**

| Season | Surface Current Speed (m/s) | Plume Diameter (m) at Depth [m] | Plume Temperature (°C) | Plume-Ambient Temperature Difference (°C) | Plume Dilution (1:x) | | Maximum Horizontal Distance (m) |
|---|---|---|---|---|---|---|---|
| | | | | | Minimum | Average | |
| Summer | Weak (0.04) | 1.7 [31.1] | 27.29 | 0.17 | 20 | 79 | 7.9 |
| | Medium (0.16) | 1.1 [30.7] | 27.23 | 0.10 | 34 | 134 | 28.9 |
| | Strong (0.33) | 0.9 [30.5] | 27.21 | 0.08 | 48 | 186 | 58.5 |
| Transitional | Weak (0.05) | 1.4 [29.2] | 25.66 | 0.25 | 14 | 57 | 6.01 |
| | Medium (0.18) | 0.9 [29.7] | 25.55 | 0.15 | 25 | 99 | 30.3 |
| | Strong (0.38) | 0.8 [29.9] | 25.49 | 0.09 | 41 | 160 | 75.2 |
| Winter | Weak (0.04) | 1.1 [29.5] | 26.21 | 0.41 | 8 | 34 | 4.2 |
| | Medium (0.17) | 0.7 [29.9] | 26.01 | 0.22 | 16 | 62 | 25.5 |
| | Strong (0.40) | 0.7 [30.0] | 25.88 | 0.10 | 38 | 147 | 86.3 |
| Annual | Weak (0.04) | 0.9 [29.6] | 26.61 | 0.62 | 6 | 23 | 2.9 |
| | Medium (0.17) | 0.6 [30.0] | 26.31 | 0.33 | 11 | 43 | 19.8 |
| | Strong (0.37) | 0.8 [30.0] | 26.05 | 0.07 | 46 | 181 | 122.7 |

**Table 3.12 Concentration of TPH at the end of the near-field stage, and the required concentration threshold and number of dilutions for the summer season. Note from Table 3.11 that dilutions at the 5$^{th}$, 50$^{th}$ and 95$^{th}$ percentile current speeds were 79, 134 and 186, respectively. Dilution rates highlighted in red indicate that suitable dilution is not achieved during the near-field stage.**

| Contaminant | Source Concentration (mg/L) | End of Near-Field Concentration (mg/L) | | | Threshold Concentration (mg/L) | Required Dilution Factor |
|---|---|---|---|---|---|---|
| | | 5th %ile | 50th %ile | 95th %ile | | |
| | | 79x Dilution | 134x Dilution | 186x Dilution | | |
| TPH | 29 | $3.7*10^{-1}$ | $2.2*10^{-1}$ | $1.6*10^{-1}$ | 0.07 | 414.3 |

**Table 3.13 Concentration of TPH at the end of the near-field stage, and the required concentration threshold and number of dilutions for the transitional season. Note from Table 3.11 that dilutions at the 5th, 50th and 95th percentile current speeds were 57, 99 and 160, respectively. Dilution rates highlighted in red indicate that suitable dilution is not achieved during the near-field stage.**

| Contaminant | Source Concentration (mg/L) | End of Near-Field Concentration (mg/L) | | | Threshold Concentration (mg/L) | Required Dilution Factor |
|---|---|---|---|---|---|---|
| | | 5th %ile | 50th %ile | 95th %ile | | |
| | | 57x Dilution | 99x Dilution | 160x Dilution | | |
| TPH | 29 | $5.1*10^{-1}$ | $2.9*10^{-1}$ | $1.8*10^{-1}$ | 0.07 | 414.3 |

**Table 3.14 Concentration of TPH at the end of the near-field stage, and the required concentration threshold and number of dilutions for the winter season. Note from Table 3.11 that dilutions at the 5th, 50th and 95th percentile current speeds were 34, 62 and 147, respectively. Dilution rates highlighted in red indicate that suitable dilution is not achieved during the near-field stage.**

| Contaminant | Source Concentration (mg/L) | End of Near-Field Concentration (mg/L) | | | Threshold Concentration (mg/L) | Required Dilution Factor |
|---|---|---|---|---|---|---|
| | | 5th %ile | 50th %ile | 95th %ile | | |
| | | 34x Dilution | 62x Dilution | 147x Dilution | | |
| TPH | 29 | $8.5*10^{-1}$ | $4.7*10^{-1}$ | $2.0*10^{-1}$ | 0.07 | 414.3 |

**Table 3.15 Concentration of TPH at the end of the near-field stage, and the required concentration threshold and number of dilutions for the annual period. Note from Table 3.11 that dilutions at the 5th, 50th and 95th percentile current speeds were 23, 43 and 181, respectively. Dilution rates highlighted in red indicate that suitable dilution is not achieved during the near-field stage.**

| Contaminant | Source Concentration (mg/L) | End of Near-Field Concentration (mg/L) | | | Threshold Concentration (mg/L) | Required Dilution Factor |
|---|---|---|---|---|---|---|
| | | 5th %ile | 50th %ile | 95th %ile | | |
| | | 23x Dilution | 43x Dilution | 181x Dilution | | |
| TPH | 29 | 1.3 | $6.7*10^{-1}$ | $1.6*10^{-1}$ | 0.07 | 414.3 |

### 3.1.3 Results – Figures

### 3.1.3.1 Flow Rate of 95 m³/day at Varying Depths

#### 3.1.3.1.1 Annualised

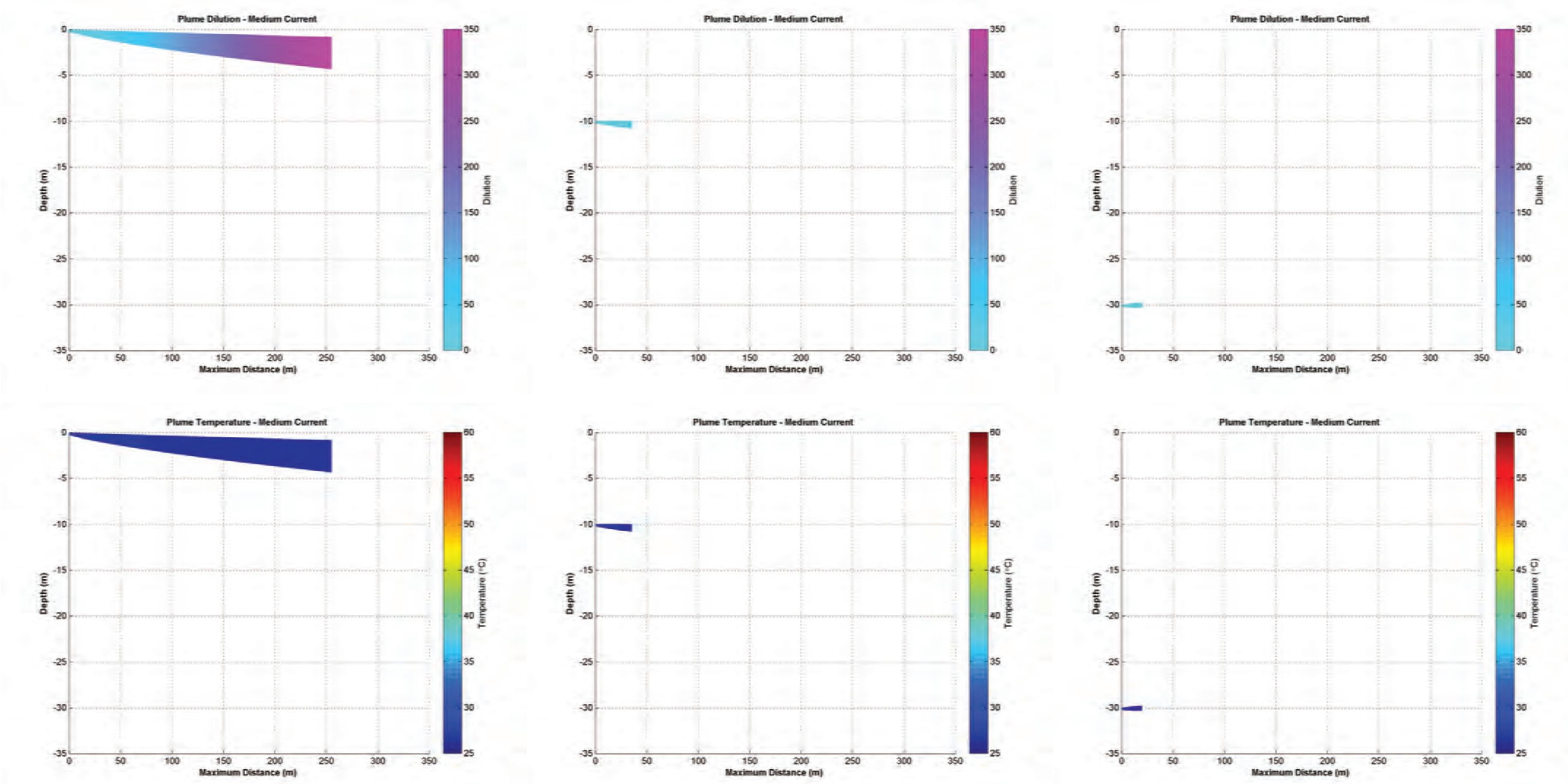



**Figure 3.1** Near-field average dilution and temperature results for constant medium annualised currents with a discharge flow rate of 95 $m^3$/d at discharge depths of 0 m (Case P1; left column), 10 m (Case P2; middle column) and 30 m (Case P3; right column).

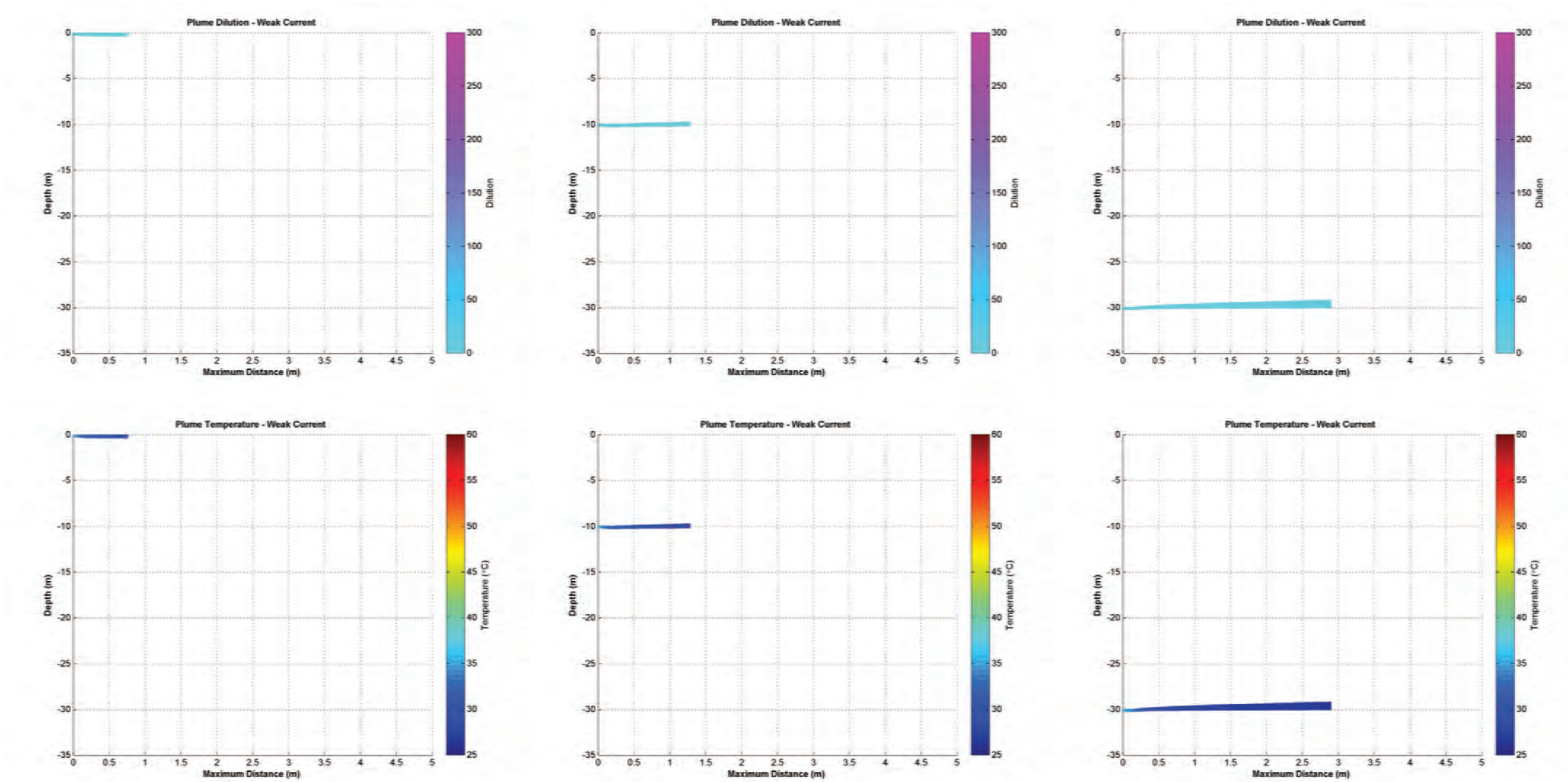



**Figure 3.2 Near-field average dilution and temperature results for constant weak annualised currents with a discharge flow rate of 95 $m^3$/d at discharge depths of 0 m (Case P1; left column), 10 m (Case P2; middle column) and 30 m (Case P3; right column).**

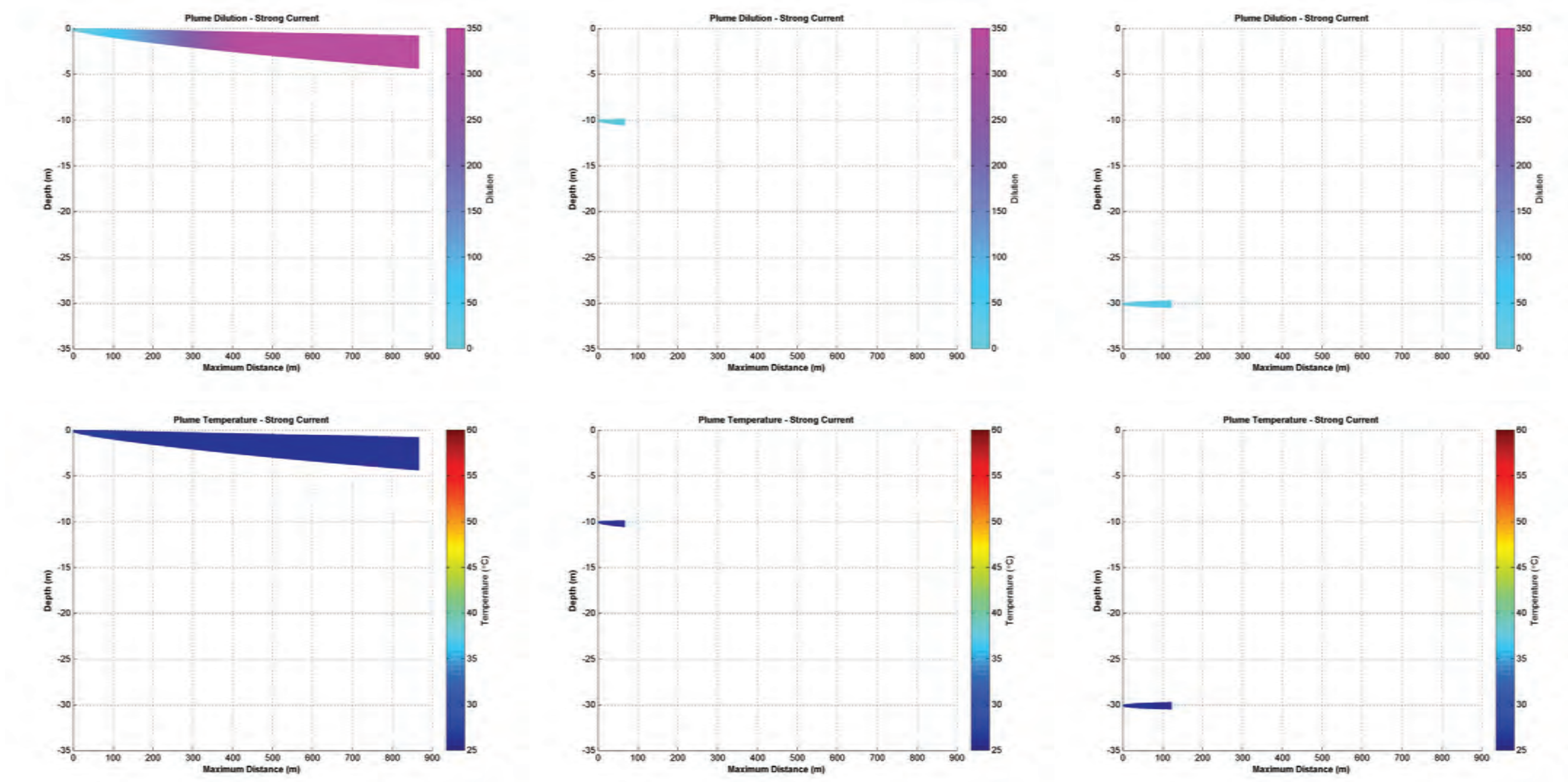



Figure 3.3 Near-field average dilution and temperature results for constant strong annualised currents with a discharge flow rate of 95 $m^3/d$ at discharge depths of 0 m (Case P1; left column), 10 m (Case P2; middle column) and 30 m (Case P3; right column).

#### 3.1.3.1.2 Summer

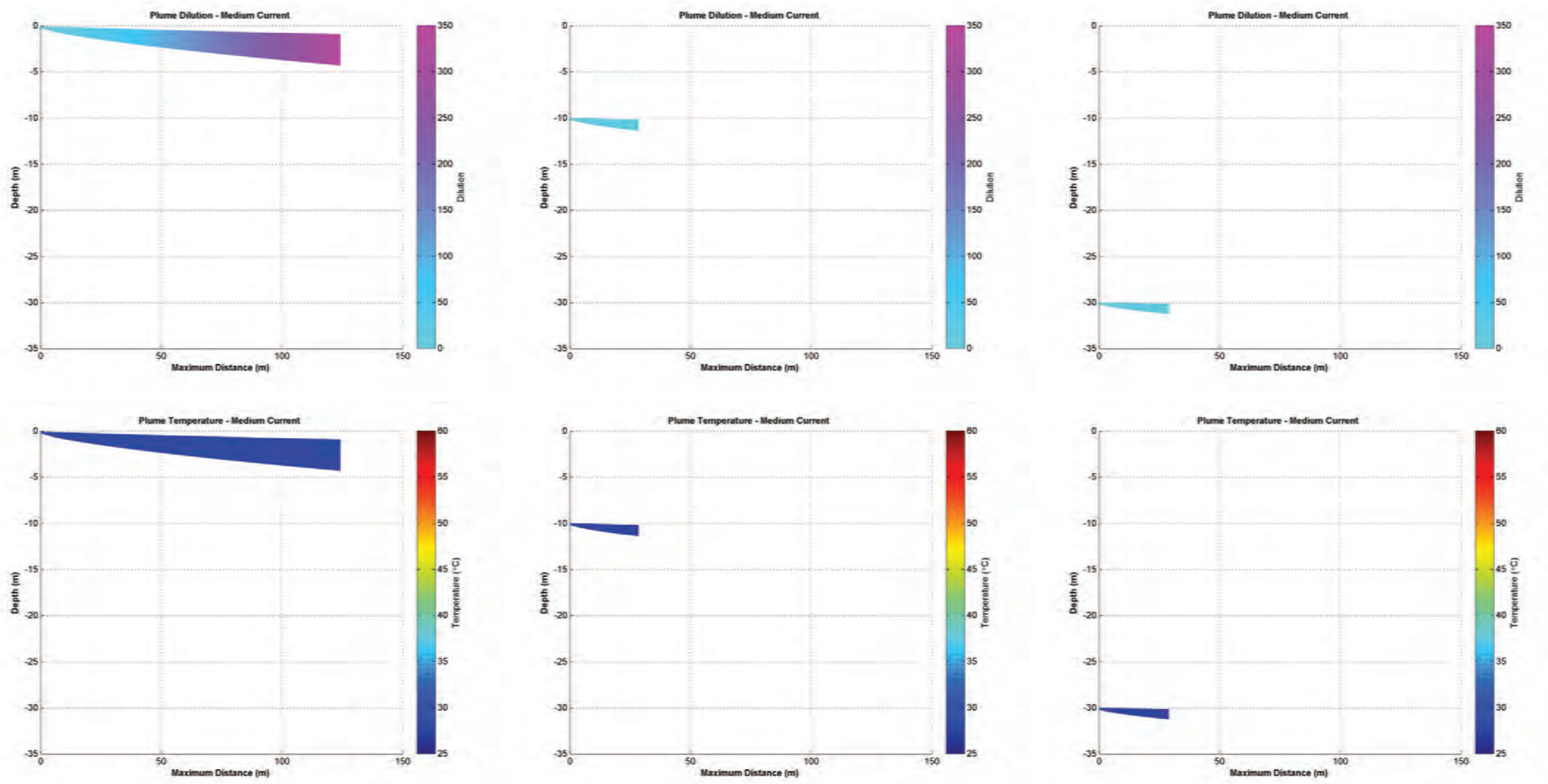



**Figure 3.4** **Near-field average dilution and temperature results for constant medium summer currents with a discharge flow rate of 95 $m^3$/d at discharge depths of 0 m (Case P1; left column), 10 m (Case P2; middle column) and 30 m (Case P3; right column).**

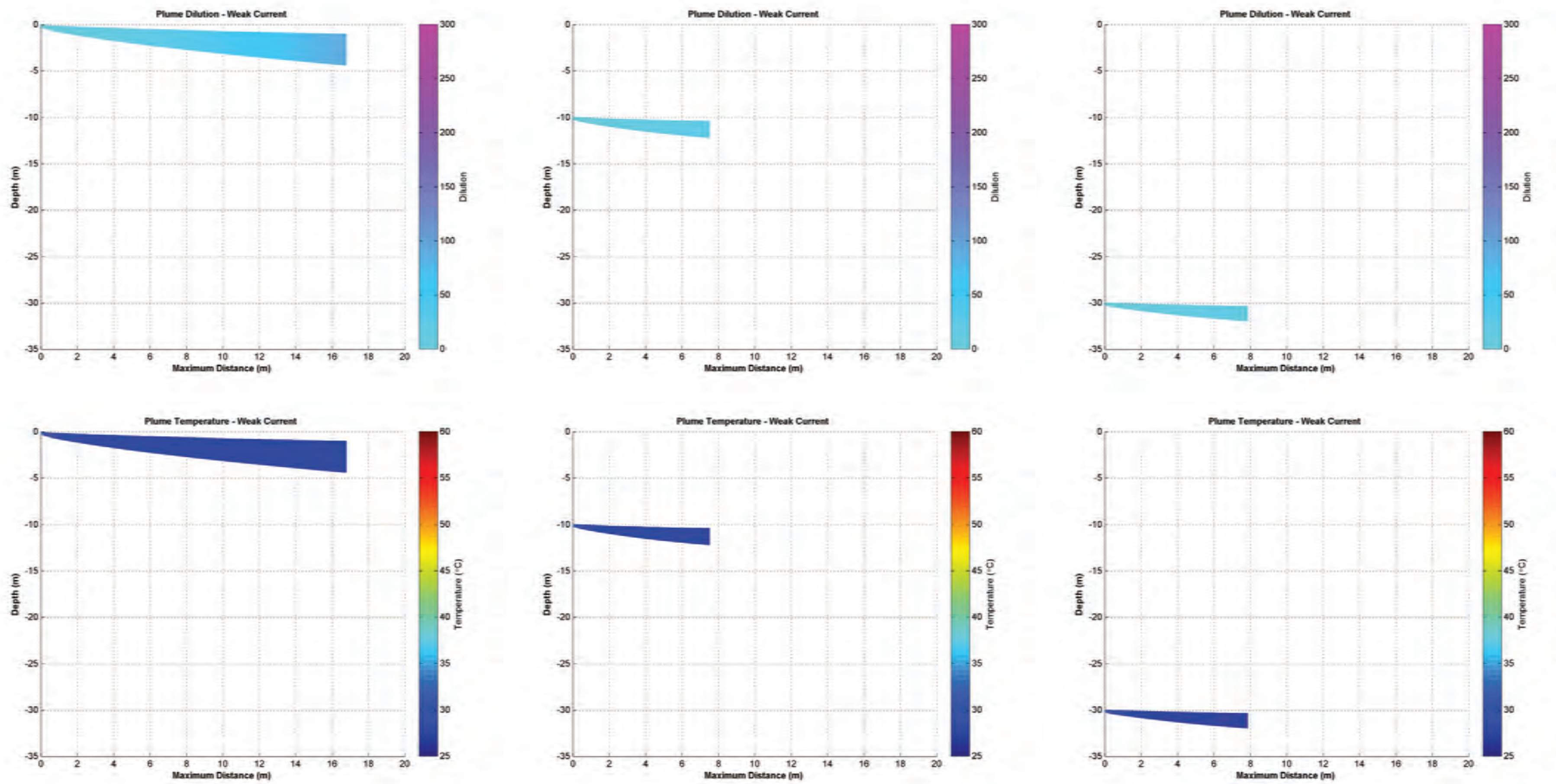



Figure 3.5 Near-field average dilution and temperature results for constant weak summer currents with a discharge flow rate of 95 m³/d at discharge depths of 0 m (Case P1; left column), 10 m (Case P2; middle column) and 30 m (Case P3; right column).

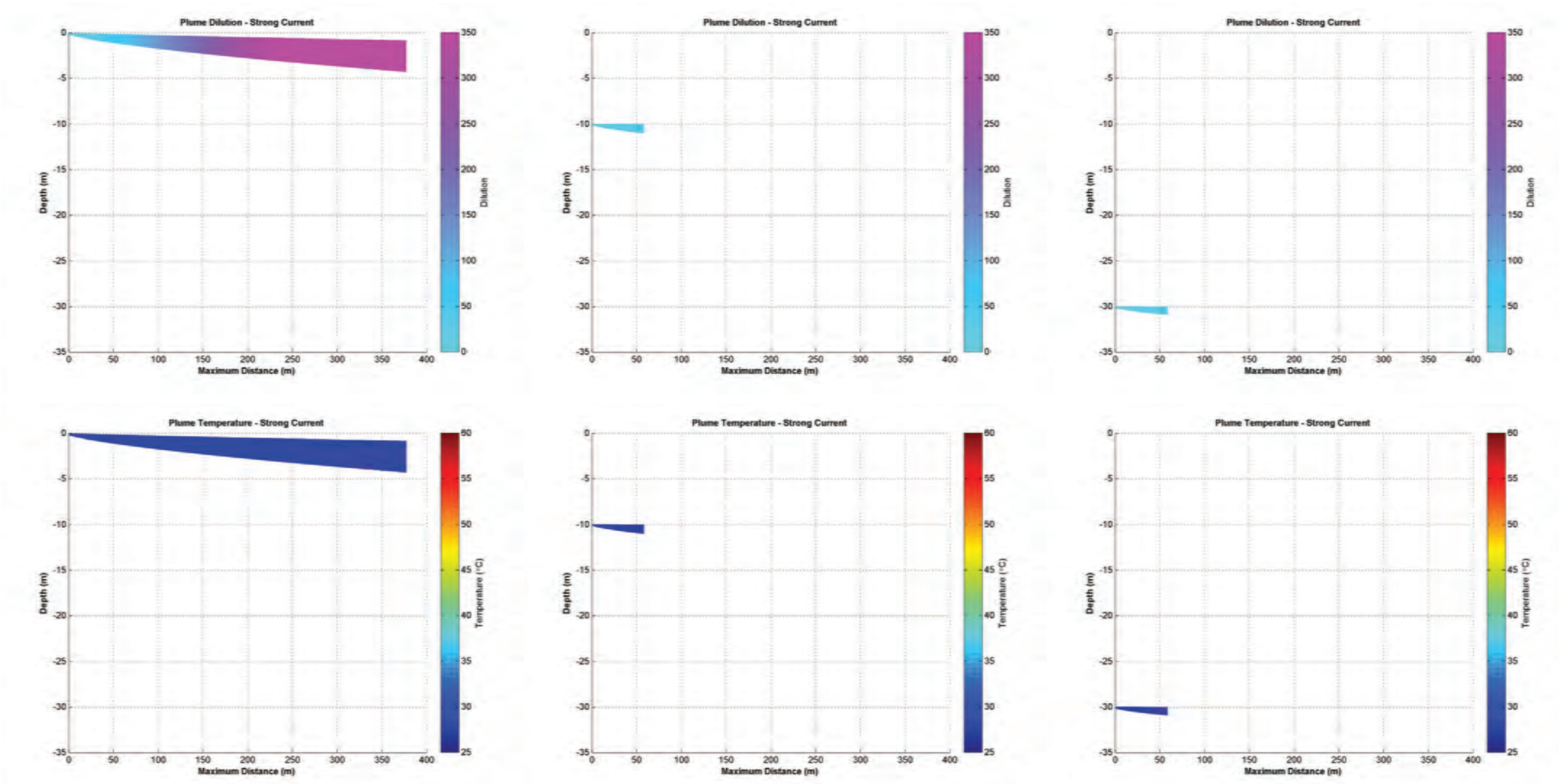



**Figure 3.6** **Near-field average dilution and temperature results for constant strong summer currents with a discharge flow rate of 95 $m^3/d$ at discharge depths of 0 m (Case P1; left column), 10 m (Case P2; middle column) and 30 m (Case P3; right column).**

### 3.1.3.1.3 Transitional

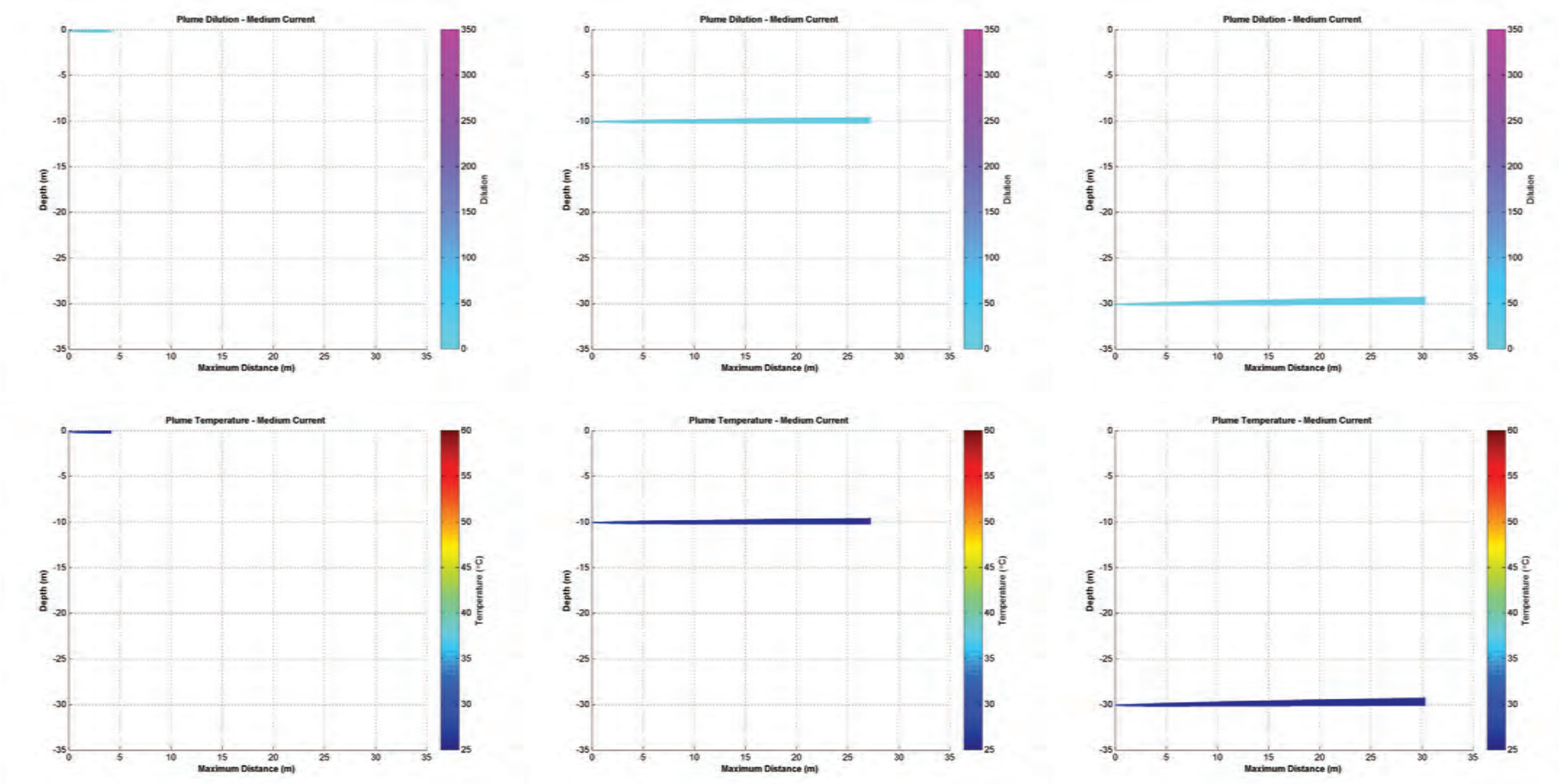



**Figure 3.7 Near-field average dilution and temperature results for constant medium transitional currents with a discharge flow rate of 95 m$^3$/d at discharge depths of 0 m (Case P1; left column), 10 m (Case P2; middle column) and 30 m (Case P3; right column).**

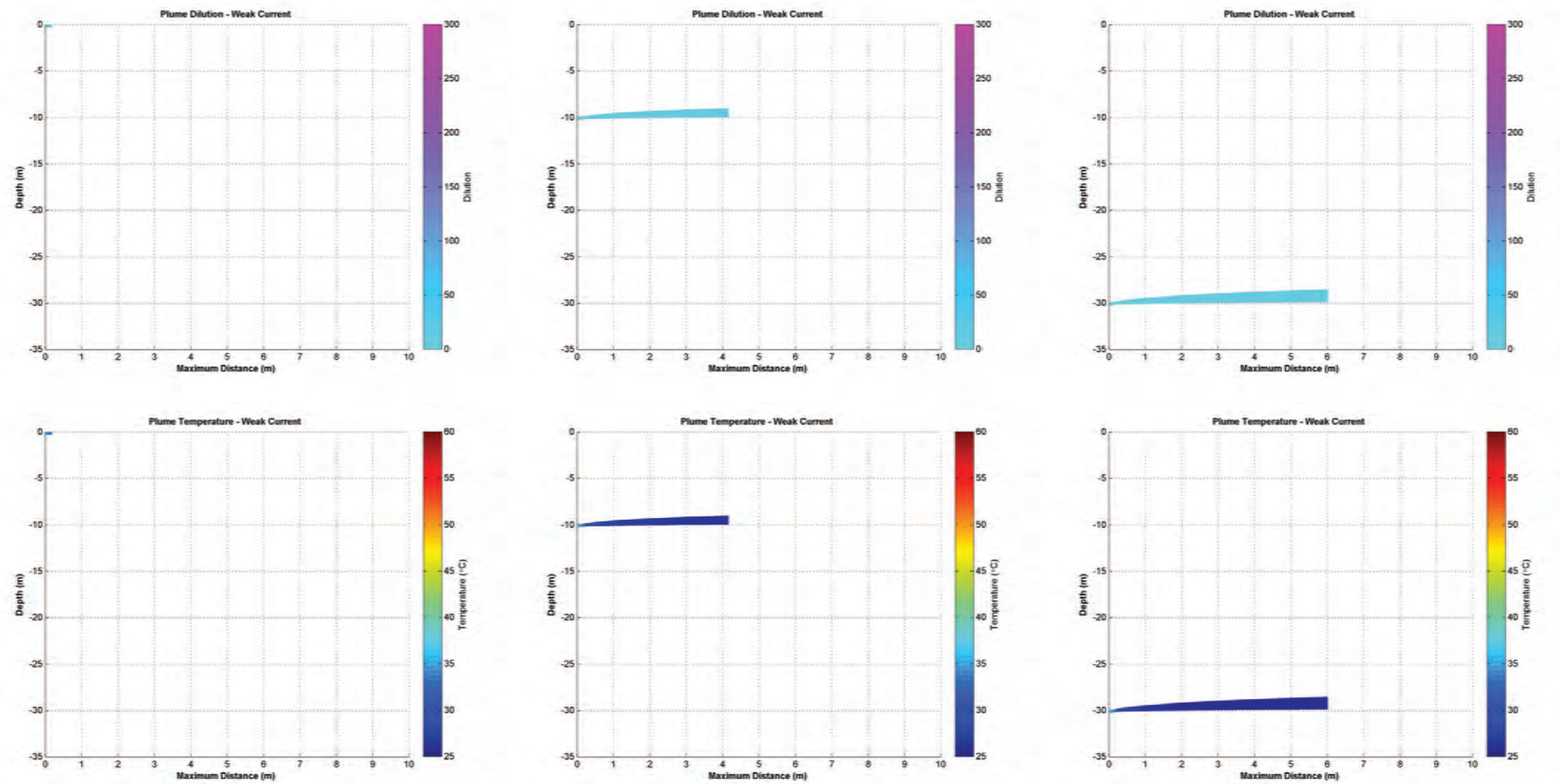



**Figure 3.8** Near-field average dilution and temperature results for constant weak transitional currents with a discharge flow rate of 95 $m^3/d$ at discharge depths of 0 m (Case P1; left column), 10 m (Case P2; middle column) and 30 m (Case P3; right column).

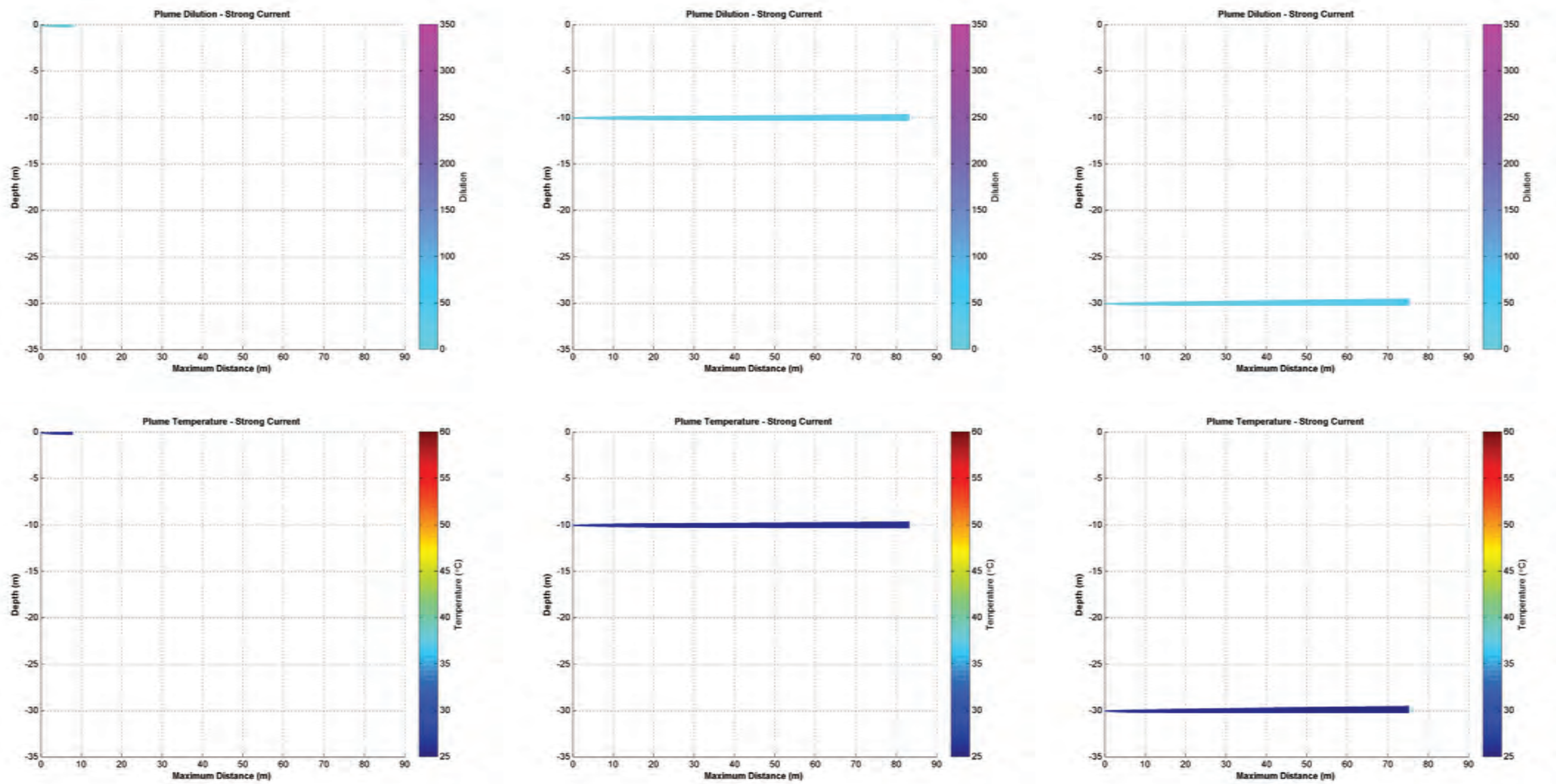



**Figure 3.9** Near-field average dilution and temperature results for constant strong transitional currents with a discharge flow rate of 95 $m^3/d$ at discharge depths of 0 m (Case P1; left column), 10 m (Case P2; middle column) and 30 m (Case P3; right column).

### 3.1.3.1.4 Winter

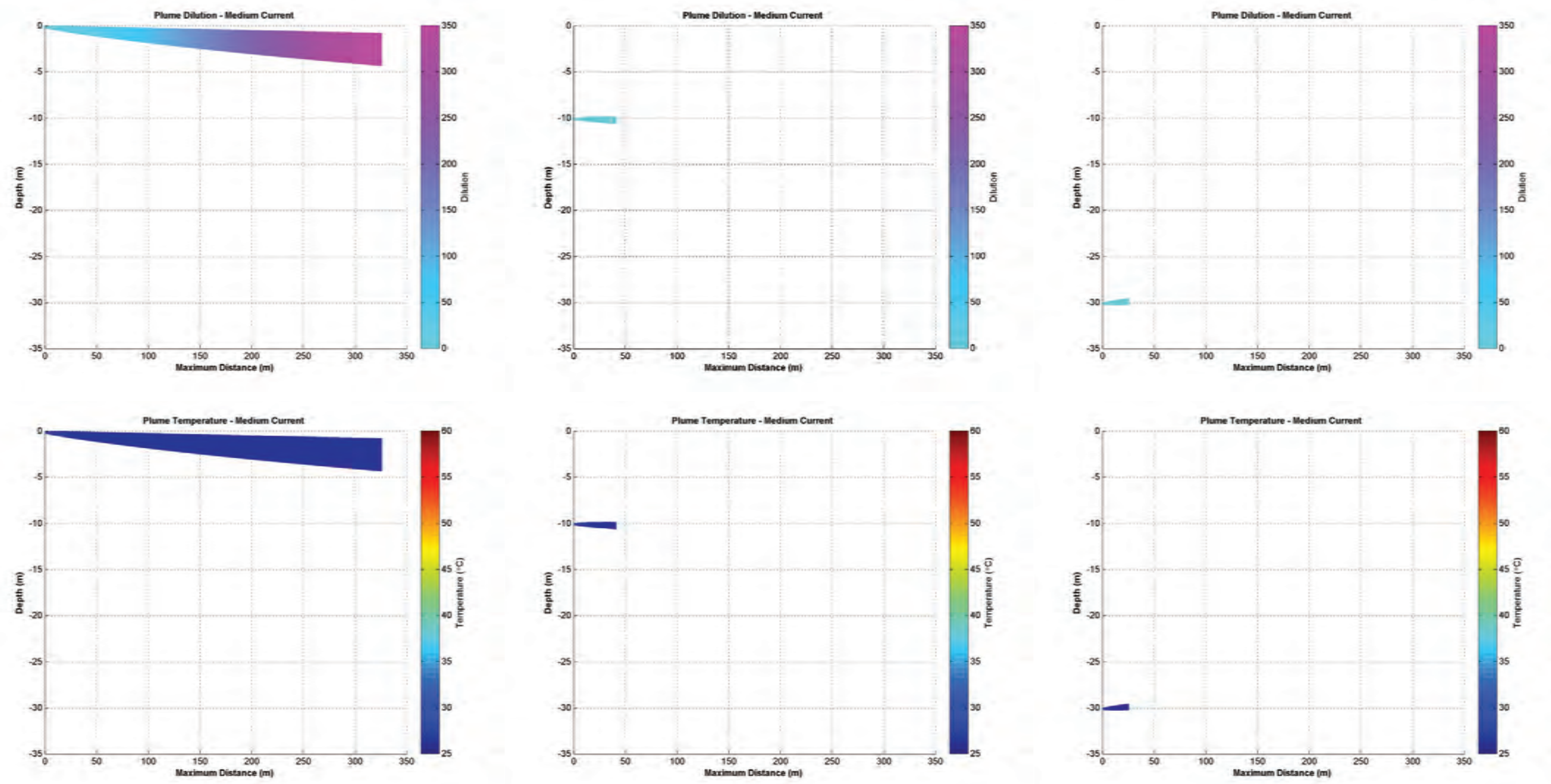



**Figure 3.10 Near-field average dilution and temperature results for constant medium winter currents with a discharge flow rate of 95 m³/d at discharge depths of 0 m (Case P1; left column), 10 m (Case P2; middle column) and 30 m (Case P3; right column).**

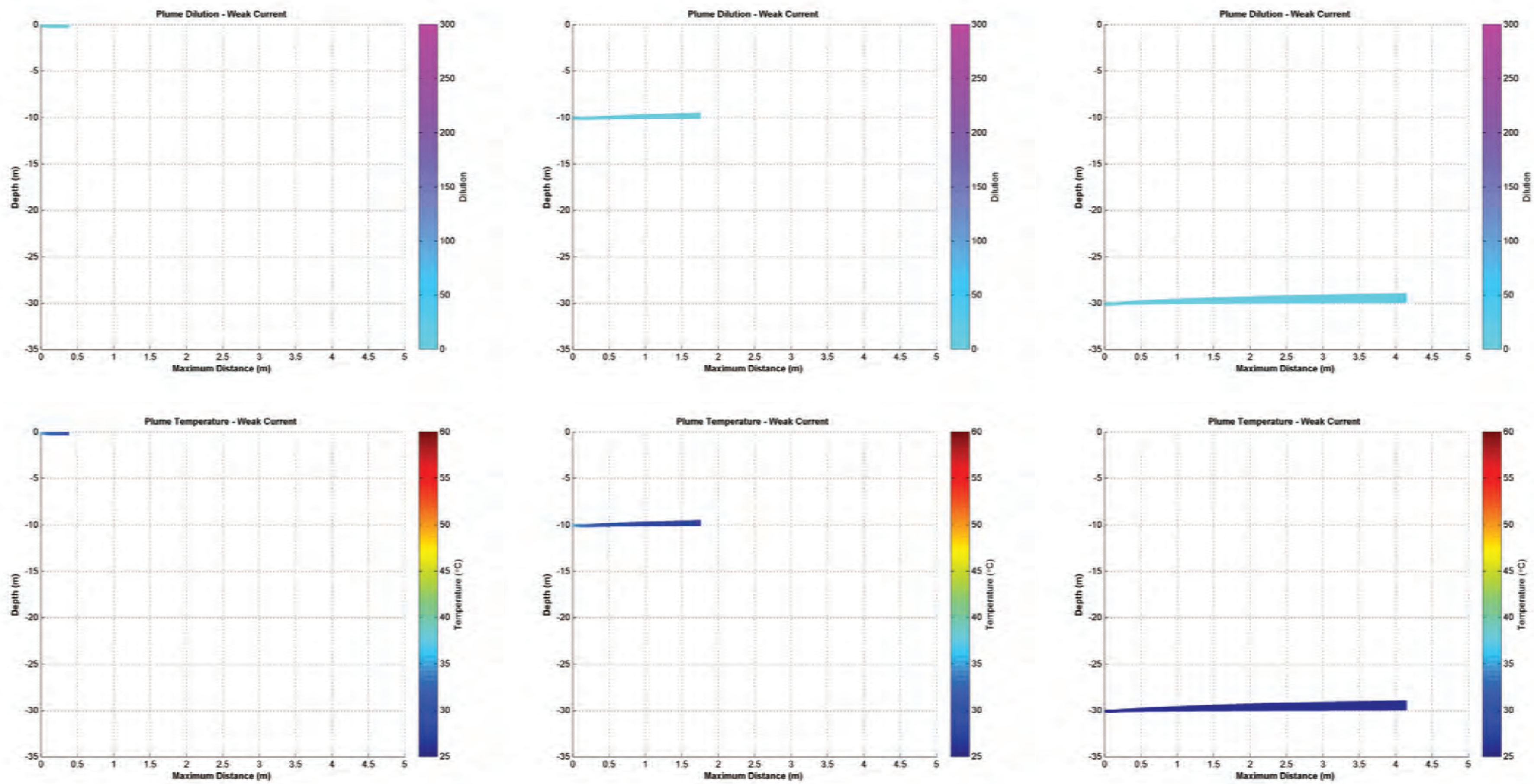



Figure 3.11 Near-field average dilution and temperature results for constant weak winter currents with a discharge flow rate of 95 m$^3$/d at discharge depths of 0 m (Case P1; left column), 10 m (Case P2; middle column) and 30 m (Case P3; right column).

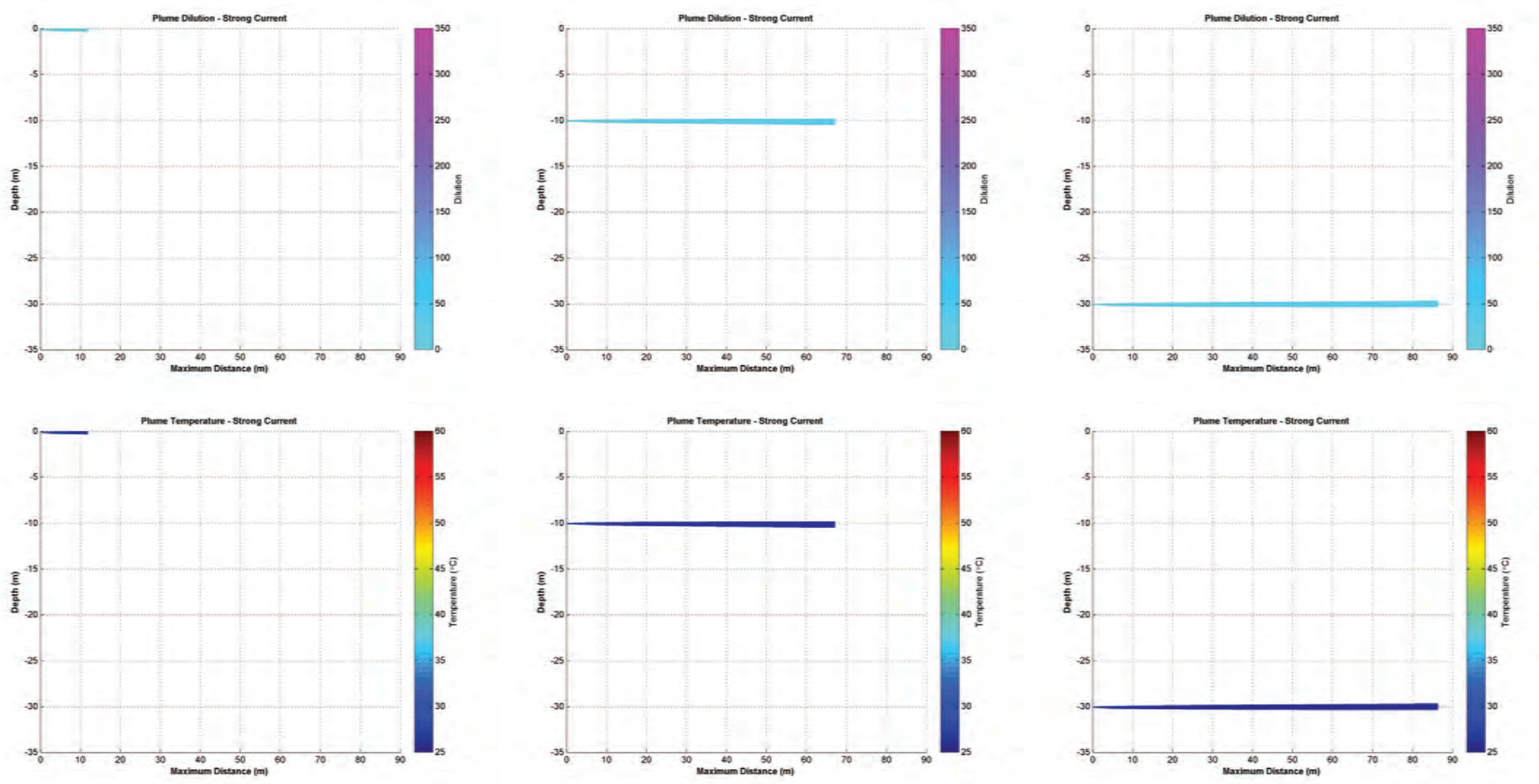



**Figure 3.12 Near-field average dilution and temperature results for constant strong winter currents with a discharge flow rate of 95 m³/d at discharge depths of 0 m (Case P1; left column), 10 m (Case P2; middle column) and 30 m (Case P3; right column).**

## 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 Interpretation of Percentile Dilution Contours

For each of the modelled discharge cases, the results for all simulations were combined and a statistical analysis performed to produce percentile contours of dilution. In the following sections, outcomes based on 95$^{th}$ and 99$^{th}$ percentile dilution contours are presented.

Calculation of 95$^{th}$ and 99$^{th}$ percentile statistics is a common approach to assessing the impact of dispersing plumes and captures the variability in outcomes, for all but the most ephemeral and extreme forcing conditions, in the data set under consideration. Impact assessment criteria for water quality are often defined using similar statistical indicators.

Note that the percentile figures do not represent the location of a plume at any point in time; they are a statistical and spatial summary of the percentage of time that particular dilution values occur across all replicate simulations and time steps. For example, if the 95$^{th}$ percentile minimum dilution at a particular location in the model domain is predicted as a value of 100, this means that for 95% of the time the dilution level will be higher than 100 and for only 5% of the time the dilution level will be lower than 100. A comparison of the plume extents shown in Figure 3.13 with those shown in Sections 3.2.4 and 3.2.5 demonstrates the significant difference between an instantaneous snapshot and a cumulative estimate of coverage over several days and many individual simulations.

Dilution contours are calculated from the ratios of dispersing contaminant concentrations in the receiving waters to the initial concentration of the contaminant in the discharge. Note that this assumes the background concentration of the constituent in the receiving waters is zero and there is no significant biodegradation of the discharged constituent over the short duration of the dispersion process.

Table 3.16 summarises the initial concentrations of TPH, as specified, and the equivalent dispersed concentrations required to yield particular dilution levels (1:100, 1:200 and 1:400). These concentrations may be useful to consider when interpreting the contour plots of percentile dilutions.

**Table 3.16 Initial concentrations of TPH and equivalent concentrations at example dilution levels.**

| TPH Parameter | TPH Concentration (mg/L) |
|---|---|
| Initial concentration in discharge | 29.0 |
| Initial concentration in receiving waters | 0.0 |
| Concentration at 1:100 dilution | 0.29 |
| Concentration at 1:200 dilution | 0.145 |
| Concentration at 1:400 dilution | 0.0725 |

### 3.2.3 General Observations

Figure 3.13 shows example time series snapshots of predicted dilutions during a single simulation at 3-hour intervals from 10:00 on 29th December 2008 to 01:00 on 30th December 2008. This simulation – selected merely to be representative of typical conditions – considers the Case P1 discharge at 0 m BMSL. 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.

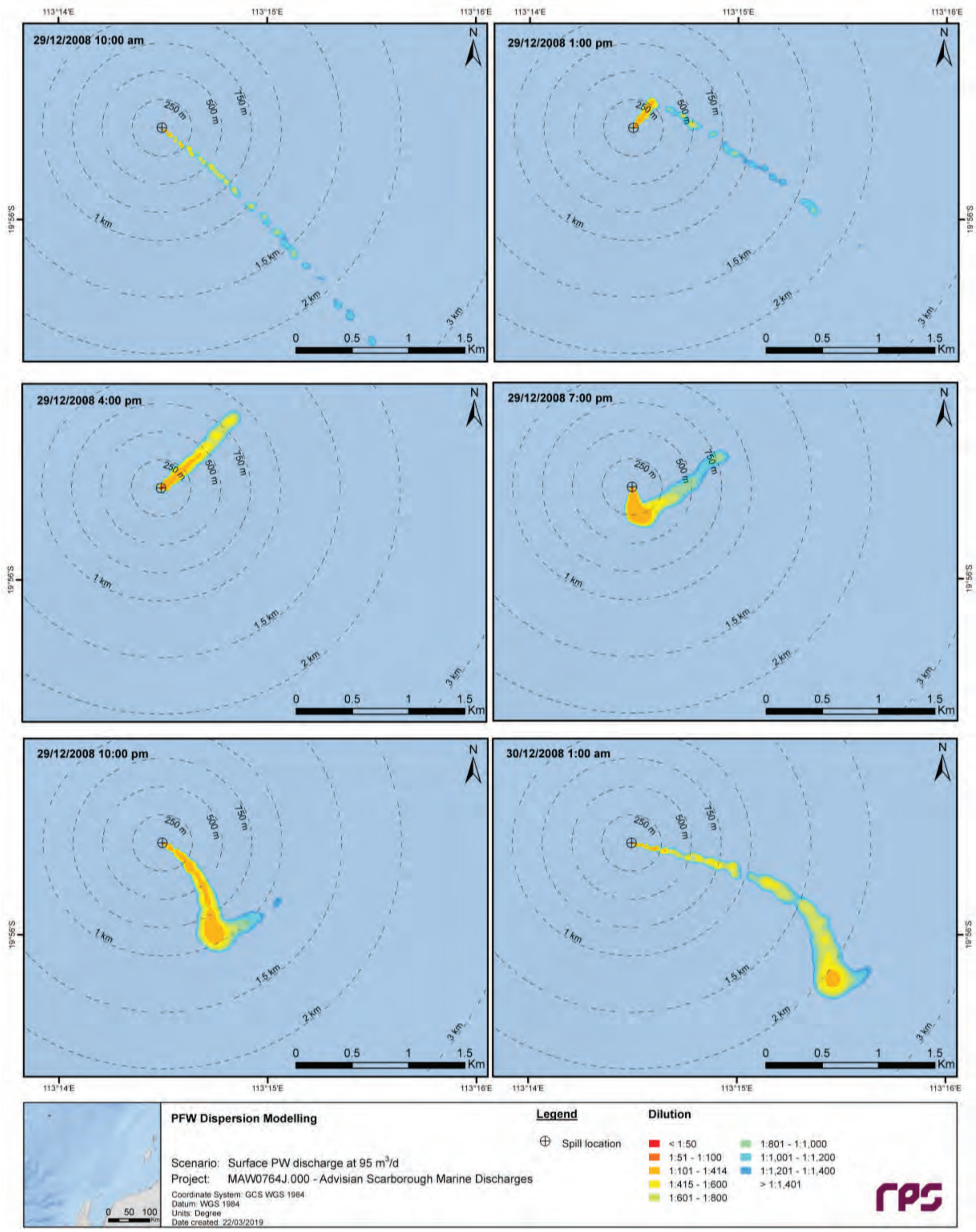



**Figure 3.13 Snapshots of predicted dilution levels, at 3-hour intervals from 10:00 on 29th December 2008 to 01:00 on 30th December 2008, for Case P1 (0 m depth discharge at 95 $m^3$/d flow rate).**

### 3.2.4 Seasonal Analysis

The model outputs over the ten-year hindcast period (2006-2015) were combined and analysed on a seasonal basis (summer, transitional and winter). This approach assists with identifying the potential exposure to surrounding sensitive receptors whilst considering inter-annual variability in ocean current conditions.

Table 3.17 and Table 3.18 summarise, for Cases P1 and P3 respectively, the minimum dilution achieved at specific radial distances from the discharge location for each season and percentile.

Table 3.19 and Table 3.20 provide, for Cases P1 and P3 respectively, summaries of the maximum distances from the discharge location to achieve 1:414 dilution for each season and percentile. The results indicate that the release of effluent under all seasonal conditions results in rapid dispersion within the ambient environment. For Case P1, dilution to reach threshold concentration is achieved for TPH within an area of influence ranging from 181 m to 221 m at the 95$^{th}$ percentile across all seasons (Table 3.19). For Case P3, the maximum spatial extents of the relevant dilution contour vary from 184 m to 229 m at the 95$^{th}$ percentile across all seasons (Table 3.20). The greatest spatial extents are observed in winter.

Table 3.21 and Table 3.22 provide, for Cases P1 and P3 respectively, summaries of the total area of coverage for the 1:414 dilution contour for each season and percentile. For Case P1, the area of exposure defined by the relevant dilution contour is predicted to reach maximums of 0.03 km$^2$ to 0.04 km$^2$ at the 95$^{th}$ percentile (Table 3.21). For Case P3, the corresponding maximum areas of exposure vary from 0.03 km$^2$ to 0.07 km$^2$ at the 95$^{th}$ percentile (Table 3.22).

Table 3.23 and Table 3.24 provide, for Cases P1 and P3 respectively, summaries of the maximum depths from the discharge location to achieve 1:414 dilution for each season and percentile. Maximum depths are observed in winter, with predictions of 5 m and 33 m for Case P1 and Case P3, respectively.

For Cases P1 and P3, Figure 3.14 to Figure 3.25 show the aggregated spatial extents of the minimum dilutions for each season and percentile. 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 3.17 Minimum dilution achieved at specific radial distances from the PW discharge location in each season for Case P1 (0 m depth discharge at 95 $m^3/d$ flow rate).

| Percentile | Season | Minimum dilution (1:x) achieved at specific radial distances from discharge location | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0.02 km | 0.05 km | 0.10 km | 0.20 km | 0.30 km | 0.40 km | 0.50 km | 0.60 km | 0.70 km | 0.80 km | 0.90 km | 1.00 km |
| 95th | Summer | 1:79.2 | 1:148.3 | 1:256.9 | 1:459.5 | 1:607.7 | 1:793.0 | 1:884.7 | 1:1,050.1 | 1:1,309.4 | 1:1,386.7 | 1:1,789.6 | 1:1,904.4 |
| | Transitional | 1:79.3 | 1:145.4 | 1:242.6 | 1:414.6 | 1:600.5 | 1:790.5 | 1:1,004.8 | 1:1,221.4 | 1:1,429.3 | 1:1,606.9 | 1:1,931.5 | 1:2,150.9 |
| | Winter | 1:73.4 | 1:149.4 | 1:232.7 | 1:394.5 | 1:512.1 | 1:646.6 | 1:767.1 | 1:973.7 | 1:1,094.8 | 1:1,287.1 | 1:1,442.2 | 1:1,606.2 |
| 99th | Summer | 1:46.6 | 1:87.6 | 1:146.5 | 1:239.4 | 1:310.1 | 1:389.3 | 1:452.1 | 1:532.2 | 1:604.6 | 1:662.5 | 1:752.2 | 1:829.3 |
| | Transitional | 1:47.6 | 1:86.4 | 1:144.5 | 1:226.1 | 1:286.1 | 1:366.0 | 1:436.0 | 1:509.9 | 1:587.9 | 1:646.4 | 1:716.0 | 1:760.1 |
| | Winter | 1:64.9 | 1:107.2 | 1:187.5 | 1:317.0 | 1:381.7 | 1:522.9 | 1:550.6 | 1:643.5 | 1:785.5 | 1:837.8 | 1:912.2 | 1:1,033.8 |

Table 3.18 Minimum dilution achieved at specific radial distances from the PW discharge location in each season for Case P3 (30 m depth discharge at 95 $m^3/d$ flow rate).

| Percentile | Season | Minimum dilution (1:x) achieved at specific radial distances from discharge location | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0.02 km | 0.05 km | 0.10 km | 0.20 km | 0.30 km | 0.40 km | 0.50 km | 0.60 km | 0.70 km | 0.80 km | 0.90 km | 1.00 km |
| 95th | Summer | 1:67.8 | 1:142.2 | 1:246.1 | 1:426.6 | 1:592.1 | 1:778.0 | 1:930.0 | 1:1,123.1 | 1:1,219.0 | 1:1,411.4 | 1:1,537.3 | 1:1,665.0 |
| | Transitional | 1:69.1 | 1:135.2 | 1:252.9 | 1:447.6 | 1:611.5 | 1:808.7 | 1:949.0 | 1:1,099.4 | 1:1,281.0 | 1:1,443.8 | 1:1,622.0 | 1:1,729.4 |
| | Winter | 1:57.3 | 1:133.4 | 1:226.5 | 1:385.0 | 1:513.3 | 1:681.2 | 1:825.9 | 1:1,002.6 | 1:1,227.7 | 1:1,445.2 | 1:1,534.8 | 1:1,860.0 |
| 99th | Summer | 1:42.9 | 1:87.7 | 1:142.0 | 1:225.8 | 1:297.3 | 1:361.4 | 1:431.9 | 1:479.0 | 1:521.9 | 1:578.4 | 1:598.9 | 1:666.9 |
| | Transitional | 1:43.7 | 1:83.5 | 1:143.1 | 1:236.6 | 1:302.9 | 1:375.4 | 1:434.6 | 1:517.9 | 1:552.4 | 1:605.8 | 1:665.7 | 1:687.6 |
| | Winter | 1:37.6 | 1:76.2 | 1:123.5 | 1:187.5 | 1:232.9 | 1:272.0 | 1:277.7 | 1:307.6 | 1:381.1 | 1:408.7 | 1:474.9 | 1:496.6 |

**Table 3.19 Maximum distance from the PW discharge location to achieve 1:414.3 dilution in each season for Case P1 (0 m depth discharge at 95 $m^3$/d flow rate).**

| Percentile | Season | Maximum distance (m) from discharge location to achieve given dilution |
|---|---|---|
| 95th | Summer | 181 |
| | Transitional | 194 |
| | Winter | 221 |
| 99th | Summer | 426 |
| | Transitional | 452 |
| | Winter | 543 |
| 100th | Summer | 2,190 |
| | Transitional | 3,231 |
| | Winter | 3,005 |

**Table 3.20 Maximum distance from the PW discharge location to achieve 1:414.3 dilution in each season for Case P3 (30 m depth discharge at 95 $m^3$/d flow rate).**

| Percentile | Season | Maximum distance (m) from discharge location to achieve given dilution |
|---|---|---|
| 95th | Summer | 191 |
| | Transitional | 184 |
| | Winter | 229 |
| 99th | Summer | 482 |
| | Transitional | 432 |
| | Winter | 810 |
| 100th | Summer | 3,244 |
| | Transitional | 3,244 |
| | Winter | 3,406 |

**Table 3.21 Total area of coverage for 1:414.3 dilution in each season for Case P1 (0 m depth discharge at 95 $m^3/d$ flow rate).**

| Percentile | Season | Total area ($km^2$) of coverage for given dilution |
|---|---|---|
| 95th | Summer | 0.033 |
| | Transitional | 0.034 |
| | Winter | 0.042 |
| 99th | Summer | 0.301 |
| | Transitional | 0.340 |
| | Winter | 0.419 |
| 100th | Summer | 1.973 |
| | Transitional | 2.266 |
| | Winter | 3.313 |

**Table 3.22 Total area of coverage for 1:414.3 dilution in each season for Case P3 (30 m depth discharge at 95 $m^3/d$ flow rate).**

| Percentile | Season | Total area ($km^2$) of coverage for given dilution |
|---|---|---|
| 95th | Summer | 0.046 |
| | Transitional | 0.034 |
| | Winter | 0.065 |
| 99th | Summer | 0.370 |
| | Transitional | 0.348 |
| | Winter | 0.623 |
| 100th | Summer | 4.673 |
| | Transitional | 5.204 |
| | Winter | 3.406 |

**Table 3.23 Maximum depth from the PW discharge location to achieve 1:414.3 dilution in each season for Case P1 (0 m depth discharge at 95 $m^3$/d flow rate).**

| Season | Maximum depth (m) from discharge location to achieve given dilution |
|---|---|
| Summer | 4 |
| Transitional | 4 |
| Winter | 5 |

**Table 3.24 Maximum depth from the PW discharge location to achieve 1:414.3 dilution in each season for Case P3 (30 m depth discharge at 95 $m^3$/d flow rate).**

| Season | Maximum depth (m) from discharge location to achieve given dilution |
|---|---|
| Summer | 33 |
| Transitional | 33 |
| Winter | 34 |

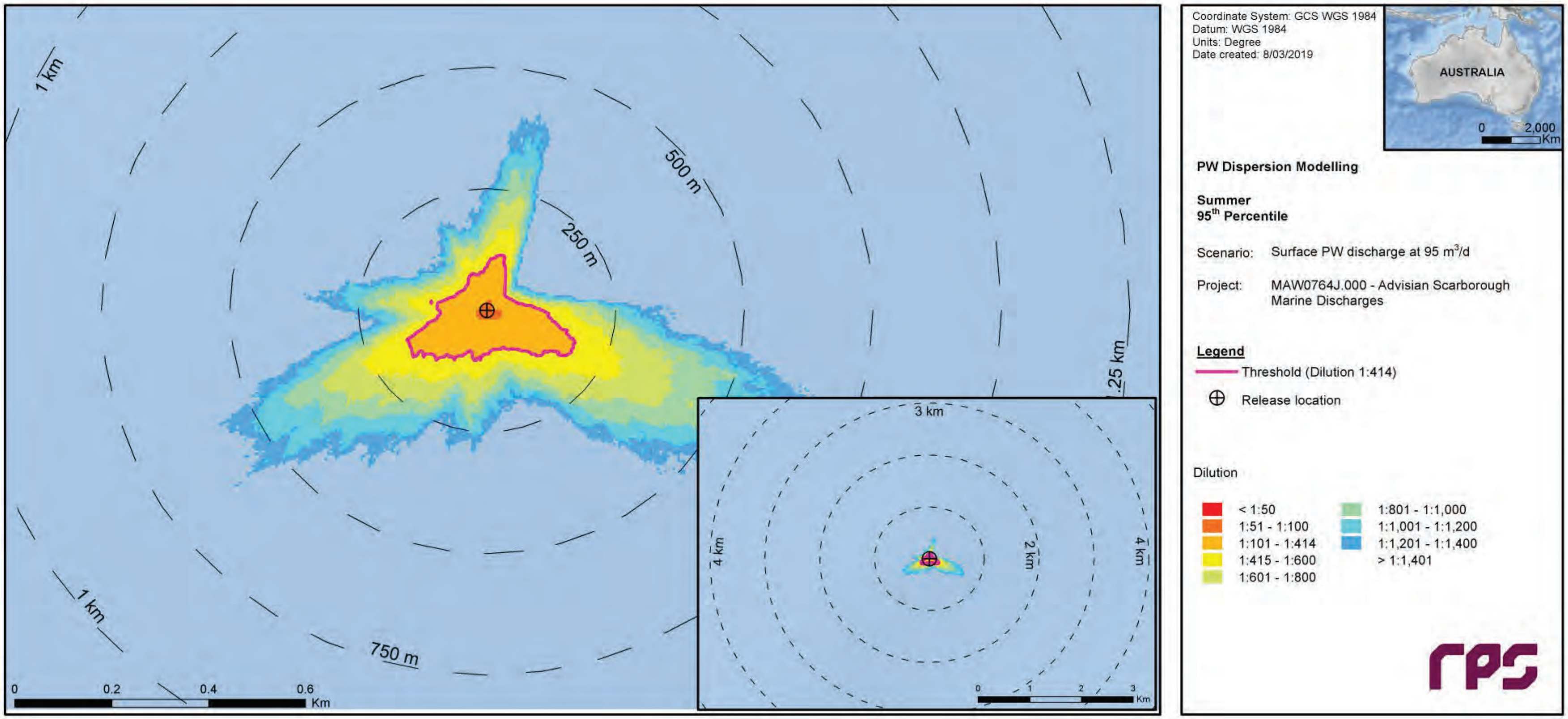



**Figure 3.14 Predicted minimum dilutions at the 95th percentile under summer conditions for Case P1 (0 m depth discharge at 95 $m^3$/d flow rate).**

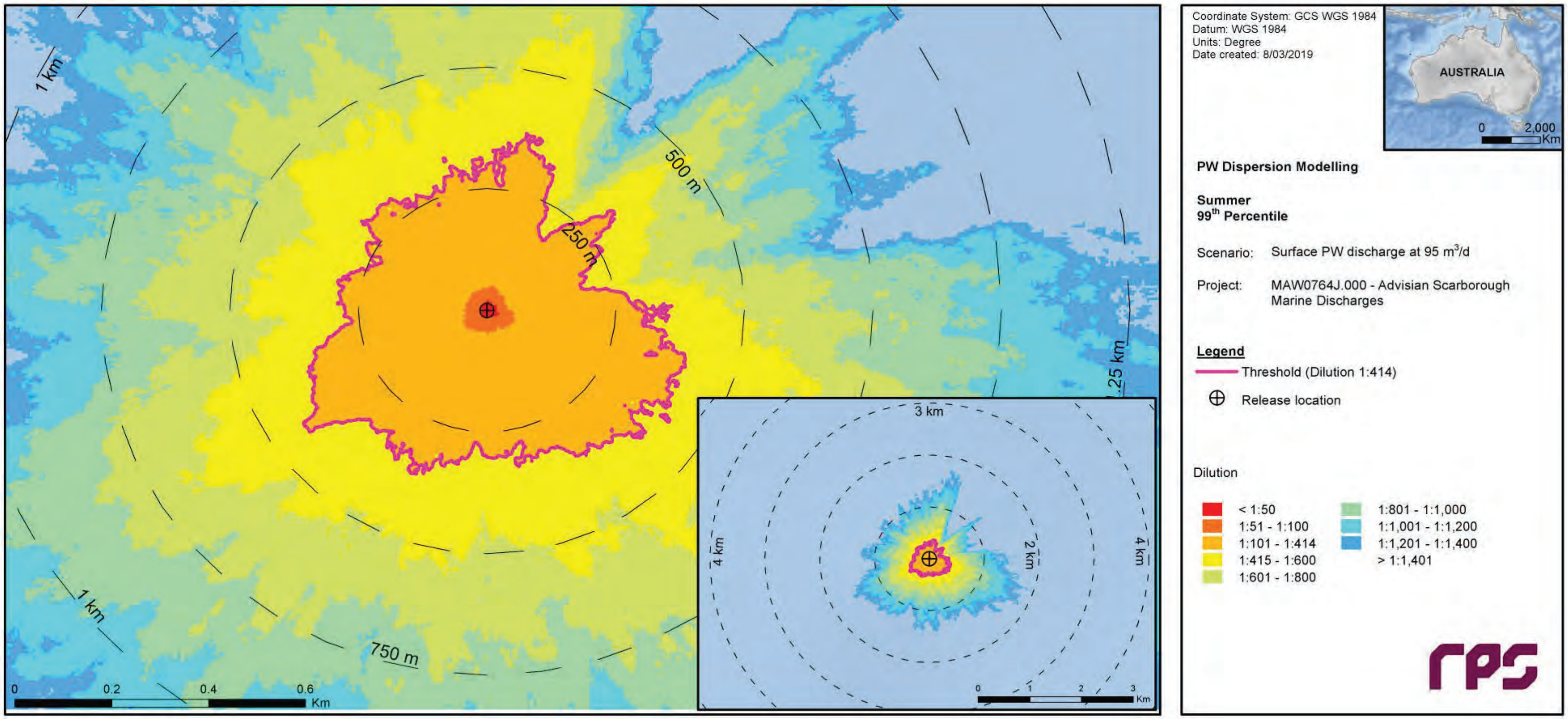



**Figure 3.15 Predicted minimum dilutions at the 99th percentile under summer conditions for Case P1 (0 m depth discharge at 95 $m^3$/d flow rate).**

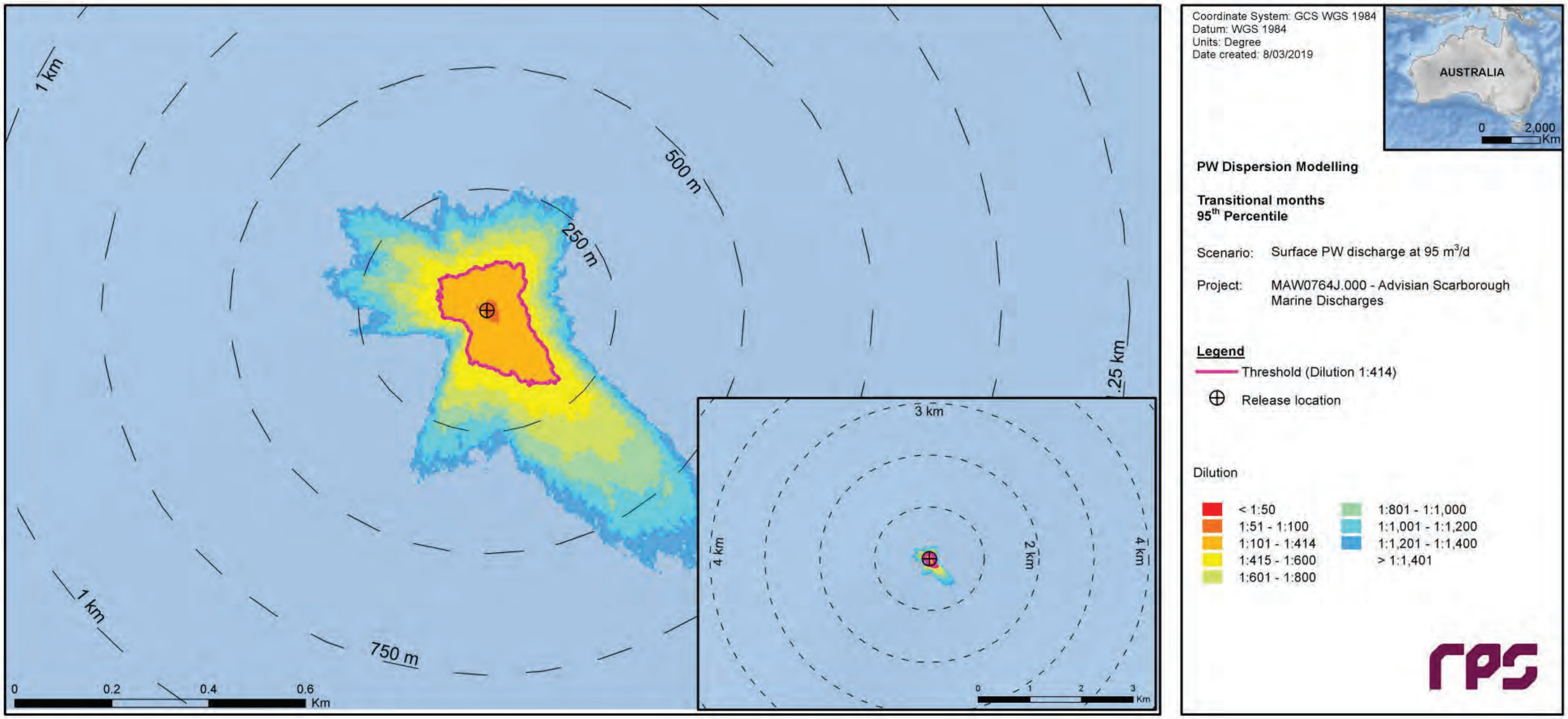



**Figure 3.16 Predicted minimum dilutions at the 95th percentile under transitional conditions for Case P1 (0 m depth discharge at 95 $m^3$/d flow rate).**

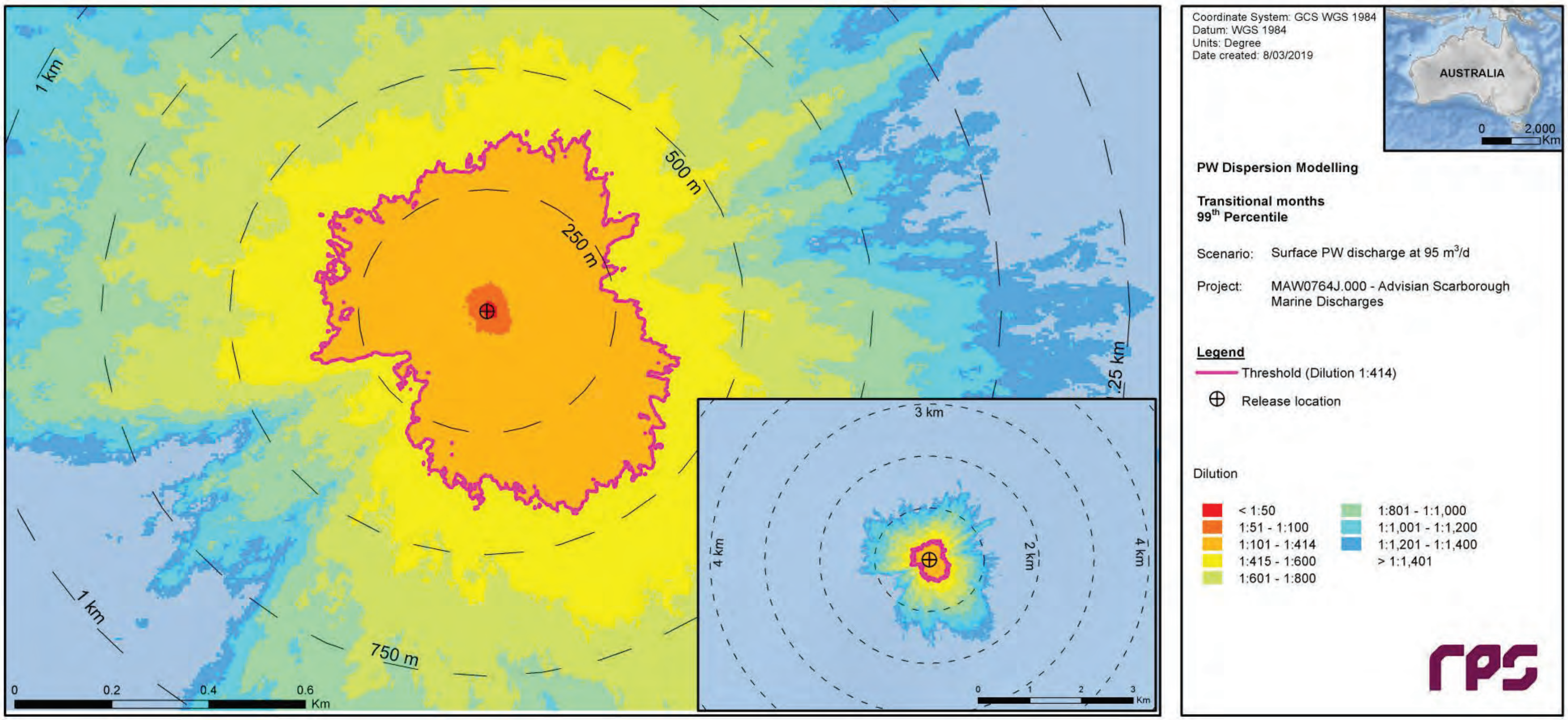



**Figure 3.17 Predicted minimum dilutions at the 99th percentile under transitional conditions for Case P1 (0 m depth discharge at 95 $m^3$/d flow rate).**

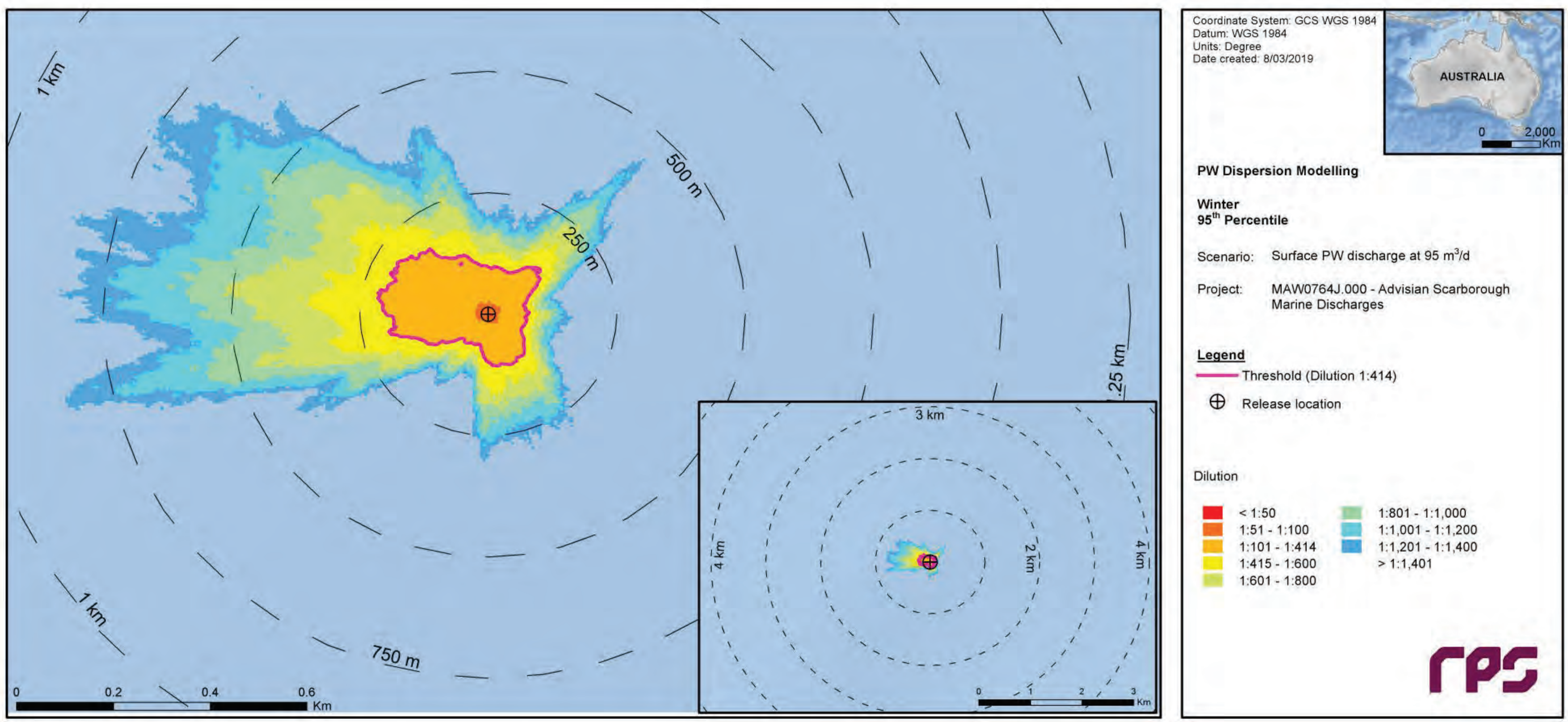



**Figure 3.18 Predicted minimum dilutions at the 95th percentile under winter conditions for Case P1 (0 m depth discharge at 95 $m^3$/d flow rate).**

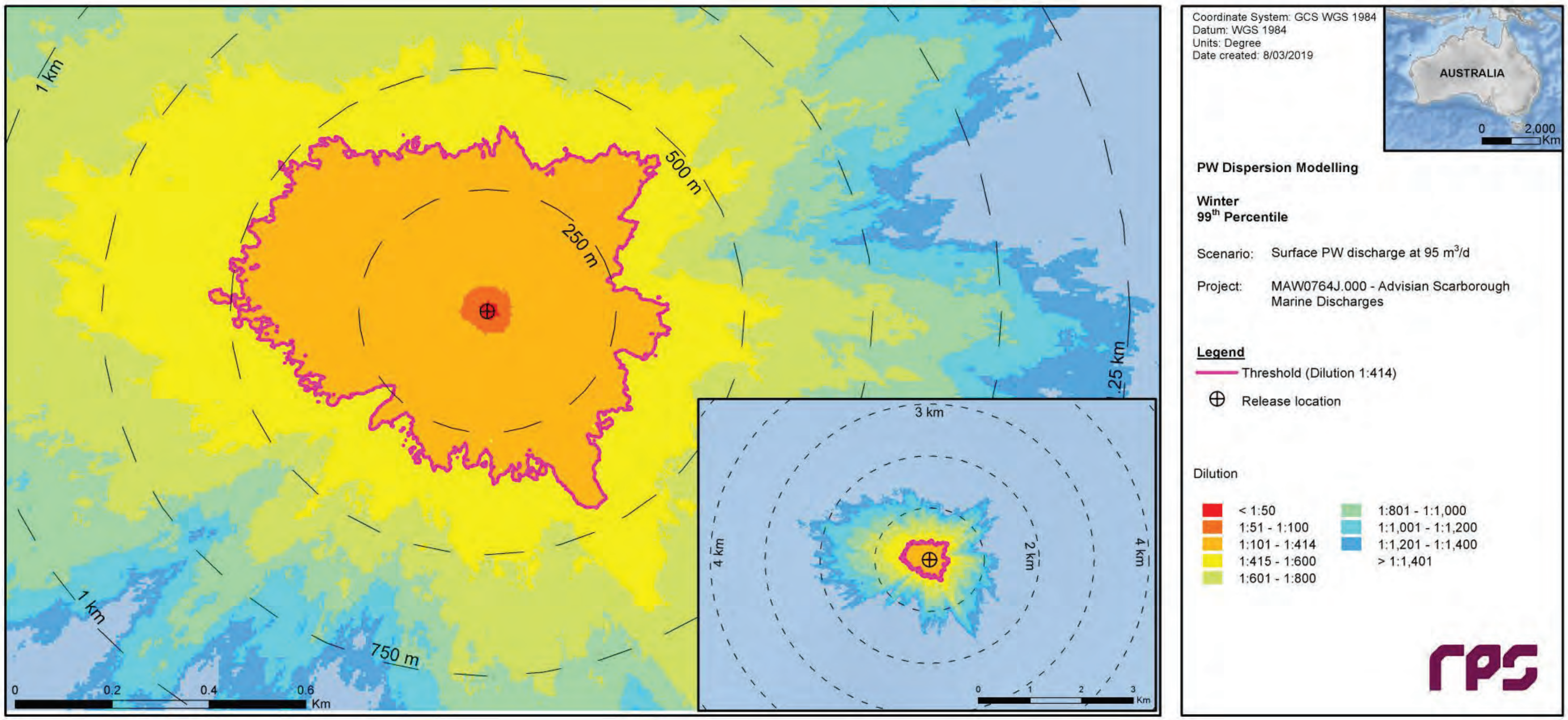



**Figure 3.19 Predicted minimum dilutions at the 99th percentile under winter conditions for Case P1 (0 m depth discharge at 95 m³/d flow rate).**

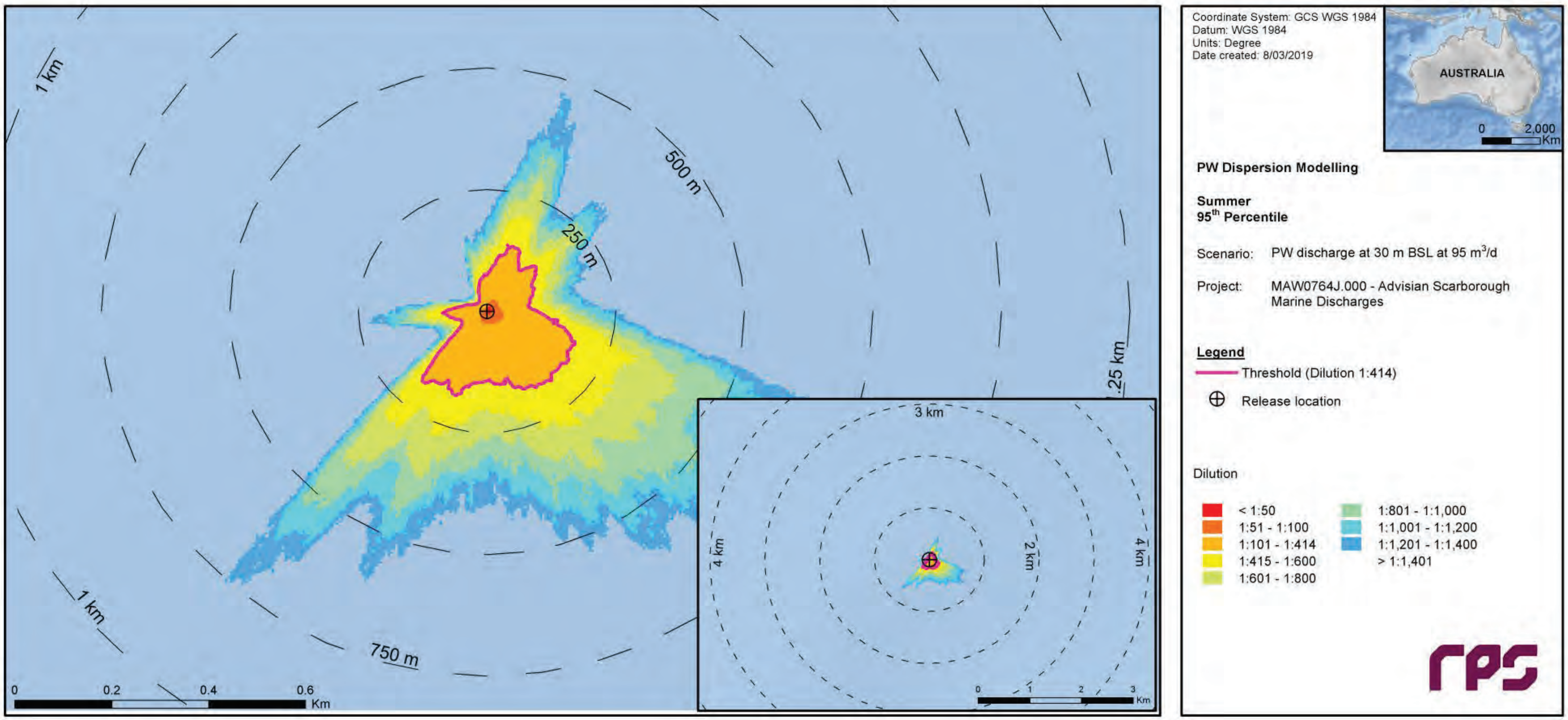



**Figure 3.20 Predicted minimum dilutions at the 95th percentile under summer conditions for Case P3 (30 m depth discharge at 95 $m^3$/d flow rate).**

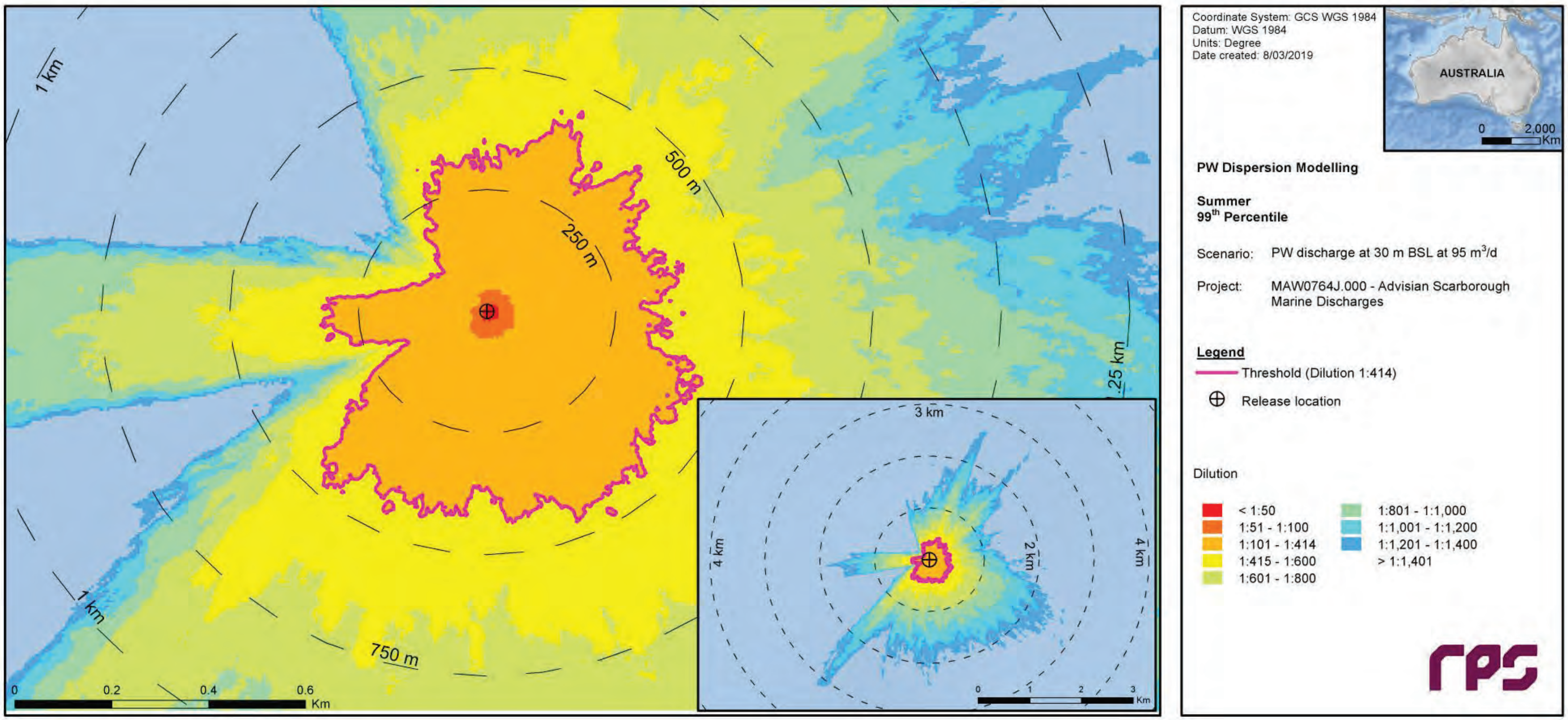



**Figure 3.21 Predicted minimum dilutions at the 99th percentile under summer conditions for Case P3 (30 m depth discharge at 95 m$^3$/d flow rate).**

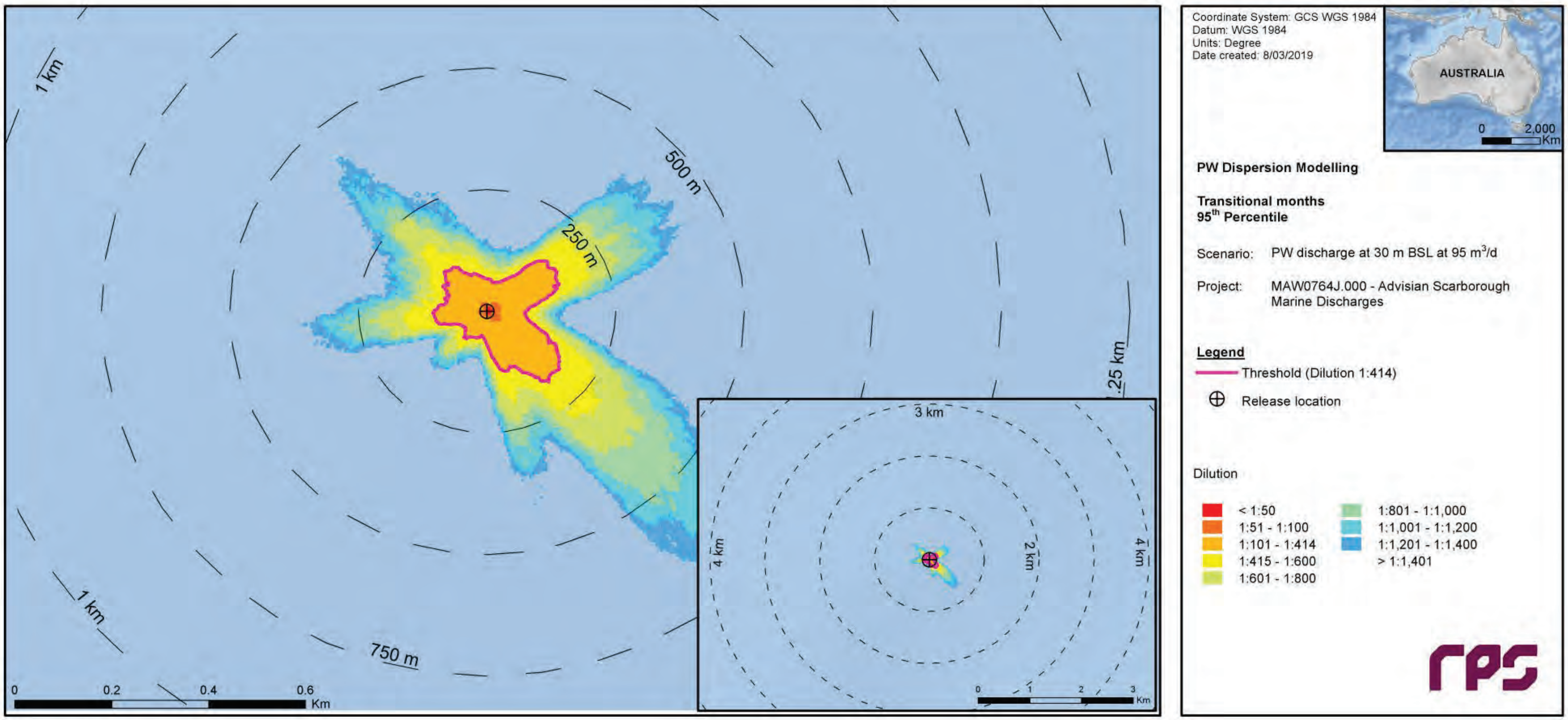



**Figure 3.22 Predicted minimum dilutions at the 95th percentile under transitional conditions for Case P3 (30 m depth discharge at 95 $m^3$/d flow rate).**

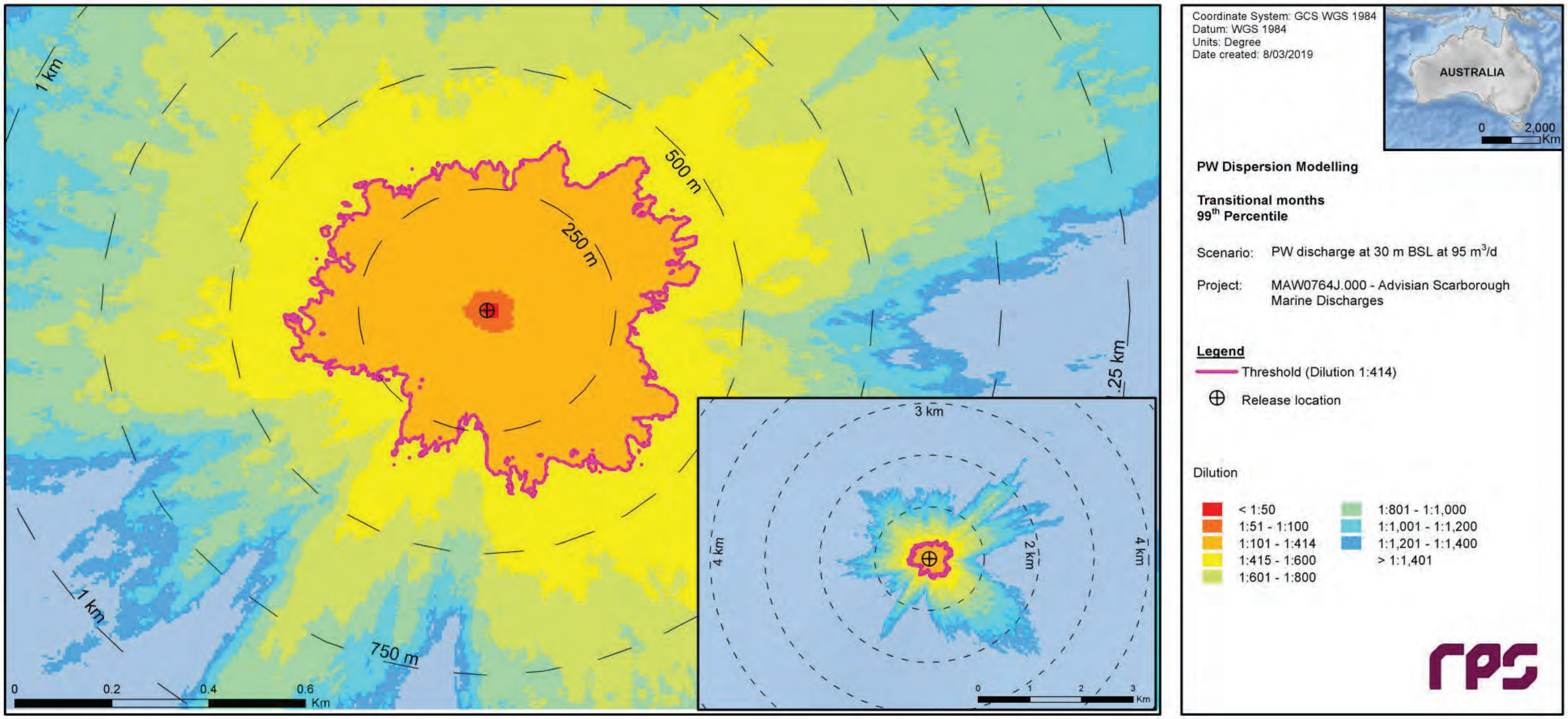



**Figure 3.23 Predicted minimum dilutions at the 99th percentile under transitional conditions for Case P3 (30 m depth discharge at 95 m$^3$/d flow rate).**

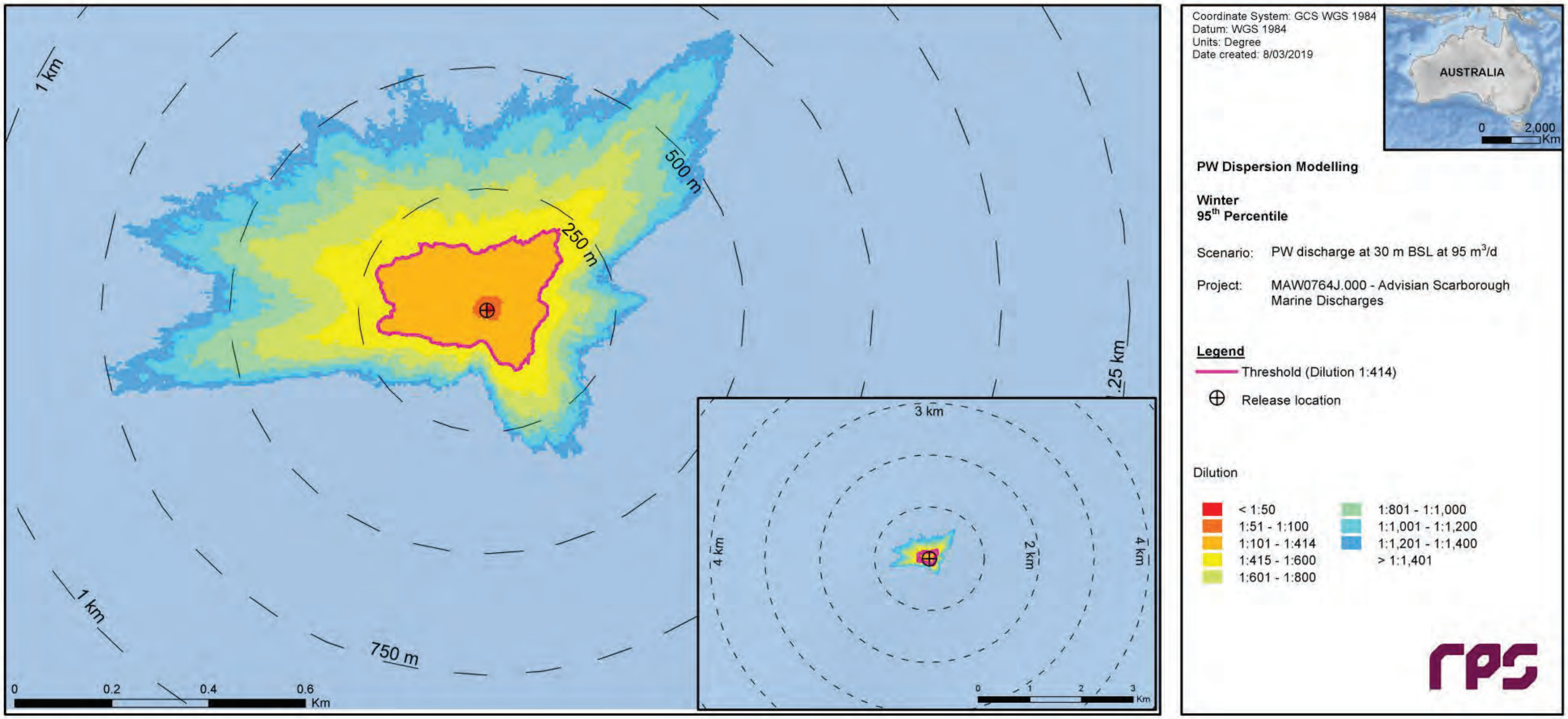



**Figure 3.24 Predicted minimum dilutions at the 95th percentile under winter conditions for Case P3 (30 m depth discharge at 95 $m^3$/d flow rate).**

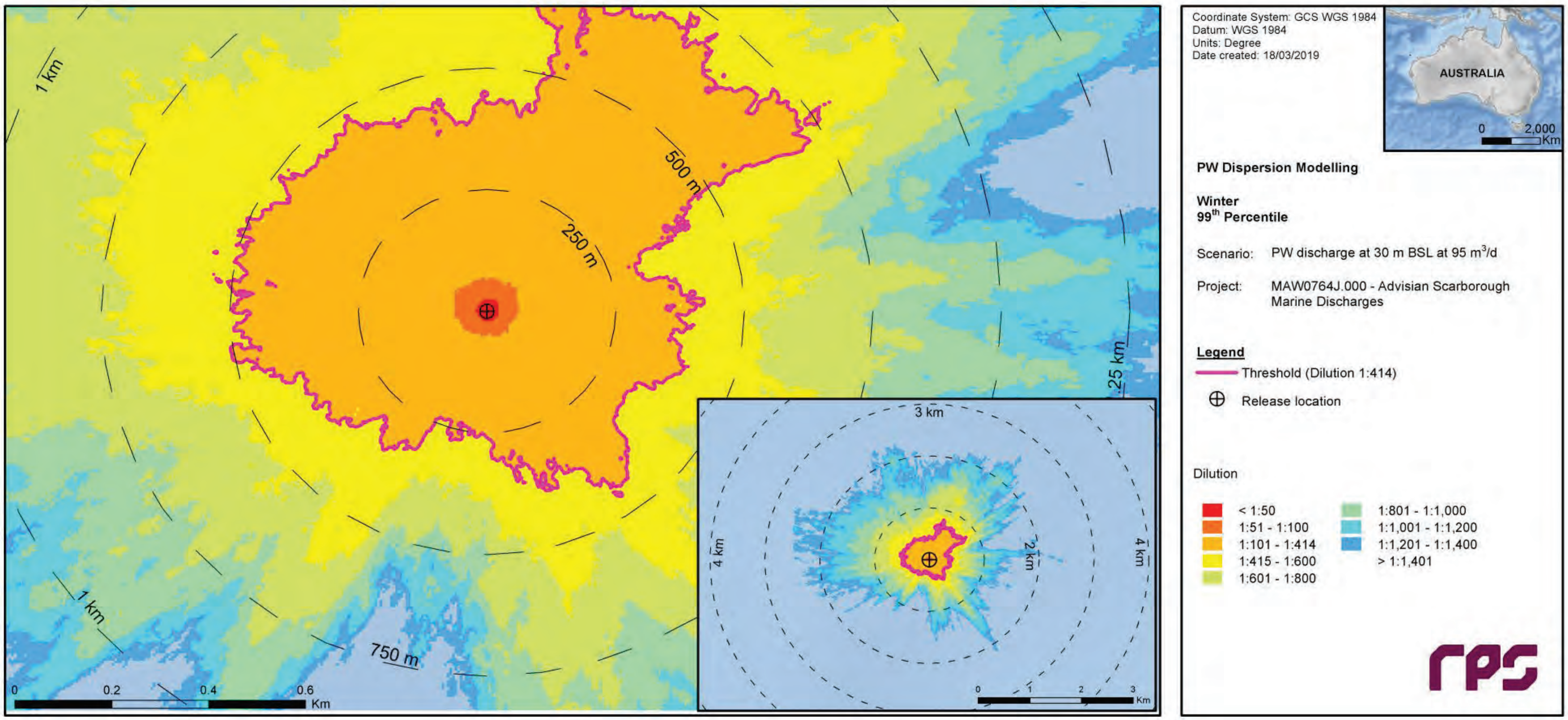



**Figure 3.25 Predicted minimum dilutions at the 99th percentile under winter conditions for Case P3 (30 m depth discharge at 95 $m^3$/d flow rate).**

### 3.2.5 Annualised Analysis

The model outputs for each season (summer, transitional and winter) over the ten-year hindcast period (2006-2015) were combined and analysed on an annualised basis.

Table 3.25 and Table 3.26 summarise, for Cases P1 and P3 respectively, the minimum dilution achieved at specific radial distances from the discharge location for each percentile over the annual period.

Table 3.27 and Table 3.28 provide, for Cases P1 and P3 respectively, summaries of the annualised maximum distances from the discharge location to achieve 1:414 dilution for each percentile. The results indicate that the release of effluent under all seasonal conditions results in rapid dispersion within the ambient environment. Dilution to reach threshold concentration is achieved for TPH within a maximum area of influence of 543 m (Case P1) and 810 m (Case P3) at the 99$^{th}$ percentile, this being the maximum spatial extent of the relevant dilution contour from the discharge location in any season.

Table 3.29 and Table 3.30 provide, for Cases P1 and P3 respectively, summaries of the total area of coverage for the 1:414 dilution contour for each percentile. The area of exposure defined by the relevant dilution contour is predicted to reach maximum values of 0.48 km$^2$ (Case P1) and 0.70 km$^2$ (Case P3) at the 99$^{th}$ percentile in any season.

For Cases P1 and P3, Figure 3.26 to Figure 3.29 show the aggregated spatial extents of the minimum dilutions for each percentile. 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 3.25 Annualised minimum dilution achieved at specific radial distances from the PW discharge location for Case P1 (0 m depth discharge at 95 $m^3$/d flow rate).**

| Percentile | Season | Minimum dilution (1:x) achieved at specific radial distances from discharge location | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0.02 km | 0.05 km | 0.10 km | 0.20 km | 0.30 km | 0.40 km | 0.50 km | 0.60 km | 0.70 km | 0.80 km | 0.90 km | 1.00 km |
| 95th | Annual | 1:79.2 | 1:145.4 | 1:232.7 | 1:394.5 | 512.1 | 1:646.6 | 1:767.1 | 1:973.7 | 1:1,094.8 | 1:1,287.1 | 1:1,442.2 | 1:1,606.2 |
| 99th | | 1:46.6 | 1:86.4 | 1:144.5 | 1:144.5 | 1:286.1 | 1:366.0 | 1:436.0 | 1:509.9 | 1:587.9 | 1:646.4 | 1:716 | 1:760.1 |

**Table 3.26 Annualised minimum dilution achieved at specific radial distances from the PW discharge location for Case P3 (30 m depth discharge at 95 $m^3$/d flow rate).**

| Percentile | Season | Minimum dilution (1:x) achieved at specific radial distances from discharge location | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0.02 km | 0.05 km | 0.10 km | 0.20 km | 0.30 km | 0.40 km | 0.50 km | 0.60 km | 0.70 km | 0.80 km | 0.90 km | 1.00 km |
| 95th | Annual | 1:57.3 | 1:133.4 | 1:226.5 | 1:385.0 | 1:513.3 | 1:681.2 | 1:825.9 | 1:1,002.6 | 1:1,219.0 | 1:1,411.4 | 1:1,534.8 | 1:1,860.0 |
| 99th | | 1:37.6 | 1:76.2 | 1:123.5 | 1:187.5 | 1:232.9 | 1:272.0 | 1:277.7 | 1:381.1 | 1:381.1 | 1:408.7 | 1:474.9 | 1:496.6 |

**Table 3.27 Annualised maximum distance from the PW discharge location to achieve 1:414.3 dilution for Case P1 (0 m depth discharge at 95 m³/d flow rate).**

| Percentile | Season | Maximum distance (m) from discharge location to achieve given dilution |
|---|---|---|
| 95th | Annual | 221 |
| 99th | | 543 |
| 100th | | 3,231 |

**Table 3.28 Annualised maximum distance from the PW discharge location to achieve 1:414.3 dilution for Case P3 (30 m depth discharge at 95 m³/d flow rate).**

| Percentile | Season | Maximum distance (m) from discharge location to achieve given dilution |
|---|---|---|
| 95th | Annual | 229 |
| 99th | | 810 |
| 100th | | 3,406 |

**Table 3.29 Annualised total area of coverage for 1:414.3 dilution for Case P1 (0 m depth discharge at 95 m³/d flow rate).**

| Percentile | Season | Total area (km²) of coverage for given dilution |
|---|---|---|
| 95th | Annual | 0.067 |
| 99th | | 0.479 |
| 100th | | 4.014 |

**Table 3.30 Annualised total area of coverage for 1:414.3 dilution for Case P3 (30 m depth discharge at 95 m³/d flow rate).**

| Percentile | Season | Total area (km²) of coverage for given dilution |
|---|---|---|
| 95th | Annual | 0.087 |
| 99th | | 0.702 |
| 100th | | 9.910 |

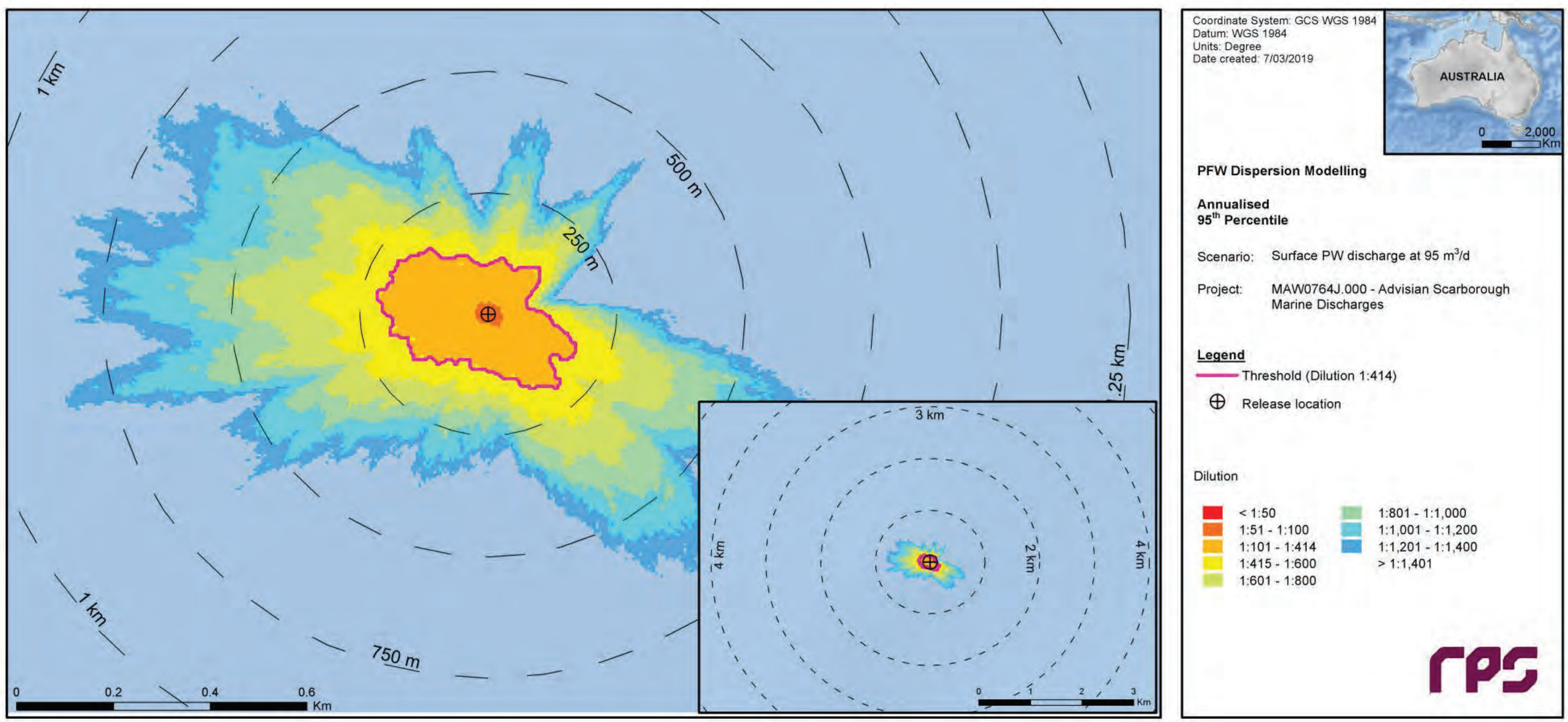



**Figure 3.26 Predicted annualised minimum dilutions at the 95th percentile for Case P1 (0 m depth discharge at 95 $m^3$/d flow rate).**

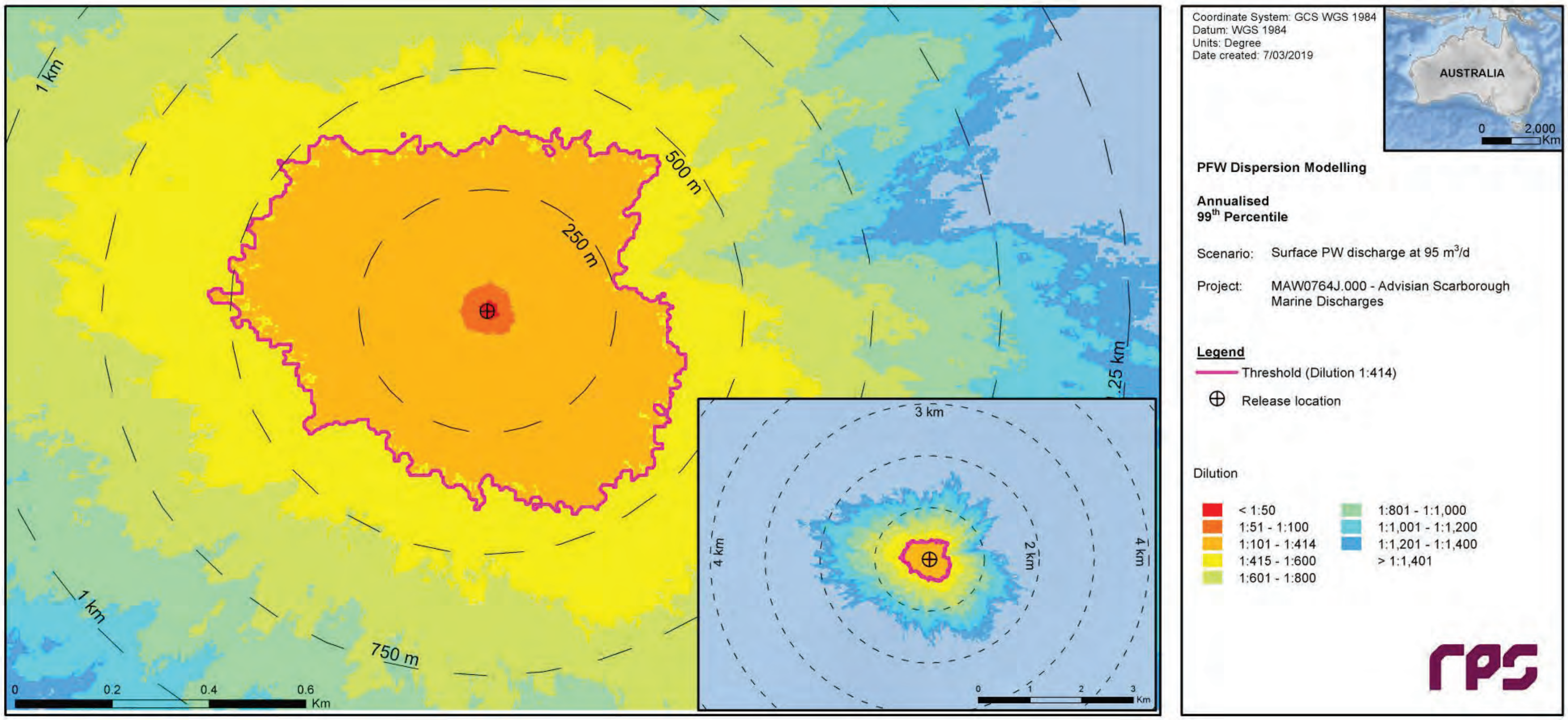



**Figure 3.27 Predicted annualised minimum dilutions at the 99th percentile for Case P1 (0 m depth discharge at 95 $m^3$/d flow rate).**

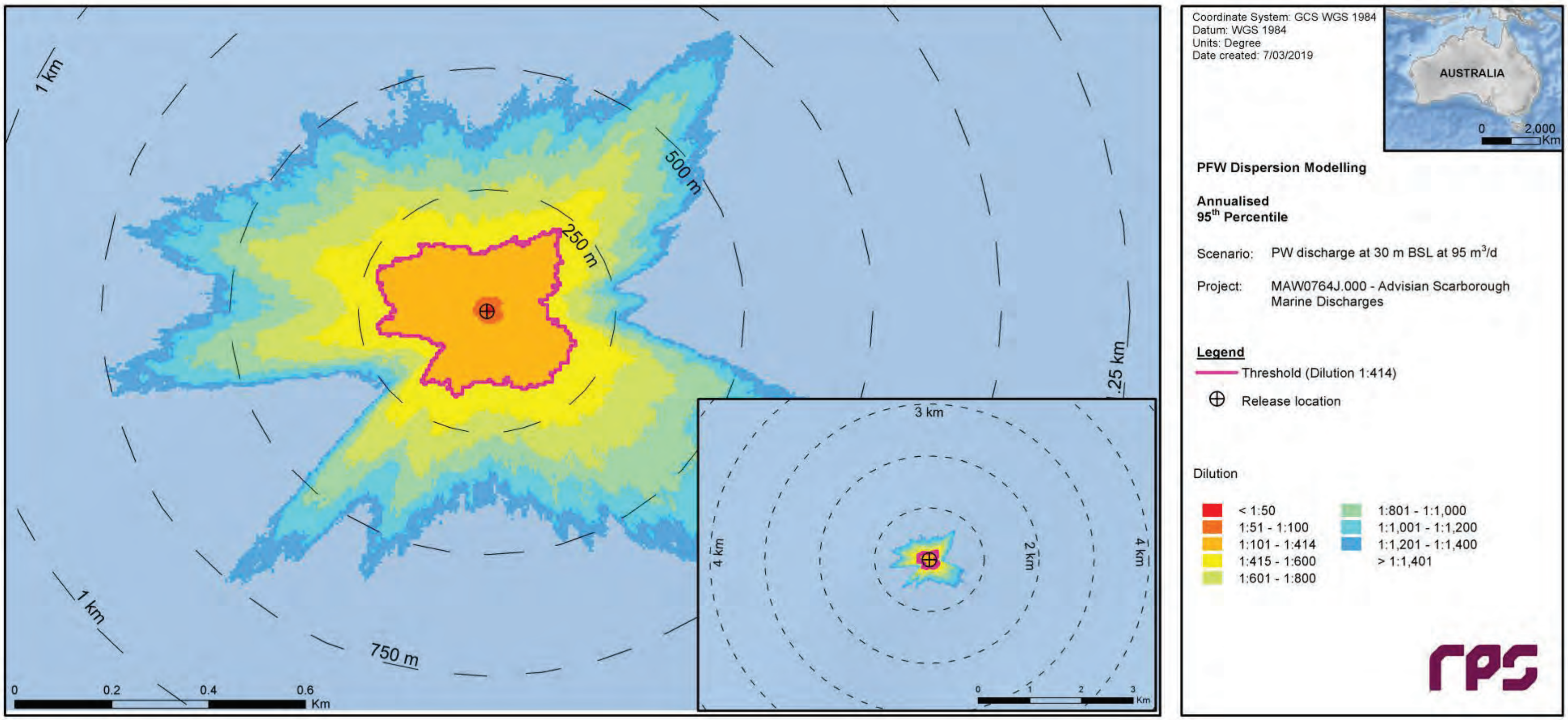



**Figure 3.28 Predicted annualised minimum dilutions at the 95th percentile for Case P3 (30 m depth discharge at 95 $m^3$/d flow rate).**

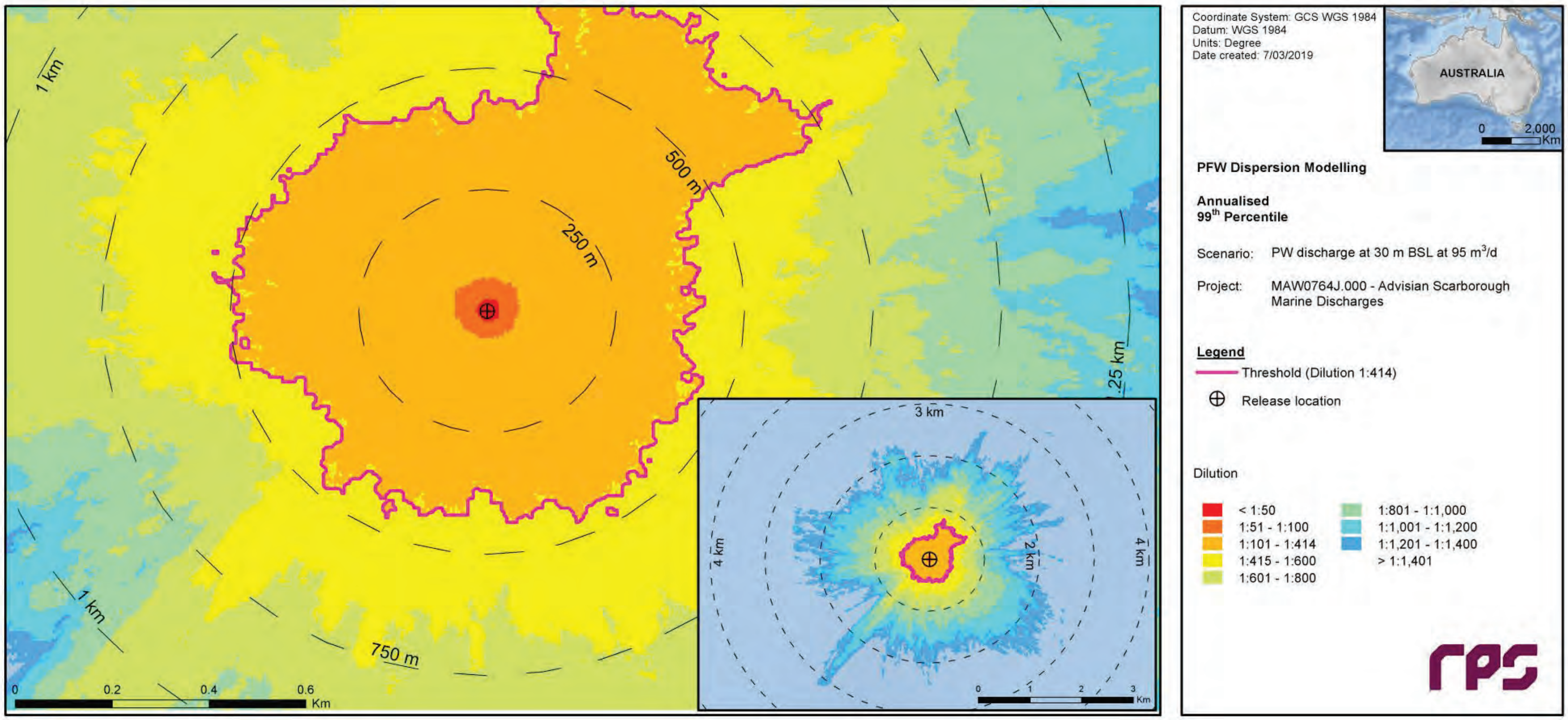



**Figure 3.29 Predicted annualised minimum dilutions at the 99th percentile for Case P3 (30 m depth discharge at 95 $m^3$/d flow rate).**

# 4 CONCLUSIONS

The main findings of the study are as follows:

## Near-Field Modelling

- 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 0 m, 10 m and 30 m below the water surface (Cases P1, P2 and P3, respectively). The surface discharges are shown to increase the extent of the turbulent mixing zone. Following this initial mixing, the near neutrally-buoyant plumes are predicted to travel laterally in the water column.
- For Case P1, the plume is predicted to plunge up to 4.4 m below the sea surface. For Cases P2 and P3, the plumes are predicted to remain at approximately the discharge depth: up to 11 m below the surface for Case P2 and up to 31 m below the surface for Case P3.
- Increased ambient current strengths are shown to increase the horizontal distance travelled by the plume from the discharge point.
- For a discharge at a 95 $m^3$/d flow rate, the maximum horizontal distance travelled by the plume under annualised average current speeds is predicted for a discharge at 0 m depth as 255 m. The dilution level for this case is predicted as 1:1,519.
- The maximum diameter of the plume at the end of the near-field zone was predicted as 3.7 m for Case P1, 1.8 m for Case P2 and 1.7 m for Case P3. Increases in current speed serve to restrict the diameter of the plume.
- For each discharge depth, 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 (at which the predictions of dispersion are halted due to the plume reaching equilibrium with the ambient receiving water) closer to the discharge point, which slows the rate of dilution.
- The average dilution levels of the plume upon reaching the trapping depth under average current speeds are predicted to be 1:1,519 for Case P1, 1:88 for Case P2 and 1:43 for Case P3. Additionally, the minimum dilution levels of the plume (i.e. dilution of the plume centreline) upon encountering the trapping depth under average current speeds are predicted to be 1:390 for Case P1, 1:22 for Case P2 and 1:11 for Case P3.
- The predictions of dilution 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 Case P1, P2 and P3 discharges indicate that the TPH constituent of the PW discharge is not expected to reach the required levels of dilution in the near field mixing zone.

## Far-Field Modelling

- For Case P1, dilution to reach threshold concentration is achieved for TPH within an area of influence extending up to 543 m at the 99th percentile. For Case P3, the maximum spatial extents of the relevant dilution contour are up to 810 m at the 99th percentile.

- For Case P1, the area of exposure defined by the relevant dilution contour is predicted to reach a maximum of 0.48 $km^2$ at the 99th percentile. For Case P3, the corresponding maximum area of exposure is up to 0.70 $km^2$ at the 99th percentile.
- Maximum depths reached by the discharges are predicted as 5 m and 33 m for Cases P1 and P3, respectively.

## Key Observations

- Due to the similarity in typical magnitude of the hindcast currents throughout the depth range of discharges under consideration, predicted outcomes are broadly similar.
- The greater variability in surface-layer currents will promote the highest levels of mixing and dilution.
- Because the discharge will be initially negatively buoyant, it will sink in the water column and even a surface discharge is unlikely to resurface in the vicinity of the discharge point prior to acclimation with ambient receiving water conditions.

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# Appendix H

## Scarborough Gas Development Hydrotest Discharge Modelling Study

# WOODSIDE SCARBOROUGH PROJECT – HYDROTEST DISCHARGE MODELLING

## Report

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# EXECUTIVE SUMMARY


RPS was commissioned by Advisian Pty Ltd (Advisian), on behalf of Woodside Energy Ltd (Woodside), to undertake a marine dispersion modelling study of proposed hydrotest discharges from subsea infrastructure associated with the Scarborough Project's Floating Production Unit (FPU).

The Scarborough gas resource, located in Commonwealth waters approximately 375 km off the Burrup Peninsula, forms part of the Greater Scarborough gas fields, comprising the Scarborough, North Scarborough, Thebe and Jupiter gas fields.

As Operator of the Greater Scarborough gas fields, Woodside is proposing to develop the gas resource through new offshore facilities. These will be connected to the mainland through an approximately 430 km trunkline.

Once installation and hook-up of subsea infrastructure is complete, the infrastructure, including the SURF (subsea, umbilical, riser, flowline) and the trunkline, will be subject to pre-commissioning integrity tests. These may be conducted using hydrotest fluids, whereby the pipeline pressure will be monitored to detect leaks. Fluids will then be left in place to provide corrosion protection prior to the introduction of reservoir fluids, at which time they will be discharged at the offshore location (subject to regulatory requirements).

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 biocide in the hydrotest discharge. This will indicate whether concentrations of this contaminant are still likely to be above stated 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 stream from the trunkline and SURF, dispersion modelling was carried out for flow rates of 795 $m^3$/hr and 220 $m^3$/hr at discharge depths of 930 m and 10 m below the water surface.

The potential area that may be influenced by the hydrotest 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). An annualised aggregation of outcomes was also assembled.

The main findings of the study are as follows:

## Near-Field Modelling

- 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 930 m (Cases 1 and 2) and 10 m (Case 3) below the water surface. The surface discharges are shown to increase the extent of the turbulent mixing zone. Following this initial mixing, the near neutrally-buoyant plumes are predicted to travel laterally in the water column.
- For Cases 1 and 2, the plumes are predicted to remain close to the seabed. For Case 3, the plume is predicted to plunge up to 19 m below the sea surface. For Cases 2 and 3, increased ambient current strengths are shown to increase the horizontal distance travelled by the plumes from the discharge point.

- The plume will reach a maximum horizontal distance of up to 152 m before reaching the trapping depth (at which the predictions of dispersion are halted due to the plume reaching equilibrium with the ambient receiving water).
- The maximum diameter of the plume at the end of the near-field zone was predicted as 23 m. Increases in current speed serve to restrict the diameter of the plume.
- For each discharge depth, 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.
- For each combination of discharge flow rate and depth, 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.
- The average dilution levels of the plume upon reaching the trapping depth under average current speeds are predicted to be 1:90 for Case 1, 1:465 for Case 2 and 1:482 for Case 3.
- The predictions of dilution 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 Case 1, 2 and 3 discharges indicate that the biocide constituent of the hydrotest discharge is not expected to reach the required levels of dilution in the near field mixing zone.

## Far-Field Modelling

- For Case 1, dilution to reach threshold concentration is achieved for biocide within an area of influence extending up to 1,388 m at the 99$^{th}$ percentile. For Case 3, the maximum spatial extents of the relevant dilution contour are up to 124 m at the 99$^{th}$ percentile.
- For Case 1, the area of exposure defined by the relevant dilution contour is predicted to reach a maximum of 2.95 km$^2$ at the 99$^{th}$ percentile. For Case 3, the corresponding maximum area of exposure is up to 0.04 km$^2$ at the 99$^{th}$ percentile.
- Maximum depths reached by the discharges are predicted as 930 m (seabed) and 12 m for Cases 1 and 3, respectively.

## Key Observations

- Due to the significant variations in magnitude of the hindcast currents between the surface and seabed, where potential discharges will occur, predicted outcomes are markedly different.
- The greater strength and variability in surface-layer currents will promote the highest levels of mixing and dilution, while transport patterns at the seabed will be dictated almost solely by tidal movements.
- Because the discharge will be initially neutrally-buoyant, it will travel laterally in the water column and even a surface discharge is unlikely to resurface in the vicinity of the discharge point prior to acclimation with ambient receiving water conditions.
- Outcomes show that below-threshold biocide concentrations are achieved closer to the discharge point for the surface discharge (220 m$^3$/hr over 20 hours) than for the seabed discharge (795 m$^3$/hr over 44 hours). This is partly attributable to the stronger currents at the surface, but primarily to the lower flow rate and much lower discharge duration in the surface-discharge case.

# 1 INTRODUCTION

## 1.1 Background

RPS was commissioned by Advisian Pty Ltd (Advisian), on behalf of Woodside Energy Ltd (Woodside), to undertake a marine dispersion modelling study of proposed hydrotest discharges from subsea infrastructure associated with the Scarborough Project's Floating Production Unit (FPU).

The Scarborough gas resource, located in Commonwealth waters approximately 375 km off the Burrup Peninsula, forms part of the Greater Scarborough gas fields, comprising the Scarborough, North Scarborough, Thebe and Jupiter gas fields.

As Operator of the Greater Scarborough gas fields, Woodside is proposing to develop the gas resource through new offshore facilities. These will be connected to the mainland through an approximately 430 km trunkline.

Once installation and hook-up of subsea infrastructure is complete, the infrastructure, including the SURF (subsea, umbilical, riser, flowline) and the trunkline, will be subject to pre-commissioning integrity tests. These may be conducted using hydrotest fluids, whereby the pipeline pressure will be monitored to detect leaks. Fluids will then be left in place to provide corrosion protection prior to the introduction of reservoir fluids, at which time they will be discharged at the offshore location (subject to regulatory requirements).

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 biocide in the hydrotest discharge. This will indicate whether concentrations of this contaminant are still likely to be above stated 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 stream from the trunkline and SURF (location shown in Table 1.1), dispersion modelling was carried out for flow rates of 795 $m^3$/hr and 220 $m^3$/hr at discharge depths of 930 m and 10 m below the water surface.

The potential area that may be influenced by the hydrotest 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). An annualised aggregation of outcomes was also assembled.

All hydrotest discharge characteristics used as input to the modelling are specified in the Model Input Form for this study (Advisian, 2018).

**Table 1.1 Location of the proposed FPU used as the release site for the hydrotest dispersion modelling assessment.**

| Release Site | Latitude (°S) | Longitude (°E) | Water Depth (m) |
|---|---|---|---|
| FPU | 19° 53' 54.715" | 113° 14' 19.561" | 930 |

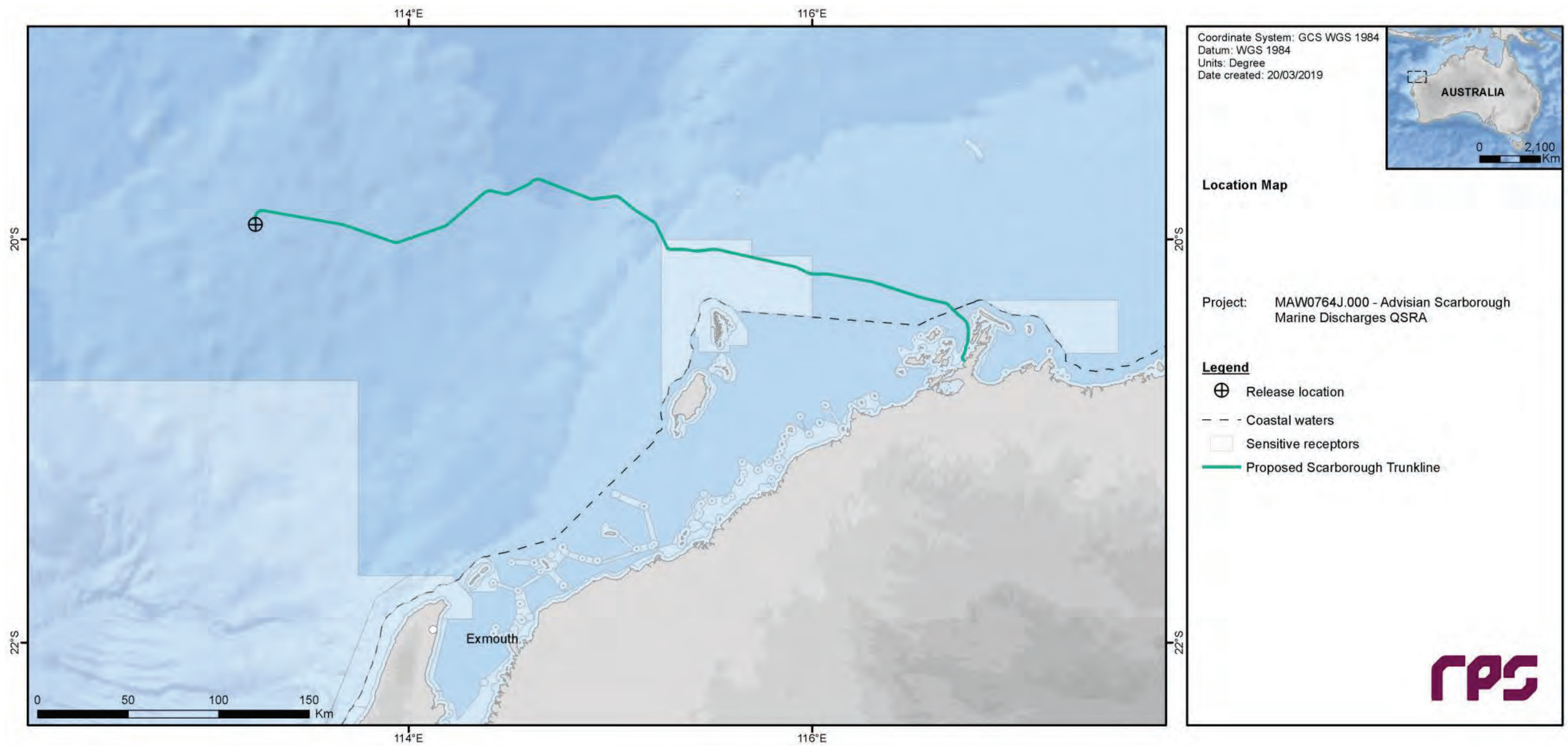


**Figure 1.1 Location of the proposed Scarborough pipeline and FPU on the North West Shelf of Australia.**

## 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 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:

- Collation of a suitable three-dimensional, spatially-varying current data set surrounding the FPU location for a ten-year (2006-2015) 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 metocean data collected in the Scarborough Project area.
- 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.
- Collation of seasonally-varying vertical water density profiles at the FPU location for use as input to the dispersion models.
- 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).
- 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.
- 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.
- 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 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 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 FPU location.

### 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.

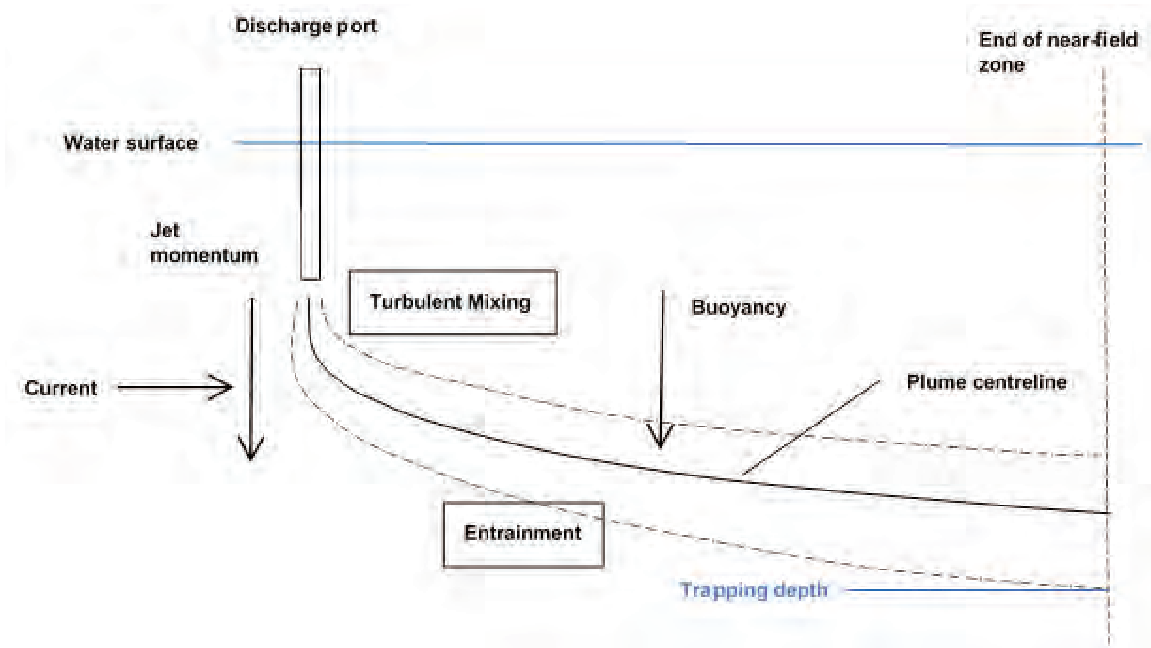


**Figure 2.1 Conceptual diagram showing the general behaviour of negatively buoyant discharge.**

### 2.1.3 Setup of Near-Field Model

#### 2.1.3.1 Discharge Characteristics

The hydrotest discharge characteristics for cases 1 to 3 are summarised in Table 2.1.

Cases 1 and 2 were assumed to occur at a depth of 930 m below mean sea level (BMSL). The flow was assumed to occur through a single outlet of 0.1 m diameter at rates of 795 $m^3$/d and 220 $m^3$/d, respectively, and have a salinity of 35 parts per thousand (ppt) and temperature equivalent to ambient seabed conditions.

Case 3 was assumed to occur at a depth of 10 m below mean sea level (BMSL). The flow was assumed to occur through a single outlet of 0.1 m diameter at a rate of 220 $m^3$/d, and have a salinity of 35 parts per thousand (ppt) and temperature equivalent to ambient near-surface conditions.

The volume of hydrotest water for Case 1 was assumed as 232,800 $m^3$ while the volume for Cases 2 and 3 was assumed as 6,360 $m^3$, representing the full volumes of the trunkline and SURF equipment, respectively. Based on the engineering definitions available at the time of commissioning the dispersion modelling study, it is anticipated that the dewatering of the pipeline will take approximately 244 hours (Case 1) and 20 hours (Cases 2 and 3), based on average flow rates of 795 $m^3$/hr and 220 $m^3$/hr.

Concentrations of the constituent of interest (biocide) within the discharges are described in Table 2.2, along with the required dilution factor to reach the defined threshold concentration (Advisian, 2018).

**Table 2.1 Summary of hydrotest discharge characteristics.**

| Parameter | Trunkline Hydrotest Discharge | SURF Hydrotest Discharge 1 | SURF Hydrotest Discharge 2 |
|---|---|---|---|
| Flow rate ($m^3$/d) | 795 | 220 | |
| Discharge volume ($m^3$) | 232,800 | 6,360 | |
| Discharge duration (hours) | 244 | 20 | |
| Outlet pipe internal diameter (m) [in] | 0.1 [4] | | |
| Outlet pipe orientation | Horizontal | Vertical (upwards) | Vertical (downwards) |
| Depth of pipe below sea surface (m) | 930 | | 10 |
| Discharge salinity (ppt) | 35 | | |
| Discharge temperature (°C) | Ambient (seabed) | | Ambient (near-surface) |

**Table 2.2 Constituent of interest within the hydrotest discharges and criteria for analysis of exposure.**

| Constituent | Source Concentration (ppm) | Threshold Concentration (ppm) | Required Dilution Factor |
|---|---|---|---|
| Biocide | 550 | 1 | 550 |

## 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 hydrotest plume. These inputs are described in the following sections.

### 2.1.3.2.1 Ambient Temperature and Salinity

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, NOAA) and its co-located World Data Center for Oceanography (Levitus *et al.*, 2013).

Table 2.3 shows the average seasonal water temperature and salinity levels at varying depths from 0 m to 930 m. This data can be considered representative of seasonal conditions at the FPU location.

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 (34.6-35.5 practical salinity unit, PSU), irrespective of season or depth.

**Table 2.3 Average temperature and salinity levels adjacent to the proposed FPU location.**

| Season | Depth (m) | Temperature (°C) | Salinity (PSU) |
|---|---|---|---|
| Summer | 0 | 27.8 | 34.7 |
| | 20 | 27.3 | 34.8 |
| | 50 | 26.2 | 34.8 |
| | 200 | 18.4 | 35.4 |
| | 500 | 8.7 | 34.7 |
| | 1,000 | 5.1 | 34.6 |
| Transitional | 0 | 26.0 | 34.7 |
| | 20 | 25.7 | 34.7 |
| | 50 | 25.1 | 34.7 |
| | 200 | 18.6 | 35.5 |
| | 500 | 8.6 | 34.6 |
| | 1,000 | 5.1 | 34.6 |
| Winter | 0 | 26.4 | 34.7 |
| | 20 | 26.3 | 34.7 |
| | 50 | 26.2 | 34.7 |
| | 200 | 19.0 | 35.4 |
| | 500 | 8.9 | 34.6 |
| | 1,000 | 5.1 | 34.6 |
| Annualised | 0 | 26.6 | 34.7 |
| | 20 | 26.3 | 34.7 |
| | 50 | 25.8 | 34.7 |
| | 200 | 18.7 | 35.4 |
| | 500 | 8.7 | 34.6 |
| | 1,000 | 5.1 | 34.6 |

#### 2.1.3.2.2 Ambient Current

Ocean current data was sourced from a 10-year hindcast data set of combined large-scale ocean (BRAN) and tidal currents. The data was statistically analysed to determine the 5$^{th}$, 50$^{th}$ and 95$^{th}$ percentile current speeds. These statistical current speeds can be considered representative of seasonal conditions at the FPU location.

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.

**Table 2.4 Adopted ambient current conditions adjacent to the proposed FPU location.**

| 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 | 2.5 | 0.041 | 0.158 | 0.326 |
| | 22.7 | 0.049 | 0.154 | 0.312 |
| | 56.7 | 0.044 | 0.138 | 0.267 |
| | 205.2 | 0.035 | 0.120 | 0.237 |
| | 545.5 | 0.032 | 0.105 | 0.221 |
| | 995.5 | 0.013 | 0.050 | 0.106 |
| Transitional | 2.5 | 0.045 | 0.177 | 0.375 |
| | 22.7 | 0.045 | 0.173 | 0.369 |
| | 56.7 | 0.043 | 0.157 | 0.322 |
| | 205.2 | 0.043 | 0.140 | 0.287 |
| | 545.5 | 0.032 | 0.118 | 0.282 |
| | 995.5 | 0.016 | 0.056 | 0.116 |
| Winter | 2.5 | 0.044 | 0.172 | 0.395 |
| | 22.7 | 0.043 | 0.166 | 0.375 |
| | 56.7 | 0.039 | 0.156 | 0.341 |
| | 205.2 | 0.036 | 0.142 | 0.307 |
| | 545.5 | 0.035 | 0.116 | 0.278 |
| | 995.5 | 0.013 | 0.052 | 0.105 |
| Annualised | 2.5 | 0.043 | 0.170 | 0.374 |
| | 22.7 | 0.045 | 0.164 | 0.361 |
| | 56.7 | 0.042 | 0.151 | 0.320 |
| | 205.2 | 0.038 | 0.135 | 0.285 |
| | 545.5 | 0.033 | 0.114 | 0.267 |
| | 995.5 | 0.014 | 0.053 | 0.109 |

# 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 (25) 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.

Two hydrotest discharge scenarios were modelled as a continuous discharge using 25 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). The hydrotest discharge characteristics for the selected cases (Trunkline and SURF 2) are summarised in Table 2.5. These cases were chosen to cover the full range of proposed discharge flow rates and depths.

**Table 2.5 Summary of far-field hydrotest discharge modelling assumptions.**

| Parameter | Trunkline Hydrotest Discharge | SURF Hydrotest Discharge 2 |
|---|---|---|
| Hindcast modelling period | 2006-2015 | |
| Seasons | Summer (December to February)<br>Transitional (March and September to November)<br>Winter (April to August)<br>Annual | |
| Flow rate ($m^3/d$) | 795 | 220 |
| Discharge volume ($m^3$) | 232,800 | 6,360 |
| Discharge duration (hours) | 244 | 20 |
| Discharge depth (m) | 930 | 10 |
| Discharge salinity (ppt) | 35 | |
| Discharge temperature (°C) | Ambient (seabed) | Ambient (near-surface) |
| Number of simulations | 75 (25 per season) | |
| Simulated discharge type | One-off | |
| Simulated discharge period (days) | Discharge duration | |

### 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.

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 5 m x 5 m to track the movement and fate of the discharge plume. The extent of the grid region measured approximately 5 km (longitude or x-axis) by 5 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 Background

The area of interest for this study is typified by strong tidal flows over the shallower regions, particularly along the inshore region of the North West Shelf and among the island groups stretching from the Dampier Archipelago to the North West Cape. 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 slicks 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 pollutants can be variably affected by combinations of tidal, wind-induced and density-induced drift currents. Depending on their local influence, it is critical 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 of pollutants. As measured current data is not available for simultaneous periods over a network of locations covering the wide area of this study, 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 mesoscale ocean models, with estimates of the tidal currents generated by an RPS model set up for the study area.

#### 2.2.5.2 Mesoscale Circulation Model

Representation of the drift currents that affect the area were available from the output of the BRAN (Bluelink ReANalysis; Oke *et al.*, 2008, 2009; Schiller *et al.*, 2008) ocean model, which is sponsored by the Australian Government through the Commonwealth Bureau of Meteorology (BoM), Royal Australian Navy, and Commonwealth Scientific and Industrial Research Organisation (CSIRO). BRAN is a data-assimilative, three-dimensional ocean model that has been run as a hindcast for many periods and is now used for ocean forecasting (Schiller *et al.*, 2008).

The BRAN predictions for drift currents are produced at a horizontal spatial resolution of approximately 0.1° over the region, at a frequency of once per day, averaged over the 24-hour period. Hence, the BRAN model data provides estimates of mesoscale circulation with horizontal resolution suitable to resolve eddies of a few tens of kilometres' diameter, as well as connecting stream currents of similar spatial scale. Drift currents that are represented over the inner shelf waters in the BRAN data are principally attributable to wind induced drift.

There are several versions of the BRAN database available. The latest BRAN simulation spans the period of January 1994 to August 2016. From this database, time series of current speed and direction were extracted for all points in the model domain for the years 2006-2015 (inclusive). The data was assumed to be a suitably representative sample of the current conditions over the study area for future years.

Figure 2.2 shows the seasonal distribution of current speeds and directions for the BRAN data point closest to the FPU location. Note that the convention for defining current direction is the direction towards which the current flows.

The data shows that current speeds and directions vary between seasons. In general, during transitional months (March and September to November) currents have the strongest average speed (0.22 m/s with a maximum of 0.56 m/s) and tend to flow south-east. During winter (April to August), current flow conditions are more variable, with lower average speed (0.21 m/s with a maximum of 0.53 m/s). During summer (December to February), the current flow occurs in a predominantly south/south-westerly direction with the lowest average speed (0.20 m/s with a maximum of 0.46 m/s).

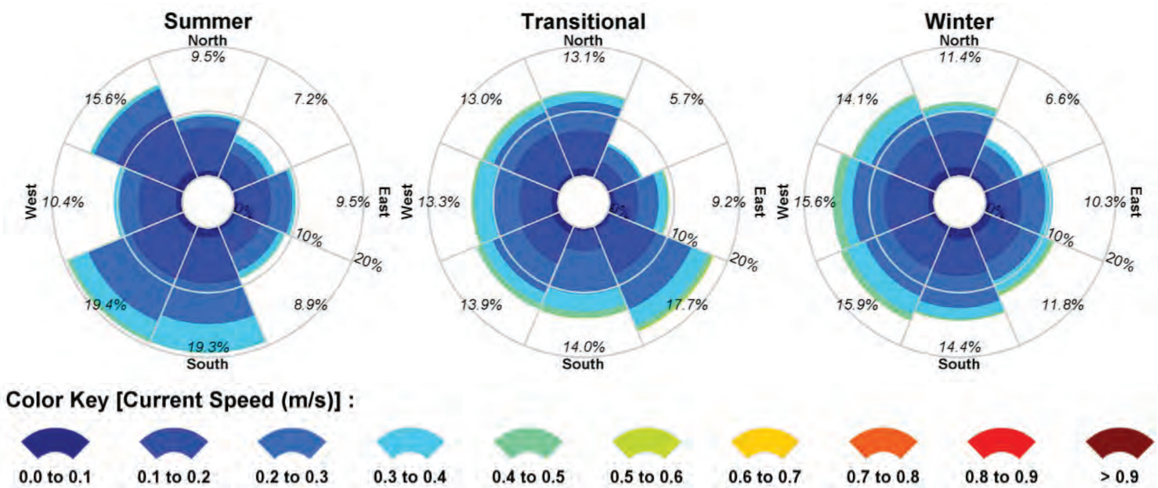


**Figure 2.2 Seasonal current distribution (2006-2015, inclusive) derived from the BRAN database near to the proposed FPU location. The colour key shows the current magnitude, the compass direction provides the direction towards which the current is flowing, and the size of the wedge gives the percentage of the record.**

## 2.2.5.3 Tidal Circulation Model

As the BRAN 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, 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).

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 2.3).

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 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.

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.

For the purpose of verification of the tidal 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 40 tidal stations within the HYDROMAP model domain, ten were used for comparison.

Water level time series for these locations are shown in Figure 2.4 for a one-month period (January 2005). 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.

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 2.5. 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.

Figure 2.6 shows the seasonal distribution of current speeds and directions for the HYDROMAP data point closest to the FPU location. Note that the convention for defining current direction is the direction towards which the current flows.

The current data indicates cyclical tidal flow directions along a northeast-southwest axis, with maximum speeds of around 0.09 m/s.

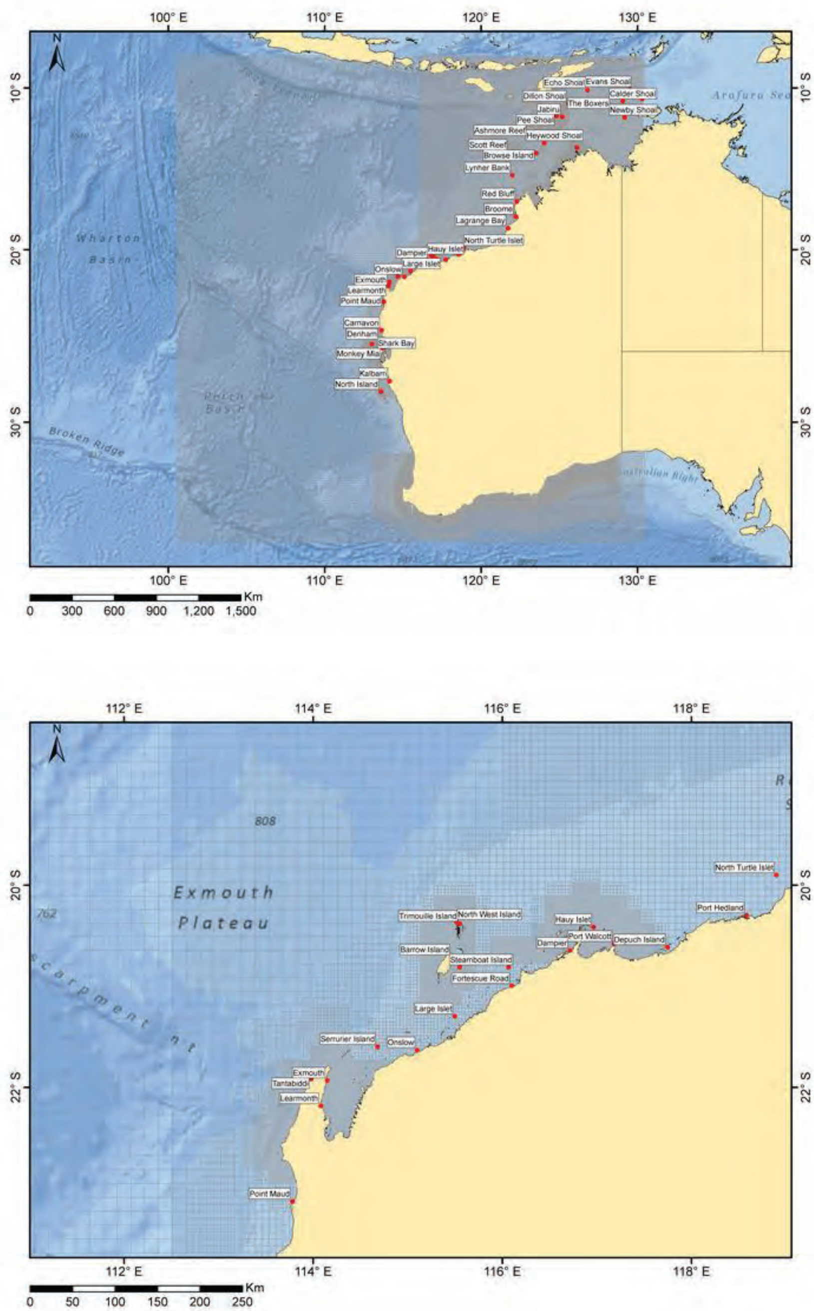


**Figure 2.3** **Hydrodynamic model grid (grey wire mesh) used to generate the tidal currents, showing locations available for tidal comparisons (red labelled dots). The top panel shows the full domain in context with the continental land mass, while the bottom panel shows a zoomed subset near the discharge locations. Higher-resolution areas are indicated by the denser mesh zones.**

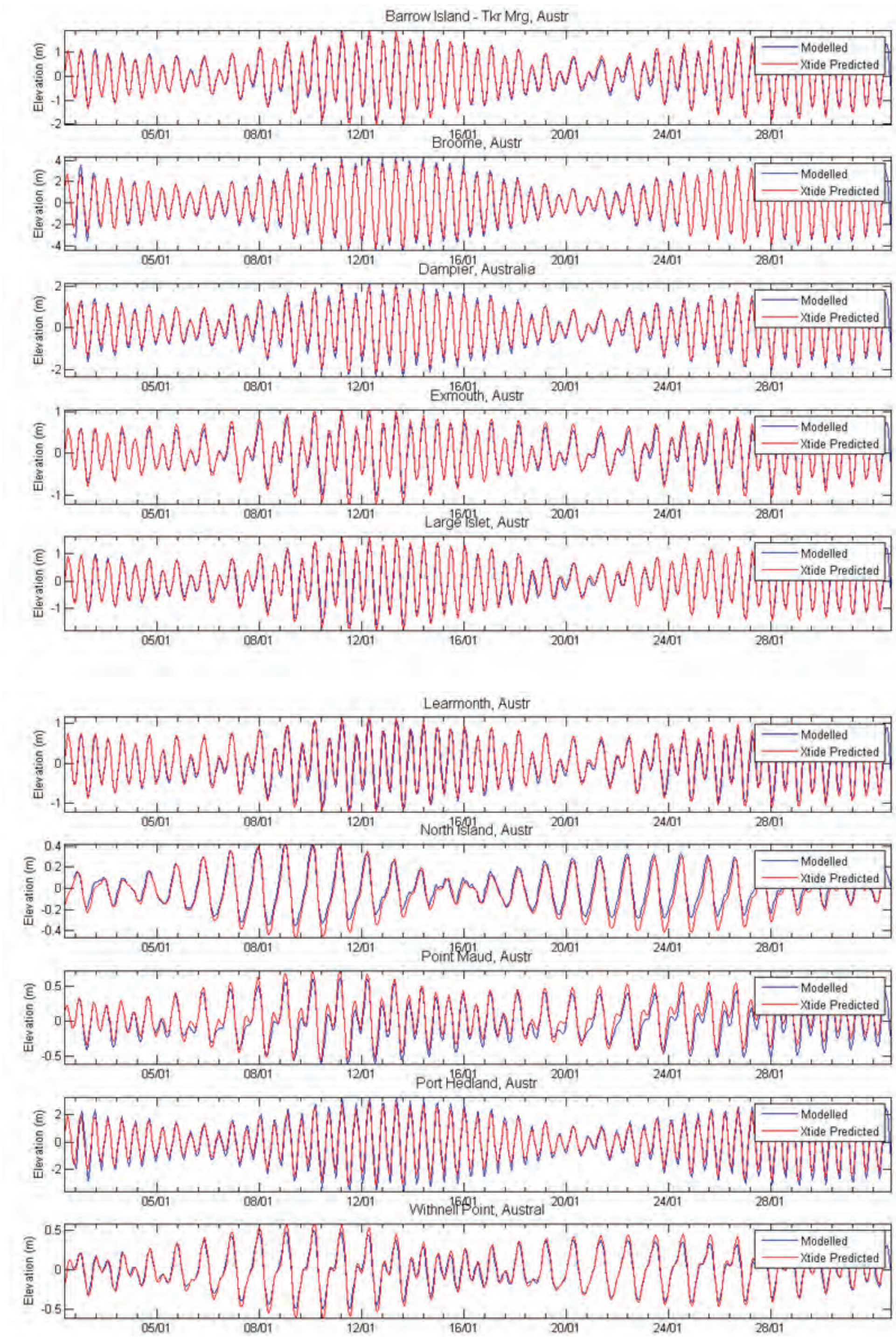


**Figure 2.4 Comparisons between the predicted (blue line) and observed (red line) surface elevation variations at ten locations in the tidal model domain for January 2005.**

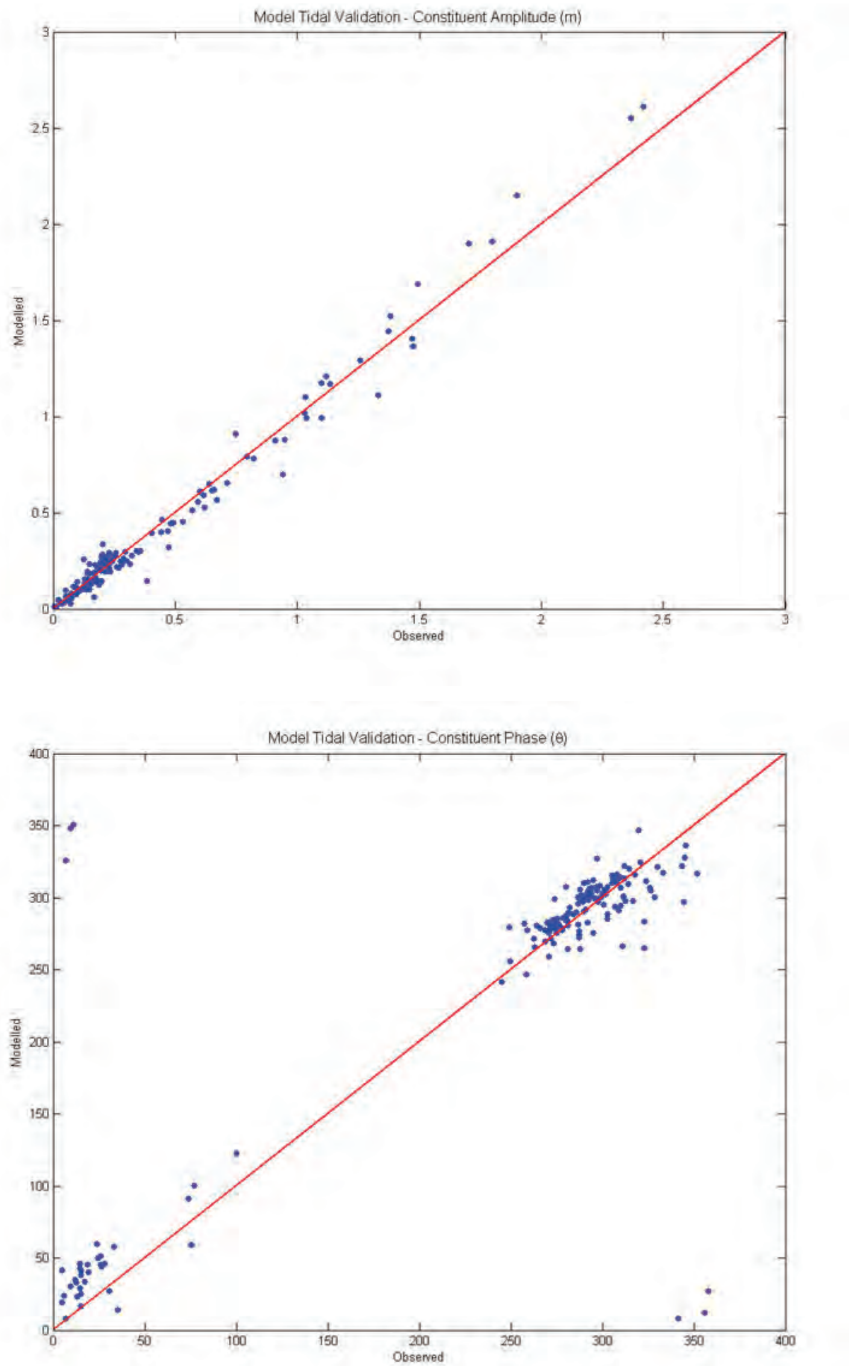


**Figure 2.5** **Comparisons between modelled and observed tidal constituent amplitudes (top) and phases (bottom) at all stations in the HYDROMAP model domain. The red line indicates a 1:1 correlation between the modelled and observed data.**

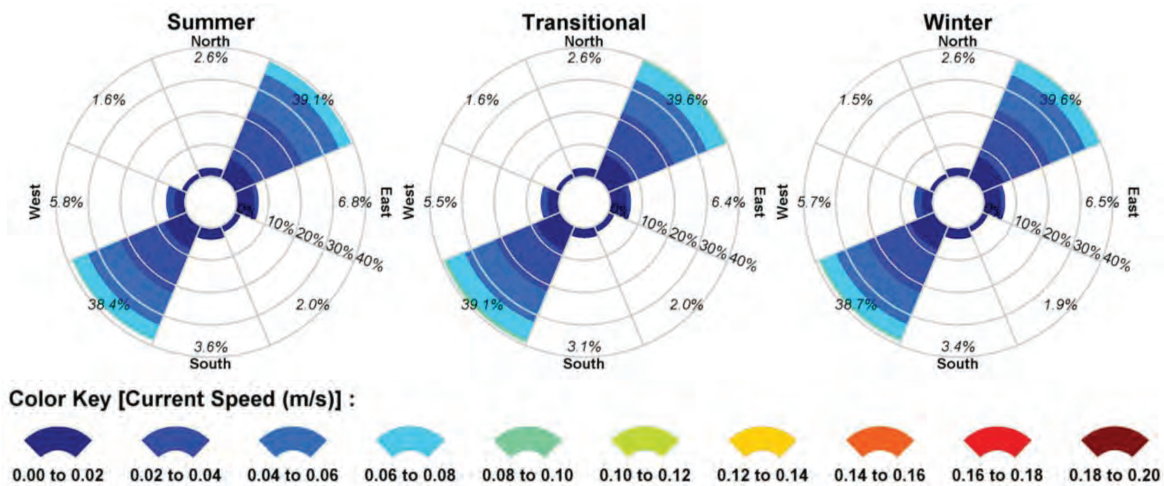


**Figure 2.6** **Seasonal current distribution (2006-2015, inclusive) derived from the HYDROMAP database near to the proposed FPU location. The colour key shows the current magnitude, the compass direction provides the direction towards which the current is flowing, and the size of the wedge gives the percentage of the record.**

# 3 MODELLING RESULTS

## 3.1 Near-Field Modelling

### 3.1.1 Overview

In the following sections, information for each of the modelled discharge cases is presented first in a table summarising the predicted plume characteristics in the near-field mixing zone under varying current speeds, and then in further tables summarising the concentrations of biocide at the end of the near-field mixing zone, the concentration threshold, and the amount of dilution for each season and for the annual period. 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 3.12 (note the differing x-axis and y-axis aspect ratios) show the change in average dilution and temperature of the plume under varying discharge rates (795 $m^3$/hr and 220 $m^3$/hr), depths (930 m and 10 m), seasonal conditions (summer, transitional, winter and annual) 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 930 m (Cases 1 and 2) and 10 m (Case 3) below the water surface. The surface discharges are shown to increase the extent of the turbulent mixing zone. Following this initial mixing, the near neutrally-buoyant plumes are predicted to travel laterally in the water column. For Cases 1 and 2, the plumes are predicted to remain close to the seabed. For Case 3, the plume is predicted to plunge up to 19 m below the sea surface depending on season. For Cases 2 and 3, increased ambient current strengths are shown to increase the horizontal distance travelled by the plumes from the discharge point.

Table 3.1, Table 3.6 and Table 3.11 show the predicted plume characteristics for the varying discharge flow rates, depths, seasonal conditions and current speeds. The plume will reach a maximum horizontal distance of between 7 m and 152 m before reaching the trapping depth.

The diameter of the plume at the end of the near-field zone ranged from 10 m to 23 m. Increases in current speed serve to restrict the diameter of the plume.

For most combinations of season, flow rate and discharge depth, 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, Table 3.6 and Table 3.11). The average dilution levels of the plume upon reaching the trapping depth under medium and strong currents are predicted to be 1:90 and 1:81 for Case 1, 1:465 and 1:629 for Case 2, and 1:482 and 1:641 for Case 3, respectively. Note that predictions of dilution 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 Case 1 (Section 3.1.2.1; Table 3.2 to Table 3.5), Case 2 (Section 3.1.2.2; Table 3.7 to Table 3.10) and Case 3 (Section 3.1.2.3; Table 3.12 to Table 3.15) discharges indicate that the biocide constituent of the hydrotest discharge is not expected to reach the required levels of dilution in the near-field mixing zone.

## 3.1.2 Results – Tables and Figures

### 3.1.2.1 Discharge Case 1: Trunkline Hydrotest Discharge at 930 m Depth

**Table 3.1 Predicted plume characteristics at the end of the near-field mixing zone for the trunkline hydrotest discharge for each season and current speed.**

| Season | Surface Current Speed (m/s) | Plume Diameter (m) at Depth [m] | Plume Temperature (°C) | Plume-Ambient Temperature Difference (°C) | Plume Dilution (1:x) | | Maximum Horizontal Distance (m) |
|---|---|---|---|---|---|---|---|
| | | | | | Minimum | Average | |
| Summer | Weak (0.04) | 10.0 [925.0] | 5.74 | 0.00 | 52 | 97 | 23.8 |
| | Medium (0.16) | 10.0 [925.0] | 5.74 | 0.00 | 52 | 90 | 21.1 |
| | Strong (0.33) | 10.0 [925.0] | 5.74 | 0.00 | 55 | 81 | 18.1 |
| Transitional | Weak (0.05) | 10.0 [925.0] | 5.71 | 0.00 | 52 | 97 | 23.7 |
| | Medium (0.18) | 10.0 [925.0] | 5.71 | 0.00 | 53 | 90 | 21.0 |
| | Strong (0.38) | 10.0 [925.0] | 5.71 | 0.00 | 54 | 78 | 17.2 |
| Winter | Weak (0.04) | 10.0 [925.0] | 5.76 | 0.00 | 52 | 97 | 23.8 |
| | Medium (0.17) | 10.0 [925.0] | 5.76 | 0.00 | 53 | 90 | 21.1 |
| | Strong (0.40) | 10.0 [925.0] | 5.76 | 0.00 | 54 | 80 | 17.6 |
| Annual | Weak (0.04) | 10.0 [925.0] | 5.73 | 0.00 | 52 | 97 | 23.8 |
| | Medium (0.17) | 10.0 [925.0] | 5.73 | 0.00 | 53 | 90 | 21.0 |
| | Strong (0.37) | 10.0 [925.0] | 5.73 | 0.00 | 55 | 80 | 17.6 |

**Table 3.2 Concentration of biocide at the end of the near-field stage, and the required concentration threshold 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 97, 90 and 81, respectively. Dilution rates highlighted in red indicate that suitable dilution is not achieved during the near-field stage.**

| Contaminant | Source Concentration (ppm) | End of Near-Field Concentration (ppm) | | | Threshold Concentration (ppm) | Required Dilution Factor |
|---|---|---|---|---|---|---|
| | | 5th %ile | 50th %ile | 95th %ile | | |
| | | 97x Dilution | 90x Dilution | 81x Dilution | | |
| Biocide | 550 | 5.7 | 6.1 | 6.8 | 1 | 550 |

**Table 3.3 Concentration of biocide at the end of the near-field stage, and the required concentration threshold 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 97, 90 and 78, respectively. Dilution rates highlighted in red indicate that suitable dilution is not achieved during the near-field stage.**

| Contaminant | Source Concentration (ppm) | End of Near-Field Concentration (ppm) | | | Threshold Concentration (ppm) | Required Dilution Factor |
|---|---|---|---|---|---|---|
| | | 5th %ile | 50th %ile | 95th %ile | | |
| | | 97x Dilution | 90x Dilution | 78x Dilution | | |
| Biocide | 550 | 5.7 | 6.1 | 7.1 | 1 | 550 |

**Table 3.4 Concentration of biocide at the end of the near-field stage, and the required concentration threshold 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 97, 90 and 80, respectively. Dilution rates highlighted in red indicate that suitable dilution is not achieved during the near-field stage.**

| Contaminant | Source Concentration (ppm) | End of Near-Field Concentration (ppm) | | | Threshold Concentration (ppm) | Required Dilution Factor |
|---|---|---|---|---|---|---|
| | | 5th %ile | 50th %ile | 95th %ile | | |
| | | 97x Dilution | 90x Dilution | 80x Dilution | | |
| Biocide | 550 | 5.7 | 6.1 | 6.9 | 1 | 550 |

**Table 3.5 Concentration of biocide at the end of the near-field stage, and the required concentration threshold and number of dilutions for the annual period. Note from Table 3.1 that dilutions at the 5th, 50th and 95th percentile current speeds were 97, 90 and 80, respectively. Dilution rates highlighted in red indicate that suitable dilution is not achieved during the near-field stage.**

| Contaminant | Source Concentration (ppm) | End of Near-Field Concentration (ppm) | | | Threshold Concentration (ppm) | Required Dilution Factor |
|---|---|---|---|---|---|---|
| | | 5th %ile | 50th %ile | 95th %ile | | |
| | | 97x Dilution | 90x Dilution | 80x Dilution | | |
| Biocide | 550 | 5.7 | 6.1 | 6.9 | 1 | 550 |

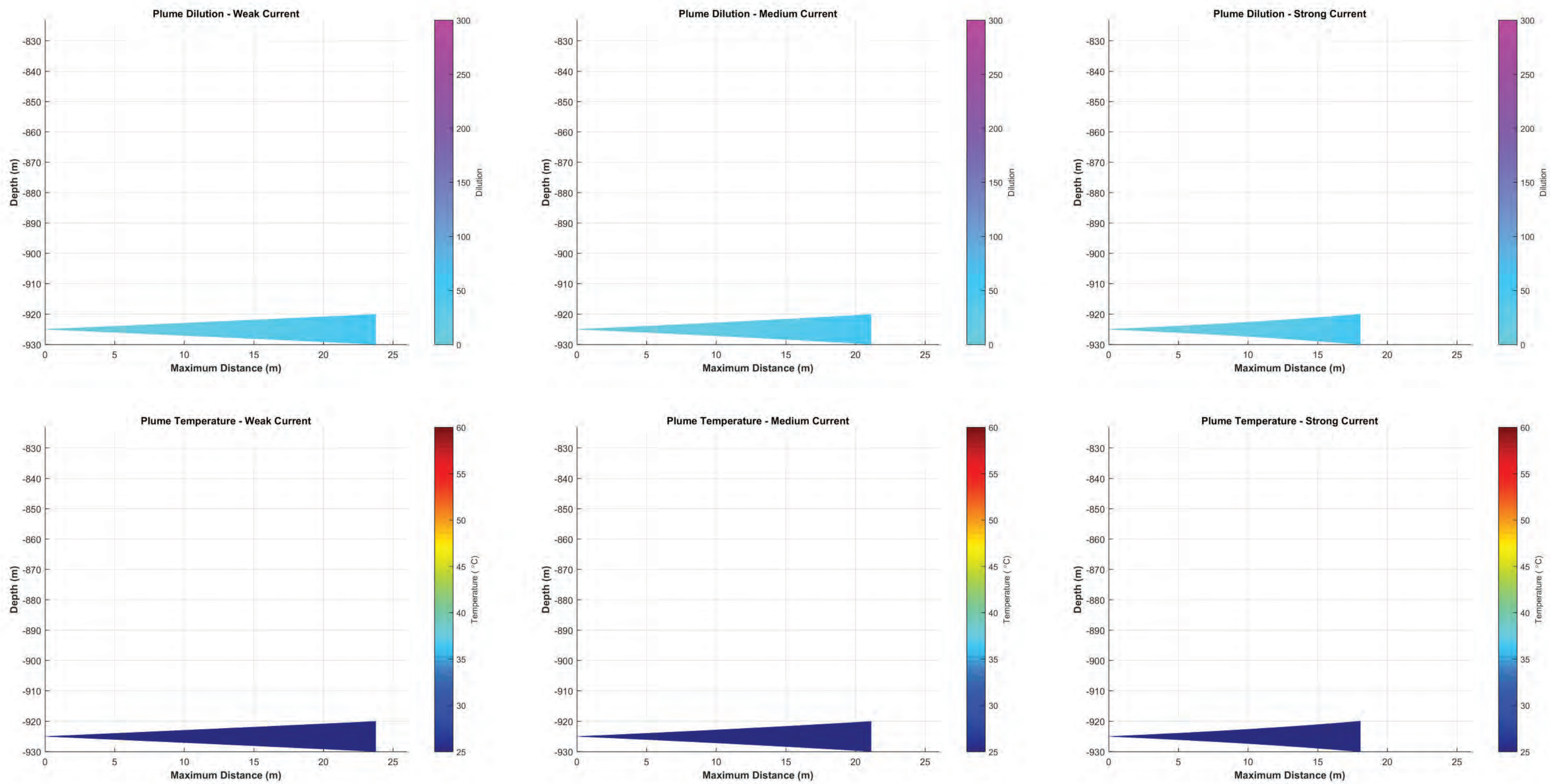


**Figure 3.1 Near-field average dilution and temperature results for constant weak, medium and strong summer currents (930 m depth discharge at 795 $m^3/hr$ flow rate).**

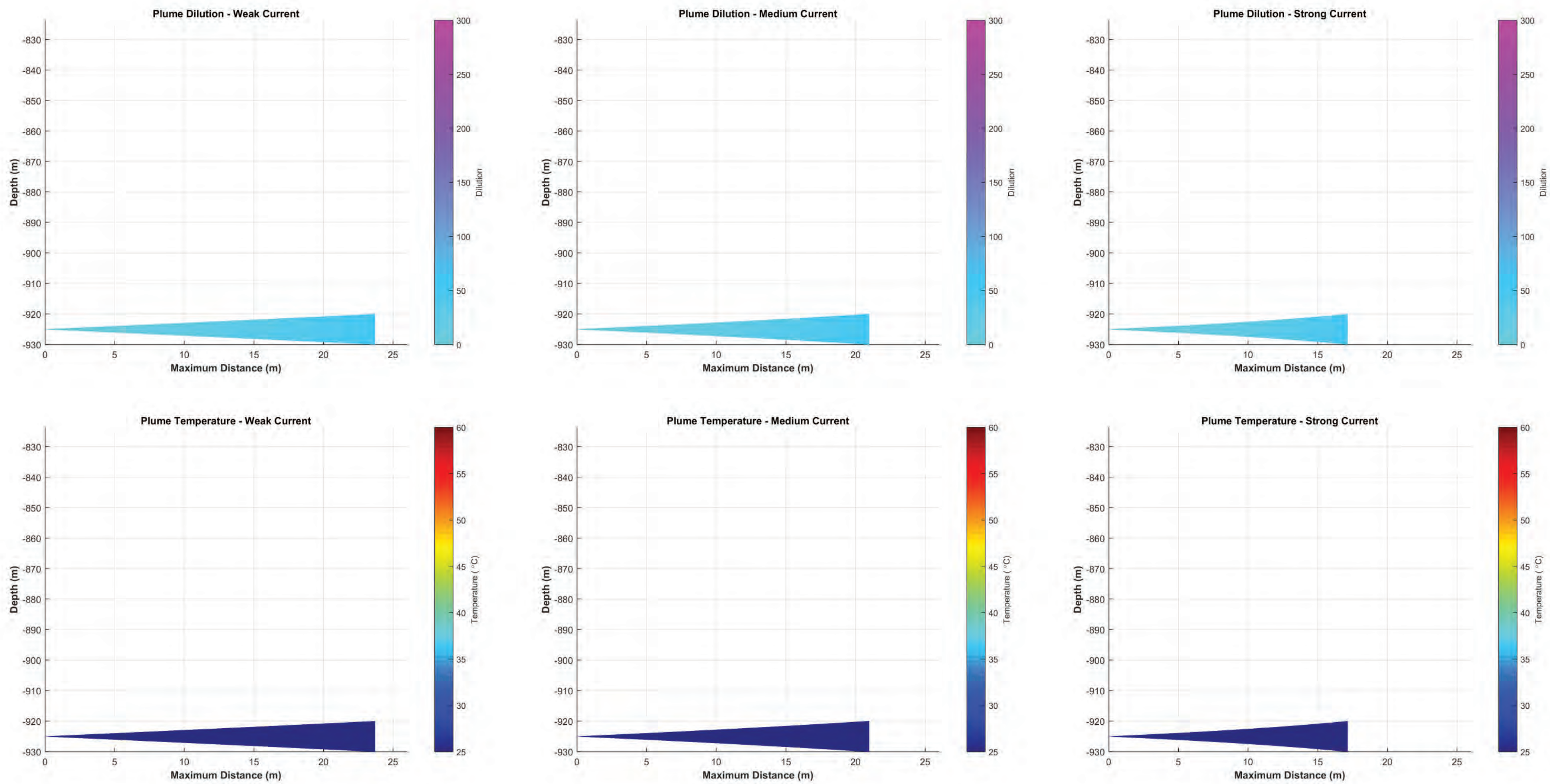


**Figure 3.2 Near-field average dilution and temperature results for constant weak, medium and strong transitional currents (930 m depth discharge at 795 m$^3$/hr flow rate).**

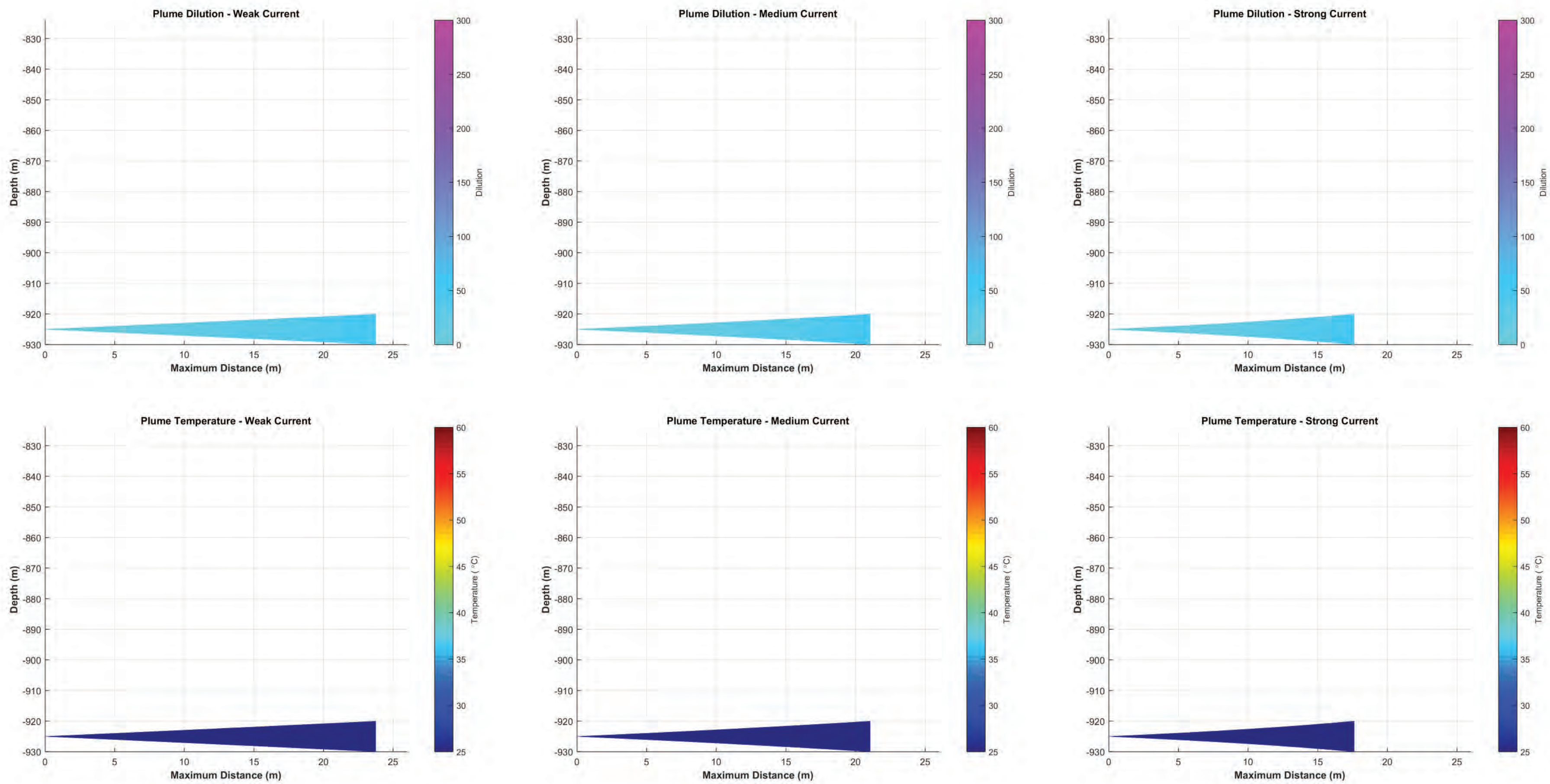


**Figure 3.3 Near-field average dilution and temperature results for constant weak, medium and strong winter currents (930 m depth discharge at 795 $m^3$/hr flow rate).**

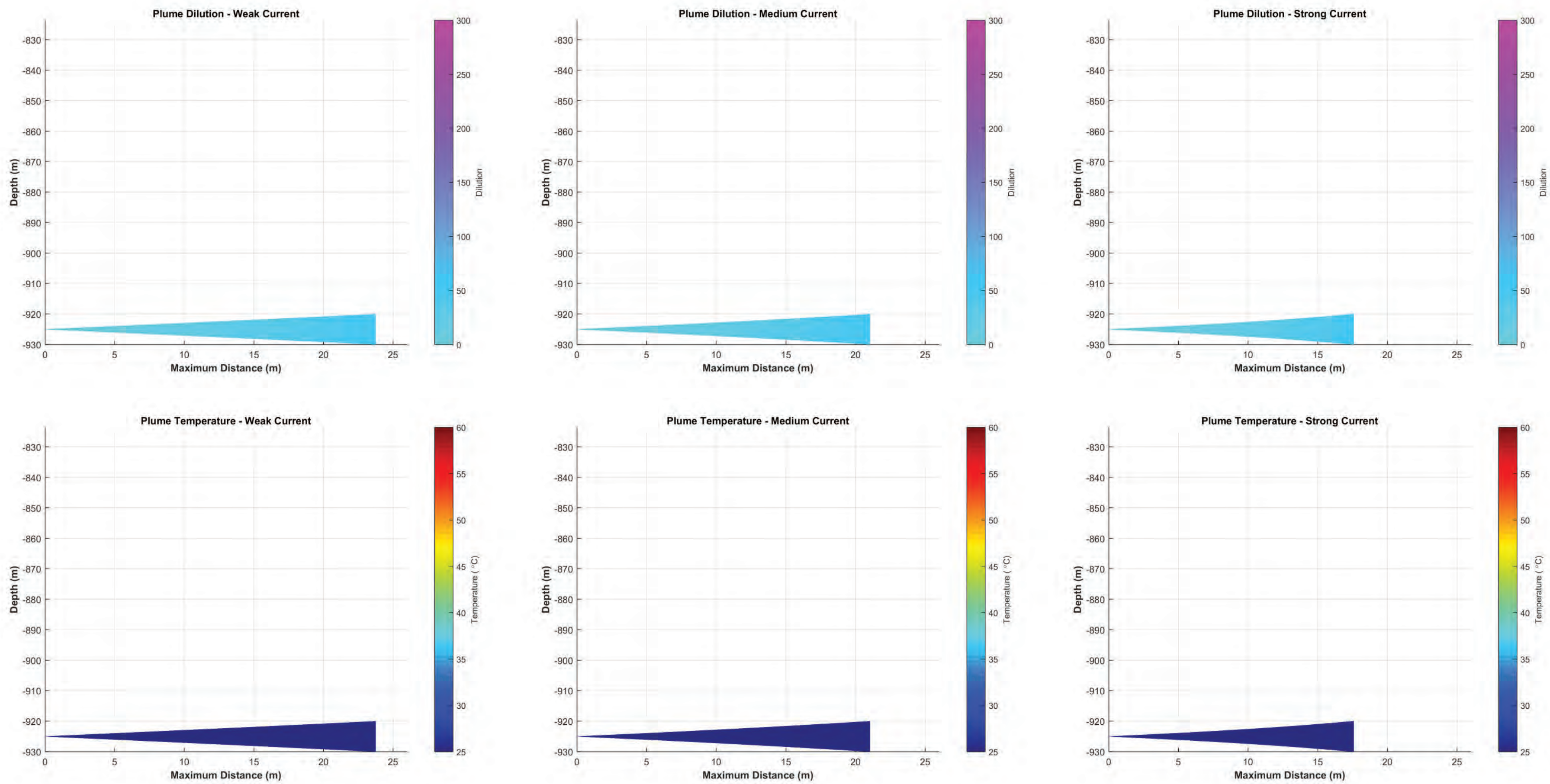


**Figure 3.4 Near-field average dilution and temperature results for constant weak, medium and strong annualised currents (930 m depth discharge at 795 $m^3$/hr flow rate).**

### 3.1.2.2 Discharge Case 2: SURF Hydrotest Discharge at 930 m Depth

**Table 3.6 Predicted plume characteristics at the end of the near-field mixing zone for the SURF hydrotest discharge for each season and current speed.**

| Season | Surface Current Speed (m/s) | Plume Diameter (m) at Depth [m] | Plume Temperature (°C) | Plume-Ambient Temperature Difference (°C) | Plume Dilution (1:x) | | Maximum Horizontal Distance (m) |
|---|---|---|---|---|---|---|---|
| | | | | | Minimum | Average | |
| Summer | Weak (0.04) | 16.4 [910.9] | 6.11 | 0.00 | 85 | 173 | 9.6 |
| | Medium (0.16) | 22.9 [914.2] | 6.10 | 0.00 | 119 | 426 | 35.8 |
| | Strong (0.33) | 18.9 [914.2] | 6.01 | 0.00 | 151 | 581 | 74.7 |
| Transitional | Weak (0.05) | 17.6 [910.3] | 6.07 | 0.00 | 89 | 188 | 11.6 |
| | Medium (0.18) | 22.8 [910.8] | 6.04 | 0.00 | 127 | 465 | 41.9 |
| | Strong (0.38) | 18.4 [914.7] | 5.95 | 0.00 | 163 | 629 | 89.4 |
| Winter | Weak (0.04) | 16.8 [910.5] | 6.11 | 0.00 | 87 | 178 | 10.2 |
| | Medium (0.17) | 22.8 [910.4] | 6.10 | 0.00 | 122 | 443 | 38.7 |
| | Strong (0.40) | 18.8 [914.5] | 6.01 | 0.00 | 159 | 613 | 83.0 |
| Annual | Weak (0.04) | 17.1 [910.9] | 6.09 | 0.00 | 88 | 182 | 10.6 |
| | Medium (0.17) | 22.9 [910.6] | 6.07 | 0.00 | 123 | 448 | 39.2 |
| | Strong (0.37) | 18.7 [914.6] | 5.98 | 0.00 | 159 | 615 | 83.7 |

**Table 3.7 Concentration of biocide at the end of the near-field stage, and the required concentration threshold and number of dilutions for the summer season. Note from Table 3.6 that dilutions at the 5$^{th}$, 50$^{th}$ and 95$^{th}$ percentile current speeds were 173, 426 and 581, respectively. Dilution rates highlighted in red indicate that suitable dilution is not achieved during the near-field stage.**

| Contaminant | Source Concentration (ppm) | End of Near-Field Concentration (ppm) | | | Threshold Concentration (ppm) | Required Dilution Factor |
|---|---|---|---|---|---|---|
| | | 5th %ile | 50th %ile | 95th %ile | | |
| | | 173x Dilution | 426x Dilution | 581x Dilution | | |
| Biocide | 550 | 3.2 | 1.3 | 0.9 | 1 | 550 |

**Table 3.8 Concentration of biocide at the end of the near-field stage, and the required concentration threshold and number of dilutions for the transitional season. Note from Table 3.6 that dilutions at the 5th, 50th and 95th percentile current speeds were 188, 465 and 629, respectively. Dilution rates highlighted in red indicate that suitable dilution is not achieved during the near-field stage.**

| Contaminant | Source Concentration (ppm) | End of Near-Field Concentration (ppm) | | | Threshold Concentration (ppm) | Required Dilution Factor |
|---|---|---|---|---|---|---|
| | | 5th %ile | 50th %ile | 95th %ile | | |
| | | 188x Dilution | 465x Dilution | 629x Dilution | | |
| Biocide | 550 | 2.9 | 1.2 | 0.9 | 1 | 550 |

**Table 3.9 Concentration of biocide at the end of the near-field stage, and the required concentration threshold and number of dilutions for the winter season. Note from Table 3.6 that dilutions at the 5th, 50th and 95th percentile current speeds were 178, 443 and 613, respectively. Dilution rates highlighted in red indicate that suitable dilution is not achieved during the near-field stage.**

| Contaminant | Source Concentration (ppm) | End of Near-Field Concentration (ppm) | | | Threshold Concentration (ppm) | Required Dilution Factor |
|---|---|---|---|---|---|---|
| | | 5th %ile | 50th %ile | 95th %ile | | |
| | | 178x Dilution | 443x Dilution | 613x Dilution | | |
| Biocide | 550 | 3.1 | 1.2 | 0.9 | 1 | 550 |

**Table 3.10 Concentration of biocide at the end of the near-field stage, and the required concentration threshold and number of dilutions for the annual period. Note from Table 3.6 that dilutions at the 5th, 50th and 95th percentile current speeds were 182, 448 and 615, respectively. Dilution rates highlighted in red indicate that suitable dilution is not achieved during the near-field stage.**

| Contaminant | Source Concentration (ppm) | End of Near-Field Concentration (ppm) | | | Threshold Concentration (ppm) | Required Dilution Factor |
|---|---|---|---|---|---|---|
| | | 5th %ile | 50th %ile | 95th %ile | | |
| | | 182x Dilution | 448x Dilution | 615x Dilution | | |
| Biocide | 550 | 3.0 | 1.2 | 0.9 | 1 | 550 |

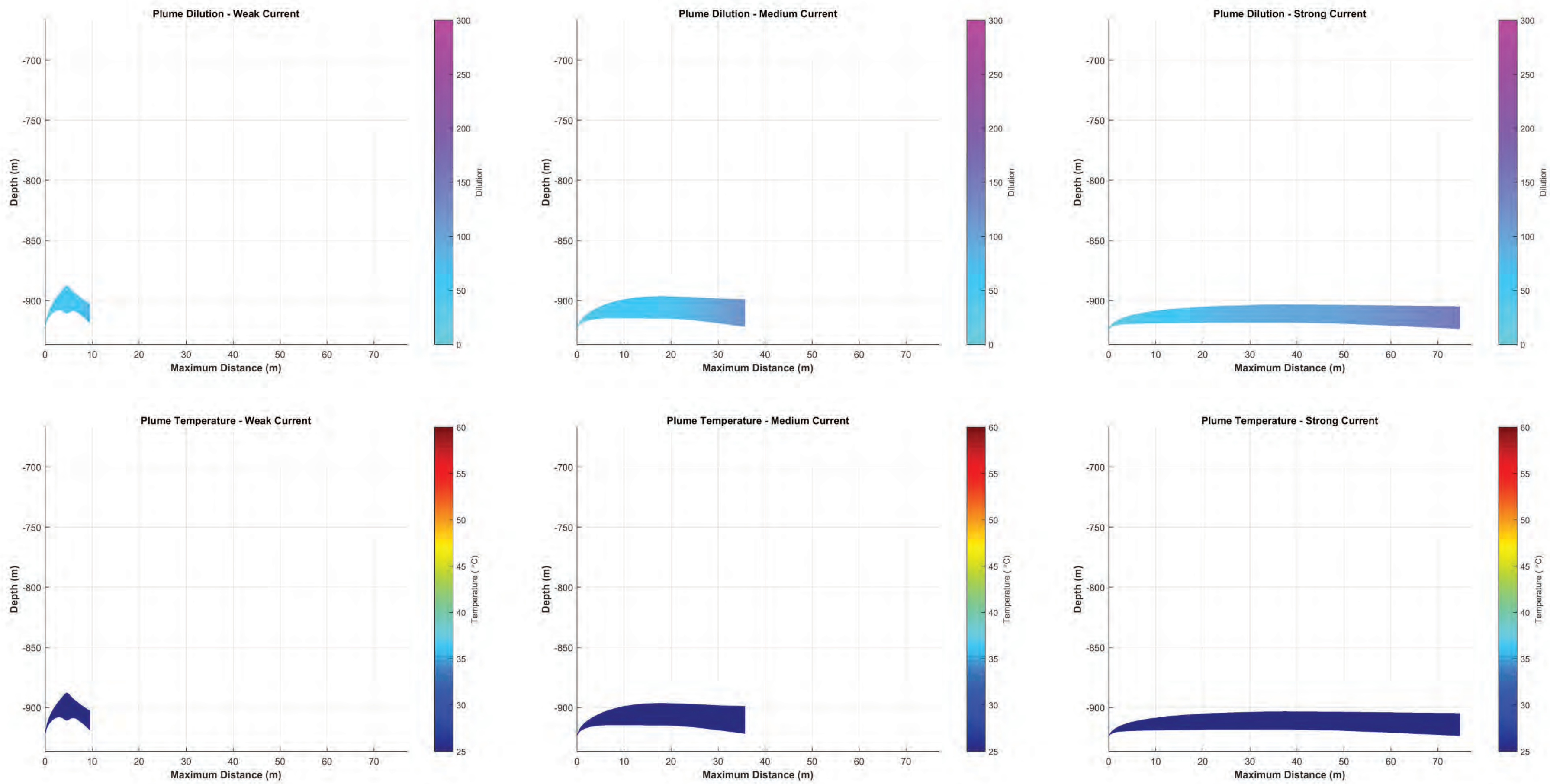


**Figure 3.5** **Near-field average dilution and temperature results for constant weak, medium and strong summer currents (930 m depth discharge at 220 m$^3$/hr flow rate).**

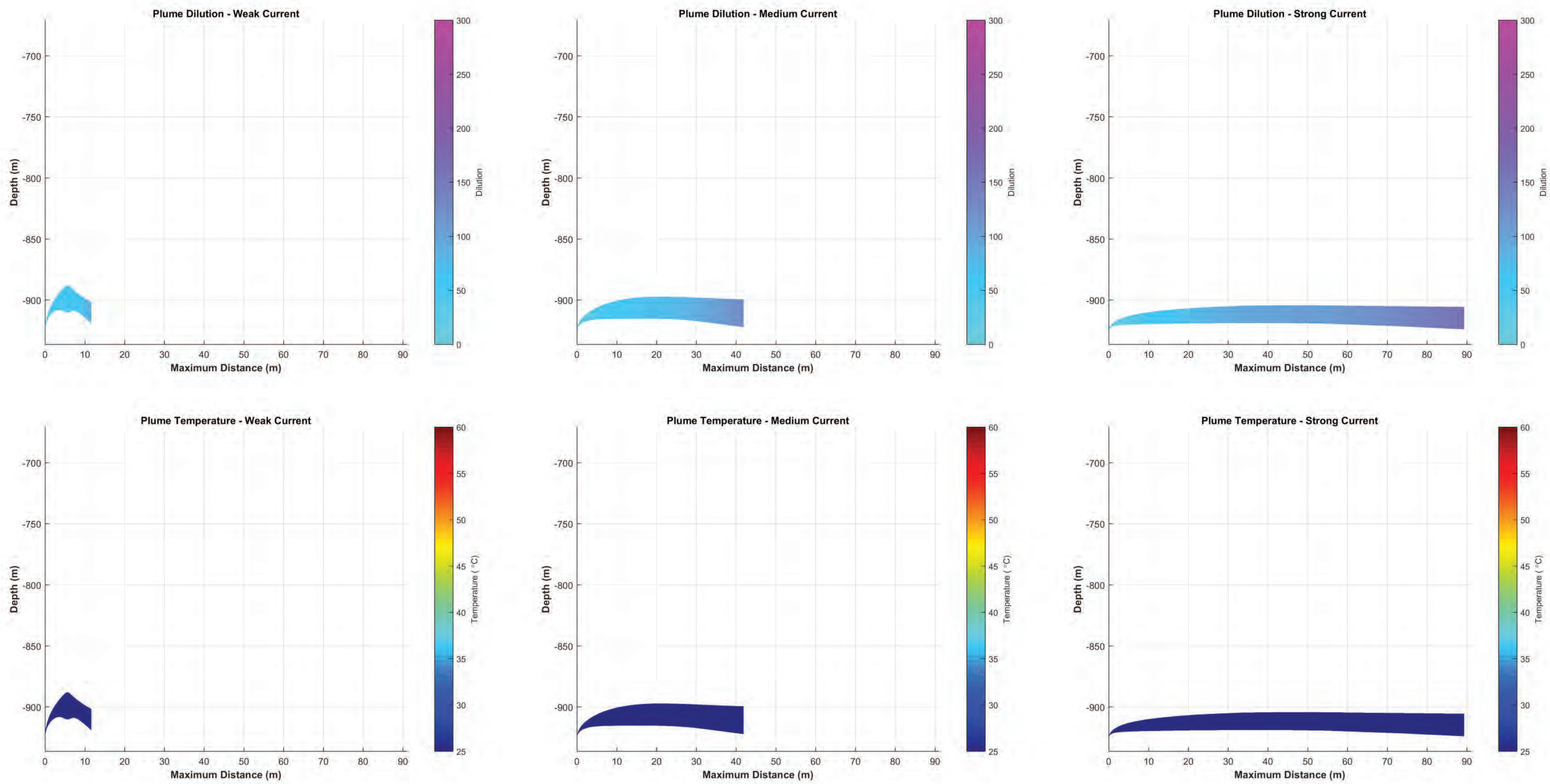


**Figure 3.6 Near-field average dilution and temperature results for constant weak, medium and strong transitional currents (930 m depth discharge at 220 m³/hr flow rate).**

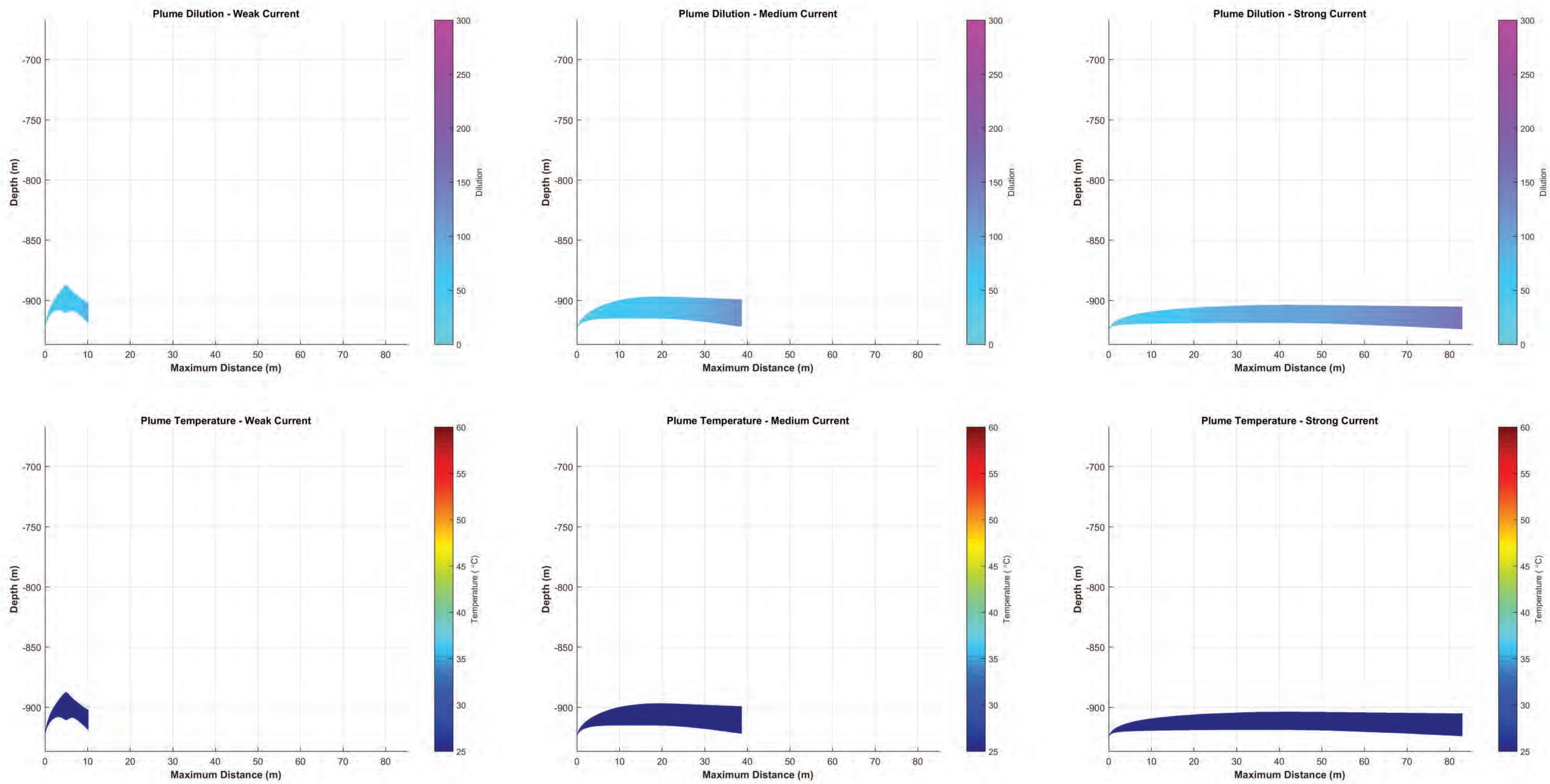


**Figure 3.7 Near-field average dilution and temperature results for constant weak, medium and strong winter currents (930 m depth discharge at 220 m³/hr flow rate).**

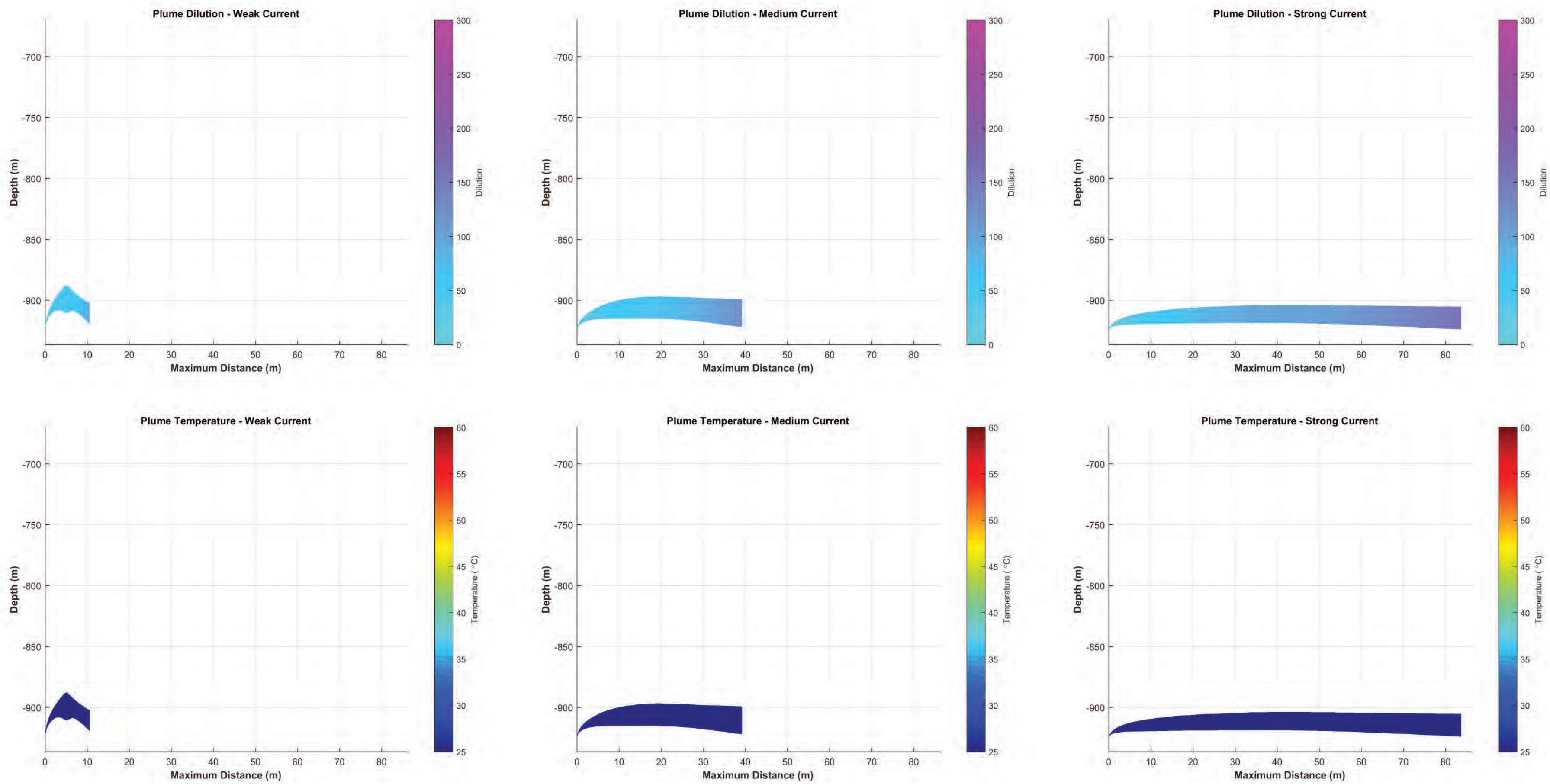


**Figure 3.8** **Near-field average dilution and temperature results for constant weak, medium and strong annualised currents (930 m depth discharge at 220 m$^3$/hr flow rate).**

### 3.1.2.3 Discharge Case 3: SURF Hydrotest Discharge at 10 m Depth

**Table 3.11 Predicted plume characteristics at the end of the near-field mixing zone for the SURF hydrotest discharge for each season and current speed.**

| Season | Surface Current Speed (m/s) | Plume Diameter (m) at Depth [m] | Plume Temperature (°C) | Plume-Ambient Temperature Difference (°C) | Plume Dilution (1:x) | | Maximum Horizontal Distance (m) |
|---|---|---|---|---|---|---|---|
| | | | | | Minimum | Average | |
| Summer | Weak (0.04) | 15.1 [28.9] | 27.40 | 0.00 | 42 | 118 | 7.5 |
| | Medium (0.16) | 12.2 [21.4] | 27.40 | 0.00 | 77 | 229 | 29.7 |
| | Strong (0.33) | 9.8 [18.2] | 27.50 | 0.00 | 101 | 395 | 63.0 |
| Transitional | Weak (0.05) | 16.8 [21.8] | 25.60 | 0.00 | 77 | 211 | 17.3 |
| | Medium (0.18) | 14.8 [17.9] | 25.70 | 0.00 | 128 | 496 | 69.3 |
| | Strong (0.38) | 11.5 [15.6] | 25.70 | 0.00 | 162 | 629 | 144.4 |
| Winter | Weak (0.04) | 16.7 [21.9] | 26.00 | 0.00 | 77 | 207 | 16.8 |
| | Medium (0.17) | 14.8 [18.2] | 26.00 | 0.00 | 125 | 482 | 65.8 |
| | Strong (0.40) | 11.3 [15.5] | 26.10 | 0.00 | 165 | 641 | 151.7 |
| Annual | Weak (0.04) | 16.4 [22.1] | 26.20 | 0.00 | 76 | 201 | 16.2 |
| | Medium (0.17) | 14.9 [18.3] | 26.20 | 0.00 | 124 | 480 | 64.9 |
| | Strong (0.37) | 11.5 [15.6] | 26.30 | 0.00 | 162 | 629 | 143.2 |

**Table 3.12 Concentration of biocide at the end of the near-field stage, and the required concentration threshold and number of dilutions for the summer season. Note from Table 3.11 that dilutions at the 5$^{th}$, 50$^{th}$ and 95$^{th}$ percentile current speeds were 118, 229 and 395, respectively. Dilution rates highlighted in red indicate that suitable dilution is not achieved during the near-field stage.**

| Contaminant | Source Concentration (ppm) | End of Near-Field Concentration (ppm) | | | Threshold Concentration (ppm) | Required Dilution Factor |
|---|---|---|---|---|---|---|
| | | 5th %ile | 50th %ile | 95th %ile | | |
| | | 118x Dilution | 229x Dilution | 395x Dilution | | |
| Biocide | 550 | 4.7 | 2.4 | 1.4 | 1 | 550 |

Table 3.13 Concentration of biocide at the end of the near-field stage, and the required concentration threshold and number of dilutions for the transitional season. Note from Table 3.11 that dilutions at the 5th, 50th and 95th percentile current speeds were 211, 496 and 629, respectively. Dilution rates highlighted in red indicate that suitable dilution is not achieved during the near-field stage.

| Contaminant | Source Concentration (ppm) | End of Near-Field Concentration (ppm) | | | Threshold Concentration (ppm) | Required Dilution Factor |
|---|---|---|---|---|---|---|
| | | 5th %ile | 50th %ile | 95th %ile | | |
| | | 211x Dilution | 496x Dilution | 629x Dilution | | |
| Biocide | 550 | 2.6 | 1.1 | 0.9 | 1 | 550 |

Table 3.14 Concentration of biocide at the end of the near-field stage, and the required concentration threshold and number of dilutions for the winter season. Note from Table 3.11 that dilutions at the 5th, 50th and 95th percentile current speeds were 207, 482 and 641, respectively. Dilution rates highlighted in red indicate that suitable dilution is not achieved during the near-field stage.

| Contaminant | Source Concentration (ppm) | End of Near-Field Concentration (ppm) | | | Threshold Concentration (ppm) | Required Dilution Factor |
|---|---|---|---|---|---|---|
| | | 5th %ile | 50th %ile | 95th %ile | | |
| | | 207x Dilution | 482x Dilution | 641x Dilution | | |
| Biocide | 550 | 2.7 | 1.1 | 0.9 | 1 | 550 |

Table 3.15 Concentration of biocide at the end of the near-field stage, and the required concentration threshold and number of dilutions for the annual period. Note from Table 3.11 that dilutions at the 5th, 50th and 95th percentile current speeds were 201, 480 and 629, respectively. Dilution rates highlighted in red indicate that suitable dilution is not achieved during the near-field stage.

| Contaminant | Source Concentration (ppm) | End of Near-Field Concentration (ppm) | | | Threshold Concentration (ppm) | Required Dilution Factor |
|---|---|---|---|---|---|---|
| | | 5th %ile | 50th %ile | 95th %ile | | |
| | | 201x Dilution | 480x Dilution | 629x Dilution | | |
| Biocide | 550 | 2.7 | 1.1 | 0.9 | 1 | 550 |

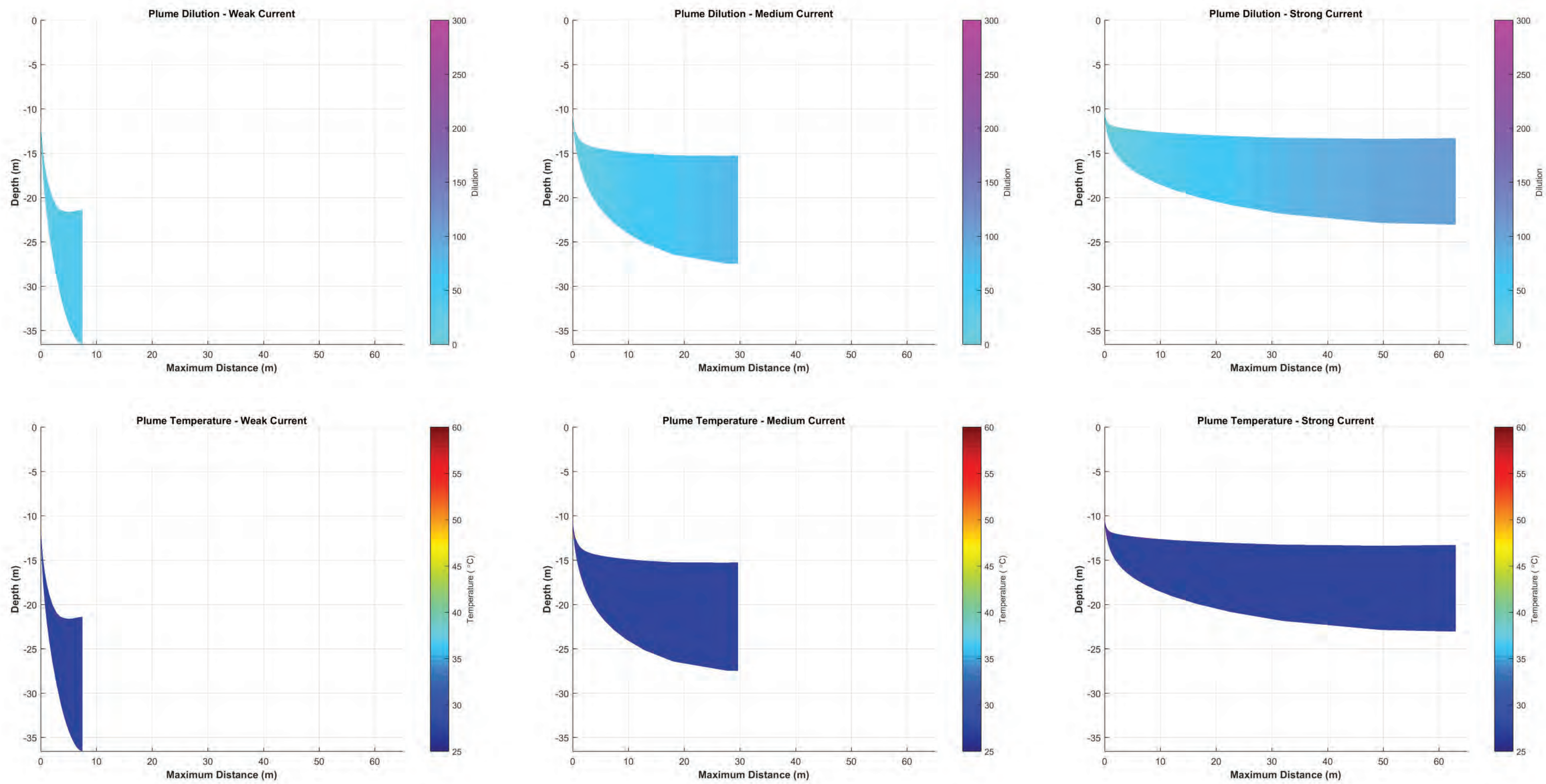


**Figure 3.9 Near-field average dilution and temperature results for constant weak, medium and strong summer currents (10 m depth discharge at 220 m$^3$/hr flow rate).**

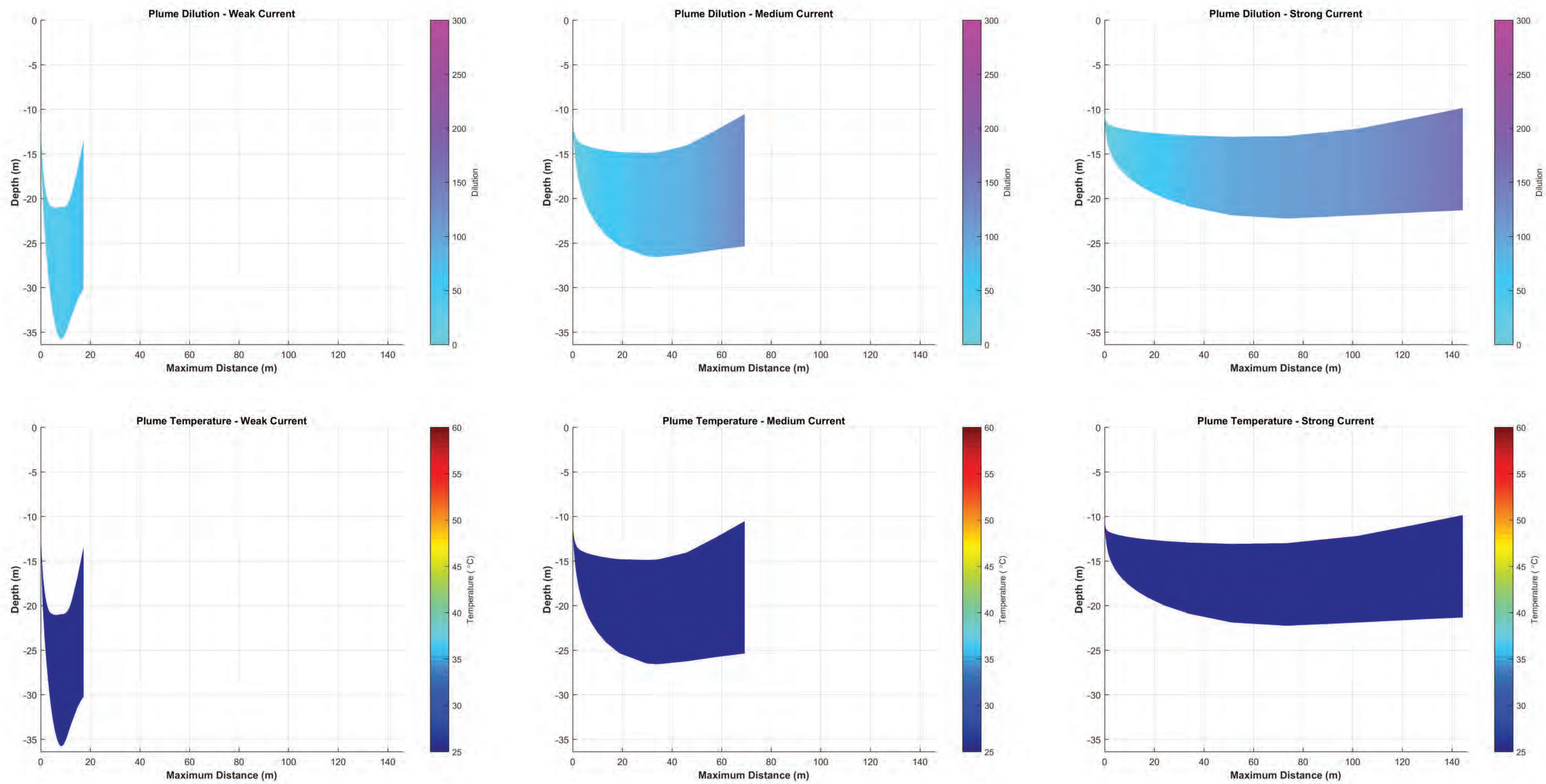


**Figure 3.10 Near-field average dilution and temperature results for constant weak, medium and strong transitional currents (10 m depth discharge at 220 $m^3$/hr flow rate).**

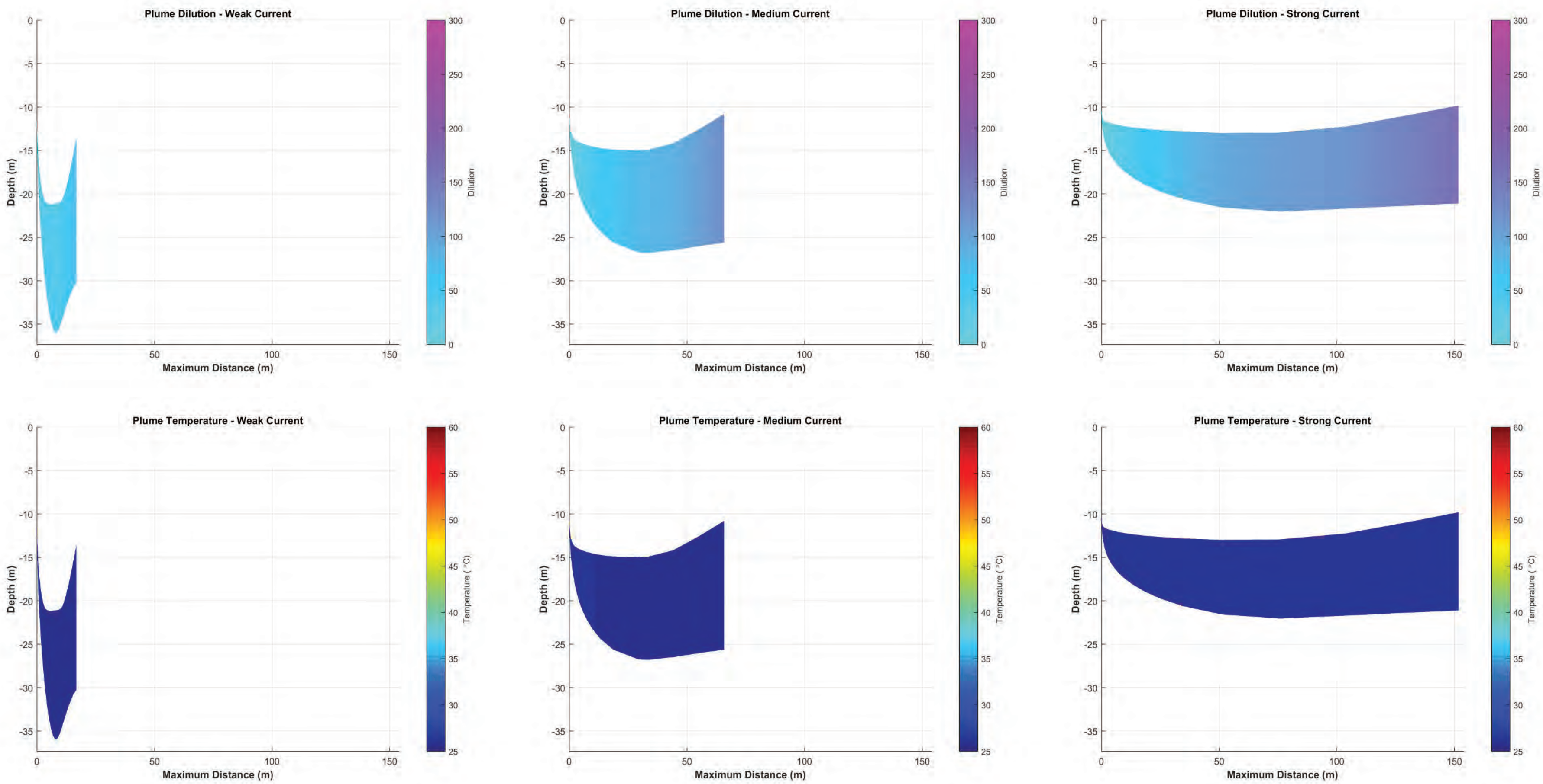


**Figure 3.11 Near-field average dilution and temperature results for constant weak, medium and strong winter currents (10 m depth discharge at 220 m$^3$/hr flow rate).**

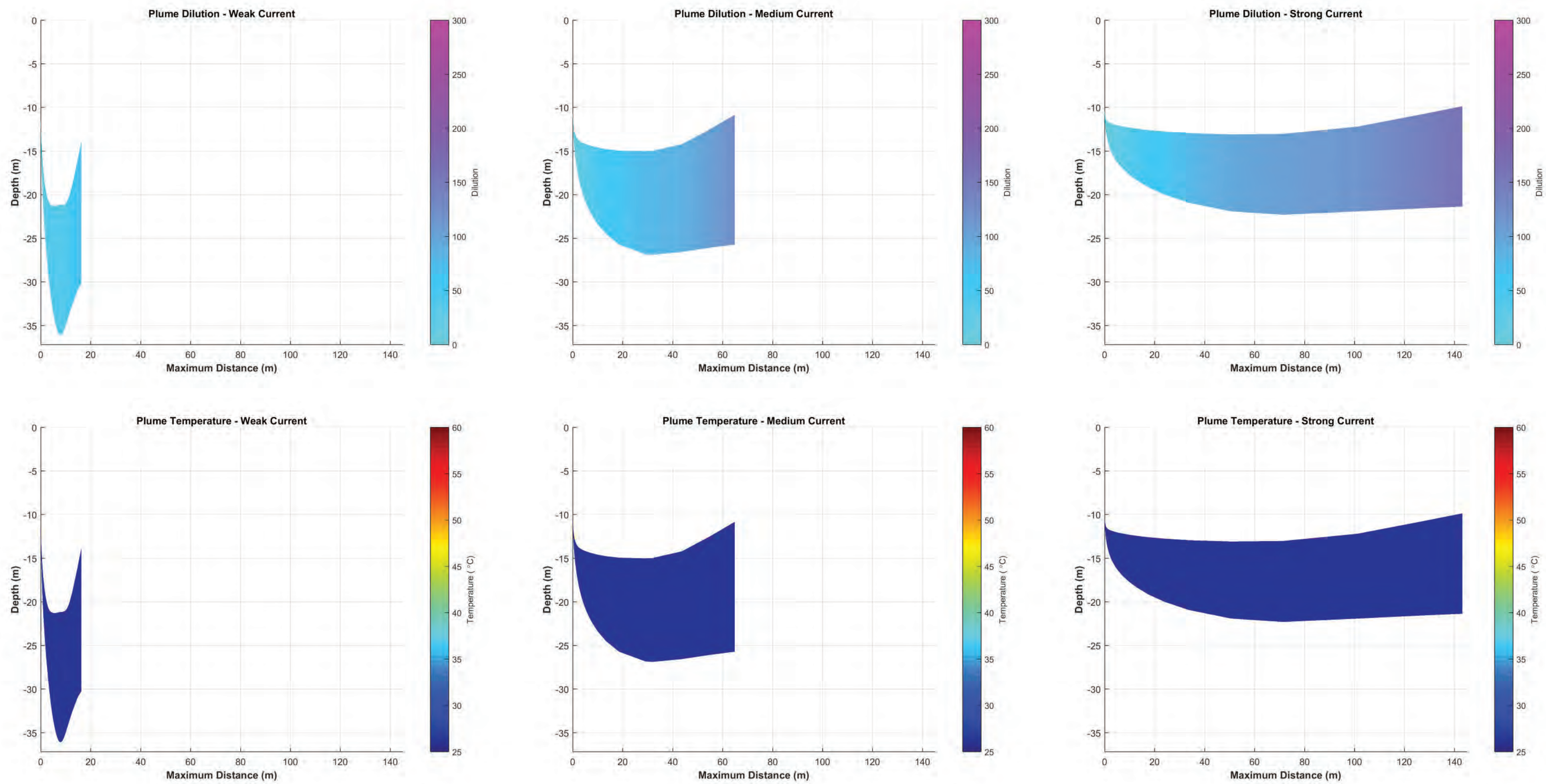


**Figure 3.12 Near-field average dilution and temperature results for constant weak, medium and strong annualised currents (10 m depth discharge at 220 $m^3$/hr flow rate).**

## 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 Interpretation of Percentile Dilution Contours

For each of the modelled discharge cases, the results for all simulations were combined and a statistical analysis performed to produce percentile contours of dilution. In the following sections, outcomes based on 95$^{th}$ and 99$^{th}$ percentile dilution contours are presented.

Calculation of 95$^{th}$ and 99$^{th}$ percentile statistics is a common approach to assessing the impact of dispersing plumes and captures the variability in outcomes, for all but the most ephemeral of forcing conditions, in the data set under consideration. Impact assessment criteria for water quality are often defined using similar statistical indicators.

Note that the percentile figures do not represent the location of a plume at any point in time; they are a statistical and spatial summary of the percentage of time that particular dilution values occur across all replicate simulations and time steps. For example, if the 95$^{th}$ percentile minimum dilution at a particular location in the model domain is predicted as a value of 100, this means that for 95% of the time the dilution level will be higher than 100 and for only 5% of the time the dilution level will be lower than 100. A comparison of the plume extents shown in Figure 3.13 with those shown in Sections 3.2.4 and 3.2.5 demonstrates the significant difference between an instantaneous snapshot and a cumulative estimate of coverage over several days and many individual simulations.

Dilution contours are calculated from the ratios of dispersing contaminant concentrations in the receiving waters to the initial concentration of the contaminant in the discharge. Note that this assumes the background concentration of the constituent in the receiving waters is zero and there is no significant biodegradation of the discharged constituent over the short duration of the dispersion process.

Table 3.16 summarises the initial concentrations of biocide, as specified, and the equivalent dispersed concentrations required to yield particular dilution levels (1:100, 1:200 and 1:400). These concentrations may be useful to consider when interpreting the contour plots of percentile dilutions.

**Table 3.16 Initial concentrations of biocide and equivalent concentrations at example dilution levels.**

| Biocide Parameter | Biocide Concentration (mg/L) |
|---|---|
| Initial concentration in discharge | 550.0 |
| Initial concentration in receiving waters | 0.0 |
| Concentration at 1:100 dilution | 5.5 |
| Concentration at 1:200 dilution | 2.75 |
| Concentration at 1:400 dilution | 1.375 |

### 3.2.3 General Observations

Figure 3.13 shows example time series snapshots of predicted dilutions during a single simulation at 3-hour intervals from 04:00 to 19:00 on 4$^{th}$ February 2010. This simulation – selected merely to be representative of typical conditions – considers the Case 1 flow rate of 795 $m^3$/d at 930 m BMSL. 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.

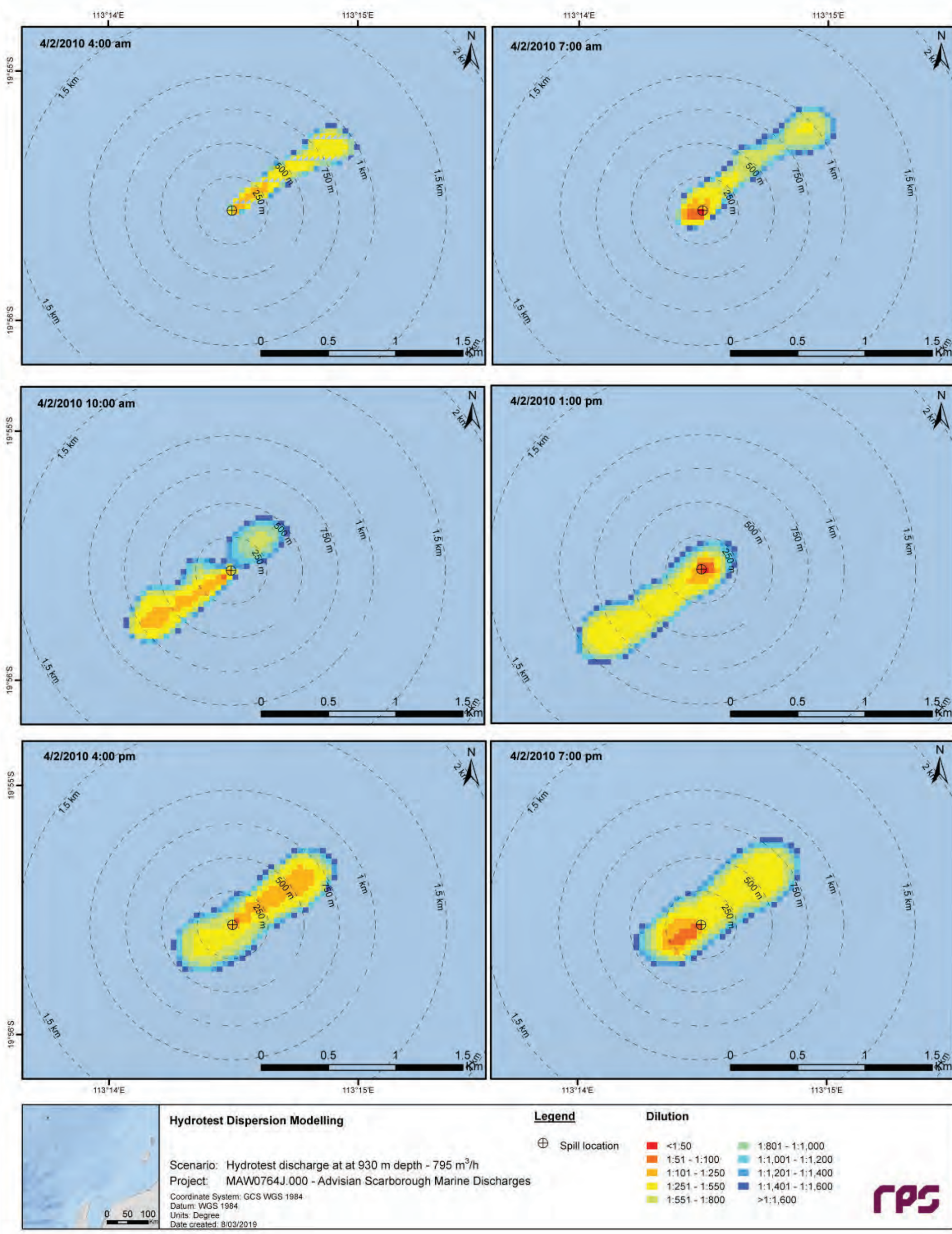


**Figure 3.13 Snapshots of predicted dilution levels, at 3-hour intervals from 04:00 to 19:00 on 4th February 2010, for Case 1 (930 m depth discharge at 795 $m^3$/hr flow rate).**

### 3.2.4 Seasonal Analysis

The model outputs over the ten-year hindcast period (2006-2015) were combined and analysed on a seasonal basis (summer, transitional and winter). This approach assists with identifying the potential exposure to surrounding sensitive receptors whilst considering inter-annual variability in ocean current conditions.

Table 3.17 and Table 3.18 summarise, for Cases 1 and 3 respectively, the minimum dilution achieved at specific radial distances from the discharge location for each season and percentile.

Table 3.19 and Table 3.20 provide, for Cases 1 and 3 respectively, summaries of the maximum distances from the discharge location to achieve 1:550 dilution for each season and percentile. The results indicate that the release of effluent under all seasonal conditions results in rapid dispersion within the ambient environment. For Case 1, dilution to reach threshold concentration is achieved for biocide within an area of influence ranging from 1,173 m to 1,196 m at the 95$^{th}$ percentile across all seasons (Table 3.19). For Case 3, the maximum spatial extent of the relevant dilution contour is 18 m at the 95$^{th}$ percentile across all seasons (Table 3.20). The greatest spatial extents are observed in the transitional months.

Table 3.21 and Table 3.22 provide, for Cases 1 and 3 respectively, summaries of the total area of coverage for the 1:550 dilution contour for each season and percentile. For Case 1, the area of exposure defined by the relevant dilution contour is predicted to reach maximums of 2.21 km$^2$ to 2.30 km$^2$ at the 95$^{th}$ percentile (Table 3.21). For Case 3, the corresponding maximum area of exposure is <0.01 km$^2$ at the 95$^{th}$ percentile (Table 3.22).

Table 3.23 and Table 3.24 provide, for Cases 1 and 3 respectively, summaries of the maximum depths from the discharge location to achieve 1:550 dilution for each season and percentile. Maximum depths are predicted as 930 m (seabed; all seasons) and 12 m (all seasons) for Case 1 and Case 3, respectively.

For Cases 1 and 3, Figure 3.14 to Figure 3.25 show the aggregated spatial extents of the minimum dilutions for each season and percentile. 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 3.17 Minimum dilution achieved at specific radial distances from the hydrotest discharge location in each season for Case 1 (930 m depth discharge at 795 $m^3$/hr flow rate).

| Percentile | Season | Minimum dilution (1:x) achieved at specific radial distances from discharge location | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0.02 km | 0.05 km | 0.10 km | 0.20 km | 0.30 km | 0.40 km | 0.50 km | 0.60 km | 0.70 km | 0.80 km | 0.90 km | 1.00 km | 1.10 km | 1.20 km | 1.30 km | 1.40 km | 1.50 km |
| 95th | Summer | 1:21.7 | 1:31.0 | 1:36.8 | 1:52.0 | 1:63.9 | 1:74.5 | 1:81.9 | 1:90.5 | 1:104.3 | 1:117.2 | 1:153.8 | 1:208.9 | 1:314.0 | 1:453.5 | 1:666.7 | 1:952.8 | 1:1,444.3 |
| | Transitional | 1:20.7 | 1:30.1 | 1:35.1 | 1:49.6 | 1:62.9 | 1:73.9 | 1:84.0 | 1:93.4 | 1:105.0 | 1:114.0 | 1:138.9 | 1:181.4 | 1:273.4 | 1:400.2 | 1:603.2 | 1:869.8 | 1:1,386.1 |
| | Winter | 1:21.8 | 1:31.8 | 1:37.3 | 1:53.3 | 1:65.3 | 1:76.5 | 1:84.8 | 1:93.1 | 1:104.3 | 1:112.3 | 1:133.6 | 1:173.2 | 1:261.2 | 1:394.9 | 1:595.8 | 1:875.4 | 1:1,324.8 |
| 99th | Summer | 1:18.5 | 1:24.6 | 1:30.5 | 1:41.4 | 1:51.0 | 1:59.1 | 1:65.9 | 1:73.4 | 1:83.1 | 1:90.6 | 1:103.9 | 1:120.1 | 1:168.1 | 1:243.5 | 1:382.9 | 1:557.4 | 1:825.5 |
| | Transitional | 1:17.6 | 1:24.2 | 1:28.1 | 1:39.9 | 1:50.6 | 1:59.7 | 1:68.4 | 1:75.6 | 1:83.3 | 1:90.0 | 1:99.4 | 1:106.8 | 1:126.3 | 1:174.2 | 1:275.8 | 1:428.9 | 1:632.9 |
| | Winter | 1:18.6 | 1:25.4 | 1:30.3 | 1:42.4 | 1:52.7 | 1:60.8 | 1:68.0 | 1:75.4 | 1:82.8 | 1:89.0 | 1:98.1 | 1:106.8 | 1:130.2 | 1:180.9 | 1:281.6 | 1:438.6 | 1:682.9 |

Table 3.18 Minimum dilution achieved at specific radial distances from the hydrotest discharge location in each season for Case 3 (10 m depth discharge at 220 $m^3$/hr flow rate).

| Percentile | Season | Minimum dilution (1:x) achieved at specific radial distances from discharge location | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0.02 km | 0.05 km | 0.10 km | 0.20 km | 0.30 km | 0.40 km | 0.50 km | 0.60 km | 0.70 km | 0.80 km | 0.90 km | 1.00 km | 1.10 km | 1.20 km | 1.30 km | 1.40 km | 1.50 km |
| 95th | Summer | 1:501.3 | 1:930.5 | 1:1,243.6 | >1:10,000 | >1:10,000 | >1:10,000 | >1:10,000 | >1:10,000 | - | - | - | - | - | - | - | - | - |
| | Transitional | 1:489.5 | 1:1,450.3 | 1:1,594.5 | >1:10,000 | >1:10,000 | >1:10,000 | >1:10,000 | >1:10,000 | - | - | - | - | - | - | - | - | - |
| | Winter | 1:387.1 | 1:1,002.1 | 1:1,149.9 | >1:10,000 | >1:10,000 | >1:10,000 | - | - | - | - | - | - | - | - | - | - | - |
| 99th | Summer | 1:309.1 | 1:367.1 | 1:435.1 | 1:775.8 | 1:1,050.9 | 1:1,370.6 | 1:1,758.5 | 1:2,007.1 | 1:2,315.7 | 1:2,609.9 | 1:2,699.5 | 1:3,124.9 | 1:3,346.2 | 1:3,724.6 | 1:4,147.3 | 1:4,531.2 | 1:4,793.6 |
| | Transitional | 1:335.7 | 1:330.3 | 1:431.6 | 1:697.9 | 1:966.3 | 1:1,316.0 | 1:1,569.5 | 1:1,828.7 | 1:2,124.7 | 1:2,297.0 | 1:2,604.5 | 1:2,838.4 | 1:3,174.4 | 1:3,525.3 | 1:3,450.6 | 1:3,980.1 | 1:4,042.6 |
| | Winter | 1:160.9 | 1:279.8 | 1:320.5 | 1:600.5 | 1:779.8 | 1:1,129.1 | 1:1,364.3 | 1:1,609.3 | 1:1,881.9 | 1:2,202.9 | 1:2,595.3 | 1:2,937.8 | 1:3,472.2 | 1:3,580.6 | 1:3,938.0 | 1:4,743.0 | 1:5,882.2 |

Table 3.19 Maximum distance from the hydrotest discharge location to achieve 1:550 dilution in each season for Case 1 (930 m depth discharge at 795 $m^3$/hr flow rate).

| Percentile | Season | Maximum distance (m) from discharge location to achieve given dilution |
|---|---|---|
| 95th | Summer | 1,173 |
| | Transitional | 1,196 |
| | Winter | 1,196 |
| 99th | Summer | 1,317 |
| | Transitional | 1,388 |
| | Winter | 1,373 |
| 100th | Summer | 1,532 |
| | Transitional | 1,564 |
| | Winter | 1,551 |

Table 3.20 Maximum distance from the hydrotest discharge location to achieve 1:550 dilution in each season for Case 3 (10 m depth discharge at 220 $m^3$/hr flow rate).

| Percentile | Season | Maximum distance (m) from discharge location to achieve given dilution |
|---|---|---|
| 95th | Summer | 18 |
| | Transitional | 18 |
| | Winter | 18 |
| 99th | Summer | 82 |
| | Transitional | 91 |
| | Winter | 124 |
| 100th | Summer | 630 |
| | Transitional | 292 |
| | Winter | 1,147 |

**Table 3.21 Total area of coverage for 1:550 dilution in each season for Case 1 (930 m depth discharge at 795 $m^3$/hr flow rate).**

| Percentile | Season | Total area ($km^2$) of coverage for given dilution |
|---|---|---|
| 95th | Summer | 2.213 |
| | Transitional | 2.266 |
| | Winter | 2.298 |
| 99th | Summer | 2.751 |
| | Transitional | 2.902 |
| | Winter | 2.900 |
| 100th | Summer | 3.531 |
| | Transitional | 3.699 |
| | Winter | 3.596 |

**Table 3.22 Total area of coverage for 1:550 dilution in each season for Case 3 (10 m depth discharge at 220 $m^3$/hr flow rate).**

| Percentile | Season | Total area ($km^2$) of coverage for given dilution |
|---|---|---|
| 95th | Summer | 0.002 |
| | Transitional | 0.002 |
| | Winter | 0.002 |
| 99th | Summer | 0.011 |
| | Transitional | 0.010 |
| | Winter | 0.029 |
| 100th | Summer | 0.144 |
| | Transitional | 0.108 |
| | Winter | 0.495 |

**Table 3.23 Maximum depth from the hydrotest discharge location to achieve 1:550 dilution in each season for Case 1 (930 m depth discharge at 795 $m^3$/hr flow rate).**

| Season | Maximum depth (m) from discharge location to achieve given dilution |
|---|---|
| Summer | 930 (seabed) |
| Transitional | 930 (seabed) |
| Winter | 930 (seabed) |

**Table 3.24 Maximum depth from the hydrotest discharge location to achieve 1:550 dilution in each season for Case 3 (10 m depth discharge at 220 $m^3$/hr flow rate).**

| Season | Maximum depth (m) from discharge location to achieve given dilution |
|---|---|
| Summer | 12 |
| Transitional | 12 |
| Winter | 12 |

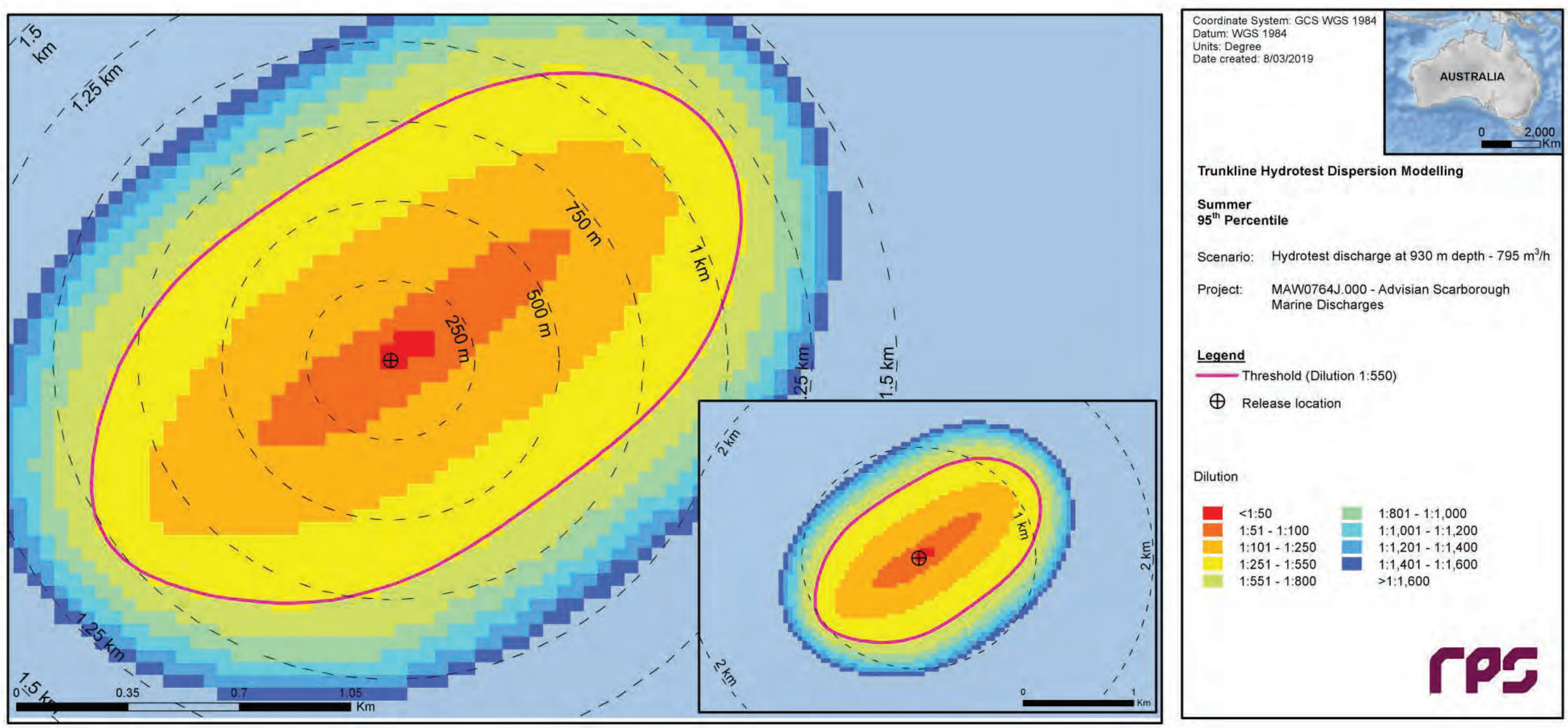


**Figure 3.14 Predicted minimum dilutions at the 95th percentile under summer conditions for Case 1 (930 m depth discharge at 795 $m^3$/hr flow rate).**

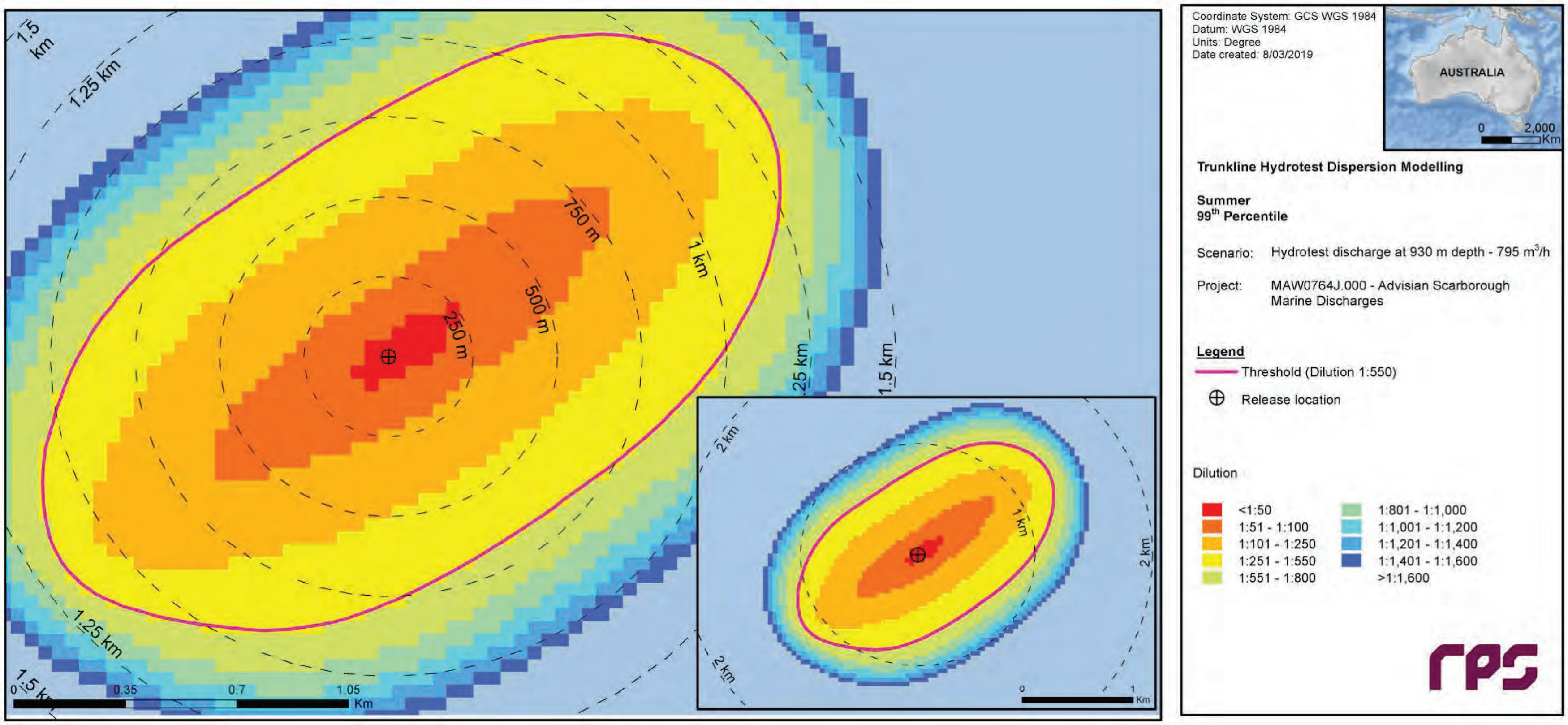


**Figure 3.15 Predicted minimum dilutions at the 99th percentile under summer conditions for Case 1 (930 m depth discharge at 795 m$^3$/hr flow rate).**

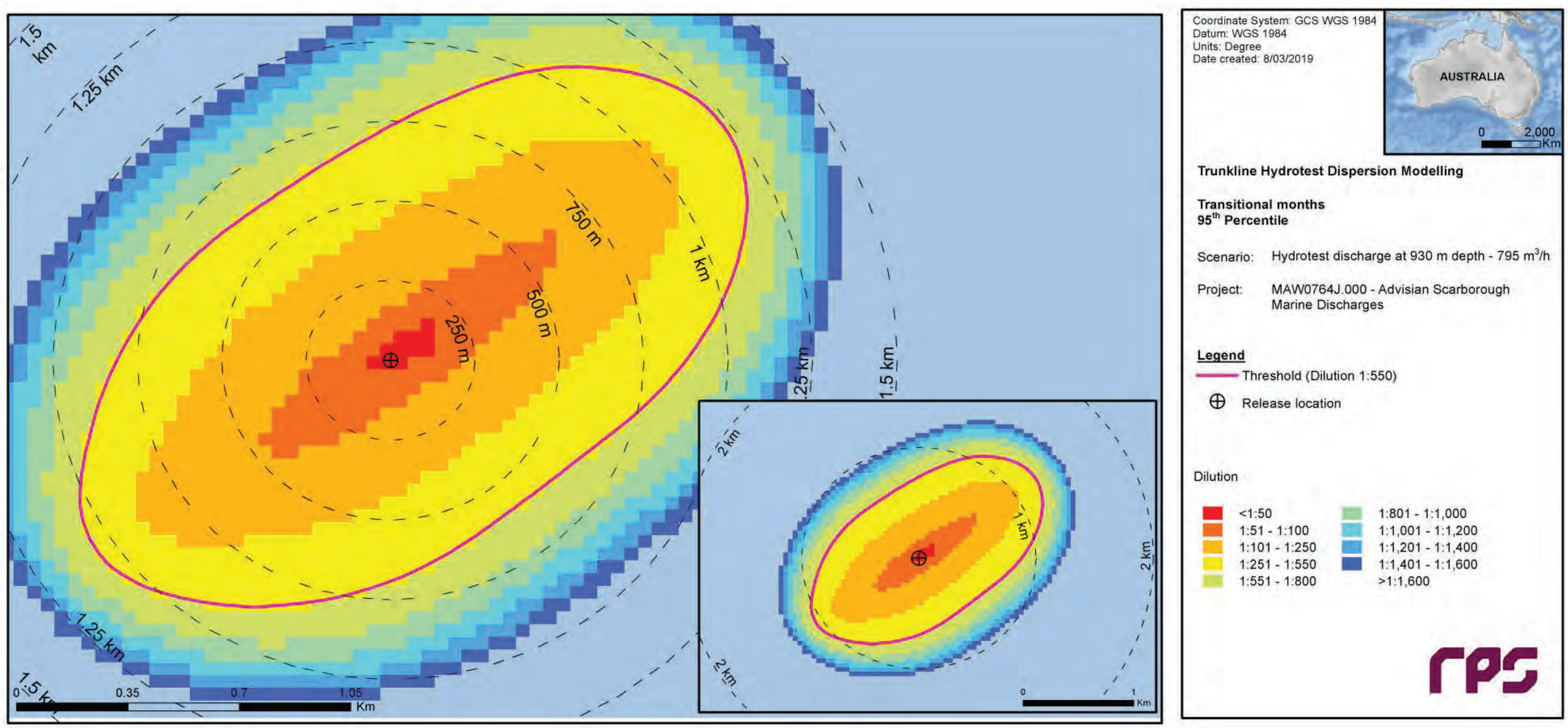


**Figure 3.16 Predicted minimum dilutions at the 95th percentile under transitional conditions for Case 1 (930 m depth discharge at 795 m$^3$/hr flow rate).**

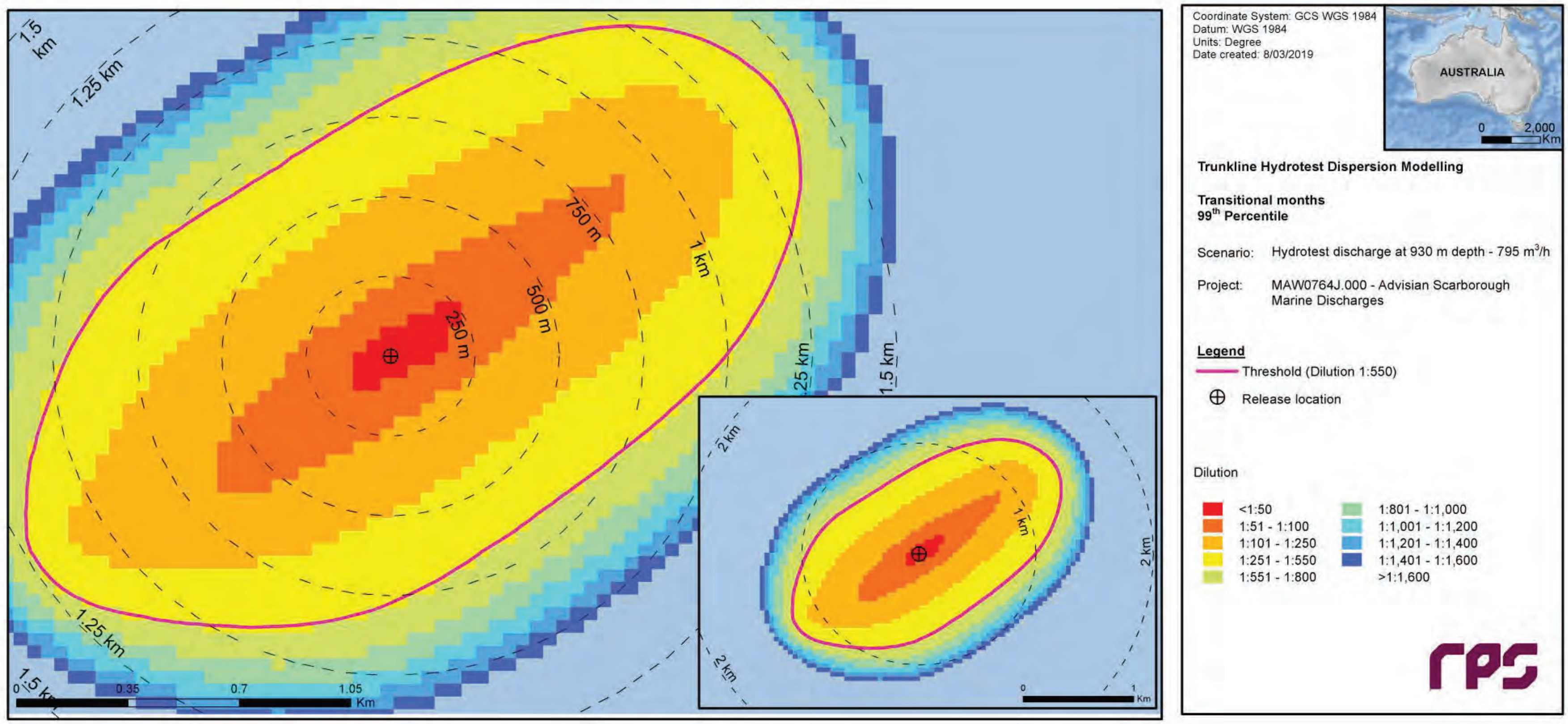


**Figure 3.17 Predicted minimum dilutions at the 99th percentile under transitional conditions for Case 1 (930 m depth discharge at 795 $m^3$/hr flow rate).**

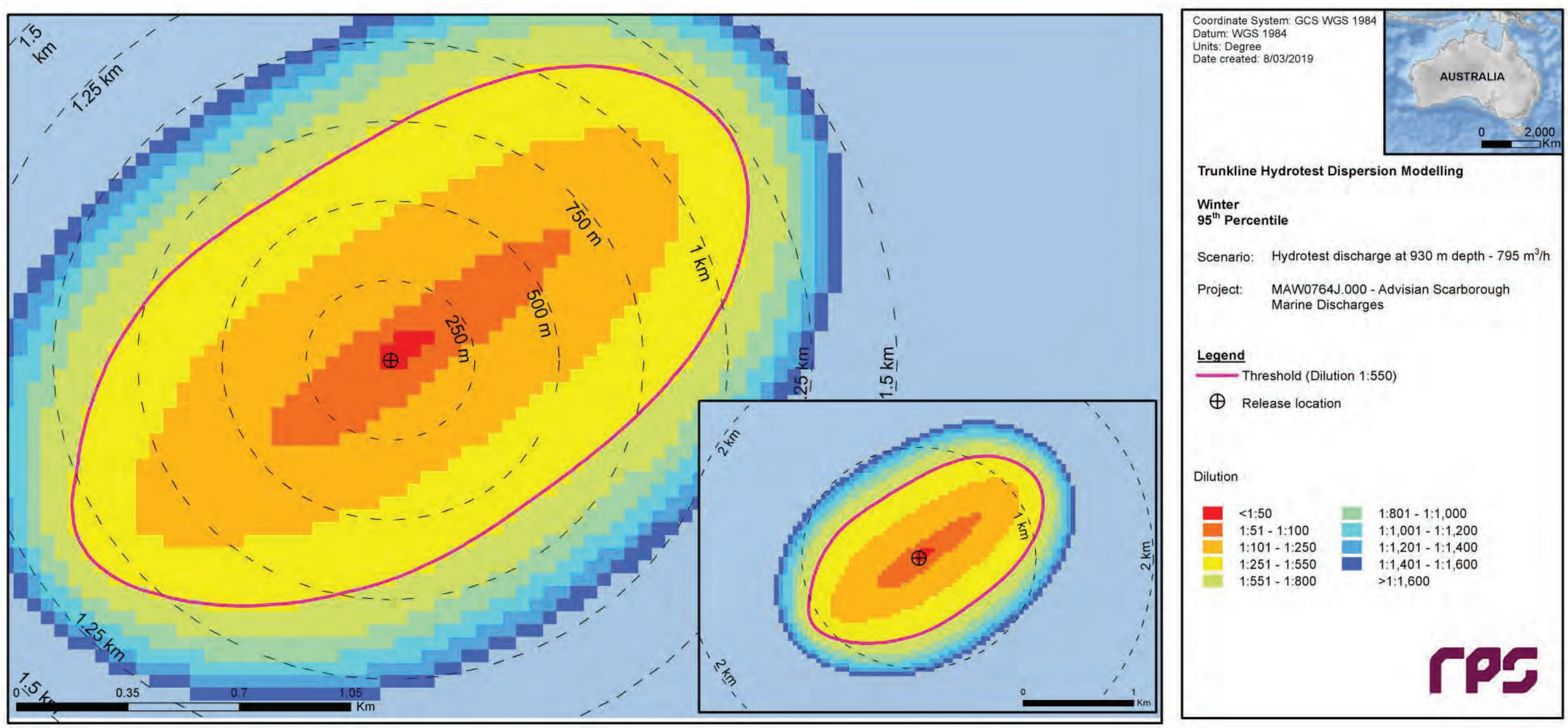


**Figure 3.18 Predicted minimum dilutions at the 95th percentile under winter conditions for Case 1 (930 m depth discharge at 795 $m^3$/hr flow rate).**

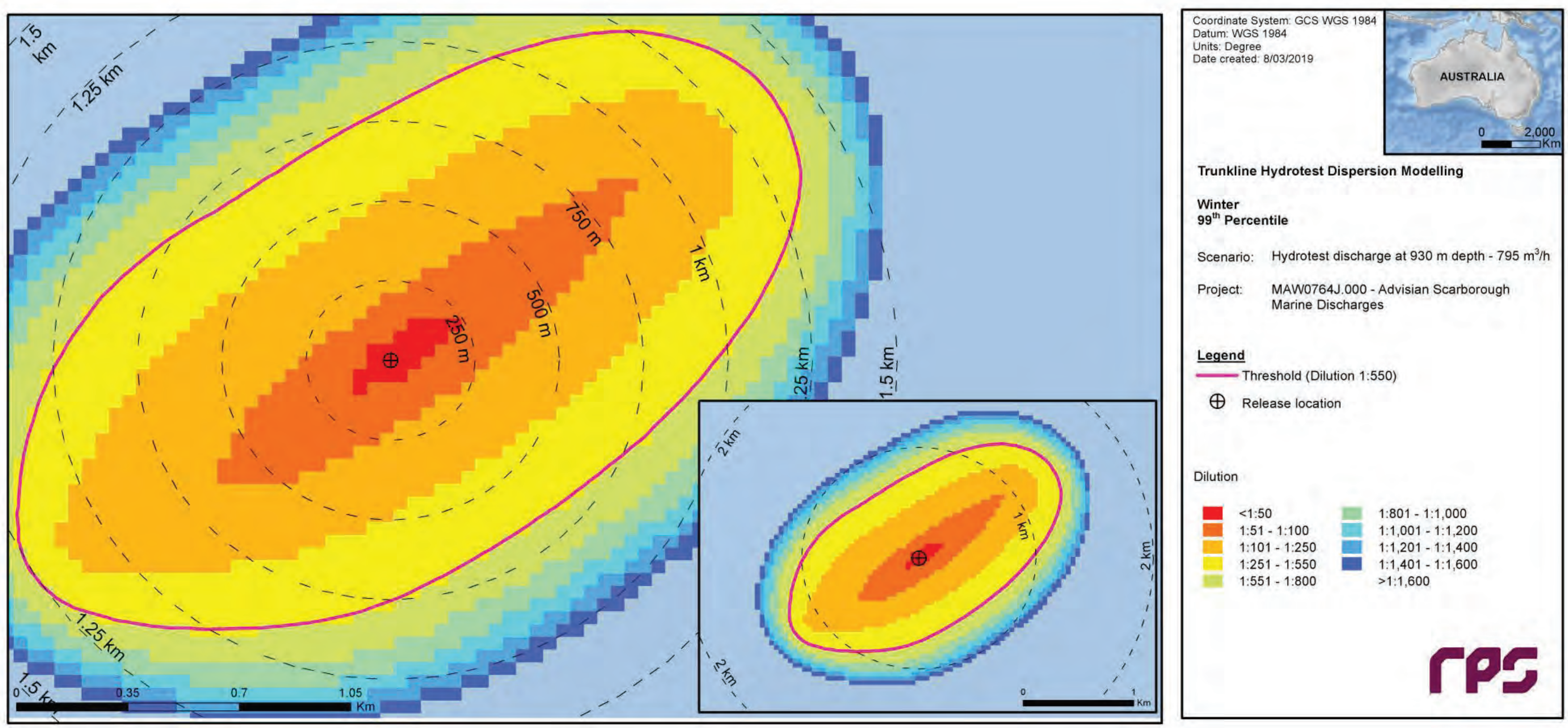


**Figure 3.19 Predicted minimum dilutions at the 99th percentile under winter conditions for Case 1 (930 m depth discharge at 795 m$^3$/hr flow rate).**

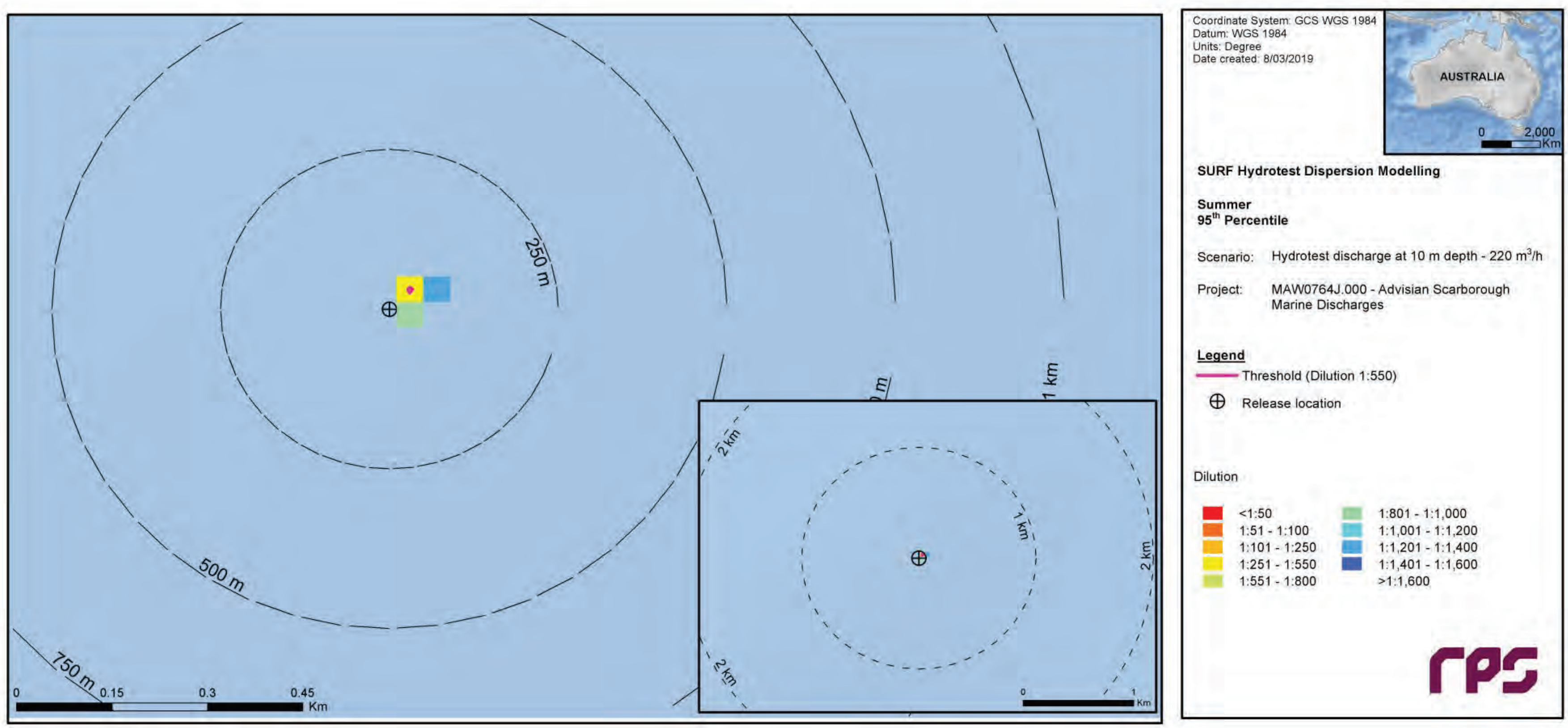


**Figure 3.20 Predicted minimum dilutions at the 95th percentile under summer conditions for Case 3 (10 m depth discharge at 220 $m^3$/hr flow rate).**

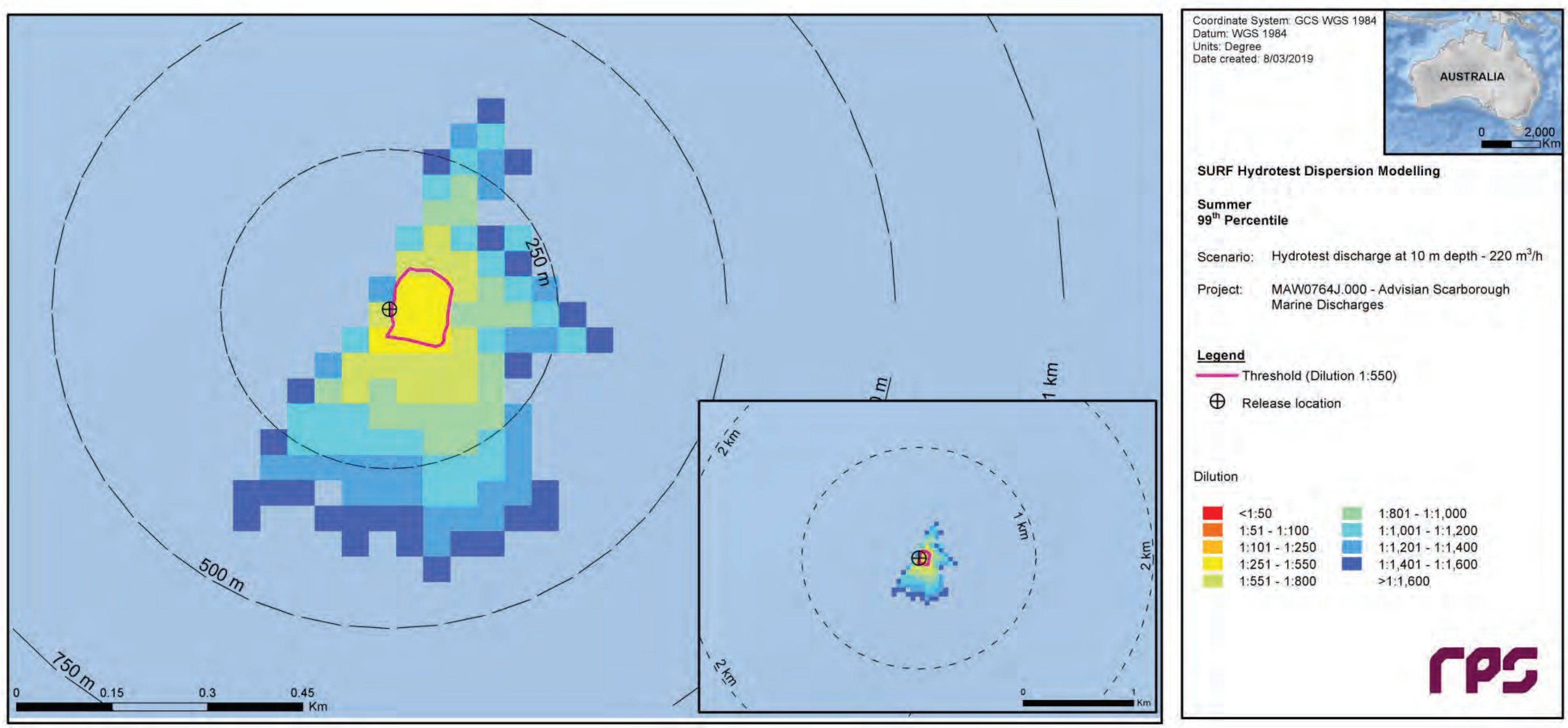


**Figure 3.21 Predicted minimum dilutions at the 99th percentile under summer conditions for Case 3 (10 m depth discharge at 220 m$^3$/hr flow rate).**

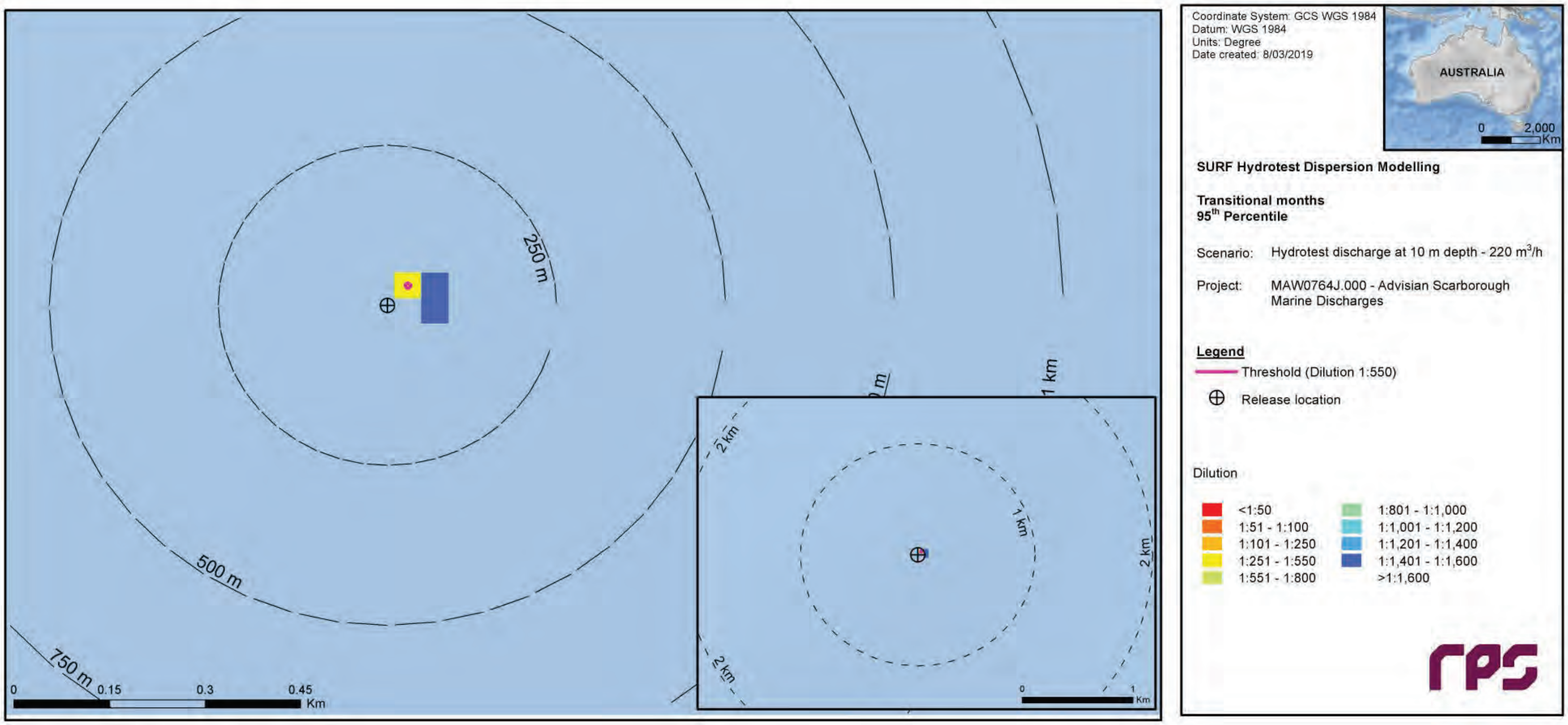


**Figure 3.22 Predicted minimum dilutions at the 95th percentile under transitional conditions for Case 3 (10 m depth discharge at 220 m$^3$/hr flow rate).**

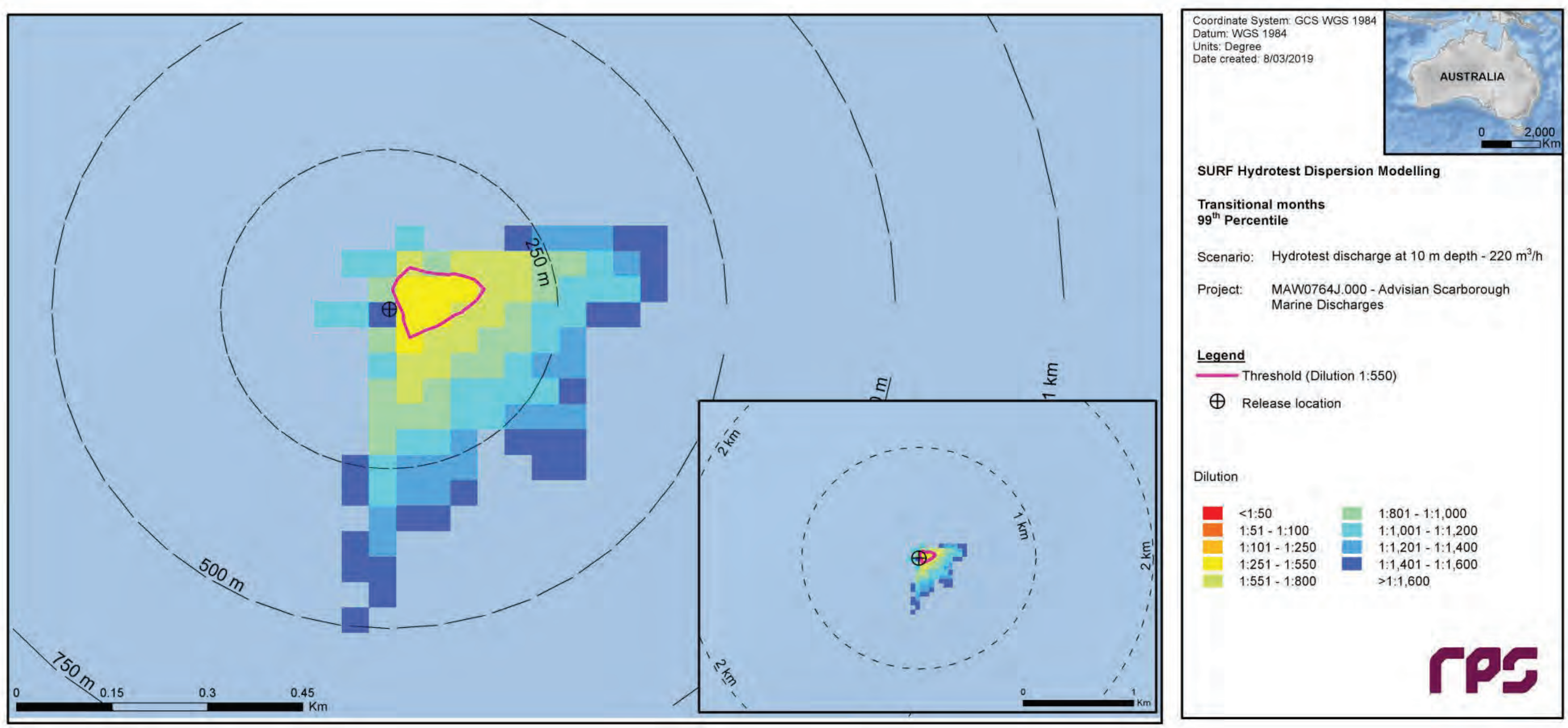


**Figure 3.23 Predicted minimum dilutions at the 99th percentile under transitional conditions for Case 3 (10 m depth discharge at 220 $m^3$/hr flow rate).**

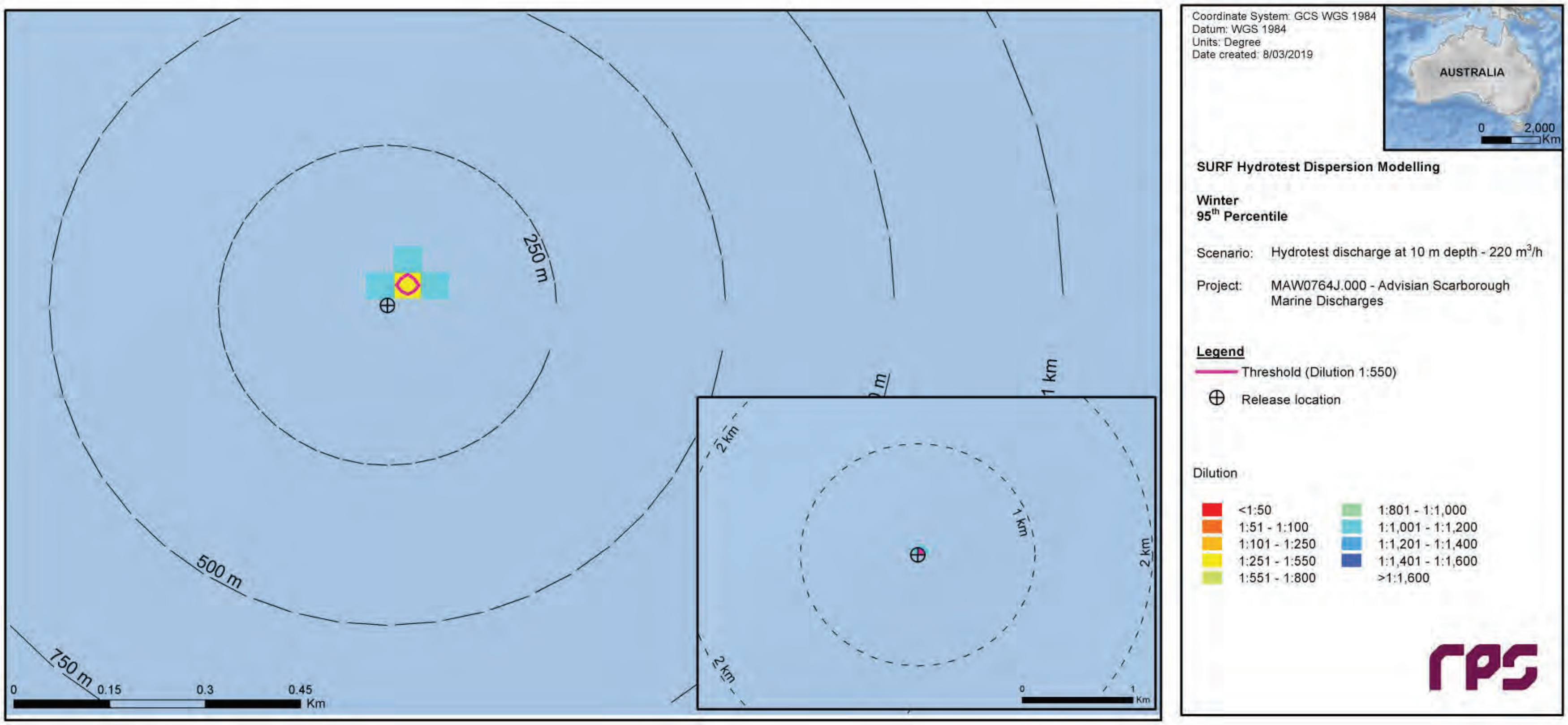


**Figure 3.24 Predicted minimum dilutions at the 95th percentile under winter conditions for Case 3 (10 m depth discharge at 220 m$^3$/hr flow rate).**

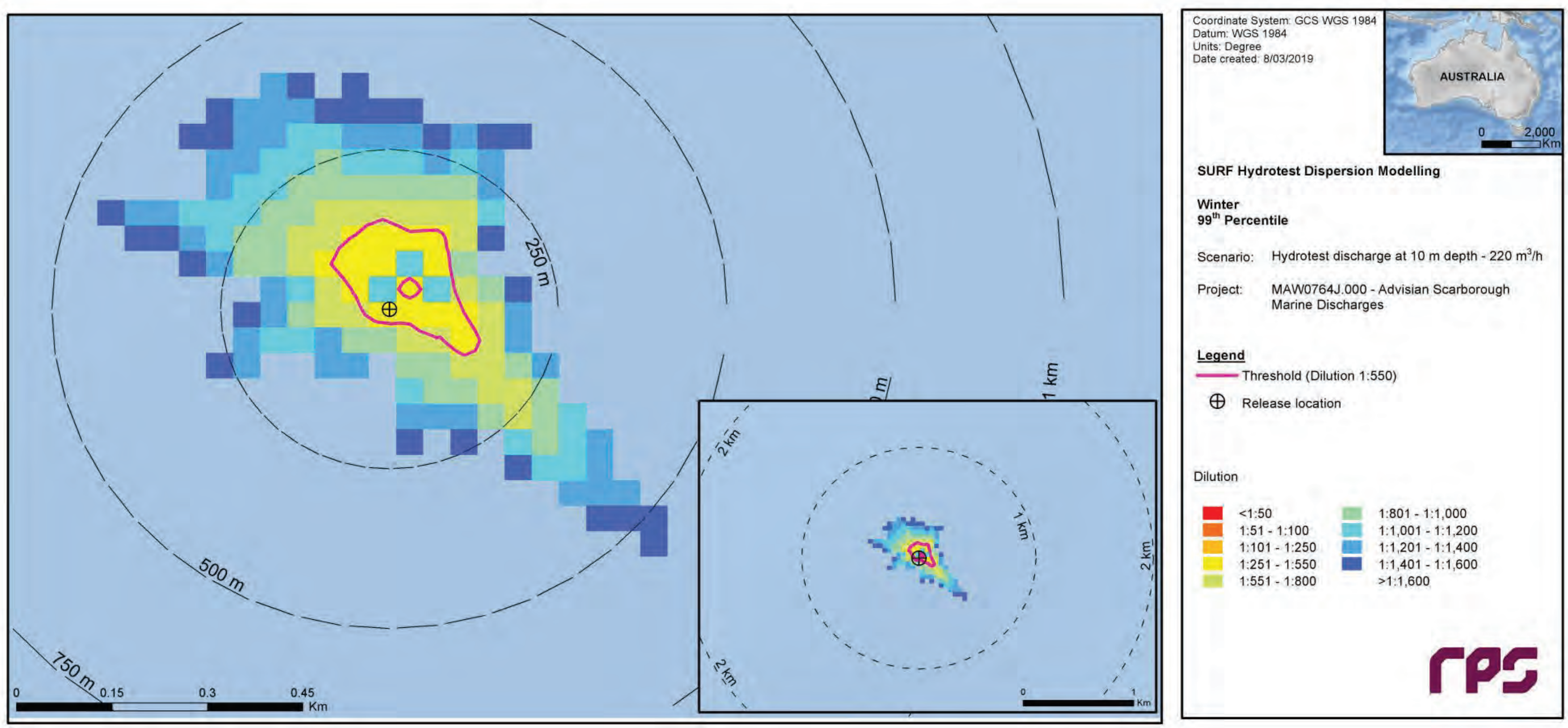


**Figure 3.25 Predicted minimum dilutions at the 99th percentile under winter conditions for Case 3 (10 m depth discharge at 220 $m^3$/hr flow rate).**

### 3.2.5 Annualised Analysis

The model outputs for each season (summer, transitional and winter) over the ten-year hindcast period (2006-2015) were combined and analysed on an annualised basis.

Table 3.25 and Table 3.26 summarise, for Cases 1 and 3 respectively, the minimum dilution achieved at specific radial distances from the discharge location for each percentile over the annual period.

Table 3.27 and Table 3.28 provide, for Cases 1 and 3 respectively, summaries of the annualised maximum distances from the discharge location to achieve 1:550 dilution for each percentile. The results indicate that the release of effluent under all seasonal conditions results in rapid dispersion within the ambient environment. Dilution to reach threshold concentration is achieved for biocide within a maximum area of influence of 1,388 m (Case 1) and 124 m (Case 3) at the 99$^{th}$ percentile, this being the maximum spatial extent of the relevant dilution contour from the discharge location in any season.

Table 3.29 and Table 3.30 provide, for Cases 1 and 3 respectively, summaries of the total area of coverage for the 1:550 dilution contour for each percentile. The area of exposure defined by the relevant dilution contour is predicted to reach maximum values of 2.95 km$^2$ (Case 1) and 0.04 km$^2$ (Case 3) at the 99$^{th}$ percentile in any season.

For Cases 1 and 3, Figure 3.26 to Figure 3.29 show the aggregated spatial extents of the minimum dilutions for each percentile. 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 3.25 Annualised minimum dilution achieved at specific radial distances from the hydrotest discharge location for Case 1 (930 m depth discharge at 795 $m^3$/hr flow rate).

| Percentile | Season | Minimum dilution (1:x) achieved at specific radial distances from discharge location | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0.02 km | 0.05 km | 0.10 km | 0.20 km | 0.30 km | 0.40 km | 0.50 km | 0.60 km | 0.70 km | 0.80 km | 0.90 km | 1.00 km | 1.10 km | 1.20 km | 1.30 km | 1.40 km | 1.50 km |
| 95th | Annual | 1:20.7 | 1:30.1 | 1:35.1 | 1:49.6 | 1:62.9 | 1:73.9 | 1:81.9 | 1:90.5 | 1:104.3 | 1:112.3 | 1:133.6 | 1:173.2 | 1:261.2 | 1:394.9 | 1:595.8 | 1:869.8 | 1:1,324.8 |
| 99th | | 1:17.6 | 1:24.2 | 1:28.1 | 1:39.9 | 1:50.6 | 1:59.1 | 1:68.0 | 1:73.4 | 1:82.8 | 1:89.0 | 1:98.1 | 1:106.8 | 1:126.3 | 1:174.2 | 1:275.8 | 1:428.9 | 1:632.9 |

Table 3.26 Annualised minimum dilution achieved at specific radial distances from the hydrotest discharge location for Case 3 (10 m depth discharge at 220 $m^3$/hr flow rate).

| Percentile | Season | Minimum dilution (1:x) achieved at specific radial distances from discharge location | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0.02 km | 0.05 km | 0.10 km | 0.20 km | 0.30 km | 0.40 km | 0.50 km | 0.60 km | 0.70 km | 0.80 km | 0.90 km | 1.00 km | 1.10 km | 1.20 km | 1.30 km | 1.40 km | 1.50 km |
| 95th | Annual | 1:387.1 | 1:930.5 | 1:1,149.9 | >1:10,000 | >1:10,000 | >1:10,000 | >1:10,000 | >1:10,000 | - | - | - | - | - | - | - | - | - |
| 99th | | 1:160.9 | 1:279.8 | 1:320.5 | 1:600.5 | 1:779.8 | 1:1,129.1 | 1:1,364.3 | 1:1,609.3 | 1:1,881.9 | 1:2,202.9 | 1:2,595.3 | 1:2,838.4 | 1:3,174.4 | 1:3,525.3 | 1:3,450.6 | 1:3,980.1 | 1:4,042.6 |

**Table 3.27 Annualised maximum distance from the hydrotest discharge location to achieve 1:550 dilution for Case 1 (930 m depth discharge at 795 $m^3$/hr flow rate).**

| Percentile | Season | Maximum distance (m) from discharge location to achieve given dilution |
|---|---|---|
| $95^{th}$ | Annual | 1,196 |
| $99^{th}$ | | 1,388 |
| $100^{th}$ | | 1,564 |

**Table 3.28 Annualised maximum distance from the hydrotest discharge location to achieve 1:550 dilution for Case 3 (10 m depth discharge at 220 $m^3$/hr flow rate).**

| Percentile | Season | Maximum distance (m) from discharge location to achieve given dilution |
|---|---|---|
| $95^{th}$ | Annual | 18 |
| $99^{th}$ | | 124 |
| $100^{th}$ | | 1,147 |

**Table 3.29 Annualised total area of coverage for 1:550 dilution for Case 1 (930 m depth discharge at 795 $m^3$/hr flow rate).**

| Percentile | Season | Total area ($km^2$) of coverage for given dilution |
|---|---|---|
| $95^{th}$ | Annual | 2.325 |
| $99^{th}$ | | 2.945 |
| $100^{th}$ | | 3.730 |

**Table 3.30 Annualised total area of coverage for 1:550 dilution for Case 3 (10 m depth discharge at 220 $m^3$/hr flow rate).**

| Percentile | Season | Total area ($km^2$) of coverage for given dilution |
|---|---|---|
| $95^{th}$ | Annual | 0.002 |
| $99^{th}$ | | 0.035 |
| $100^{th}$ | | 0.522 |

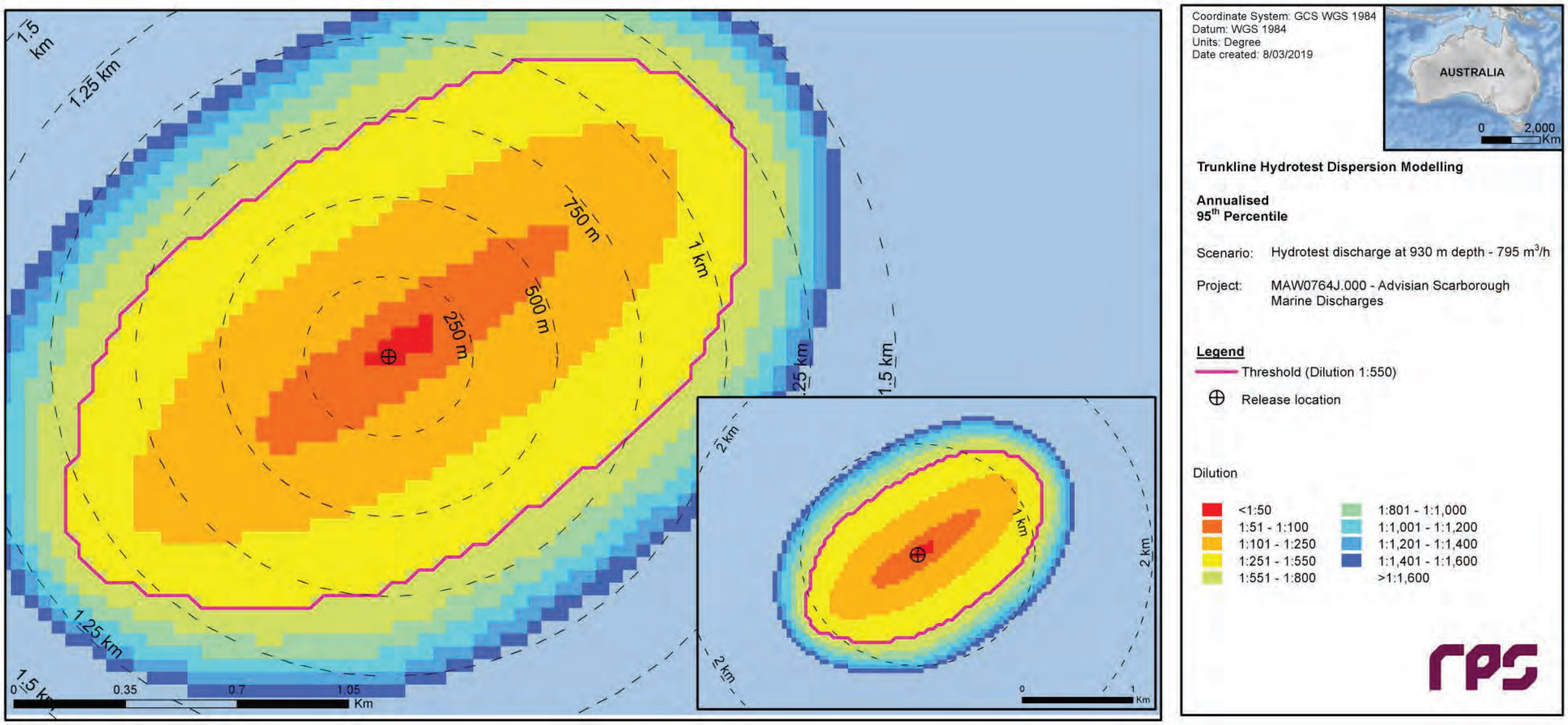


**Figure 3.26 Predicted annualised minimum dilutions at the 95th percentile for Case 1 (930 m depth discharge at 795 $m^3$/hr flow rate).**

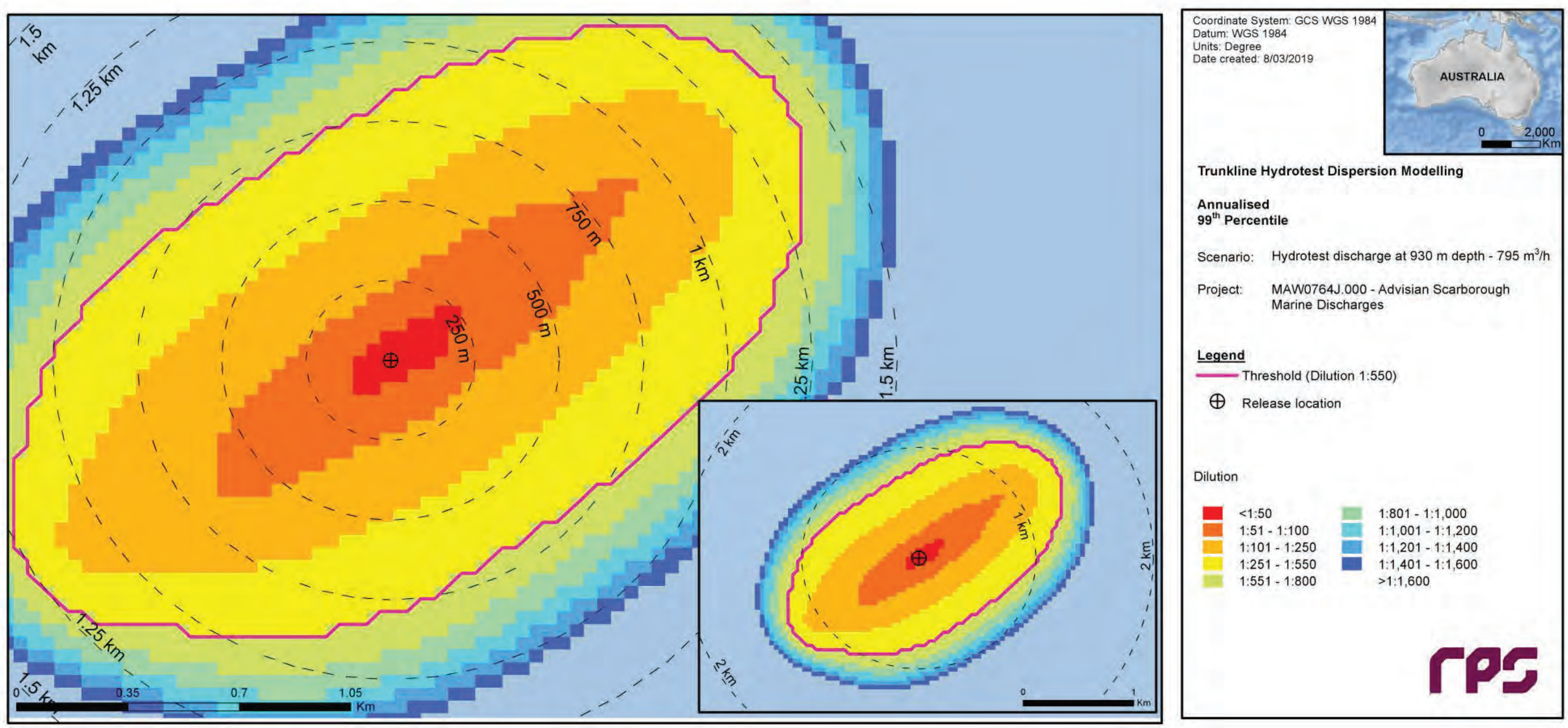


**Figure 3.27 Predicted annualised minimum dilutions at the 99th percentile for Case 1 (930 m depth discharge at 795 $m^3$/hr flow rate).**

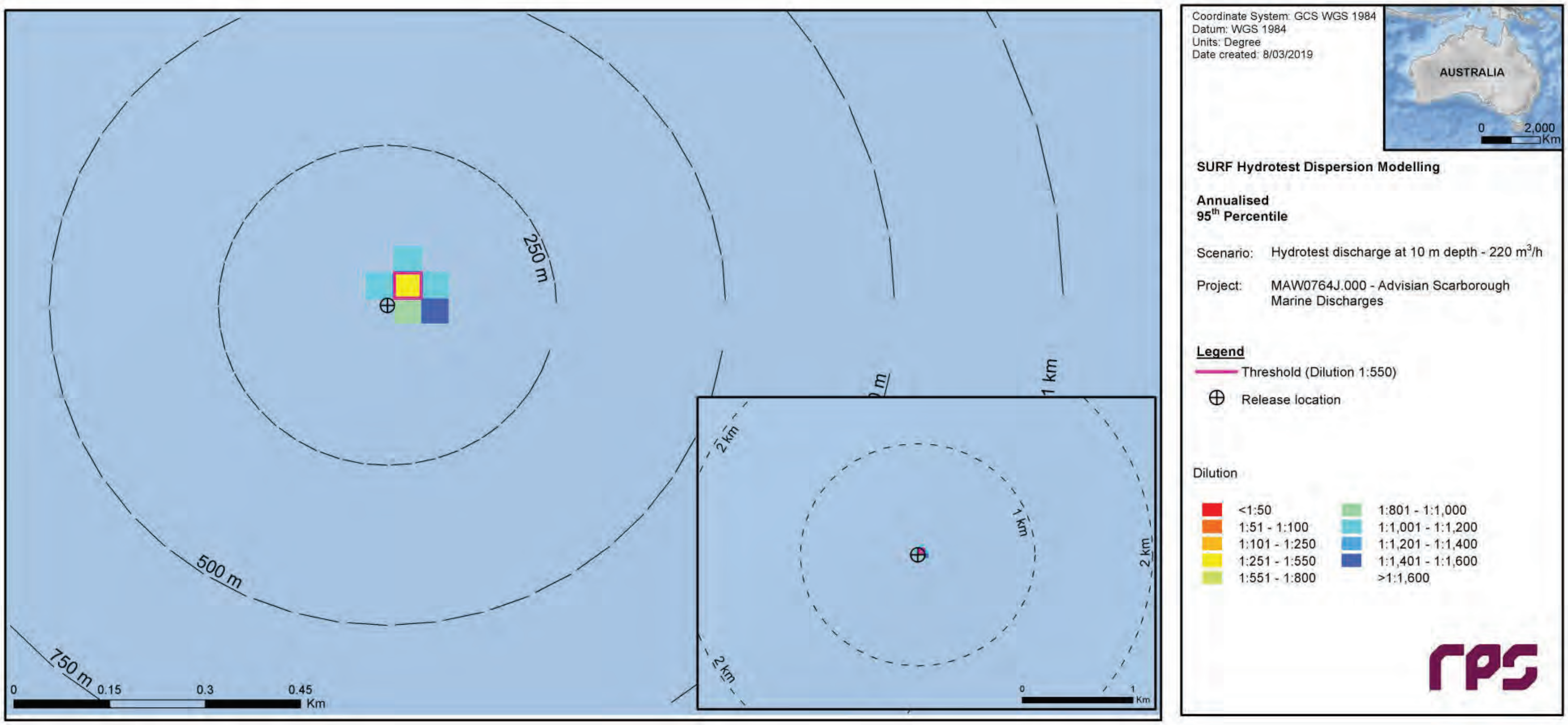


**Figure 3.28 Predicted annualised minimum dilutions at the 95th percentile for Case 3 (10 m depth discharge at 220 $m^3$/hr flow rate).**

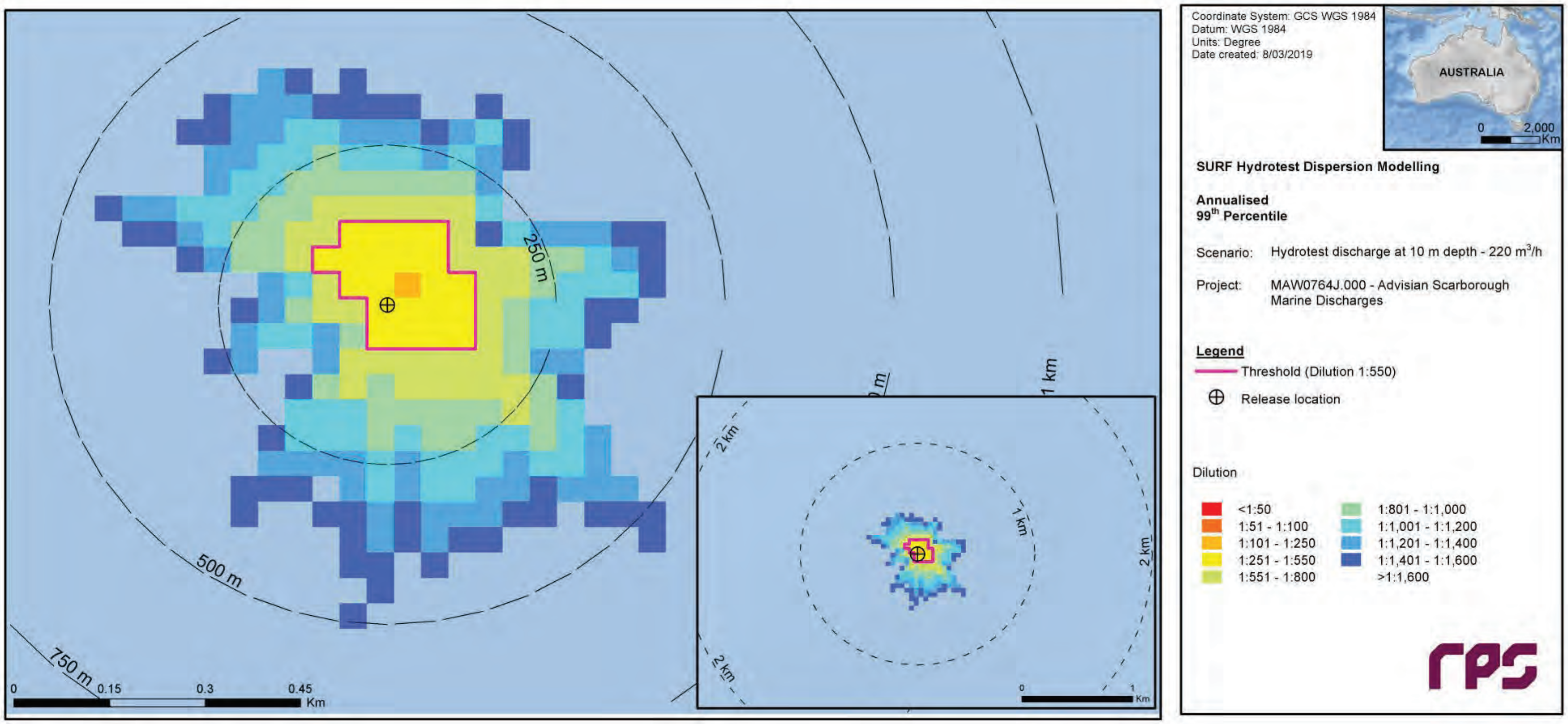


**Figure 3.29 Predicted annualised minimum dilutions at the 99th percentile for Case 3 (10 m depth discharge at 220 m$^3$/hr flow rate).**

# 4 CONCLUSIONS

The main findings of the study are as follows:

## Near-Field Modelling

- 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 930 m (Cases 1 and 2) and 10 m (Case 3) below the water surface. The surface discharges are shown to increase the extent of the turbulent mixing zone. Following this initial mixing, the near neutrally-buoyant plumes are predicted to travel laterally in the water column.
- For Cases 1 and 2, the plumes are predicted to remain close to the seabed. For Case 3, the plume is predicted to plunge up to 19 m below the sea surface. For Cases 2 and 3, increased ambient current strengths are shown to increase the horizontal distance travelled by the plumes from the discharge point.
- The plume will reach a maximum horizontal distance of up to 152 m before reaching the trapping depth (at which the predictions of dispersion are halted due to the plume reaching equilibrium with the ambient receiving water).
- The maximum diameter of the plume at the end of the near-field zone was predicted as 23 m. Increases in current speed serve to restrict the diameter of the plume.
- For each discharge depth, 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.
- For each combination of discharge flow rate and depth, 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.
- The average dilution levels of the plume upon reaching the trapping depth under average current speeds are predicted to be 1:90 for Case 1, 1:465 for Case 2 and 1:482 for Case 3.
- The predictions of dilution 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 Case 1, 2 and 3 discharges indicate that the biocide constituent of the hydrotest discharge is not expected to reach the required levels of dilution in the near field mixing zone.

## Far-Field Modelling

- For Case 1, dilution to reach threshold concentration is achieved for biocide within an area of influence extending up to 1,388 m at the 99$^{th}$ percentile. For Case 3, the maximum spatial extents of the relevant dilution contour are up to 124 m at the 99$^{th}$ percentile.
- For Case 1, the area of exposure defined by the relevant dilution contour is predicted to reach a maximum of 2.95 km$^2$ at the 99$^{th}$ percentile. For Case 3, the corresponding maximum area of exposure is up to 0.04 km$^2$ at the 99$^{th}$ percentile.
- Maximum depths reached by the discharges are predicted as 930 m (seabed) and 12 m for Cases 1 and 3, respectively.

# Key Observations

- Due to the significant variations in magnitude of the hindcast currents between the surface and seabed, where potential discharges will occur, predicted outcomes are markedly different.
- The greater strength and variability in surface-layer currents will promote the highest levels of mixing and dilution, while transport patterns at the seabed will be dictated almost solely by tidal movements.
- Because the discharge will be initially neutrally-buoyant, it will travel laterally in the water column and even a surface discharge is unlikely to resurface in the vicinity of the discharge point prior to acclimation with ambient receiving water conditions.
- Outcomes show that below-threshold biocide concentrations are achieved closer to the discharge point for the surface discharge (220 $m^3$/hr over 20 hours) than for the seabed discharge (795 $m^3$/hr over 44 hours). This is partly attributable to the stronger currents at the surface, but primarily to the lower flow rate and much lower discharge duration in the surface-discharge case.

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# Appendix I

## Scarborough Gas Development Quantitative Spill Risk Assessment Modelling Study

# WOODSIDE SCARBOROUGH PROJECT – QUANTITATIVE SPILL RISK ASSESSMENT

## Report

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# EXECUTIVE SUMMARY

RPS was commissioned by Advisian Pty Ltd (Advisian), on behalf of Woodside Energy Ltd (Woodside), to undertake a quantitative spill risk assessment of three hydrocarbon spill scenarios related to the Scarborough Project.

The Scarborough gas resource, located in Commonwealth waters approximately 375 km off the Burrup Peninsula, forms part of the Greater Scarborough gas fields, comprising the Scarborough, North Scarborough, Thebe and Jupiter gas fields.

As Operator of the Greater Scarborough gas fields, Woodside is proposing to develop the gas resource through new offshore facilities. These will be connected to the mainland through an approximately 430 km trunkline.

The Scarborough gas field consists of gas which is classified as 'dry' with only trace levels of condensate, and as such a loss of well control event will not have a significant liquid component. As such, the exposure from an unplanned hydrocarbon release is based on a release of marine diesel oil (MDO) from a vessel.

The assessment focused on the risk of exposure to hydrocarbons for surrounding resources and sensitive receptors if defined spill scenarios were to occur. The main objectives of the study were to provide an assessment, through stochastic spill modelling, of the probabilities of oil contact (at greater than defined minimum concentrations), the potential concentrations that might be involved, and the minimum state of weathering of the oil in case of a release of hydrocarbons.

Woodside identified three hydrocarbon spill scenarios for investigation. Each scenario was modelled in a stochastic manner and assessed over an annual period in this study.

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.

The main findings of this study are as follows:

## Metocean Influences

- Tidal flows will have a significant influence on the trajectory of any oil spilled at the modelled release sites, irrespective of the seasonal conditions.
- Large-scale drift currents will have a significant influence on the trajectory of any oil spilled at the modelled release sites, irrespective of the seasonal conditions. The prevailing drift currents will determine the trajectory of oil that is entrained beneath the water surface.
- Interactions with the prevailing wind will provide additional variation in the trajectory of spilled oil.
- Due to the location of the hypothetical spill site and the dominance of tidal flows, the coastal areas predicted to be most likely to be impacted by spilled oil are those bordering Mermaid Sound and its numerous passages.

## Oil Characteristics and Weathering Behaviour

- Marine diesel is a mixture of volatile and persistent hydrocarbons with low percentages of highly volatile and residual components. If exposed to the atmosphere, around 41% of the mass would be expected to evaporate in around 24 hours, another 54% within a few days, and the remaining 5% would be expected to persist in the marine environment until decayed. The influence of entrainment will regulate the degree of mass retention in the environment.

- During the surface release, floating oil will be susceptible to entrainment into the wave-mixed layer under typical wind conditions. Evaporation rates will be significant, given the moderate proportion of volatile compounds in the oil (41%). The low-volatility fraction of the oil (54%) will take longer durations of the order of days to evaporate, and the residual fraction of 5% is expected to persist in the environment until degradation processes occur. Considering the spill volume, there is a low potential for dissolution of soluble aromatic compounds.

# Summary of Stochastic Assessment Results

## Scenario 1: Short-Term (Instantaneous) Surface Release of Marine Diesel after a Vessel Collision outside Mermaid Sound

- Floating oil at concentrations equal to or greater than the 10 g/m$^2$, 50 g/m$^2$ and 100 g/m$^2$ thresholds could potentially be found up to 29 km, 21 km and 18 km from the spill site, respectively.
- The Dampier Archipelago shoreline receptor is predicted to be contacted by floating oil concentrations at the 10 g/m$^2$ threshold with a probability of 2% and a minimum time to contact of 27 hours.
- Potential for accumulation of oil on shorelines is predicted to be low, with a maximum accumulated volume and concentration of 3 m$^3$ and 156 g/m$^2$, respectively, forecast at the Dampier Archipelago.
- Entrained oil at concentrations equal to or greater than the 500 ppb threshold is predicted to be found up to around 163 km from the spill site.
- The Dampier MP and Dampier Archipelago receptors are predicted to receive entrained oil concentrations at the 500 ppb threshold with probabilities of 44% and 23%, respectively.
- The maximum entrained oil concentration forecast for any receptor is predicted as 10.9 ppm within the Dampier Archipelago.
- Dissolved aromatic hydrocarbons at concentrations equal to or greater than the 500 ppb threshold are predicted to be found up to around 34 km from the spill site.
- The Dampier MP is predicted to receive dissolved aromatic hydrocarbon concentrations at the 500 ppb threshold with a probability of 2%.
- The maximum dissolved aromatic hydrocarbon concentration forecast for any receptor is predicted as 635 ppb within the Dampier MP.

## Scenario 2: Short-Term (Instantaneous) Surface Release of Marine Diesel after a Vessel Collision within Montebello Marine Park

- Floating oil at concentrations equal to or greater than the 10 g/m$^2$, 50 g/m$^2$ and 100 g/m$^2$ thresholds could potentially be found up to 39 km, 36 km and 33 km from the spill site, respectively.
- Given that the spill location lies within the Montebello MP receptor area, floating oil at concentrations equal to or greater than 100 g/m$^2$ are forecast with a probability of 100% and a minimum time to contact of less than 1 hour.
- Potential for accumulation of oil on shorelines is predicted to be low, with a maximum accumulated volume and concentration of <1 m$^3$ and 1 g/m$^2$, respectively, forecast at Barrow Island.

- Entrained oil at concentrations equal to or greater than the 500 ppb threshold is predicted to be found up to around 308 km from the spill site.
- The Montebello MP and Muiron Islands MMA-WHA receptors are predicted to receive entrained oil concentrations at the 500 ppb threshold with probabilities of 70% and 7%, respectively.
- The maximum entrained oil concentration forecast for any receptor is predicted as 157.0 ppm within the Montebello MP.
- Dissolved aromatic hydrocarbons at concentrations equal to or greater than the 500 ppb threshold are predicted to be found up to around 85 km from the spill site.
- The Montebello MP is predicted to receive dissolved aromatic hydrocarbon concentrations at the 500 ppb threshold with a probability of 2%.
- The maximum dissolved aromatic hydrocarbon concentration forecast for any receptor is predicted as 2.0 ppm within the Montebello MP.

## Scenario 3: Short-Term (Instantaneous) Surface Release of Marine Diesel after a Vessel Collision at the FPU Location

- Floating oil at concentrations equal to or greater than the 10 g/m$^2$, 50 g/m$^2$ and 100 g/m$^2$ thresholds could potentially be found up to 113 km, 60 km and 58 km from the spill site, respectively.
- No shoreline receptors are predicted to be contacted by floating oil concentrations at any of the assessed thresholds.
- No accumulation of oil on shorelines is predicted.
- Entrained oil at concentrations equal to or greater than the 500 ppb threshold is predicted to be found up to around 476 km from the spill site.
- The Gascoyne MP receptor is predicted to receive entrained oil concentrations at the 500 ppb threshold with a probability of 8%.
- The maximum entrained oil concentration forecast for any receptor is predicted as 7.2 ppm within the Gascoyne MP.
- Dissolved aromatic hydrocarbons at concentrations equal to or greater than the 500 ppb threshold are predicted to be found up to around 74 km from the spill site.
- No receptors are predicted to receive dissolved aromatic hydrocarbon concentrations at the 500 ppb threshold.
- The maximum dissolved aromatic hydrocarbon concentration forecast for any receptor is predicted as 462 ppb within the Gascoyne MP.

# 1 INTRODUCTION

## 1.1 Background

RPS was commissioned by Advisian Pty Ltd (Advisian), on behalf of Woodside Energy Ltd (Woodside), to undertake a quantitative spill risk assessment of three hydrocarbon spill scenarios related to the Scarborough Project.

The Scarborough gas resource, located in Commonwealth waters approximately 375 km off the Burrup Peninsula, forms part of the Greater Scarborough gas fields, comprising the Scarborough, North Scarborough, Thebe and Jupiter gas fields.

As Operator of the Greater Scarborough gas fields, Woodside is proposing to develop the gas resource through new offshore facilities. These will be connected to the mainland through an approximately 430 km trunkline.

The Scarborough gas field consists of gas which is classified as 'dry' with only trace levels of condensate, and as such a loss of well control event will not have a significant liquid component. As such, the exposure from an unplanned hydrocarbon release is based on a release of marine diesel oil (MDO) from a vessel.

The assessment focused on the risk of exposure to hydrocarbons for surrounding resources and sensitive receptors if defined spill scenarios were to occur. The main objectives of the study were to provide an assessment, through stochastic spill modelling, of the probabilities of oil contact (at greater than defined minimum concentrations), the potential concentrations that might be involved, and the minimum state of weathering of the oil in case of a release of hydrocarbons.

Woodside identified three hydrocarbon spill scenarios for investigation (Advisian, 2019). Each scenario was modelled in a stochastic manner and assessed over an annual period in this study.

The regional context of the spill location for each assessed scenario is shown in Figure 1.1.

The details of the scenarios assessed in this study are summarised in Table 1.1 and listed here:

- Scenario 1: A short-term (instantaneous) surface release of 2,000 $m^3$ of marine diesel, representing loss of vessel fuel tank integrity after a collision outside Mermaid Sound (20° 21' 3.28" S, 116° 42' 5.58" E).
- Scenario 2: A short-term (instantaneous) surface release of 2,000 $m^3$ of marine diesel, representing loss of vessel fuel tank integrity after a collision within Montebello Marine Park (MP) (20° 03' 1.44" S, 115° 31' 35.04" E).
- Scenario 3: A short-term (instantaneous) surface release of 2,000 $m^3$ of marine diesel, representing loss of vessel fuel tank integrity after a collision at the FPU location (19° 53' 54.72" S, 113° 14' 19.56" E).

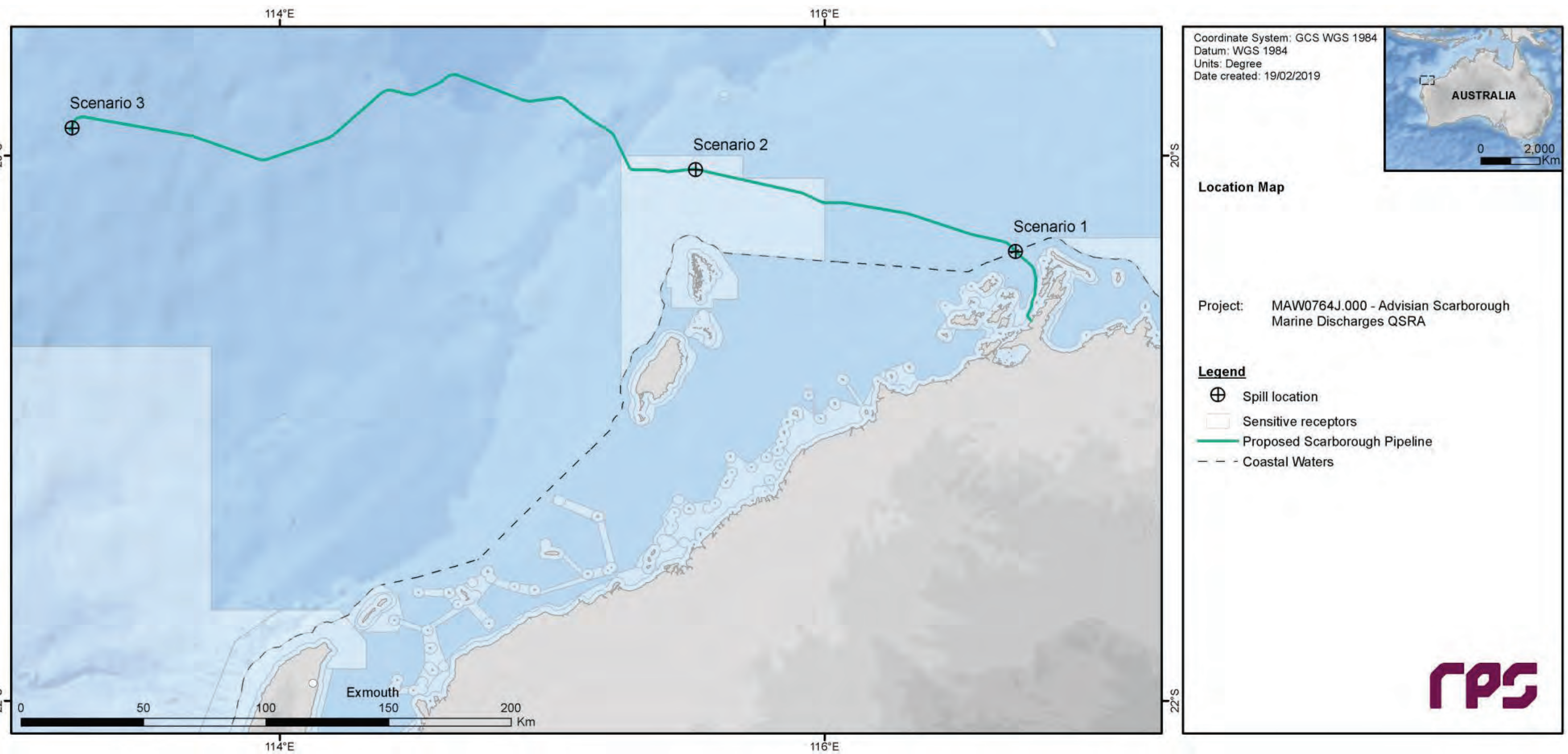



**Figure 1.1 Locations of the modelled hydrocarbon spill scenario release sites.**

## 1.2 Stochastic Modelling of Spill Scenarios

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.

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 slicks 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 slick oil 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. 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 the North West Shelf of Australia and spanning 10 years (2006-2015, 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 to quantify annualised risks of contact at surrounding locations.

Each simulation was run for the duration of the specified spill, plus a further period after the cessation of discharge to allow a sufficient time period for oil concentrations to decrease below the 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.

It is important to note that the modelling results presented in this document relate to the predicted outcomes once defined spill events have occurred. The probability of the spill scenarios occurring is not considered. The results should therefore be viewed as a guide to the likely outcomes should the spill scenarios occur. 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 is likely to be affected during any one single spill event. The contours should therefore be judged as contours of probability and not representations of the area swept by individual spill slicks.

Risk estimates were calculated from the multiple replicate simulations for each assessed scenario, including the probability of contact, the minimum time to contact, and the potential concentrations that might be involved.

The results of the stochastic modelling are presented in Section 3.

**Table 1.1 Summary of the hydrocarbon spill scenarios assessed in a stochastic manner in this study.**

| Scenario | Description | Oil Type | Spilled Volume ($m^3$) | Release Coordinates | Release Depth (m BMSL) | Spill Duration | Simulation Duration | Period |
|---|---|---|---|---|---|---|---|---|
| 1 | Loss of vessel fuel tank integrity after a collision outside Mermaid Sound | Marine Diesel | 2,000 | 20° 21' 03.28" S 116° 42' 05.58 " E | 0 | Instantaneous | 42 days | Annual |
| 2 | Loss of vessel fuel tank integrity after a collision within Montebello Marine Park (MP) | Marine Diesel | 2,000 | 20° 03' 01.44" S 115° 31' 35.04 " E | 0 | Instantaneous | 42 days | Annual |
| 3 | Loss of vessel fuel tank integrity after a collision at the FPU location | Marine Diesel | 2,000 | 19° 53' 54.72" S 113° 14' 19.56 " E | 0 | Instantaneous | 42 days | Annual |

## 1.3 Deterministic Analysis of Spill Scenarios

After assessing the stochastic modelling outcomes for all scenarios, Woodside determined there was a requirement for additional model outputs to be provided for selected replicate simulations of each scenario in order to contextualise the stochastic contours.

The results of the deterministic analysis are presented in Section 4.

## 1.4 Report Structure

The far-field computational models, risk assessment methodology, environmental data used as input to the models, environmental threshold trigger levels defined for the assessment and characteristics of the oil type used in the modelling of the defined scenarios are described in detail in Section 2.

Contour figures and tabulated results showing risk estimates for the receptors nominated by Woodside, produced for defined floating oil, entrained oil and dissolved aromatic hydrocarbon threshold concentrations, are presented in Section 3 to summarise the stochastic modelling outcomes.

Spatial figures for floating oil, entrained oil, dissolved aromatic hydrocarbons and shoreline oil are presented in Section 4 to summarise the outcomes of the deterministic analysis and modelling.

The overall findings of the study are summarised in Section 5.

# 2 MODELLING METHODOLOGY

## 2.1 Description of the SIMAP Model

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 slick and the 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 slick), 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 surface slicks and oil 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.

Evaporation rates vary over space and time dependent on the prevailing sea temperatures, wind and current speeds, the surface area of the slick and entrained droplets 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 of slicks. 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 the surface slick 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.
- Decayed hydrocarbons.

## 2.2 Calculation of Exposure Risks

The stochastic model within SIMAP performs a large number of simulations for a given spill site, randomly varying the spill time for each simulation. The model uses the spill time to select samples of current and wind data from a long time-series of wind and current data for the area. Hence, the transport and weathering of each slick will be subject to a different sample of wind and current conditions.

This stochastic sampling approach provides an objective measure of the possible outcomes of a spill, because environmental conditions will be selected at a rate that is proportional to the frequency that these conditions occur over the study region. More simulations will tend to use the most commonly occurring conditions, while conditions that are more unusual will be represented less frequently.

During each simulation, the SIMAP model records the location (by latitude, longitude and depth) of each of the particles (representing a given mass of oil) on or in the water column, at regular time steps. For any particles that contact a shoreline, the model records the accumulation of oil mass that arrives on each section of shoreline over time, less any mass that is lost to evaporation and/or subsequent removal by current and wind forces.

The collective records from all simulations are then analysed by dividing the study region into a three-dimensional grid. For oil particles that are classified as being at the water surface (floating oil), the sum of the mass in all oil particles (including accounting for spreading and dispersion effects) located within a grid cell, divided by the area of the cell provides estimates of the concentration of oil in that grid cell, at each time step. For entrained and dissolved oil particles, concentrations are calculated at each time step by summing the mass of particles within a grid cell and dividing by the volume of the grid cell.

The concentrations of oil calculated for each grid cell, at each time step, are then analysed to determine whether concentration estimates exceed defined threshold concentrations over time.

Risks are then summarised as follows:

- The probability of exposure to a location is calculated by dividing the number of spill simulations where any instantaneous contact occurred above a specified threshold at that location by the total number of replicate spill simulations. For example, if contact occurred at a location (above a specified threshold) during 21 out of 100 simulations, a probability of exposure of 21% is indicated.
- The minimum potential time to a shoreline location is calculated by the shortest time over which oil at a concentration above a particular threshold was calculated to travel from the source to the location in any of the replicate simulations.
- The maximum potential concentration of oil predicted for each shoreline section is the greatest mass per $m^2$ of shoreline calculated to strand at any location within that section during any of the replicate simulations.
- The average of the maximum concentrations of oil predicted to potentially accumulate on each shoreline section is calculated by determining the greatest mass per $m^2$ of shoreline during each replicate simulation and calculating an average of these estimates across the simulations. Note that this statistic has been previously referred to as the “mean expected maximum” in earlier reports.

- Similar treatments are undertaken for entrained oil and dissolved aromatic hydrocarbons.

Thus, the minimum time to shoreline and the maximum potential concentration estimates indicate the worst potential outcome of the modelled spill scenario for each section of shoreline. However, the average over the replicates presents an average of the potential outcomes, in terms of oil that could strand.

Note also that results quoted for sections of shoreline or shoal are derived for any individual location within that section or shoal, as a conservative estimate. Locations will represent shoreline lengths of the order of ~1 km, while sections or regions will represent shorelines spanning tens to hundreds of kilometres and we do not imply that the maximum potential concentrations quoted will occur over the full extent of each section. We therefore warn against multiplying the maximum concentration estimates by the full area of the section because this will greatly overestimate the total volume expected on that section.

The maximum entrained hydrocarbon and maximum dissolved aromatic hydrocarbon concentration are calculated for water locations surrounding each defined shoreline (see Section 3.1). These zones are defined to provide a buffer area around shallow (<10 m) habitats to allow for spatial errors in model forecasts. The greatest calculated value at any time step during any replicate simulation is listed. These values therefore represent worst-case localised estimates (within a grid cell). The averages over all replicate values represent a central tendency of these simulated worst-case estimates.

## 2.3 Inputs to the Risk Assessment

### 2.3.1 Current Data

#### 2.3.1.1 Background

The area of interest for this study is typified by strong tidal flows over the shallower regions, particularly along the inshore region of the North West Shelf and among the island groups stretching from the Dampier Archipelago to the North West Cape. 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 slicks 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 oil can be variably affected by combinations of tidal, wind-induced and density-induced drift currents. Depending on their local influence, it is critical to consider all these potential advective mechanisms to rigorously understand patterns of potential transport from a given spill location.

To appropriately allow for temporal and spatial variation in the current field, spill modelling requires the current speed and direction over a spatial grid covering the potential migration of oil. As measured current data is not available for simultaneous periods over a network of locations covering the wide area of this study, 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 mesoscale ocean models, with estimates of the tidal currents generated by an RPS model set up for the study area.

#### 2.3.1.2 Mesoscale Circulation Model

Representation of the drift currents that affect the area were available from the output of the BRAN (Bluelink ReANalysis; Oke *et al.*, 2008, 2009; Schiller *et al.*, 2008) ocean model, which is sponsored by the Australian Government through the Commonwealth Bureau of Meteorology (BoM), Royal Australian Navy, and

Commonwealth Scientific and Industrial Research Organisation (CSIRO). BRAN is a data-assimilative, three-dimensional ocean model that has been run as a hindcast for many periods and is now used for ocean forecasting (Schiller *et al.*, 2008).

The BRAN predictions for drift currents are produced at a horizontal spatial resolution of approximately 0.1° over the region, at a frequency of once per day, averaged over the 24-hour period. Hence, the BRAN model data provides estimates of mesoscale circulation with horizontal resolution suitable to resolve eddies of a few tens of kilometres' diameter, as well as connecting stream currents of similar spatial scale. Drift currents that are represented over the inner shelf waters in the BRAN data are principally attributable to wind induced drift.

There are several versions of the BRAN database available. The latest BRAN simulation spans the period of January 1994 to August 2016. From this database, time series of current speed and direction were extracted for all points in the model domain for the years 2006-2015 (inclusive). The data was assumed to be a suitably representative sample of the current conditions over the study area for future years.

Figure 2.1 to Figure 2.3 show the monthly distribution of current speeds and directions for the BRAN data points closest to the spill locations for Scenarios 1 to 3. Note that the convention for defining current direction is the direction towards which the current flows.

The current data indicates higher average current speeds are characteristic of the May to September period, with the highest average speeds (0.26 m/s) occurring at the Scenario 3 spill site in September. Lower average current speeds at the release locations are more common during the February to April period, with lowest average speeds (0.04 m/s) occurring at the Scenario 1 spill site in April. Peak current speeds across all months and sites are approximately 0.7 m/s.

Throughout the year, westerly currents are dominant at the Scenario 2 spill site and westerly/south-westerly currents are dominant at the Scenario 3 spill site. Current directions at the Scenario 1 spill site are seasonal, with north-easterly currents dominant between September and March, and south-westerly currents dominant between April and August.

The extracted current data near the spill locations provides an insight into the expected initial behaviour of any released oil due to the drift currents alone. Oil moving beyond the release sites, particularly towards the coast, would be subject to considerable variation in the drift current regime.

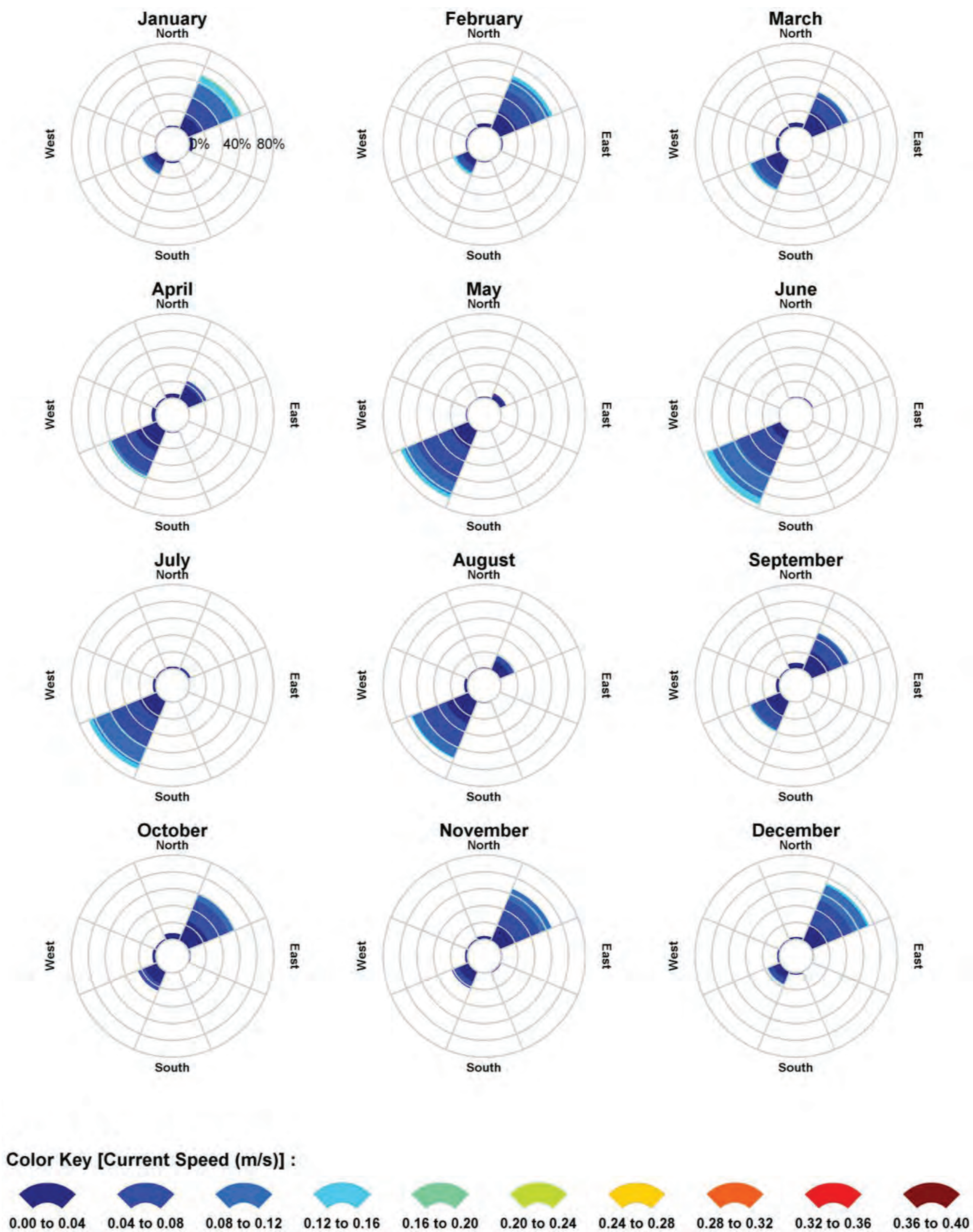



**Figure 2.1** **Monthly current distribution (2006-2015, inclusive) derived from the BRAN database near to the Scenario 1 spill location. The colour key shows the current magnitude, the compass direction provides the direction towards which the current is flowing, and the size of the wedge gives the percentage of the record.**

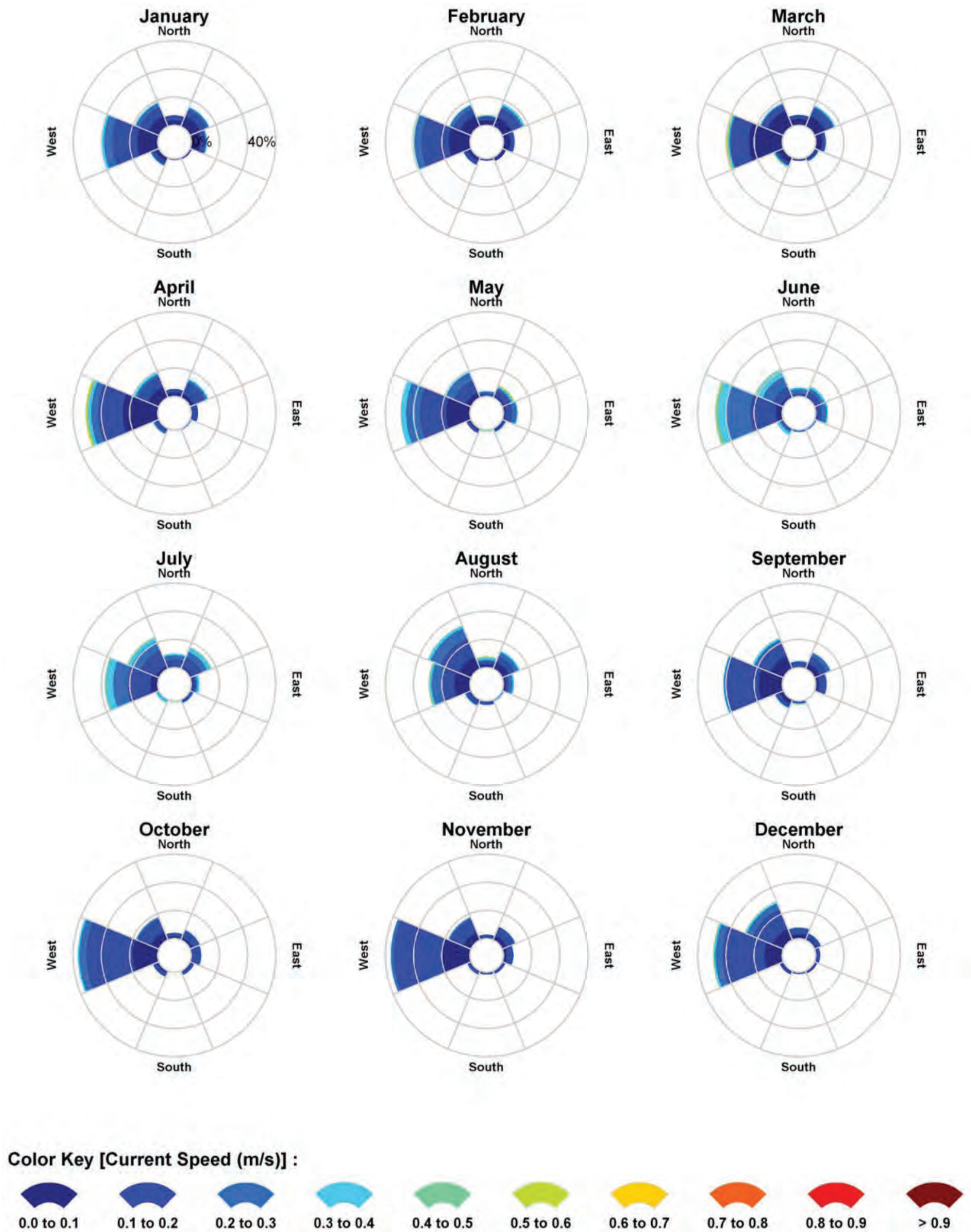



**Figure 2.2 Monthly current distribution (2006-2015, inclusive) derived from the BRAN database near to the Scenario 2 spill location. The colour key shows the current magnitude, the compass direction provides the direction towards which the current is flowing, and the size of the wedge gives the percentage of the record.**

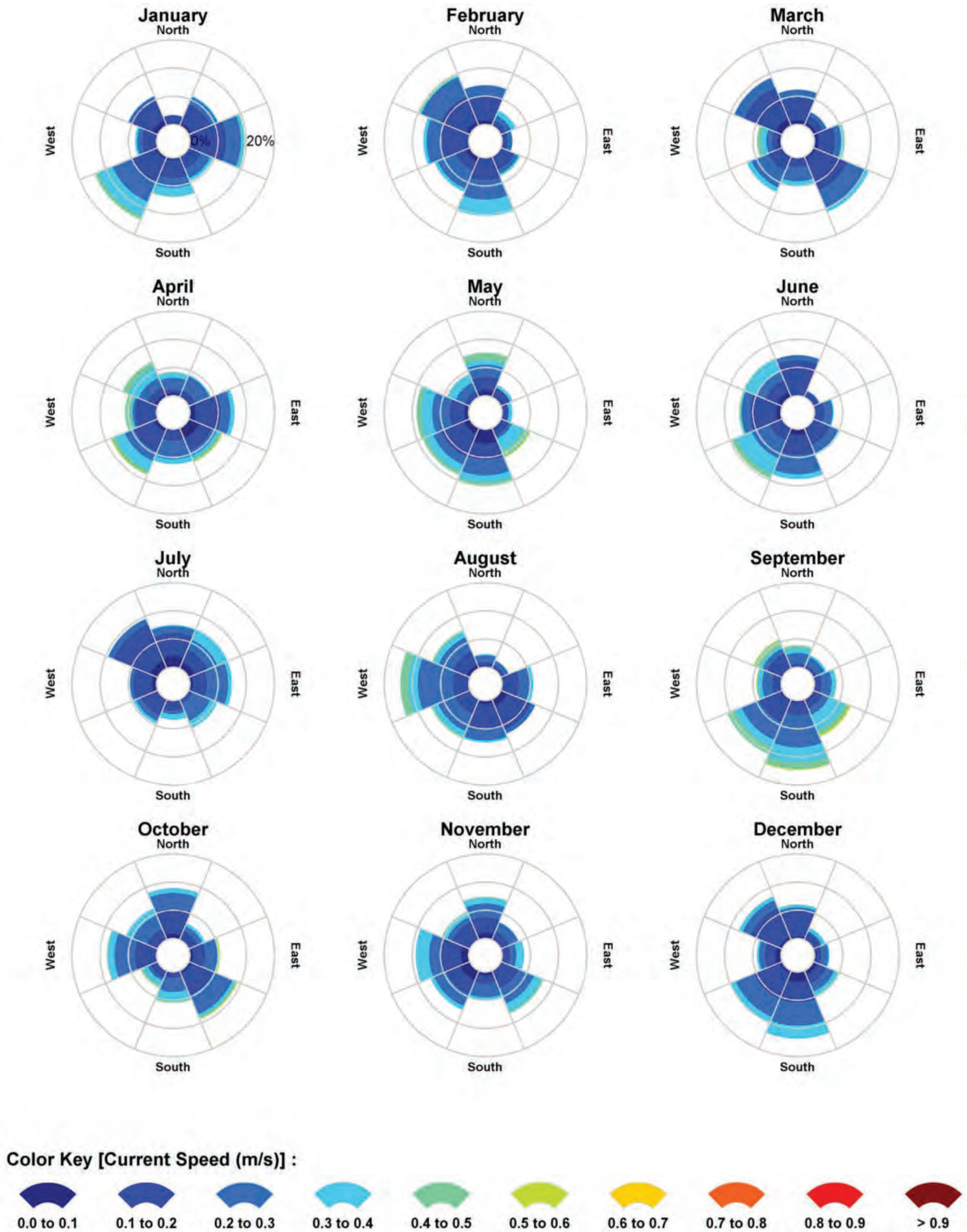



**Figure 2.3 Monthly current distribution (2006-2015, inclusive) derived from the BRAN database near to the Scenario 3 spill location. The colour key shows the current magnitude, the compass direction provides the direction towards which the current is flowing, and the size of the wedge gives the percentage of the record.**

#### 2.3.1.3 Tidal Circulation Model

As the BRAN 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, 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).

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 2.4).

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.

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.

For the purpose of verification of the tidal 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 40 tidal stations within the HYDROMAP model domain, ten were used for comparison.

Water level time series for these locations are shown in Figure 2.5 for a one-month period (January 2005). 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.

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.

Figure 2.7 to Figure 2.9 show the monthly distribution of current speeds and directions for the HYDROMAP data points closest to the spill locations for Scenarios 1 to 3. Note that the convention for defining current direction is the direction towards which the current flows.

The current data indicates cyclical tidal flow directions along an east-west axis at the Scenario 1 site, an east-southeast/west-northwest axis at the Scenario 2 site, and a northeast-southwest axis at the Scenario 3 site. Maximum speeds at the Scenario 1 and 2 sites are in the range 0.5-0.6 m/s, with peak speeds at the Scenario 3 site being around 0.09 m/s.

The extracted current data near the spill locations provides an insight into the expected initial behaviour of any released oil due to the tidal currents alone. Oil moving beyond the release sites, particularly towards the coast, would be subject to considerable variation in the tidal current regime.

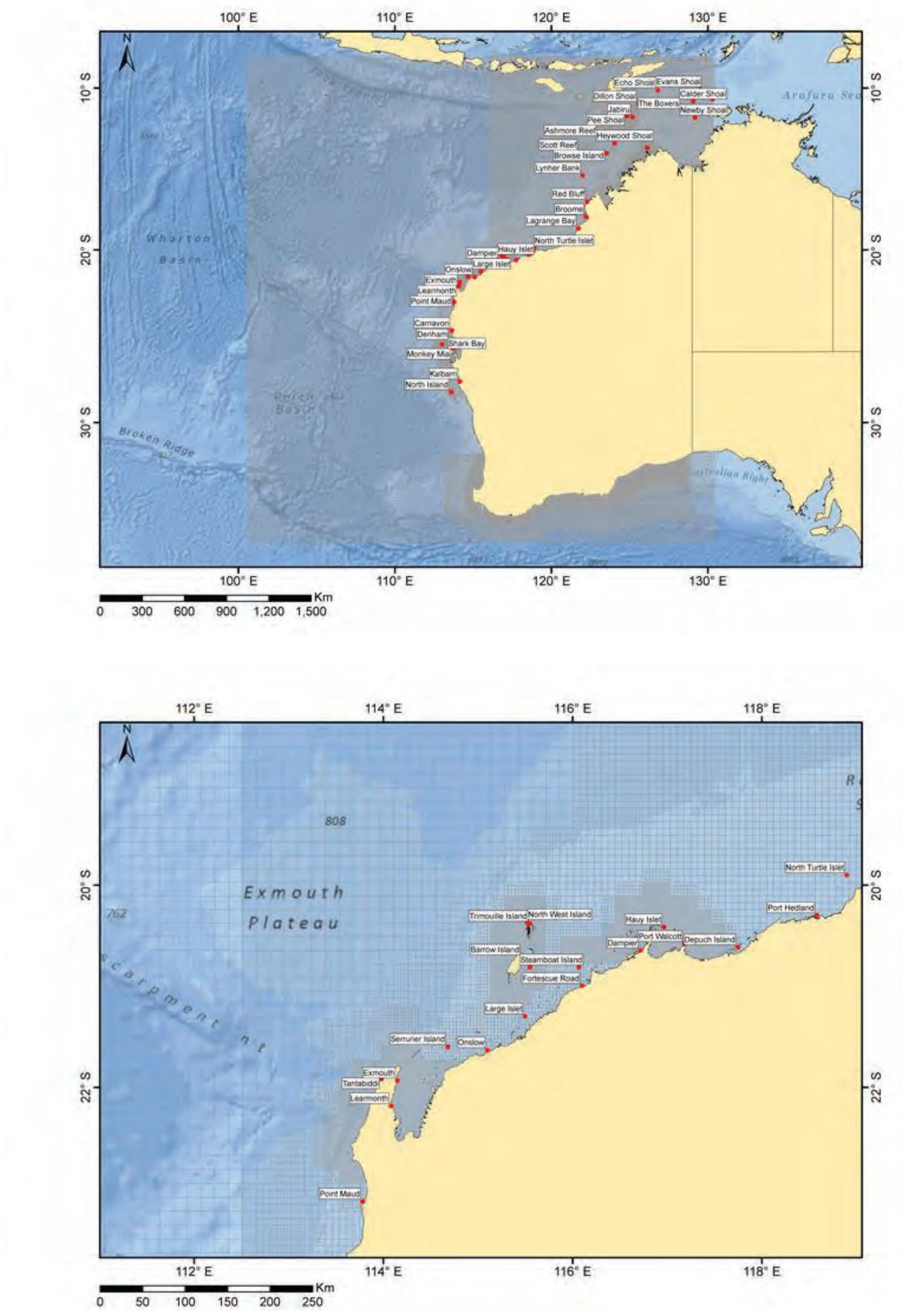



**Figure 2.4** **Hydrodynamic model grid (grey wire mesh) used to generate the tidal currents, showing locations available for tidal comparisons (red labelled dots). The top panel shows the full domain in context with the continental land mass, while the bottom panel shows a zoomed subset near the spill locations. Higher-resolution areas are indicated by the denser mesh zones.**

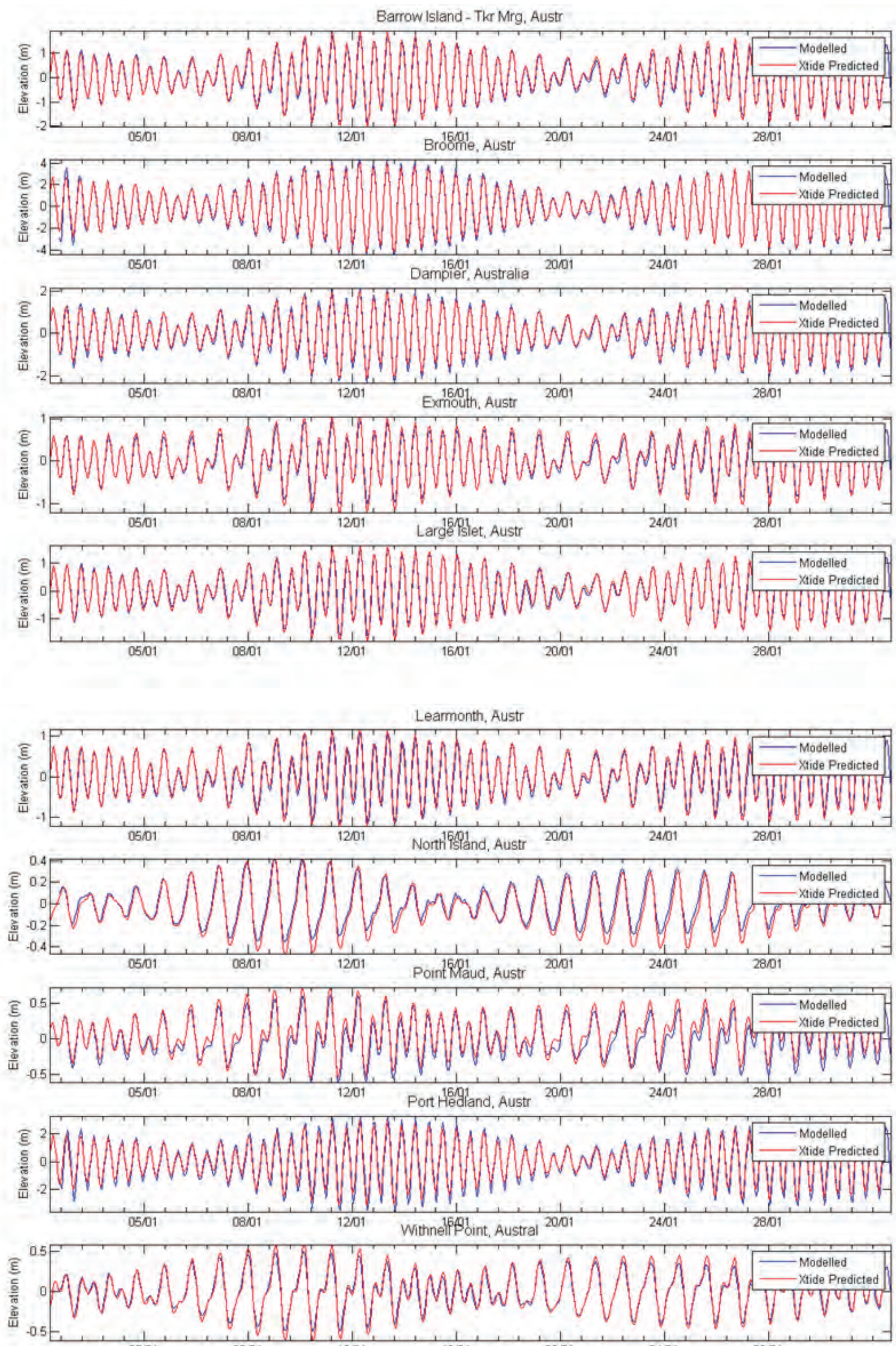
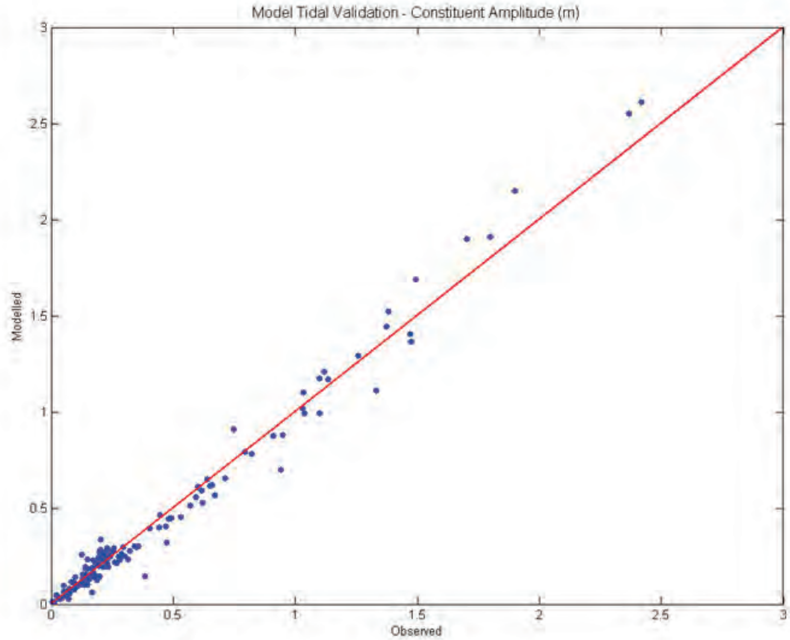



**Figure 2.5 Comparisons between the predicted (blue line) and observed (red line) surface elevation variations at ten locations in the tidal model domain for January 2005.**



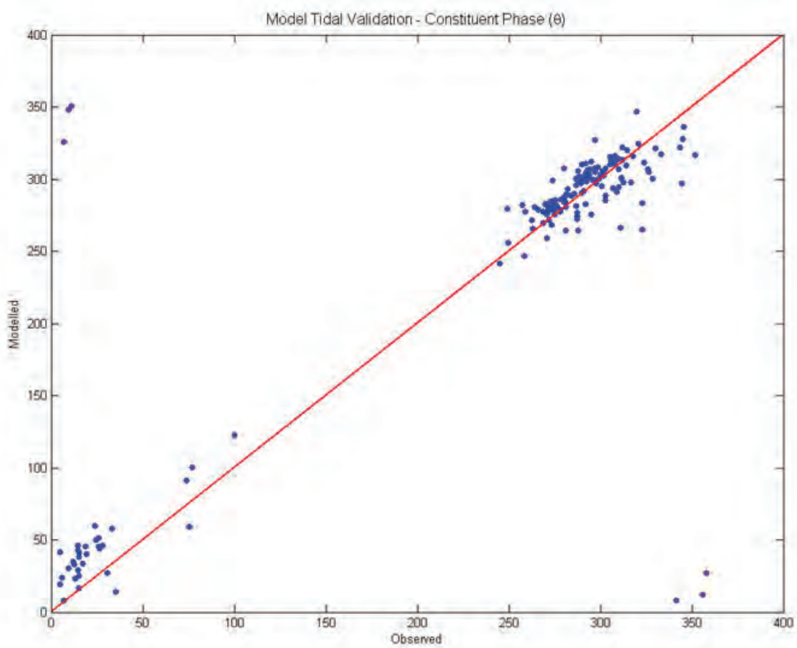




**Figure 2.6 Comparisons between modelled and observed tidal constituent amplitudes (top) and phases (bottom) at all stations in the HYDROMAP model domain. The red line indicates a 1:1 correlation between the modelled and observed data.**

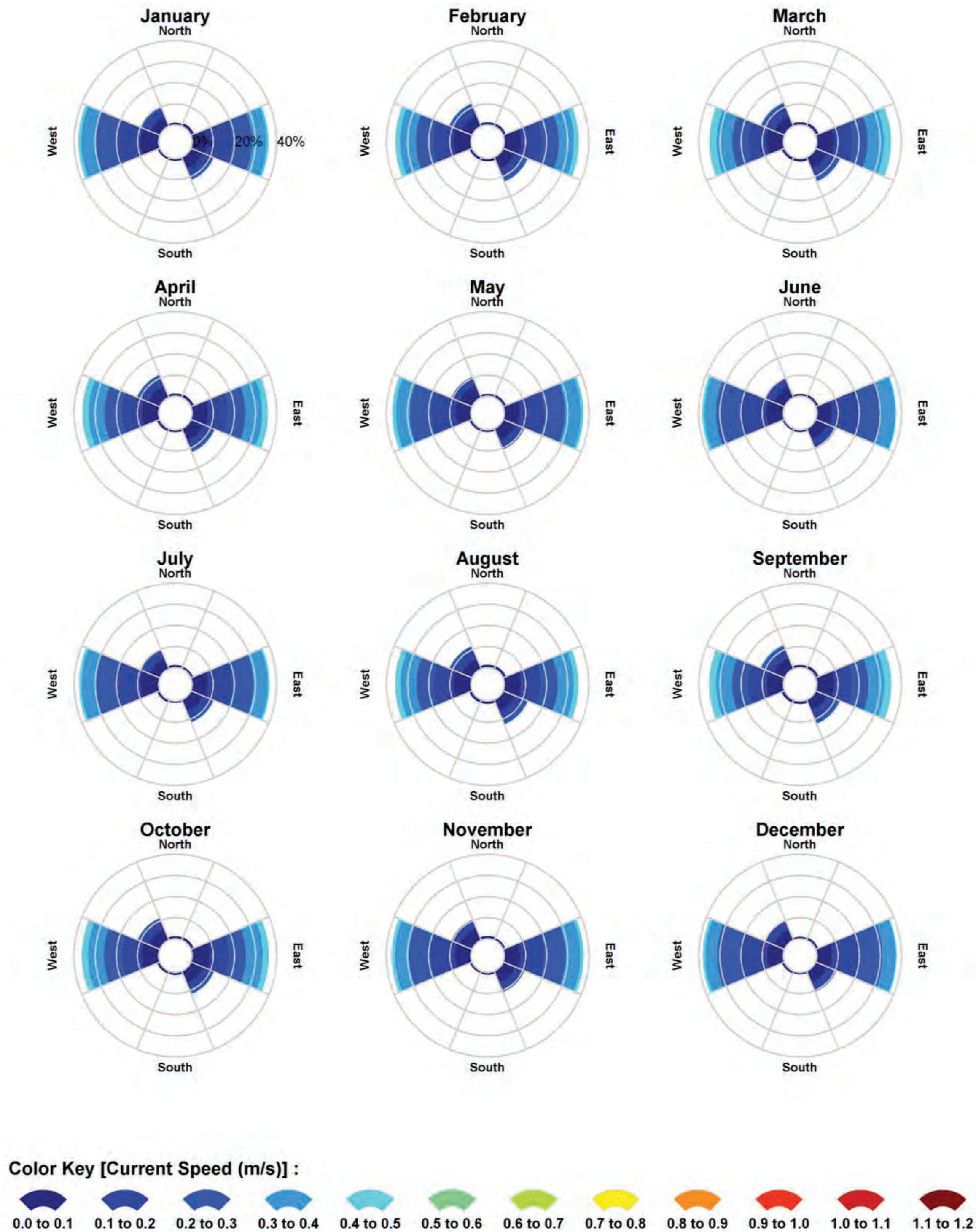



**Figure 2.7 Monthly current distribution (2006-2015, inclusive) derived from the HYDROMAP database near to the Scenario 1 spill location. The colour key shows the current magnitude, the compass direction provides the direction towards which the current is flowing, and the size of the wedge gives the percentage of the record.**

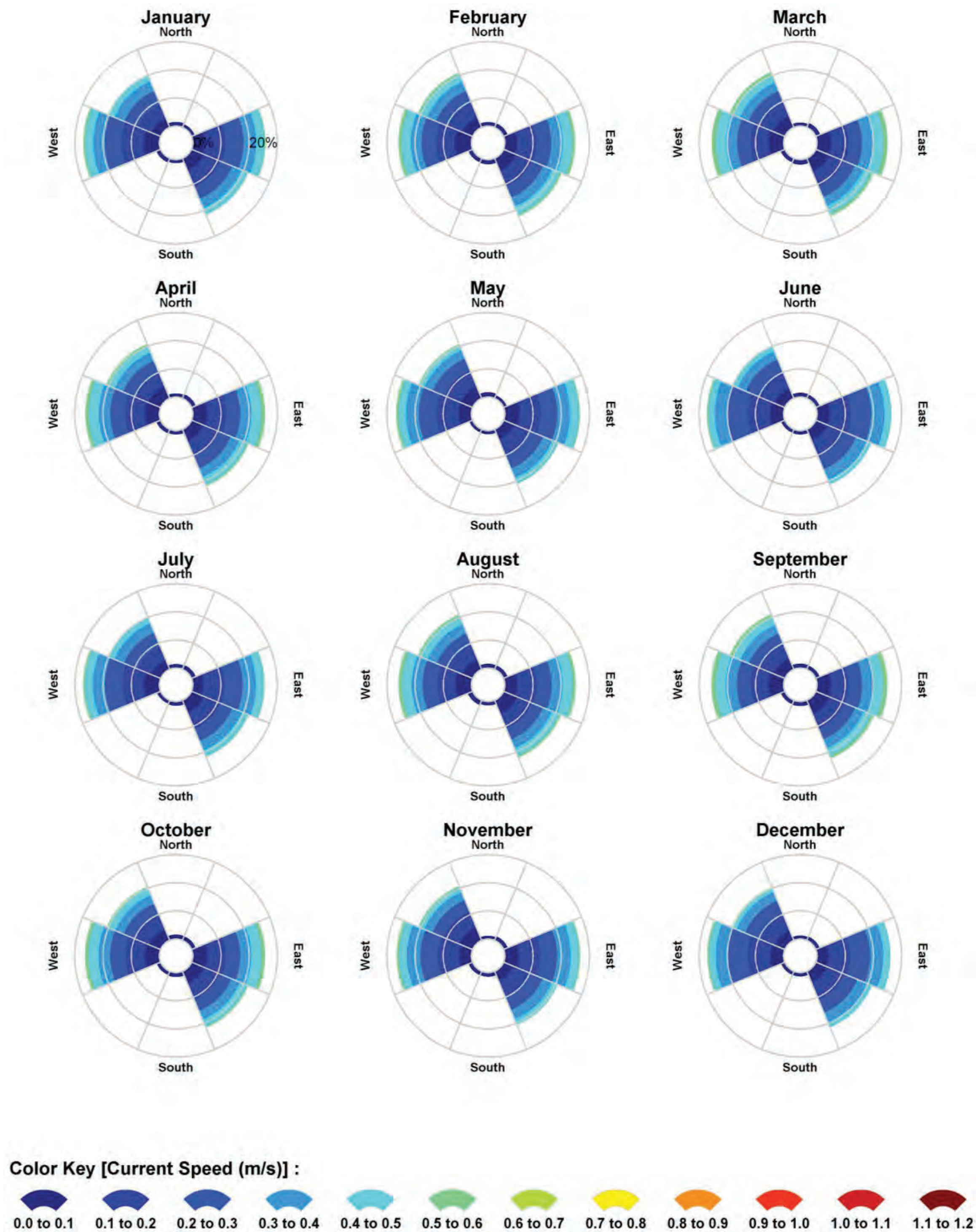



**Figure 2.8** **Monthly current distribution (2006-2015, inclusive) derived from the HYDROMAP database near to the Scenario 2 spill location. The colour key shows the current magnitude, the compass direction provides the direction towards which the current is flowing, and the size of the wedge gives the percentage of the record.**

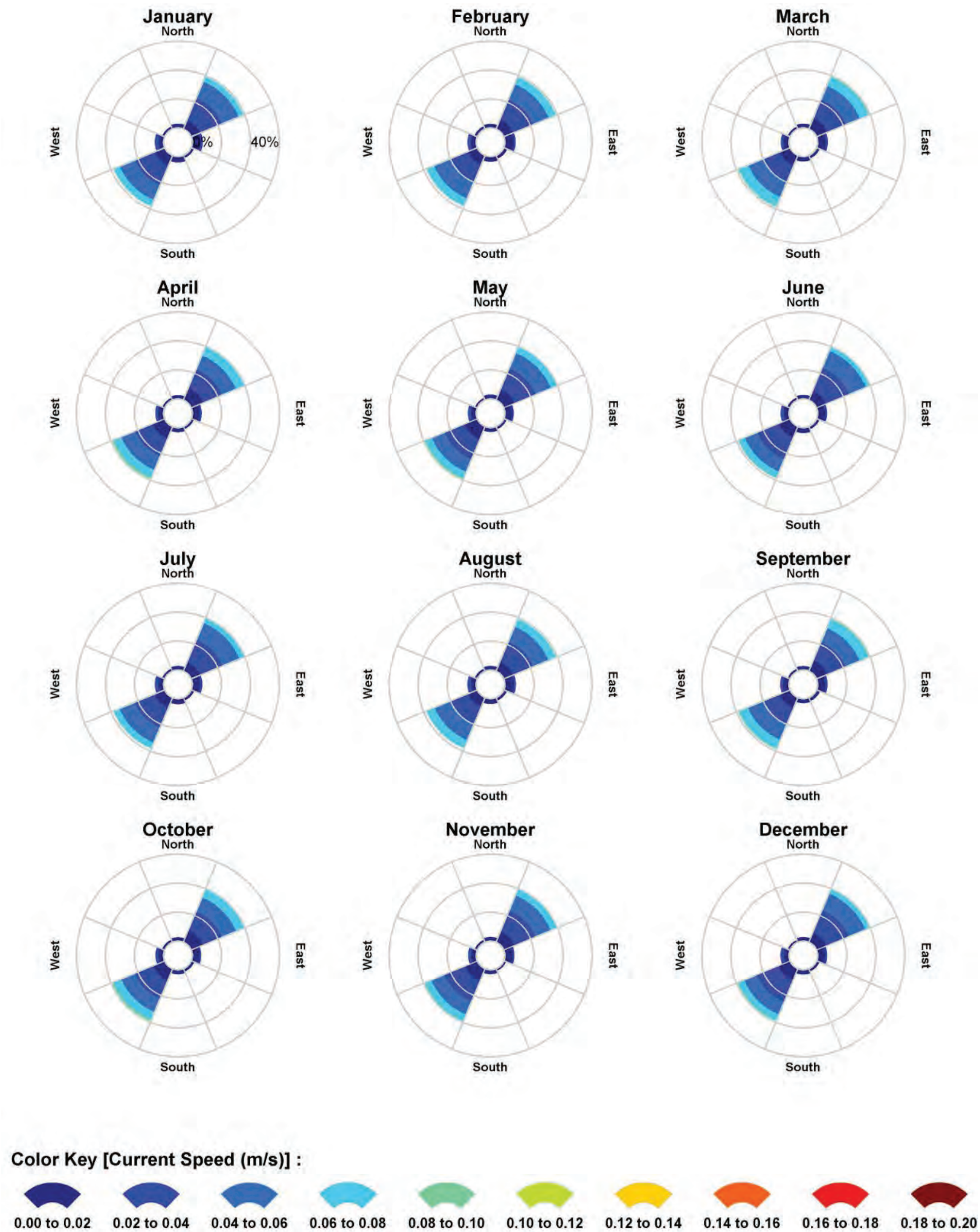



**Figure 2.9 Monthly current distribution (2006-2015, inclusive) derived from the HYDROMAP database near to the Scenario 3 spill location. The colour key shows the current magnitude, the compass direction provides the direction towards which the current is flowing, and the size of the wedge gives the percentage of the record.**

### 2.3.2 Wind Data

To account for the influence of the wind on surface-bound oil slicks, representation of the wind conditions was provided by spatial wind fields sourced from the National Center for Environmental Prediction (NCEP), via the National Oceanic and Atmospheric Administration (NOAA) and Cooperative Institute for Research in Environmental Sciences (CIRES) Climate Diagnostics Center (CDC). 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 (2006-2015, inclusive). The data was assumed to be a suitably representative sample of the wind conditions over the study area for future years.

Figure 2.10 to Figure 2.12 show the monthly distribution of wind speed and direction for the CFSR data points closest to the spill locations for Scenarios 1 to 3. Note that the convention for defining wind direction is the direction from which the wind blows.

The wind data indicates similar trends in wind direction at the Scenario 1 and 2 spill locations, with predominantly easterly directions between May and July, and westerly/south-westerly directions dominating in the October to February period. At the Scenario 3 spill location, easterly/south-easterly directions are most common between April and August, with southerly directions most prominent between September and March. Average wind speeds across the year at the three spill locations vary in the range 5.9-6.5 m/s, with year-round maximum speeds of 25.5-29.4 m/s.

The extracted wind data near the spill location suggests possible initial trajectories due to the wind acting on surface slicks in the absence of any current effects. Note that the actual trajectories of surface slicks will be the net result of a combination of the prevailing wind and current vectors acting at a given time and location.

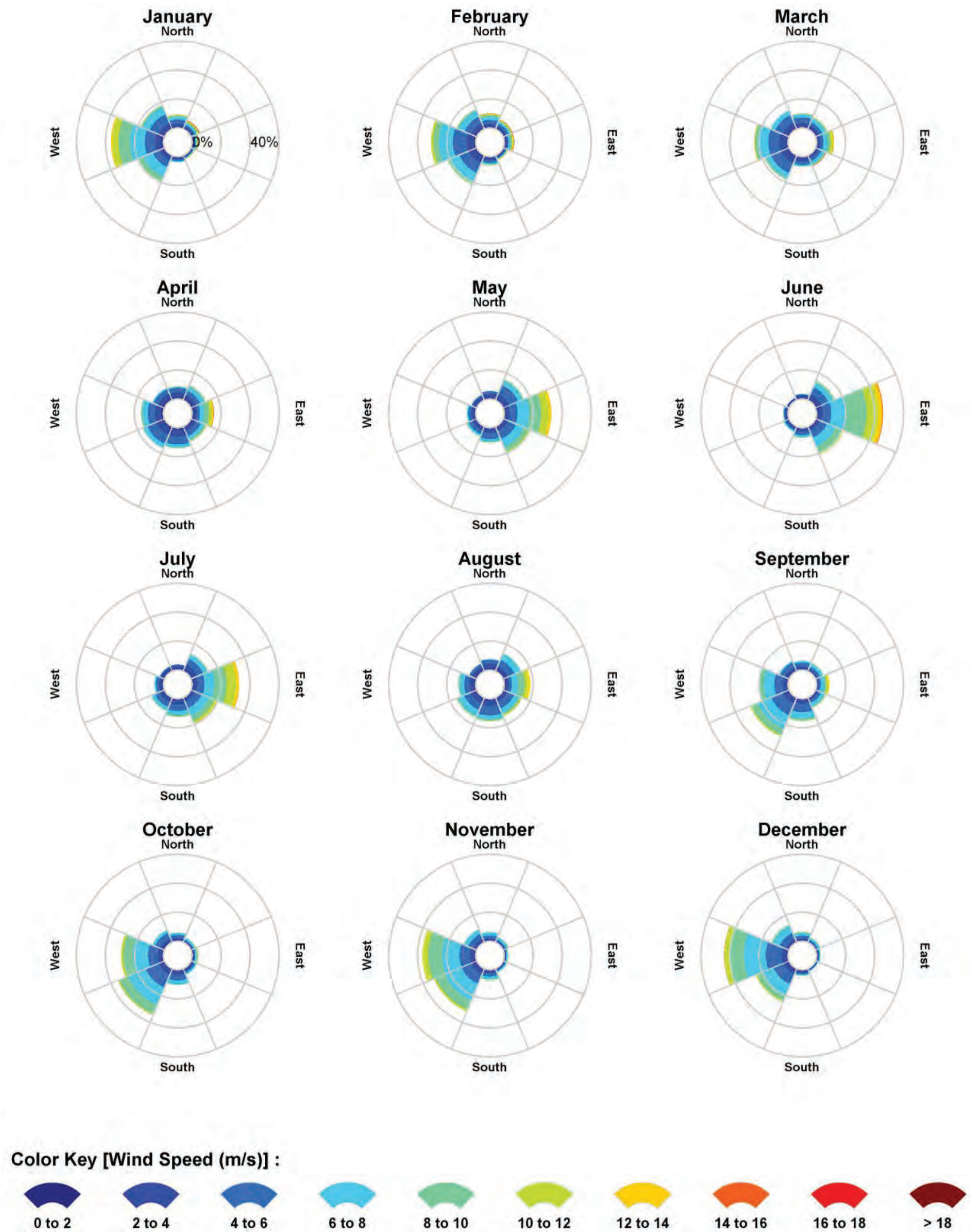



**Figure 2.10 Monthly wind distribution (2006-2015, inclusive) derived from the CFSR database near to the Scenario 1 spill location. The colour key shows the wind magnitude, the compass direction provides the direction from which the wind is blowing, and the size of the wedge gives the percentage of the record.**

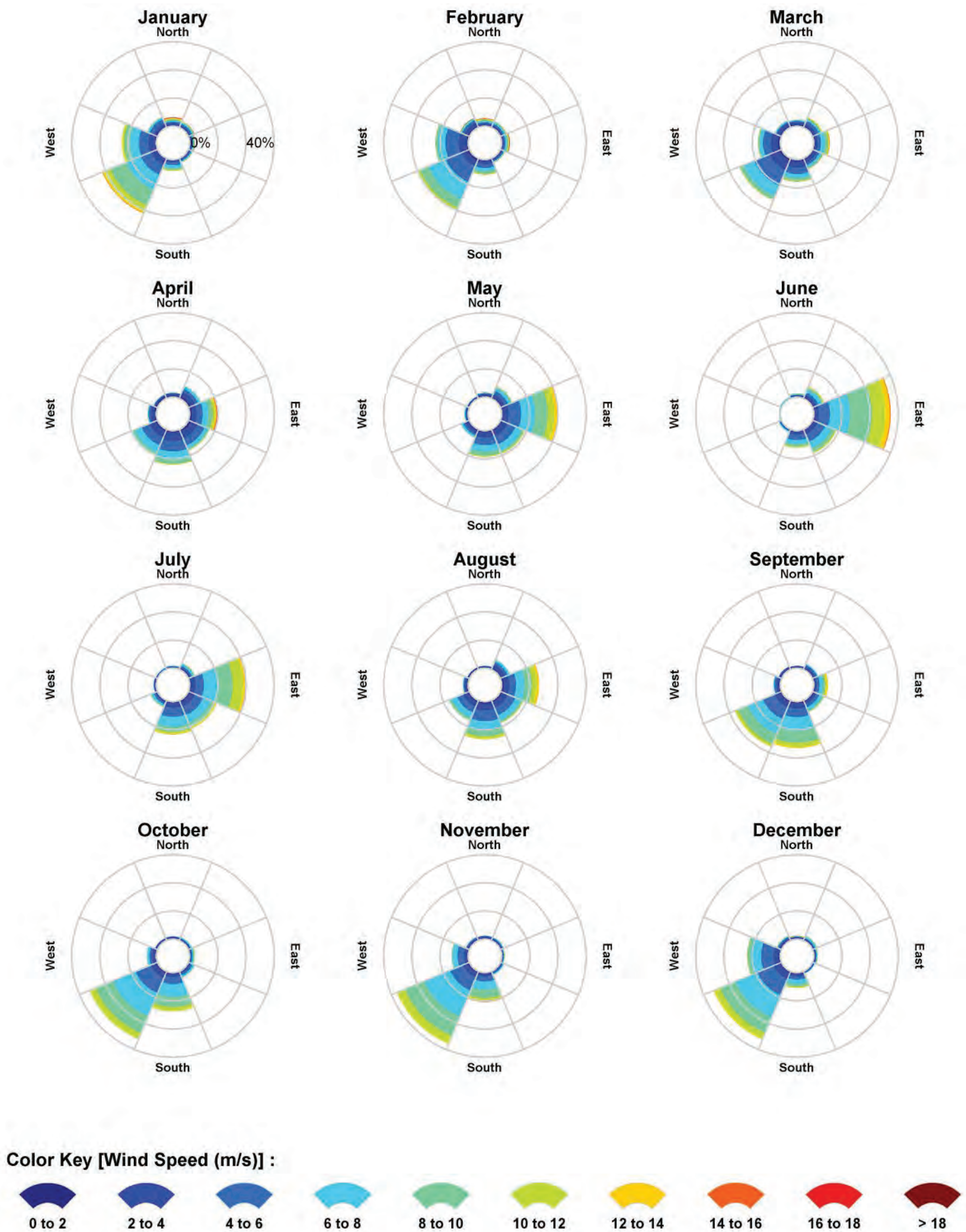



**Figure 2.11 Monthly wind distribution (2006-2015, inclusive) derived from the CFSR database near to the Scenario 2 spill location. The colour key shows the wind magnitude, the compass direction provides the direction from which the wind is blowing, and the size of the wedge gives the percentage of the record.**

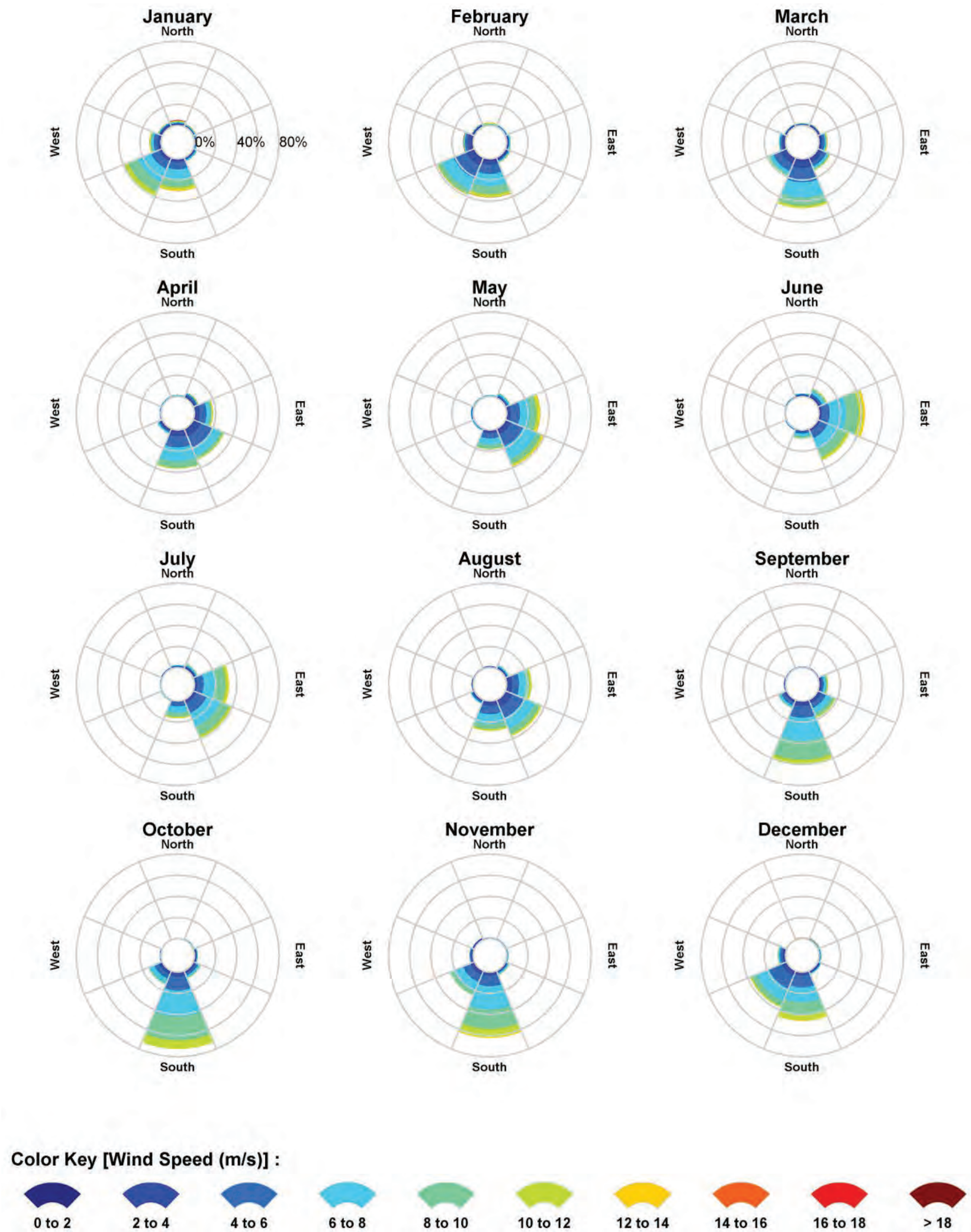



**Figure 2.12** **Monthly wind distribution (2006-2015, inclusive) derived from the CFSR database near to the Scenario 3 spill location. The colour key shows the wind magnitude, the compass direction provides the direction from which the wind is blowing, and the size of the wedge gives the percentage of the record.**

### 2.3.3 Water Temperature and Salinity Data

The World Ocean Atlas 2013 (WOA13) is provided by NOAA and is a hindcast model of the climatological fields of in situ temperature, salinity, and a number of additional variables (NOAA, 2013a). WOA13 has a 0.25° resolution and has standard depth levels ranging from the water surface to 5,500 m (Locarnini *et al.*, 2013; Zweng *et al.*, 2013). Vertical profiles of sea temperature and salinity at the spill locations were retrieved from a data point in the WOA13 database near the Scarborough Project (19° 53' 54.60" S, 116° 14' 19.68" E), with monthly averages used as input to SIMAP.

Figure 2.13 shows the variation in water temperature and salinity both seasonally and over depth. During the period from May to September, surface mixing is evident over the upper 50-150 m of the water column (where the depth is approximately 1,000 m at this location). In contrast, during the period from October to April, the surface mixed layer is shallower, indicating stronger thermal stratification. The average temperature over the upper 200 m of the water column varies between approximately 15-29 °C across the year, while the average salinity over this depth range varies between approximately 34.6-35.8 PSU year-round.

### 2.3.4 Dispersion

A horizontal dispersion coefficient of 5 $m^2/s$ was used to account for dispersive processes acting at the surface that are below the scale of resolution of the input current field, based on typical values for coastal waters (Okubo, 1971). Dispersion rates within the water column (applicable for entrained and dissolved plumes of hydrocarbons) were specified at 1 $m^2/s$, based on empirical data for the dispersion of hydrocarbon plumes over the North West Shelf (King & McAllister, 1998).

### 2.3.5 Replication

Multiple replicate simulations were completed for the defined scenarios to account for trends and variations in the trajectory and weathering of spilled oil, with an even number of replicates completed using samples of metocean data that commenced within each month. For Scenarios 1-3, a total of 100 replicate simulations were run over an annual period.

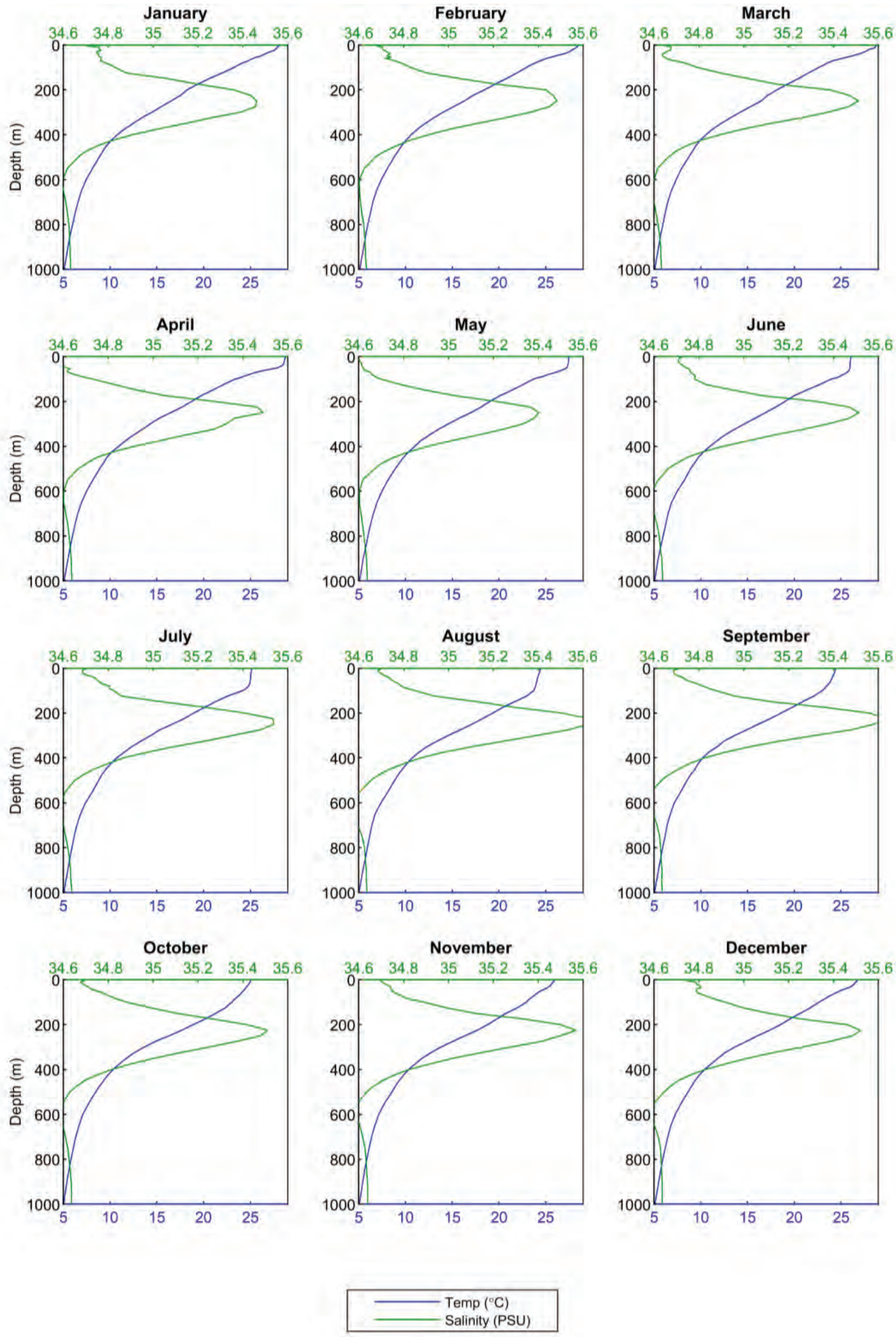



**Figure 2.13 Temperature (blue line) and salinity (green line) profiles derived from the WOA13 database near the Scarborough Project (19° 53' 54.60" S, 113° 14' 19.68" E). Depth of 0 m is the water surface.**

## 2.3.6 Contact Thresholds

### 2.3.6.1 Overview

The SIMAP model will track oil concentrations to very low levels. Hence, it is useful to define meaningful threshold concentrations for the recording of contact by oil components and determining the probability of exposure at a location (calculated from the number of replicate simulations in which this contact occurred).

The judgement of meaningful levels is complicated and will depend upon 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 oil. The latter factor is further complicated by the change in the composition of an oil type over time due to weathering processes. Without specific testing of the oil types, at different states of weathering against a wide range of the potential local receptors, such considerations are beyond the scope of this investigation.

For this case, thresholds for floating, entrained and dissolved aromatic hydrocarbons were specified by Woodside for use in defining the potential zone of influence of the spill event. These thresholds are summarised in Table 2.1 and discussed afterwards.

**Table 2.1 Summary of the thresholds applied in this study.**

| Floating Oil Concentration ($g/m^2$) | Shoreline Oil Concentration ($g/m^2$) | Entrained Oil Concentration (ppb) | Dissolved Aromatic Hydrocarbon Concentration (ppb) |
|---|---|---|---|
| 10 | 100 | 500 | 500 |
| 50 | | | |
| 100 | 250 | | |

### 2.3.6.2 Floating Oil

Floating oil concentrations are relevant to describing the risks of oil coating emergent reefs, vegetation in the littoral zone and shoreline habitats, as well as the risk to wildlife found on the water surface, such as marine mammals, reptiles and birds. Floating oil is also visible at relatively low concentrations (> ~0.05 $g/m^2$). Hence, the area affected by visible oil, which might trigger social or economic impacts, will be larger than the area where biological impacts might be expected.

Estimates for the minimal thickness of floating oil that might result in harm to seabirds through ingestion from preening of contaminated feathers, or the loss of the thermal protection of their feathers, has been estimated by different researchers at approximately 10 $g/m^2$ (French-McCay, 2009) to 25 $g/m^2$ (Koops *et al.*, 2004). Hence, the 10 $g/m^2$ threshold is likely to be moderately conservative in terms of environmental harm for effects on seabirds, for example. The lower threshold of 1 $g/m^2$ is likely to be an indicator of where there is a visual presence of an oil slick that may trigger social and economic impacts but where there is little potential for environmental impact.

It is important to note that real spill events generate surface slicks that break up into multiple patches separated by areas of open water. Concentrations calculated and presented in this study represent necessary areal averaging over discrete model cells, and therefore indicate the potential for both higher and lower relative concentrations in the surrounding space.

#### 2.3.6.3 Shoreline Oil

Shoreline oil concentrations are relevant to describing the risks of oil contact/stranding on shorelines and beaches. 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, 2013b). This threshold is also recommended in the Australian Maritime Safety Authority'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). The 250 $g/m^2$ threshold is above the minimum thresholds observed to cause ecological impact and would therefore be considered high exposure.

#### 2.3.6.4 Entrained Oil

Oil can be entrained into the water column from surface slicks due to wind and wave-induced turbulence, or be generated subsea by a pressurised discharge at depth. Entrained oil presents a number of possible mechanisms for exerting exposure. The entrained oil droplets may contain soluble compounds and hence have the potential to generate elevated concentrations of dissolved hydrocarbons (e.g. if mixed by breaking waves against a shoreline). Physical and chemical effects of the entrained oil droplets have also been demonstrated through direct contact with organisms; for example, through physical coating of gills and body surfaces, or accidental ingestion (NRC, 2005).

A review of the concentrations of physically entrained oil that has been demonstrated to have harmful effects in laboratory studies (NRC, 2005) showed wide variation depending on the test organisms and the initial oil mixture. For mortality of molluscs, reported $LC_{50}$ values range from 500 ppb to 2,000 ppb with 96-hour exposure. Wider exposure sensitivities are displayed by species of crustaceans (100 ppb to 258,000 ppm) with 96-hour exposure, while marine fish larvae appear yet more sensitive with $LC_{50}$ values as low as 45 ppb after 24-hour exposure.

As an indication of potential exposure, a threshold for concentrations of entrained oil was defined at 500 ppb. This threshold is particularly relevant for short duration (acute) exposure to organisms or fixed habitats affected by the dynamically-varying oil plume. A lower threshold, such as 10 ppb – which would be considered a conservative estimate of the lowest concentration that may be harmful to sensitive marine organisms over relatively long exposure times (tens of hours; French, 2000) – would be more meaningful for larvae and organisms that might be entrained (and therefore moving) within the oil plumes.

#### 2.3.6.5 Dissolved Aromatic Hydrocarbons

The mode of action of soluble hydrocarbons is a narcotic effect resulting from uptake into the tissues of organisms. This effect is additive, increasing with exposure concentration or with time of exposure (French, 2000; NRC, 2005) For many oil mixtures, the concentration of aromatic hydrocarbons, and specifically the polyaromatic hydrocarbons (PAHs), in the water-soluble fraction is the best predictor of the toxicity of the oil.

As an indication of potential exposure, a threshold for concentrations of dissolved aromatic hydrocarbons was defined at 500 ppb. Because exposure times may be short (<1-2 hours) in the case of a slick passing over a fixed habitat (such as a reef), due to fluctuations in the plume location with changing environmental conditions, and because marine organisms can typically tolerate concentrations of toxic hydrocarbons that are two or more orders of magnitude higher over such short durations (Pace *et al.*, 1995; French, 2000), the 500 ppb threshold is likely to be indicative of potentially harmful exposure to fixed habitats over short exposure durations.

## 2.3.7 Oil Characteristics

### 2.3.7.1 Overview

Characteristics of marine diesel are summarised in Table 2.2.

**Table 2.2 Characteristics of the oil type used in the modelling of Scenarios 1-3.**

| Oil Type | Density (g/cm$^3$) | Viscosity (cP) | Component | Volatile (%) | Semi-Volatile (%) | Low Volatility (%) | Residual (%) | Aromatics (%) |
|---|---|---|---|---|---|---|---|---|
| | | | Boiling point (°C) | <180<br>C4 to C10 | 180 - 265<br>C11 to C15 | 265 - 380<br>C16 to C20 | >380<br>>C20 | Of whole oil<br><380 BP |
| Marine Diesel | 0.829<br>at 25 °C | 4.000<br>at 25 °C | % of total | 6.0 | 34.6 | 54.4 | 5.0 | 3.0 |
| | | | % aromatics | 1.8 | 1.0 | 0.2 | - | - |

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.

The aromatic components within the volatile to low-volatility range are also soluble (with decreasing solubility following decreasing volatility) and will dissolve across the oil-water interface. The rate of dissolution will increase with increase in surface area. Hence, dissolution rates will be higher under discharge conditions that generate smaller oil droplets.

Atmospheric weathering will commence if and when oil droplets float to the water surface. Typical evaporation times once the hydrocarbons reach the surface and are exposed to the atmosphere are:

- 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
- Not applicable for the residual compounds (BP > 380 °C), which will resist evaporation, persist in the marine environment for longer periods, and be subject to relatively slow degradation.

The actual fate of released oil in the marine environment will depend greatly on the amount of oil that reaches the surface, either through the initial release or by rising after discharge in the water column.

### 2.3.7.2 Marine Diesel

Marine diesel is a mixture of volatile and persistent hydrocarbons with low proportions of highly volatile and residual components. In general, about 6% of the oil mass should evaporate within the first 12 hours (BP < 180 °C); a further 35% should evaporate within the first 24 hours (180 °C < BP < 265 °C); and a further 54% should evaporate over several days (265 °C < BP < 380 °C). Approximately 5% of the oil is shown to be persistent. The aromatic content of the oil is approximately 3%.

If released in the marine environment and in contact with the atmosphere (i.e. surface spill), approximately 41% by mass of this oil is predicted to evaporate over the first couple of days depending upon the prevailing conditions, with further evaporation slowing over time. The heavier (low volatility) components of the oil have a tendency to entrain into the upper water column due to wind-generated waves, but can subsequently resurface if wind-waves abate. Therefore, the heavier components of this oil can remain entrained or on the sea surface for an extended period, with associated potential for dissolution of the soluble aromatic fraction.

### 2.3.8 Weathering Characteristics

#### 2.3.8.1 Overview

A series of model weather tests were conducted to illustrate the potential behaviour of marine diesel when exposed to idealised and representative environmental conditions:

- Instantaneous release (1-hour discharge) onto the water surface at a discharge rate of 50 $m^3$/hr under calm wind conditions (constant 5 knots), assuming low seasonal water temperature (27 °C) and average air temperature (25 °C). Slick also subject to ambient tidal and drift currents.
- Instantaneous release (1-hour discharge) onto the water surface at a discharge rate of 50 $m^3$/hr under variable wind conditions (4-19 knots, drawn from representative data files), assuming low seasonal water temperature (27 °C) and average air temperature (25 °C). Slick also subject to ambient tidal and drift currents.

The first case is indicative of cumulative weathering rates under calm conditions that would not generate entrainment, while the second case may represent conditions that could cause a minor degree of entrainment. Both scenarios provide examples of potential behaviour during periods of a spill event, once the oil reaches the surface.

#### 2.3.8.2 Marine Diesel

The mass balance forecast for the constant-wind case (Figure 2.14) for marine diesel shows that approximately 45% of the oil is predicted to evaporate within 24 hours. Under these calm conditions the majority of the remaining oil on the water surface will weather at a slower rate due to being comprised of the longer-chain compounds with higher boiling points. Evaporation of the residual compounds will slow significantly, and they will then be subject to more gradual decay through biological and photochemical processes.

Under the variable-wind case (Figure 2.15), where the winds are of greater strength, entrainment of marine diesel into the water column is indicated to be significant. Approximately 24 hours after the spill, around 45% of the oil mass is forecast to have entrained and a further 35% is forecast to have evaporated, leaving only a small proportion of the oil floating on the water surface (<1%). The residual compounds will tend to remain entrained beneath the surface under conditions that generate wind waves (approximately >6 m/s).

The increased level of entrainment in the variable-wind case will result in a higher percentage of biological and photochemical degradation, where the decay of the floating slicks and oil droplets in the water column occurs at an approximate rate of 1.8% per day with an accumulated total of ~13% after 7 days, in comparison to a rate of ~0.2% per day and an accumulated total of 1.5% after 7 days in the constant-wind case. Given the large proportion of entrained oil and the tendency for it to remain mixed in the water column, the remaining hydrocarbons will decay and/or evaporate over time scales of several weeks to a few months. This long weathering duration will extend the area of potential effect, requiring the break-up and dispersion of the slicks and droplets to reduce concentrations below the thresholds considered in this study.

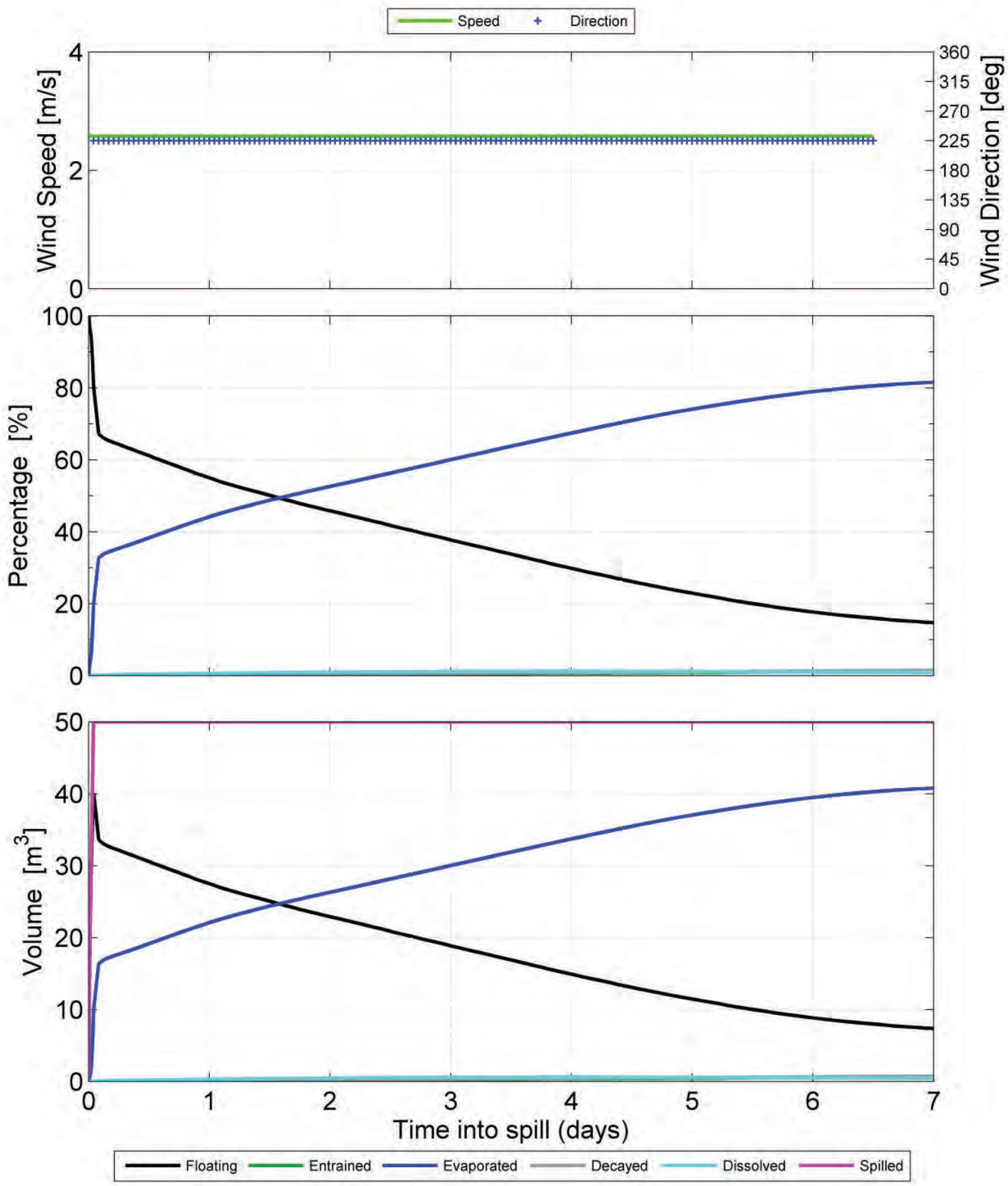



**Figure 2.14 Mass balance plot representing, as proportion (middle panel) and volume (bottom panel), the weathering of marine diesel spilled onto the water surface as a one-off release (50 m$^3$ over 1 hour) and subject to a constant 5 kn (2.6 m/s) wind at 27 °C water temperature and 25 °C air temperature.**

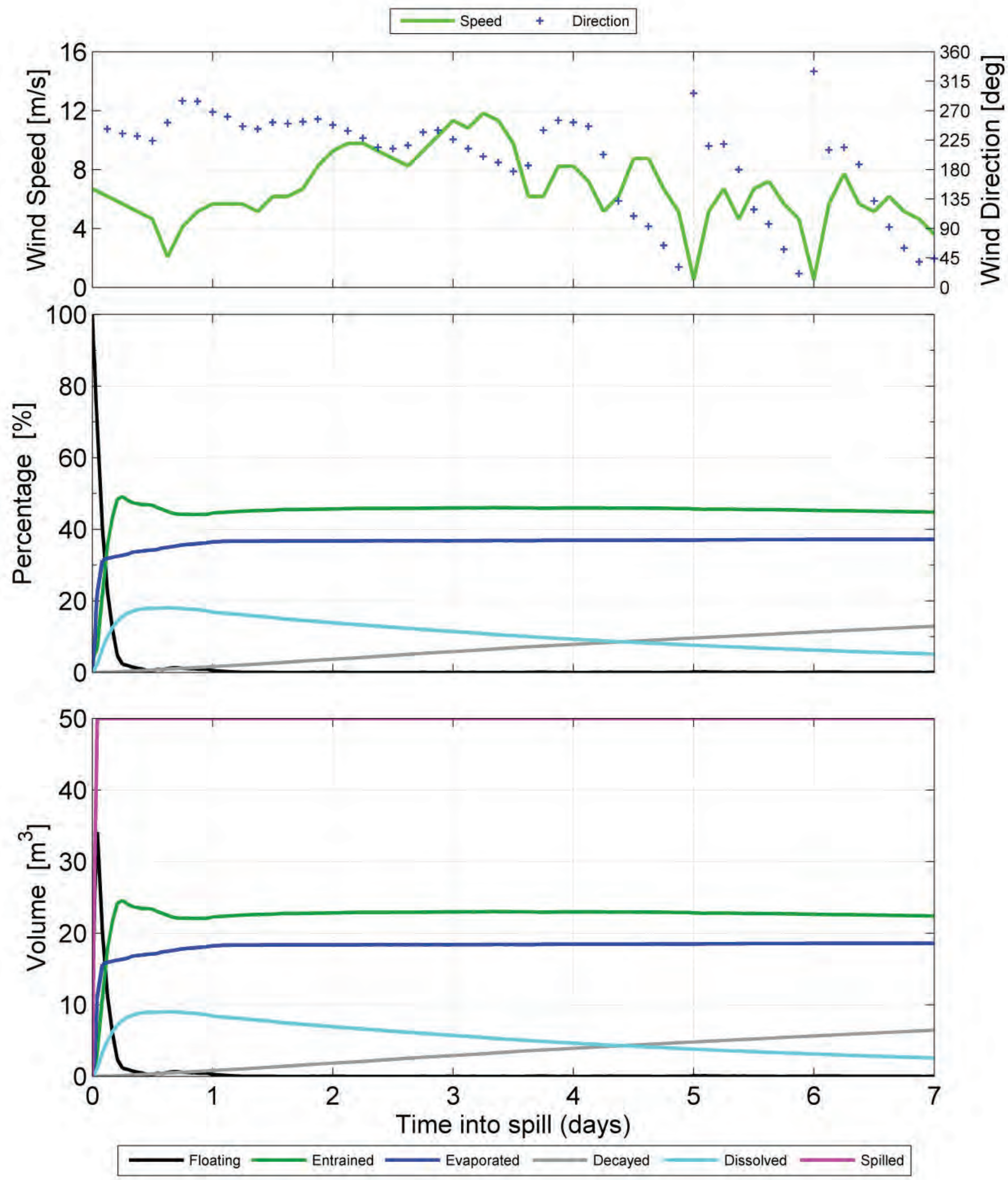



**Figure 2.15 Mass balance plot representing, as proportion (middle panel) and volume (bottom panel), the weathering of marine diesel spilled onto the water surface as a one-off release (50 $m^3$ over 1 hour) and subject to variable wind at 27 °C water temperature and 25 °C air temperature.**

# 3 STOCHASTIC ASSESSMENT RESULTS

## 3.1 Overview

Predictions for the probability of contact and time to contact by oil concentrations equalling or exceeding defined thresholds for floating oil, entrained oil and dissolved aromatic hydrocarbons are provided in the following sections to summarise the results of the annualised stochastic modelling.

Contour maps present estimates for the annualised probability of contact by instantaneous concentrations of at least the defined minimum threshold concentrations (10 g/m$^2$, 50 g/m$^2$ and 100 g/m$^2$ for floating oil; 100 g/m$^2$ and 250 g/m$^2$ for shoreline oil; 500 ppb for entrained oil and dissolved aromatic hydrocarbons) for at least one time step. These contours summarise the outcomes for all replicate simulations commencing across the annual period – a total of 200 replicate simulations for each assessed scenario.

Readers should note that the contour maps presented in this report do not represent the predicted coverage of any one hydrocarbon spill or a depiction of a slick or plume at any particular instant in time. Rather, the contours are a composite of a large number of theoretical slick paths, integrated over the full duration of the simulations relevant to the assessed 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 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 the spill scenario were to occur in the future. 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, we do not attribute a probability of nil to areas beyond the lowest probability contour.

Tables are presented to summarise estimates of contact risk for locations within potentially sensitive receptors that were defined by Woodside. All sensitive receptors historically considered for Woodside spill risk assessments were included in the analysis, with those outlined here being the receptors shown to be at risk of contact for each assessed scenario.

The probability estimates for contact by floating oil that are presented in the tables summarise the probability that oil will arrive at shorelines as floating films at the specified threshold concentration or greater for at least one time step (1 hour).

The minimum time estimates shown in the tables present the shortest time for any oil to drift from the source to any part of the sensitive receptor, relative to the commencement of the spill. These times then indicate the minimum weathering time for oil that might make contact with the resource.

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 0.8 km length). Accumulated concentrations are calculated by summing the mass of oil 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 extreme estimate. 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.

Note that it is possible that oil films arriving at concentrations that are less than the threshold may accumulate over the course of a spill event to result in concentrations that apparently exceed the threshold. Hence, the mean expected and maximum concentrations of accumulated oil can exceed the threshold applied to the probability calculations for the arrival of floating oil even where no instantaneous exceedances above threshold are predicted. 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. Buffer zones were defined with consideration of the bathymetry bordering each receptor, natural boundaries, or sensible legislative boundaries.

The modelling for each assessed scenario assumed no mitigation efforts are undertaken to collect or otherwise affect the natural transport and weathering of the oil.

The predicted outcomes based on the modelling results are discussed in the following sections in terms of floating, entrained and dissolved aromatic hydrocarbons. Discussion is based around the outcomes of stochastic risk contours. Plots of the Zones of Consequence (ZoCs) and minimum time to exceedance of concentration thresholds are presented for the assessed thresholds.

Figure 3.1 shows transect lines intersecting at the release locations along which maximum entrained oil and dissolved aromatic hydrocarbon concentrations in the water column were extracted for each assessed scenario.

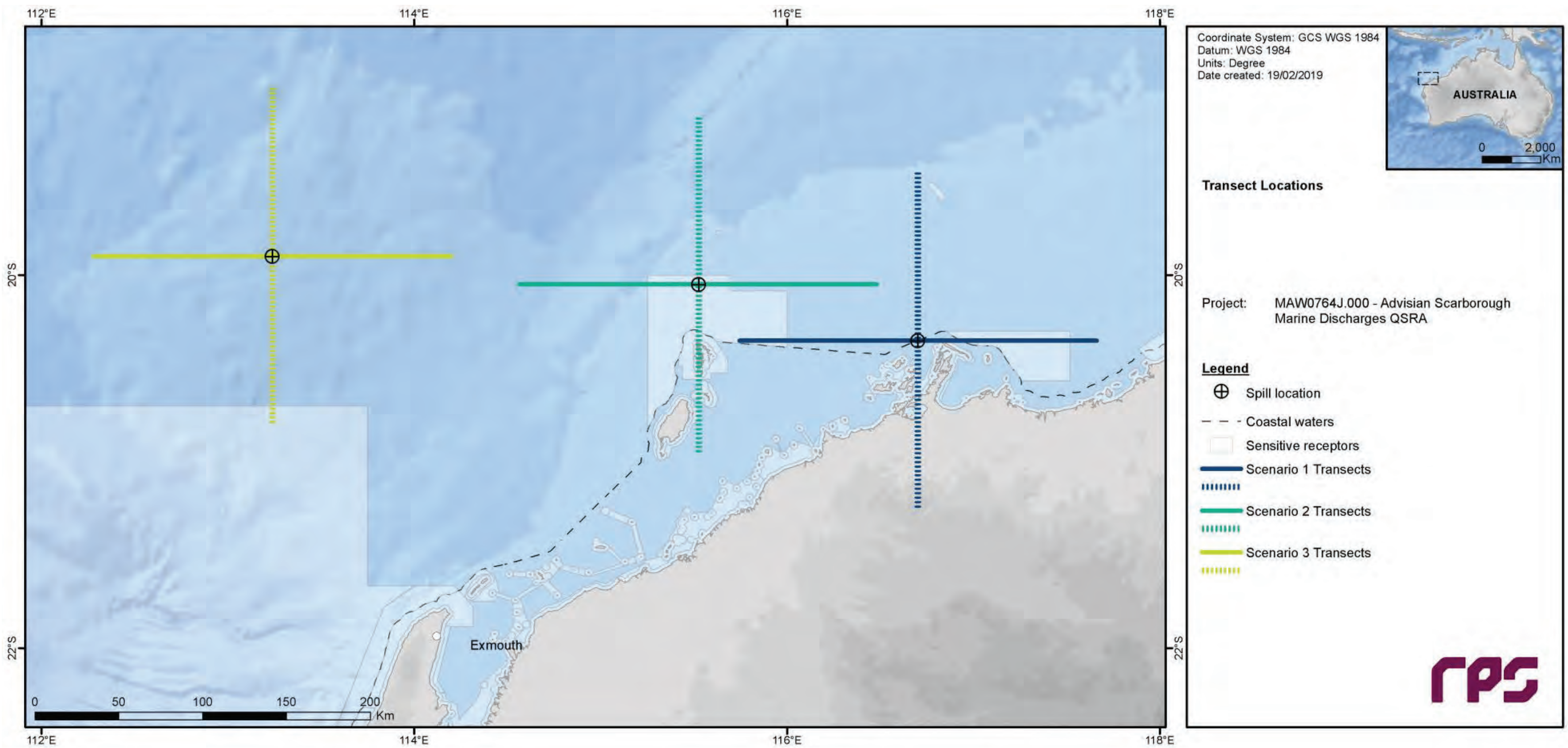



**Figure 3.1** **Locations of cross-sections, over a varying latitude (dashed line) and longitude (solid line), along which the distributions of maximum entrained oil and dissolved aromatic hydrocarbon concentrations were extracted for each spill scenario in this study.**

## 3.2 Scenario 1: Short-Term (Instantaneous) Surface Release of Marine Diesel after a Vessel Collision outside Mermaid Sound

### 3.2.1 Discussion of Results

#### 3.2.1.1 Overview

This scenario investigated the probability of exposure to surrounding regions by oil resulting from a short-term (instantaneous) surface release of 2,000 m$^3$ of marine diesel outside Mermaid Sound during operations at any time of year, with no mitigation measures applied.

Considering the discharge characteristics, the properties of the oil and its expected weathering behaviour, floating oil will be susceptible to entrainment into the wave-mixed layer under typical wind conditions. Evaporation rates will be significant, given the moderate proportion of volatile compounds in the oil (41%). The low-volatility fraction of the oil (54%) will take longer durations of the order of days to evaporate, and the residual fraction of 5% is expected to persist in the environment until degradation processes occur. Considering the spill volume, there is a low potential for dissolution of soluble aromatic compounds.

#### 3.2.1.2 Floating and Shoreline Oil

The probability contour figures for floating oil indicate that concentrations equal to or greater than the 10 g/m$^2$, 50 g/m$^2$ and 100 g/m$^2$ thresholds could potentially be found, in the form of slicks, up to 29 km, 21 km and 18 km from the spill site, respectively (Figure 3.2, Figure 3.3 and Figure 3.4).

The Dampier Archipelago shoreline receptor is predicted to be contacted by floating oil concentrations at the 10 g/m$^2$ threshold with a probability of 2% and a minimum time to contact of 27 hours (Table 3.1). Probabilities of floating oil contact at the 50 g/m$^2$ and 100 g/m$^2$ thresholds are forecast to be equal to or less than 1% for other shoreline receptors.

Potential for accumulation of oil on shorelines is predicted to be low, with a maximum accumulated volume of 3 m$^3$ and a maximum local accumulated concentration on shorelines of 156 g/m$^2$ forecast at the Dampier Archipelago (Table 3.1).

The forecast annualised minimum times to contact, ZoC and smoothed ZoC for floating oil at or above the 10 g/m$^2$, 50 g/m$^2$ and 100 g/m$^2$ threshold concentrations are depicted in Figure 3.5 to Figure 3.7, Figure 3.8 to Figure 3.10 and Figure 3.11 to Figure 3.13, respectively.

#### 3.2.1.3 Entrained Oil

Entrained oil at concentrations equal to or greater than the 500 ppb threshold is predicted to be found up to around 163 km from the spill site (Figure 3.15).

The Dampier MP and Dampier Archipelago receptors are predicted to receive entrained oil concentrations at the 500 ppb threshold with probabilities of 44% and 23%, respectively (Table 3.2). The maximum entrained oil concentration is forecast as 10.9 ppm within the Dampier Archipelago.

The forecast annualised minimum times to contact, ZoC and smoothed ZoC for entrained oil at or above the 500 ppb threshold concentration are depicted in Figure 3.16, Figure 3.17 and Figure 3.18, respectively.

The cross-sectional transects of maximum entrained oil concentrations in the vicinity of the release site show that concentrations above 25,000 ppb are expected to extend from the sea surface to depths of around 20 m (Figure 3.19).

#### 3.2.1.4 Dissolved Aromatic Hydrocarbons

Dissolved aromatic hydrocarbons at concentrations equal to or greater than the 500 ppb threshold are predicted to be found up to around 34 km from the spill site (Figure 3.20).

The Dampier MP receptor is predicted to receive dissolved aromatic hydrocarbon concentrations at the 500 ppb threshold with a probability of 2% (Table 3.3). The maximum dissolved aromatic hydrocarbon concentration is forecast as 635 ppb within the Dampier MP.

The forecast annualised minimum times to contact, ZoC and smoothed ZoC for dissolved aromatic hydrocarbons at or above the 500 ppb threshold concentration are depicted in Figure 3.21, Figure 3.22 and Figure 3.23, respectively.

The cross-sectional transects of maximum dissolved aromatic hydrocarbon concentrations in the vicinity of the release site show that concentrations above 1,000 ppb are expected to extend from the sea surface to depths of around 20 m (Figure 3.24).

## 3.2.2 Results Tables and Figures

### 3.2.2.1 Floating and Shoreline Oil

**Table 3.1 Expected annualised floating and shoreline oil outcomes at sensitive receptors resulting from an instantaneous surface release of marine diesel after a vessel collision outside Mermaid Sound.**

| Receptor | Probability (%) of floating oil concentration ≥10 g/m² | Probability (%) of floating oil concentration ≥50 g/m² | Probability (%) of floating oil concentration ≥100 g/m² | Minimum time to receptor (hours) for floating oil at ≥10 g/m² | Minimum time to receptor (hours) for floating oil at ≥50 g/m² | Minimum time to receptor (hours) for floating oil at ≥100 g/m² | Probability (%) of shoreline oil concentration ≥100 g/m² | Probability (%) of shoreline oil concentration ≥250 g/m² | Minimum time to receptor (hours) for shoreline oil at ≥100 g/m² | Minimum time to receptor (hours) for shoreline oil at ≥250 g/m² | Maximum local accumulated concentration (g/m²) averaged over all replicate simulations | Maximum local accumulated concentration (g/m²) in the worst replicate simulation | Maximum accumulated volume (m³) along this shoreline, averaged over all replicate simulations | Maximum accumulated volume (m³) along this shoreline, in the worst replicate simulation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Barrow Island | <1 | <1 | <1 | NC | NC | NC | <1 | <1 | NC | NC | <0.1 | 4.6 | <1 | <1 |
| Dampier Archipelago | 2 | 1 | <1 | 27 | 42 | NC | 1 | <1 | 53 | NC | 2.8 | 156 | <1 | 3 |
| Glomar Shoals* | <1 | <1 | <1 | NC | NC | NC | NA | NA | NA | NA | NA | NA | NA | NA |
| Montebello Islands | <1 | <1 | <1 | NC | NC | NC | <1 | <1 | NC | NC | <0.1 | 4.2 | <1 | <1 |
| Muiron Islands MMA-WHA | <1 | <1 | <1 | NC | NC | NC | <1 | <1 | NC | NC | <0.1 | 3.4 | <1 | <1 |
| Ningaloo Coast North WHA | <1 | <1 | <1 | NC | NC | NC | <1 | <1 | NC | NC | <0.1 | 1.5 | <1 | <1 |
| Ningaloo RUZ* | <1 | <1 | <1 | NC | NC | NC | NA | NA | NA | NA | NA | NA | NA | NA |
| Pilbara - Middle Pilbara - Islands & Shoreline | <1 | <1 | <1 | NC | NC | NC | <1 | <1 | NC | NC | <0.1 | 4.3 | <1 | <1 |
| Pilbara - Northern Pilbara - Islands & Shoreline | <1 | <1 | <1 | NC | NC | NC | <1 | <1 | NC | NC | NC | NC | <1 | <1 |
| Pilbara Islands - Southern Island Group | <1 | <1 | <1 | NC | NC | NC | <1 | <1 | NC | NC | 0.3 | 7 | <1 | <1 |
| Rankin Bank* | <1 | <1 | <1 | NC | NC | NC | NA | NA | NA | NA | NA | NA | NA | NA |
| Lowendal Islands | <1 | <1 | <1 | NC | NC | NC | <1 | <1 | NC | NC | <0.1 | 2 | <1 | <1 |
| Montebello MP* | <1 | <1 | <1 | NC | NC | NC | NA | NA | NA | NA | NA | NA | NA | NA |
| Montebello State Marine Park | <1 | <1 | <1 | NC | NC | NC | <1 | <1 | NC | NC | <0.1 | 4.2 | <1 | <1 |
| Muiron Islands | <1 | <1 | <1 | NC | NC | NC | <1 | <1 | NC | NC | <0.1 | 3.4 | <1 | <1 |
| Dampier MP* | 2 | <1 | <1 | 37 | NC | NC | NA | NA | NA | NA | NA | NA | NA | NA |
| Eighty Mile Beach MP* | <1 | <1 | <1 | NC | NC | NC | NA | NA | NA | NA | NA | NA | NA | NA |
| Gascoyne MP* | <1 | <1 | <1 | NC | NC | NC | NA | NA | NA | NA | NA | NA | NA | NA |
| WA Coastline | 3 | 1 | <1 | 26 | 43 | NC | 1 | <1 | 53 | NC | 2.8 | 156 | <1 | 3 |

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.

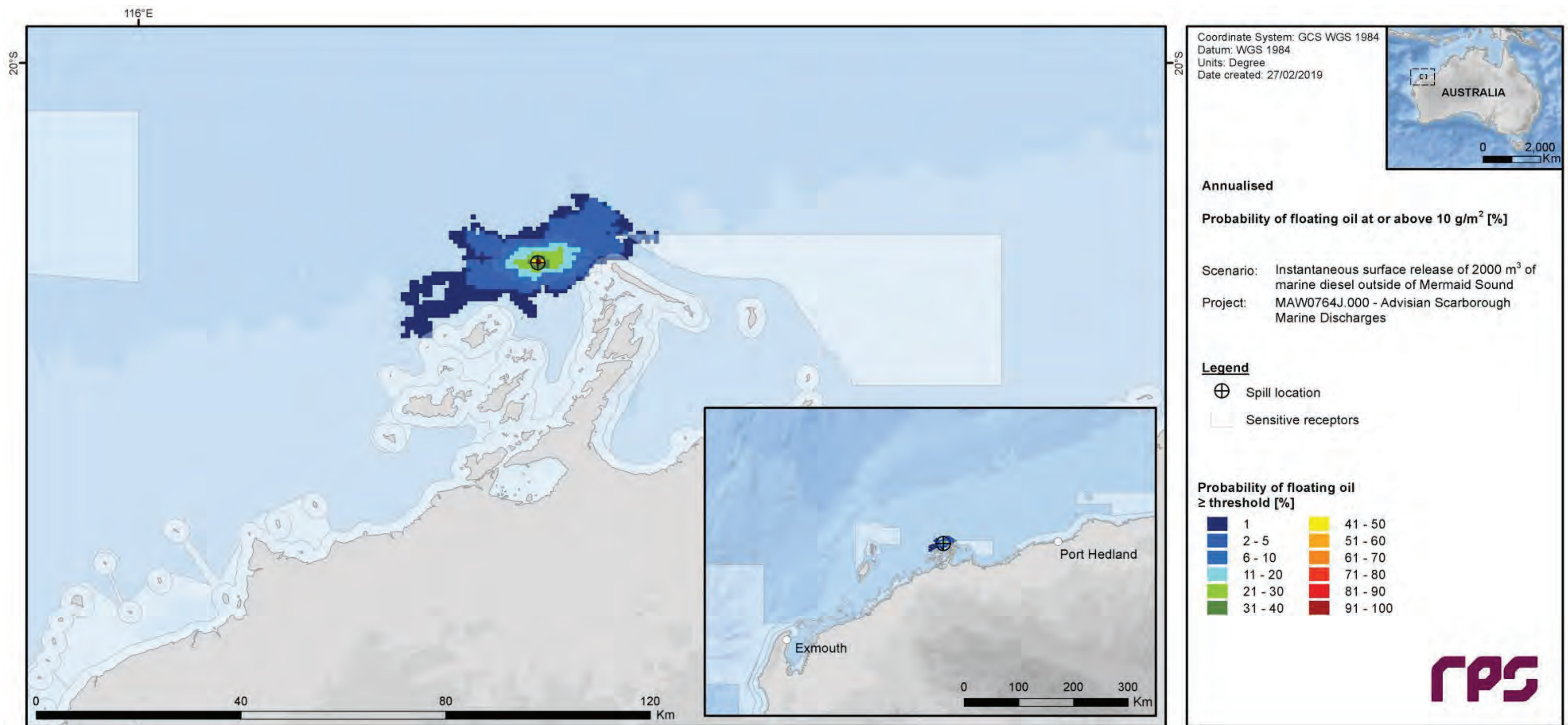



**Figure 3.2** **Predicted annualised probability of floating oil concentrations at or above 10 g/m² resulting from an instantaneous surface release of marine diesel after a vessel collision outside Mermaid Sound.**

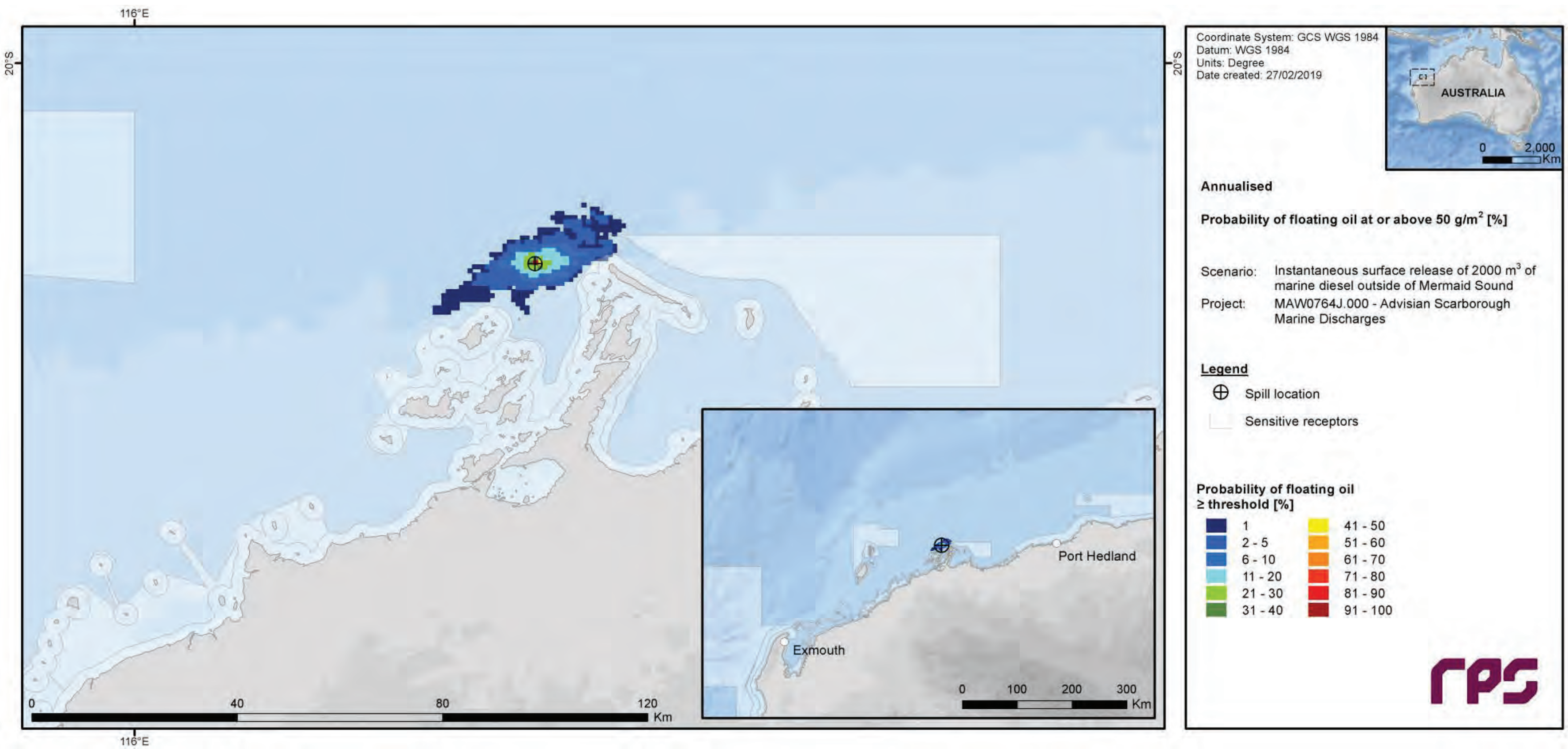



**Figure 3.3** **Predicted annualised probability of floating oil concentrations at or above 50 g/m² resulting from an instantaneous surface release of marine diesel after a vessel collision outside Mermaid Sound.**

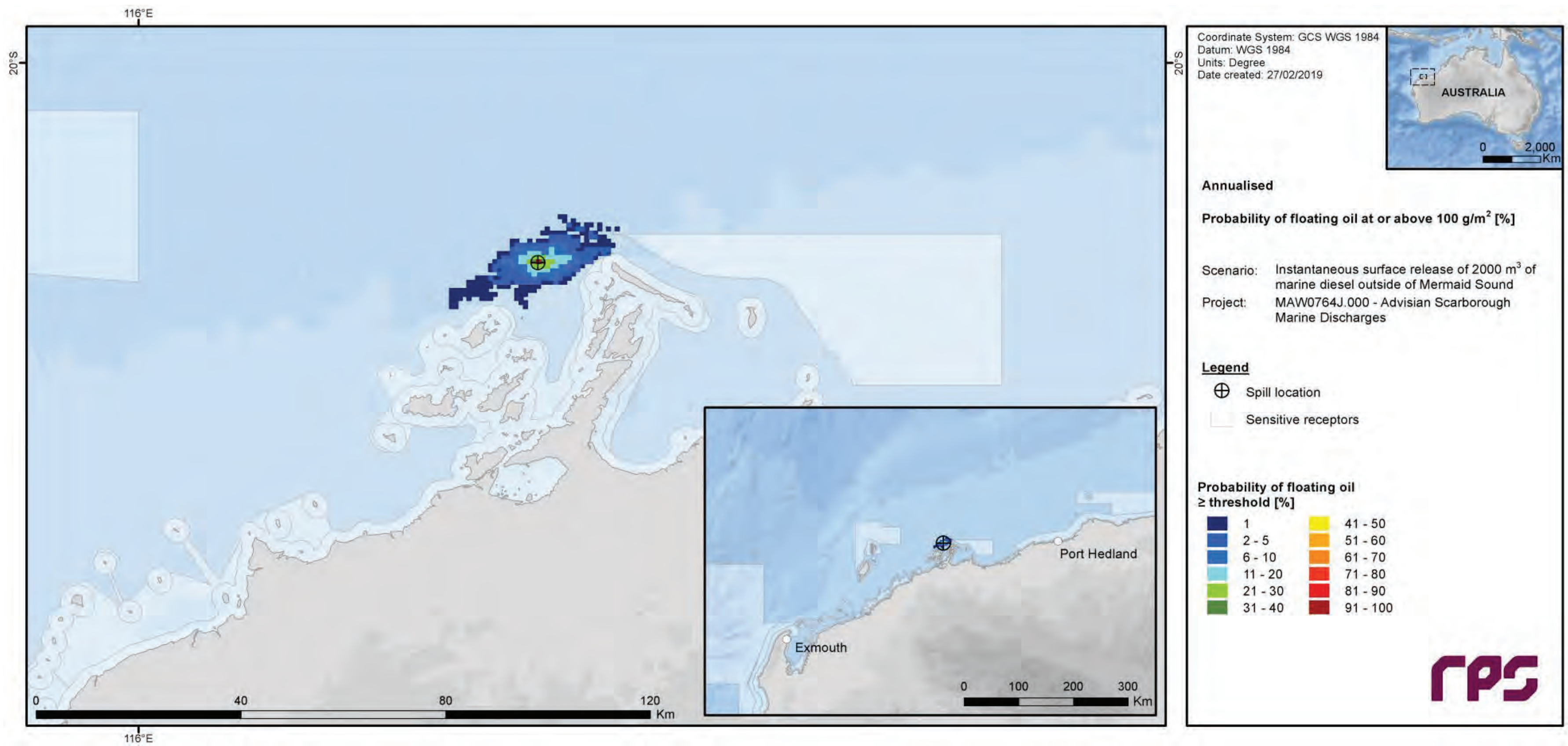



**Figure 3.4** **Predicted annualised probability of floating oil concentrations at or above 100 g/m² resulting from an instantaneous surface release of marine diesel after a vessel collision outside Mermaid Sound.**

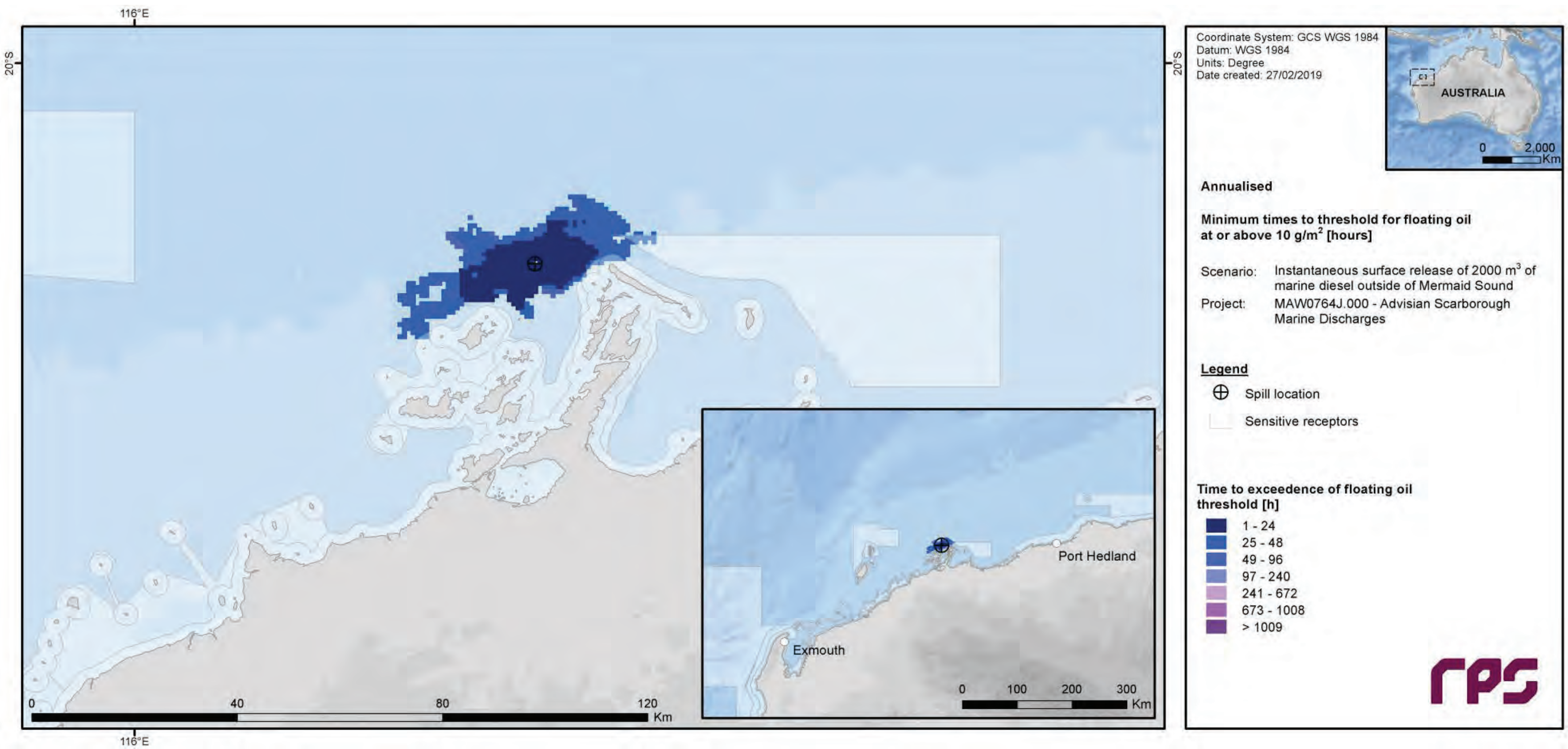



**Figure 3.5** **Predicted annualised minimum times to contact by floating oil concentrations at or above 10 g/m² resulting from an instantaneous surface release of marine diesel after a vessel collision outside Mermaid Sound.**

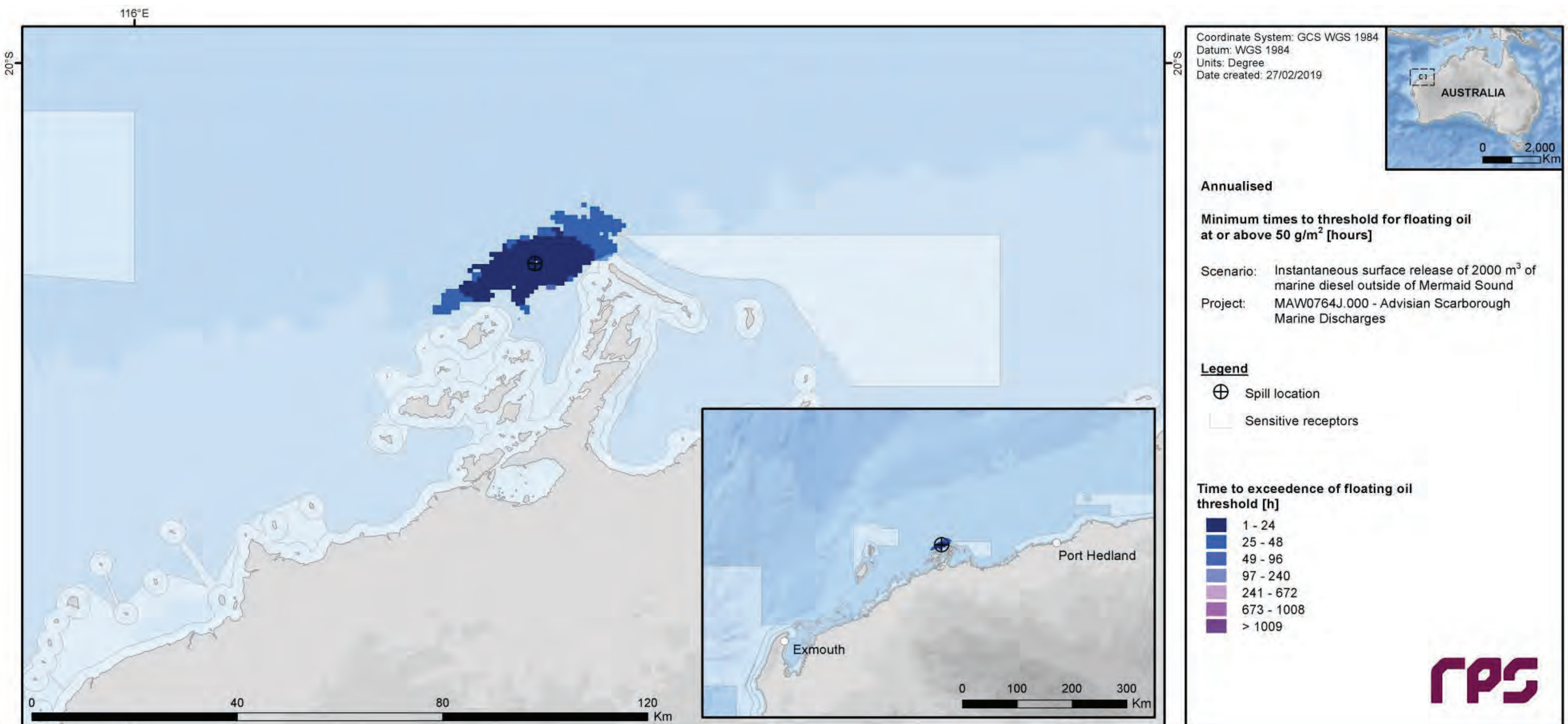



**Figure 3.6 Predicted annualised minimum times to contact by floating oil concentrations at or above 50 g/m² resulting from an instantaneous surface release of marine diesel after a vessel collision outside Mermaid Sound.**

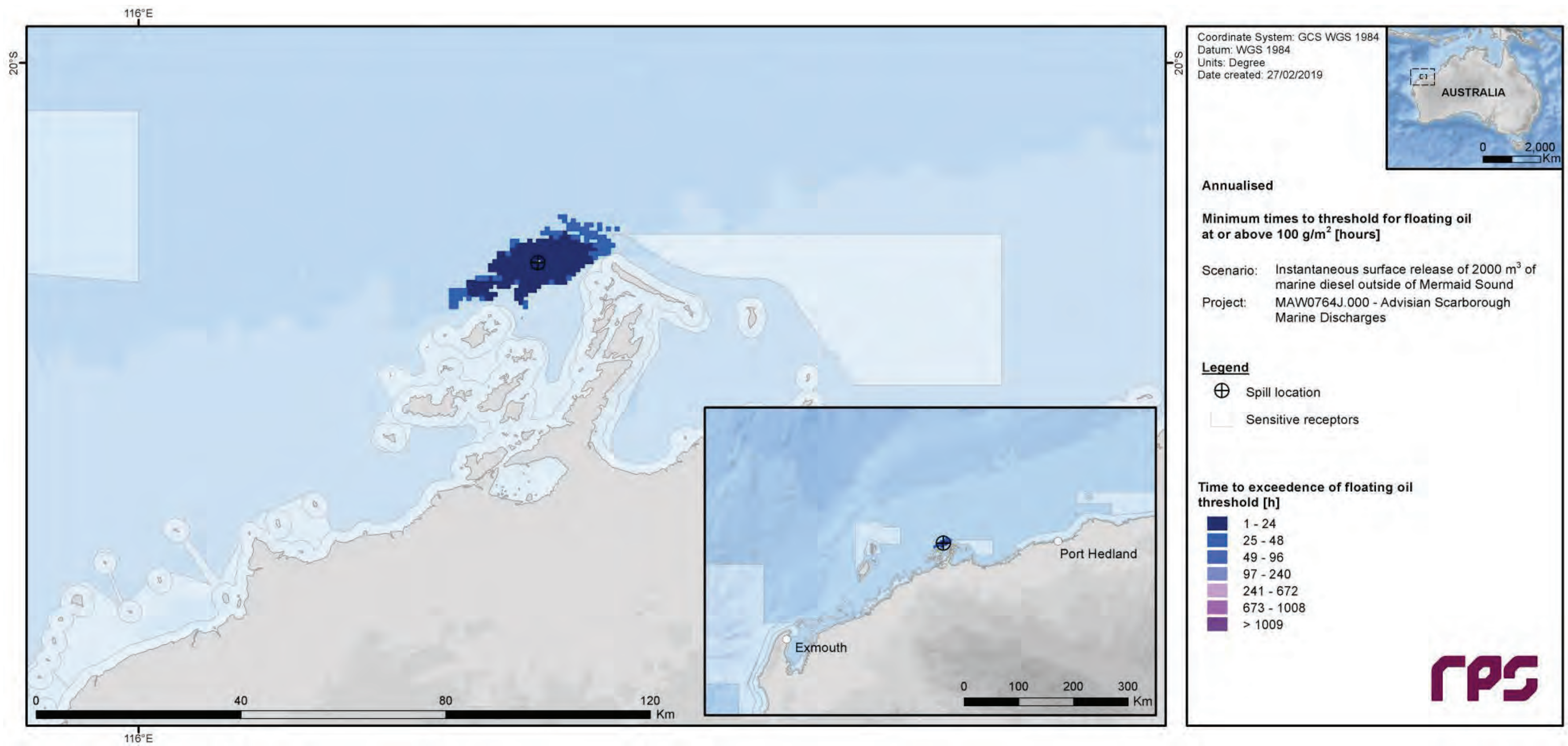



**Figure 3.7** **Predicted annualised minimum times to contact by floating oil concentrations at or above 100 g/m$^2$ resulting from an instantaneous surface release of marine diesel after a vessel collision outside Mermaid Sound.**

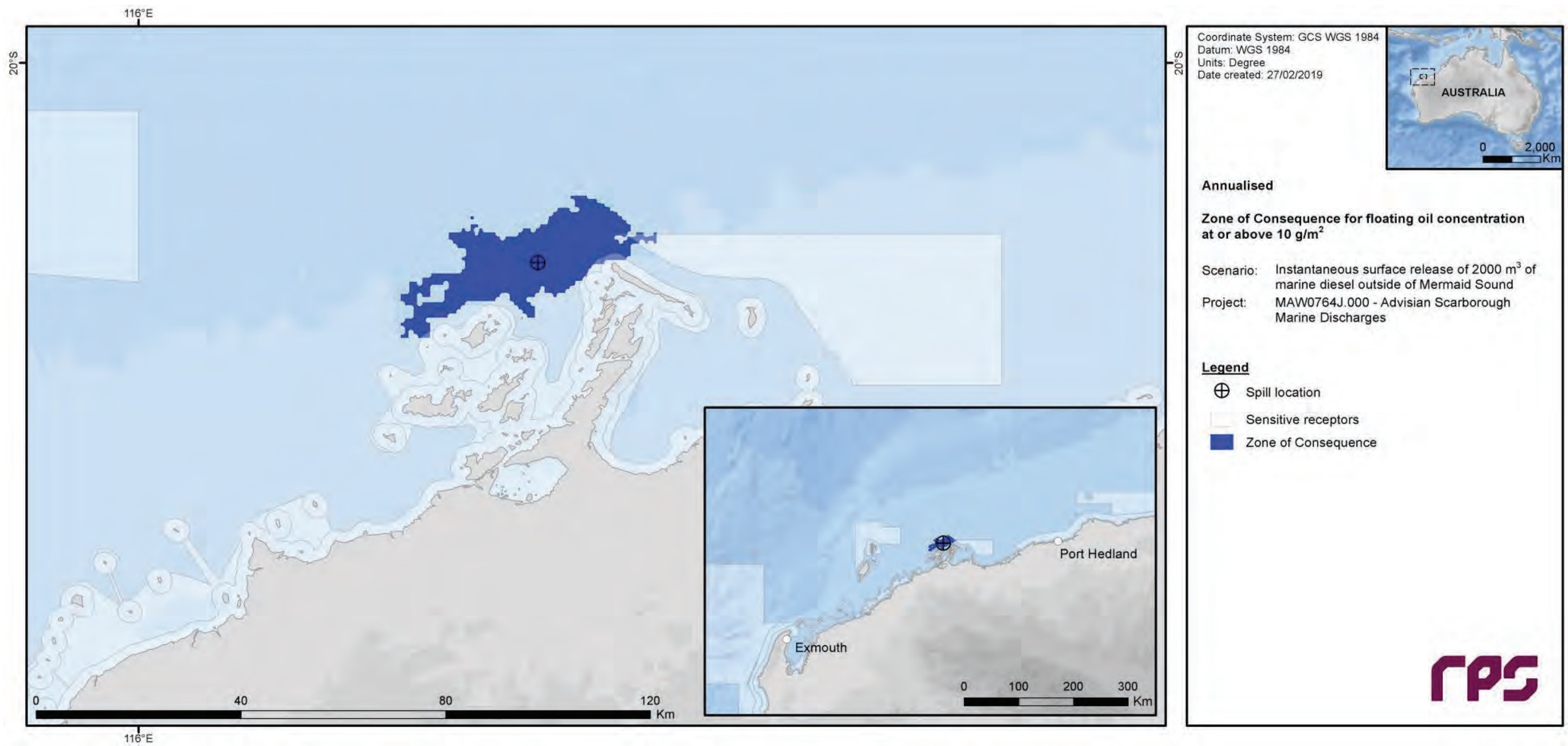



**Figure 3.8 Predicted annualised Zone of Consequence of floating oil concentrations at or above 10 g/m$^2$ resulting from an instantaneous surface release of marine diesel after a vessel collision outside Mermaid Sound.**

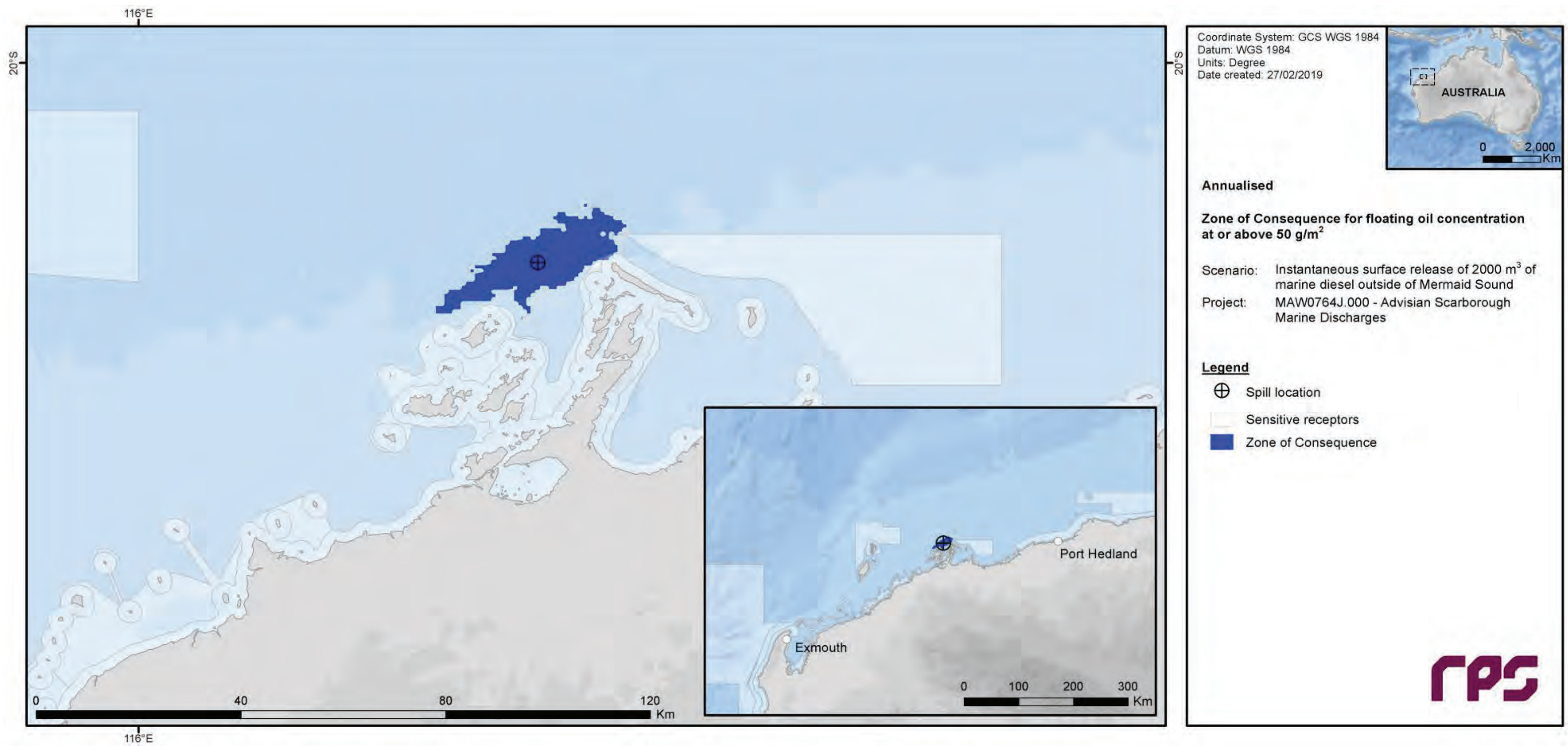



**Figure 3.9** **Predicted annualised Zone of Consequence of floating oil concentrations at or above 50 g/m$^2$ resulting from an instantaneous surface release of marine diesel after a vessel collision outside Mermaid Sound.**

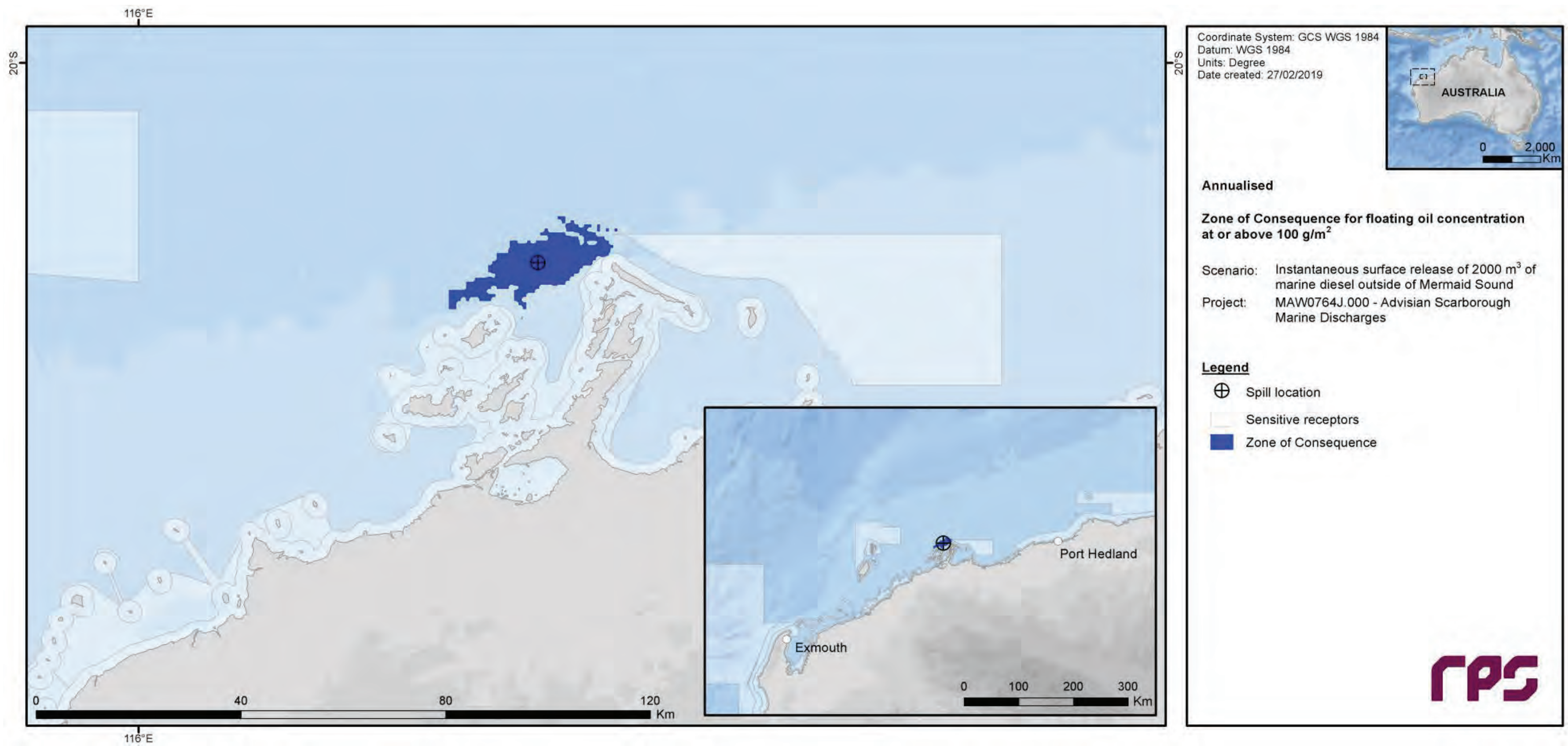



**Figure 3.10 Predicted annualised Zone of Consequence of floating oil concentrations at or above 100 g/m$^2$ resulting from an instantaneous surface release of marine diesel after a vessel collision outside Mermaid Sound.**

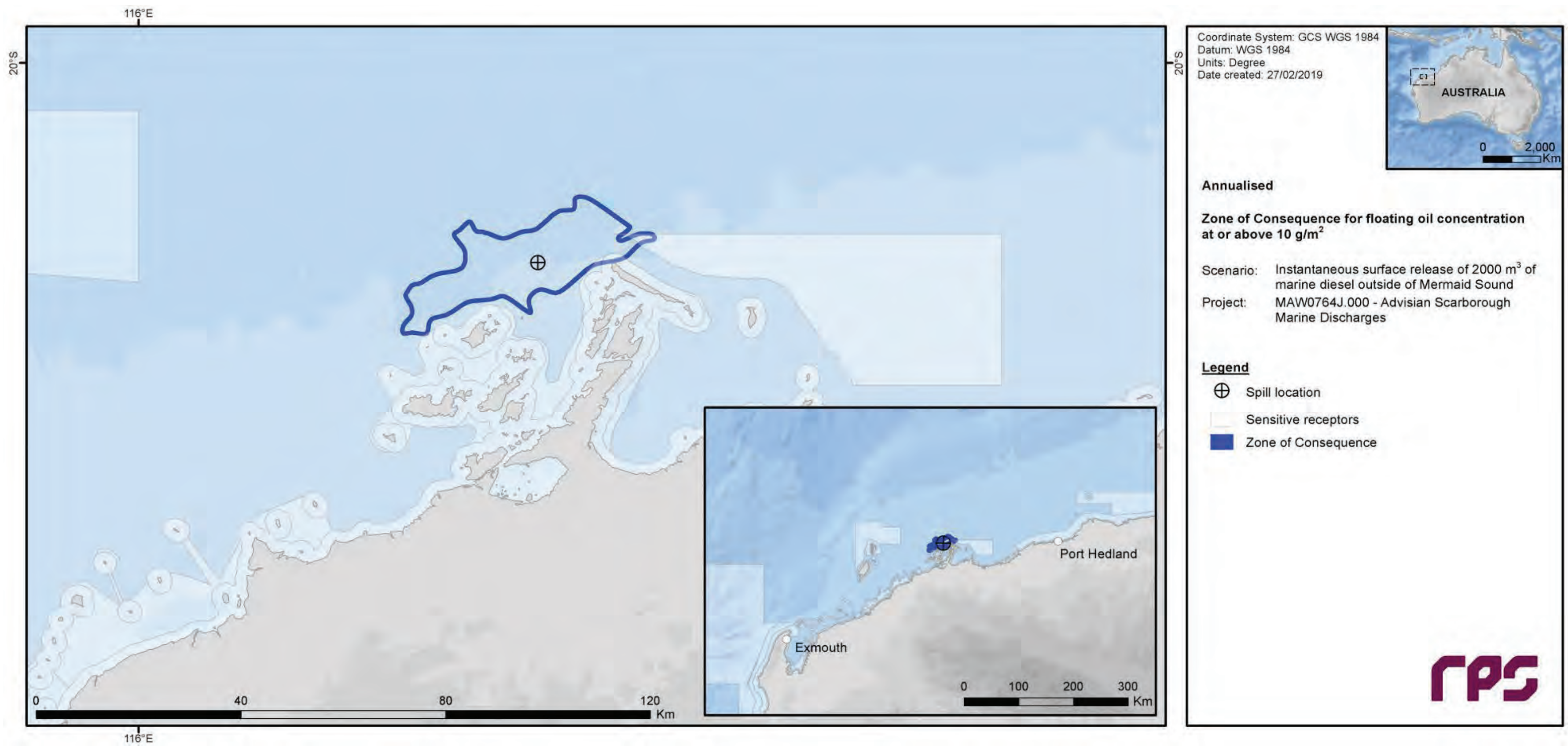



**Figure 3.11 Predicted annualised smoothed Zone of Consequence of floating oil concentrations at or above 10 g/m$^2$ resulting from an instantaneous surface release of marine diesel after a vessel collision outside Mermaid Sound.**

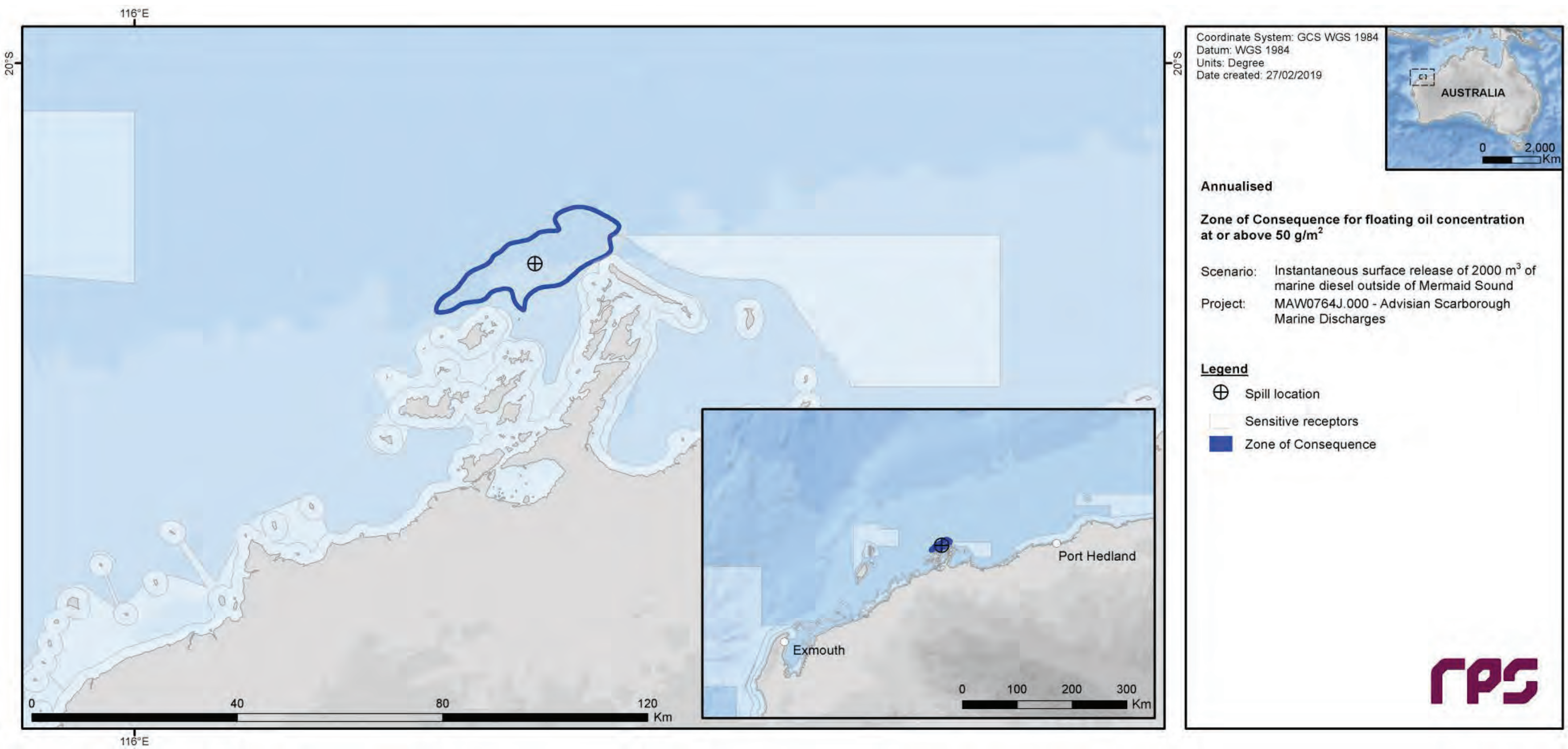



**Figure 3.12 Predicted annualised smoothed Zone of Consequence of floating oil concentrations at or above 50 g/m$^2$ resulting from an instantaneous surface release of marine diesel after a vessel collision outside Mermaid Sound.**

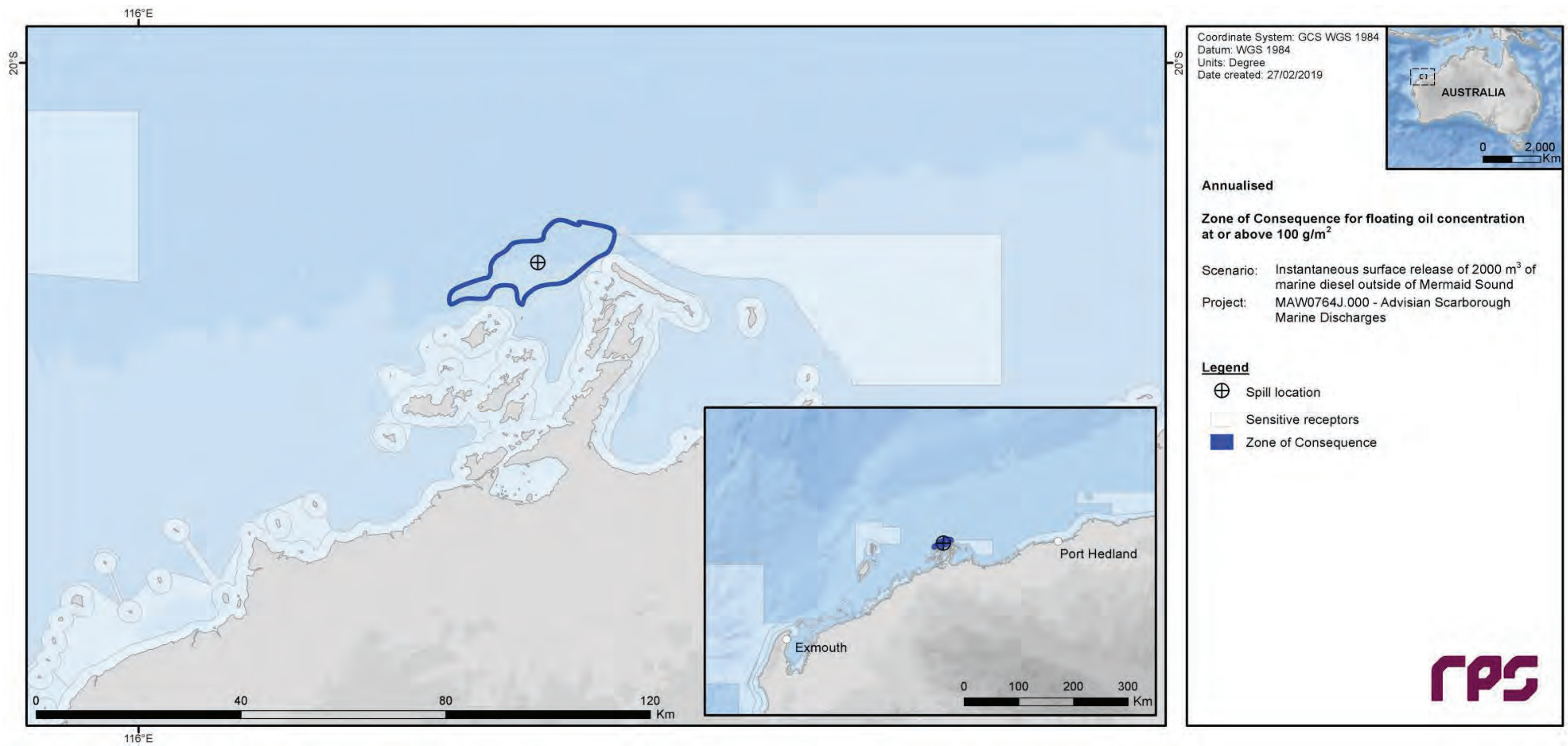



**Figure 3.13 Predicted annualised smoothed Zone of Consequence of floating oil concentrations at or above 100 g/m$^2$ resulting from an instantaneous surface release of marine diesel after a vessel collision outside Mermaid Sound.**

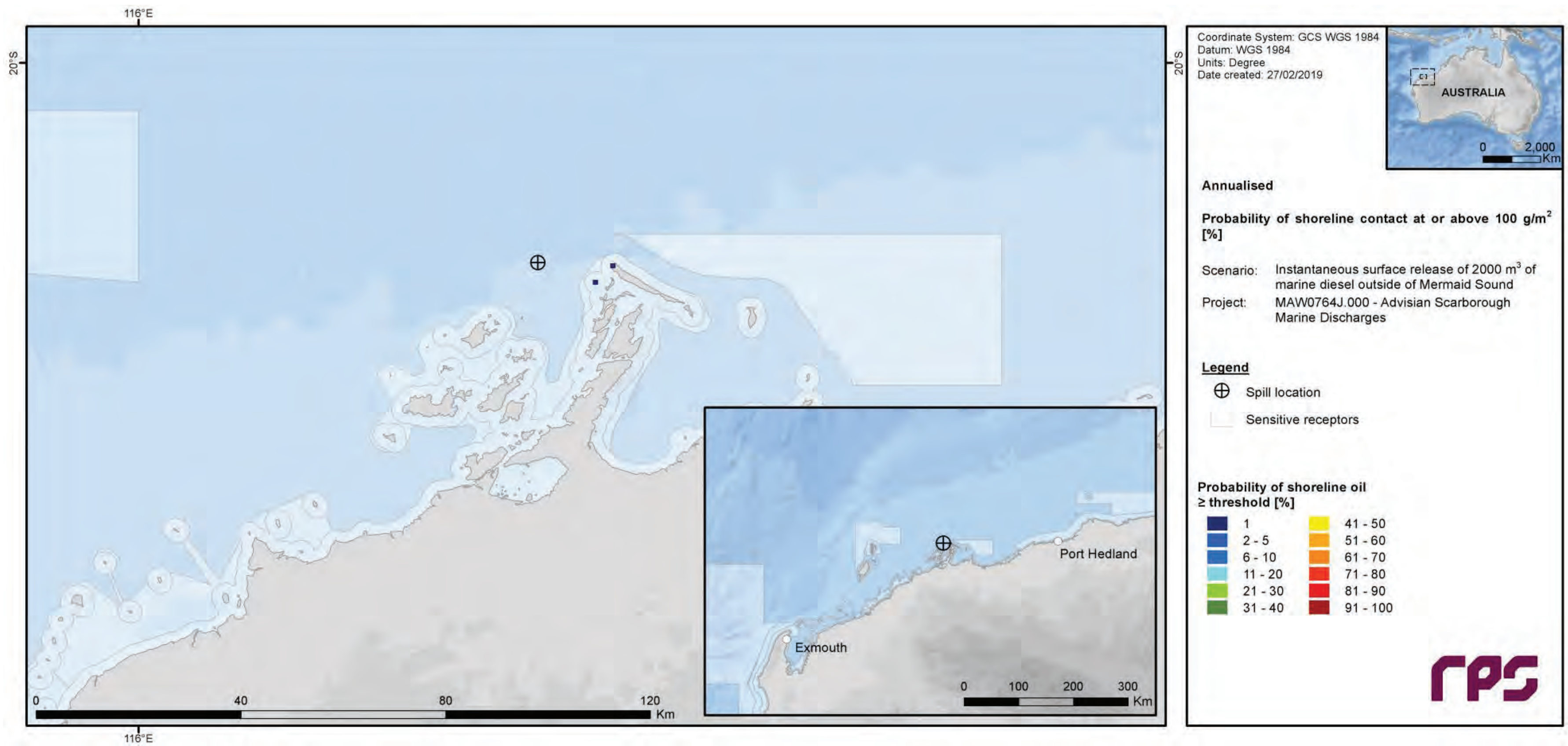



**Figure 3.14 Predicted annualised probability of shoreline oil concentrations at or above 100 g/m$^2$ resulting from an instantaneous surface release of marine diesel after a vessel collision outside Mermaid Sound.**

#### 3.2.2.2 Entrained Oil

**Table 3.2 Expected annualised entrained oil outcomes at sensitive receptors resulting from an instantaneous surface release of marine diesel after a vessel collision outside Mermaid Sound.**

| Receptor | Probability (%) of entrained oil concentration ≥500 ppb | Minimum time to receptor (hours) for entrained oil at ≥500 ppb | Maximum entrained oil concentration (ppb) averaged over all replicate simulations | Maximum entrained oil concentration (ppb), at any depth, in the worst replicate simulation |
|---|---|---|---|---|
| Barrow Island | <1 | NC | 6 | 72 |
| Dampier Archipelago | 23 | 15 | 583 | 10,911 |
| Glomar Shoals* | <1 | NC | 3 | 3 |
| Montebello Islands | <1 | NC | 15 | 235 |
| Muiron Islands MMA-WHA | <1 | NC | 9 | 185 |
| Ningaloo Coast North WHA | <1 | NC | 4 | 70 |
| Ningaloo RUZ | <1 | NC | 4 | 70 |
| Pilbara - Middle Pilbara - Islands & Shoreline | <1 | NC | 14 | 150 |
| Pilbara - Northern Pilbara - Islands & Shoreline | <1 | NC | 3 | 79 |
| Pilbara Islands - Southern Island Group | <1 | NC | 15 | 192 |
| Rankin Bank* | <1 | NC | <1 | 13 |
| Lowendal Islands | <1 | NC | 4 | 66 |
| Montebello MP | 1 | 433 | 30 | 822 |
| Montebello State Marine Park | <1 | NC | 16 | 263 |
| Muiron Islands | <1 | NC | 9 | 172 |
| Dampier MP | 44 | 20 | 1,215 | 10,407 |
| Eighty Mile Beach MP | <1 | NC | 6 | 161 |
| Gascoyne MP | <1 | NC | 4 | 222 |
| WA Coastline | 23 | 15 | 583 | 6,832 |

NC: No contact to receptor predicted for specified threshold.

* Probabilities and maximum concentrations calculated at depth of submerged feature.

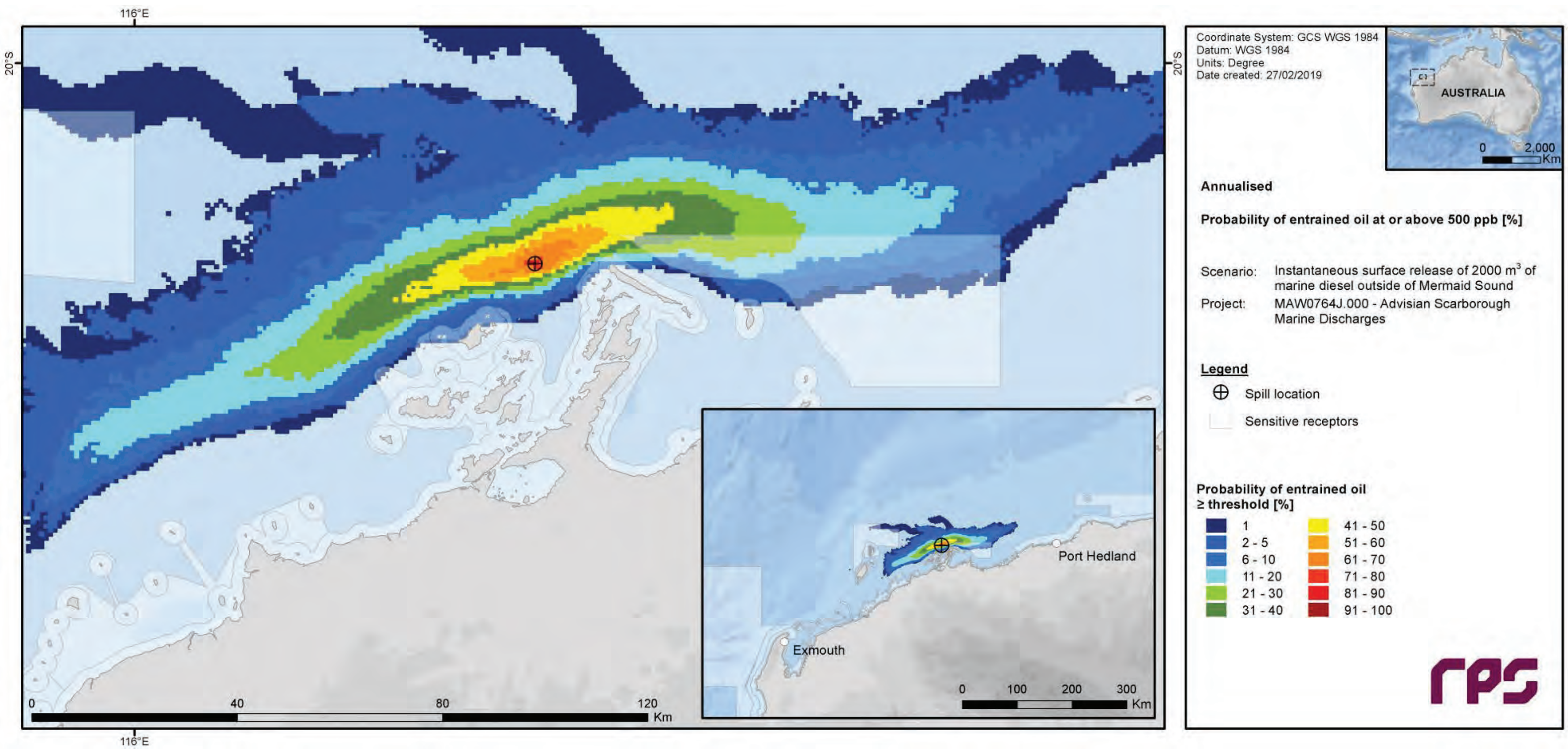



**Figure 3.15 Predicted annualised probability of entrained oil concentrations at or above 500 ppb resulting from an instantaneous surface release of marine diesel after a vessel collision outside Mermaid Sound.**

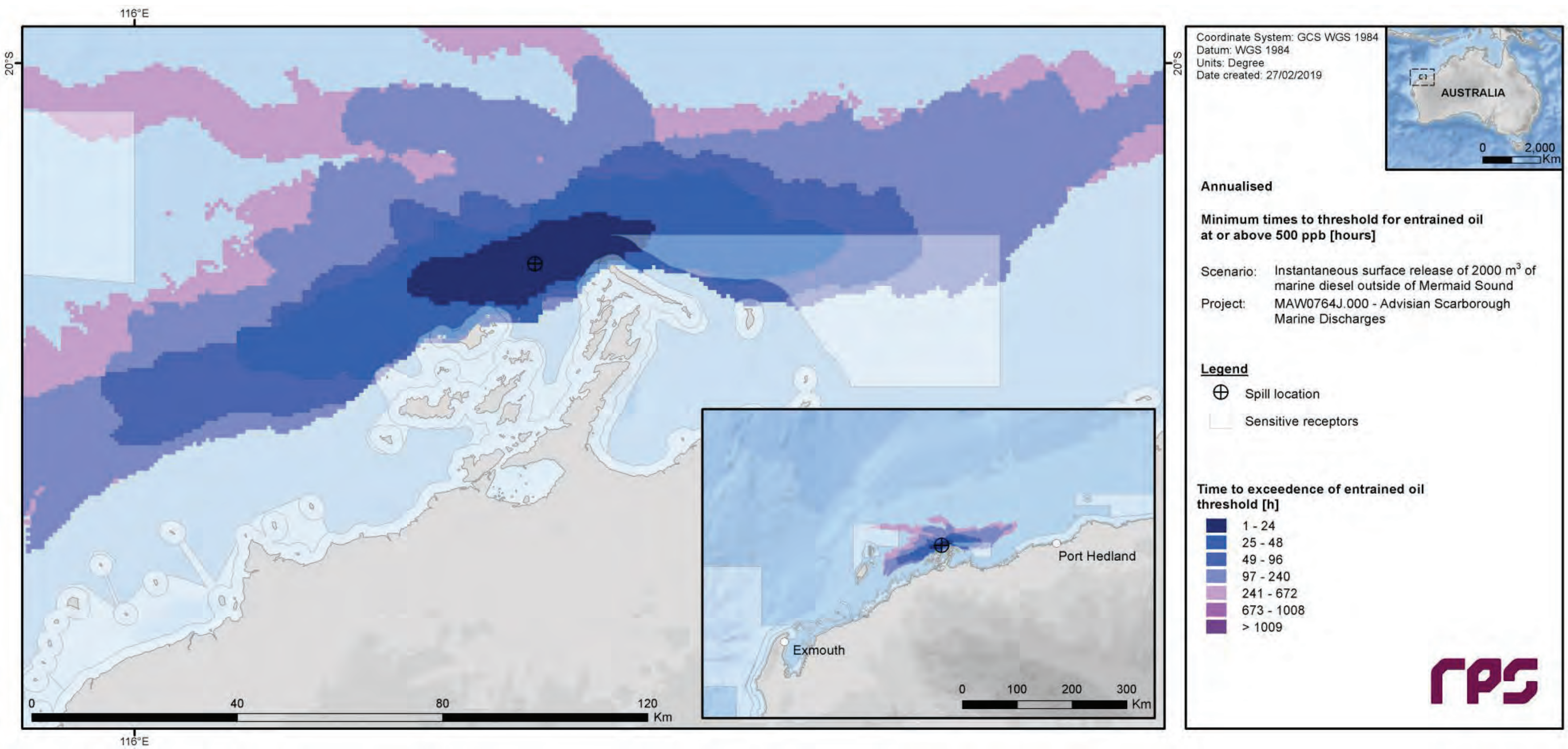



**Figure 3.16 Predicted annualised minimum times to contact by entrained oil concentrations at or above 500 ppb resulting from an instantaneous surface release of marine diesel after a vessel collision outside Mermaid Sound.**

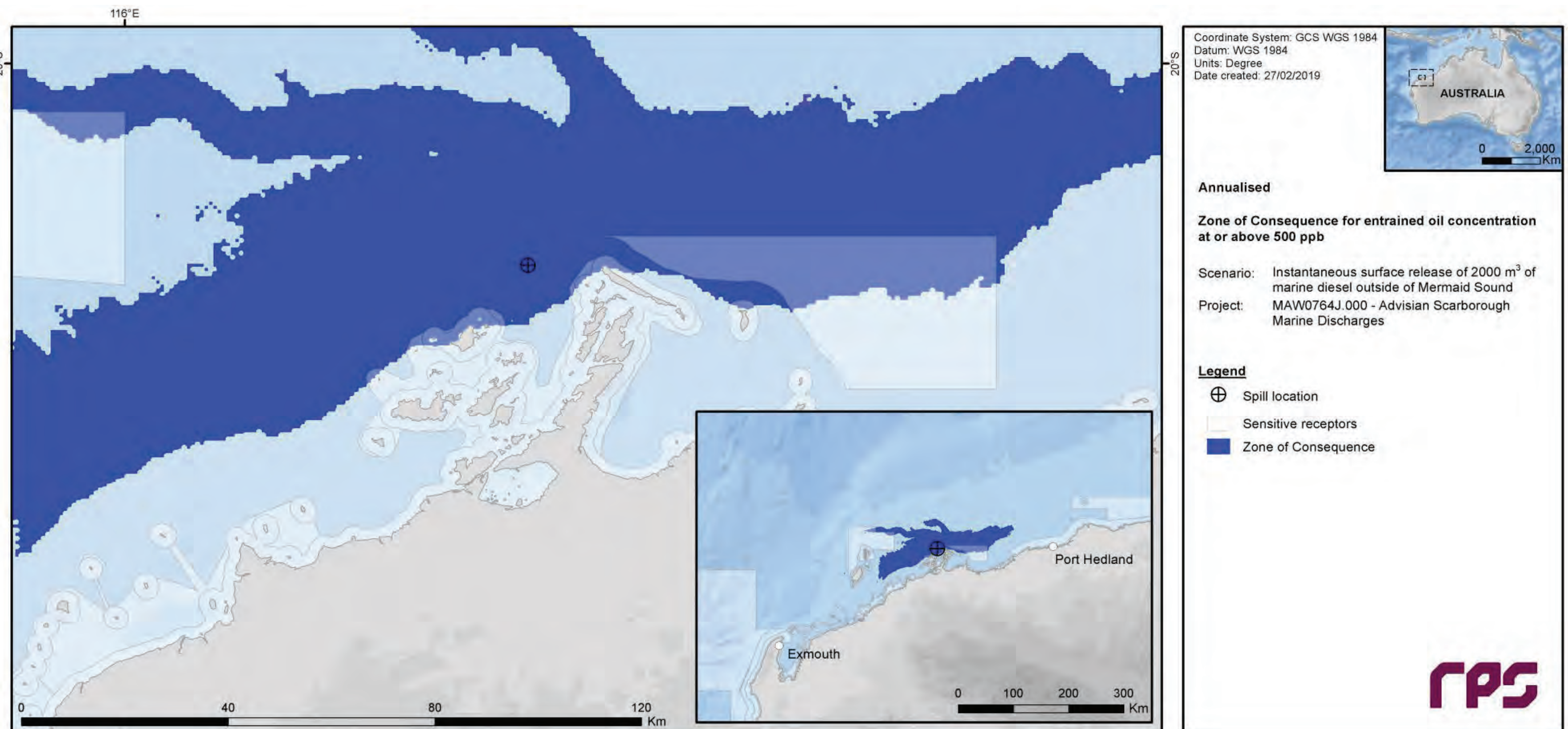



**Figure 3.17 Predicted annualised Zone of Consequence of entrained oil concentrations at or above 500 ppb resulting from an instantaneous surface release of marine diesel after a vessel collision outside Mermaid Sound.**

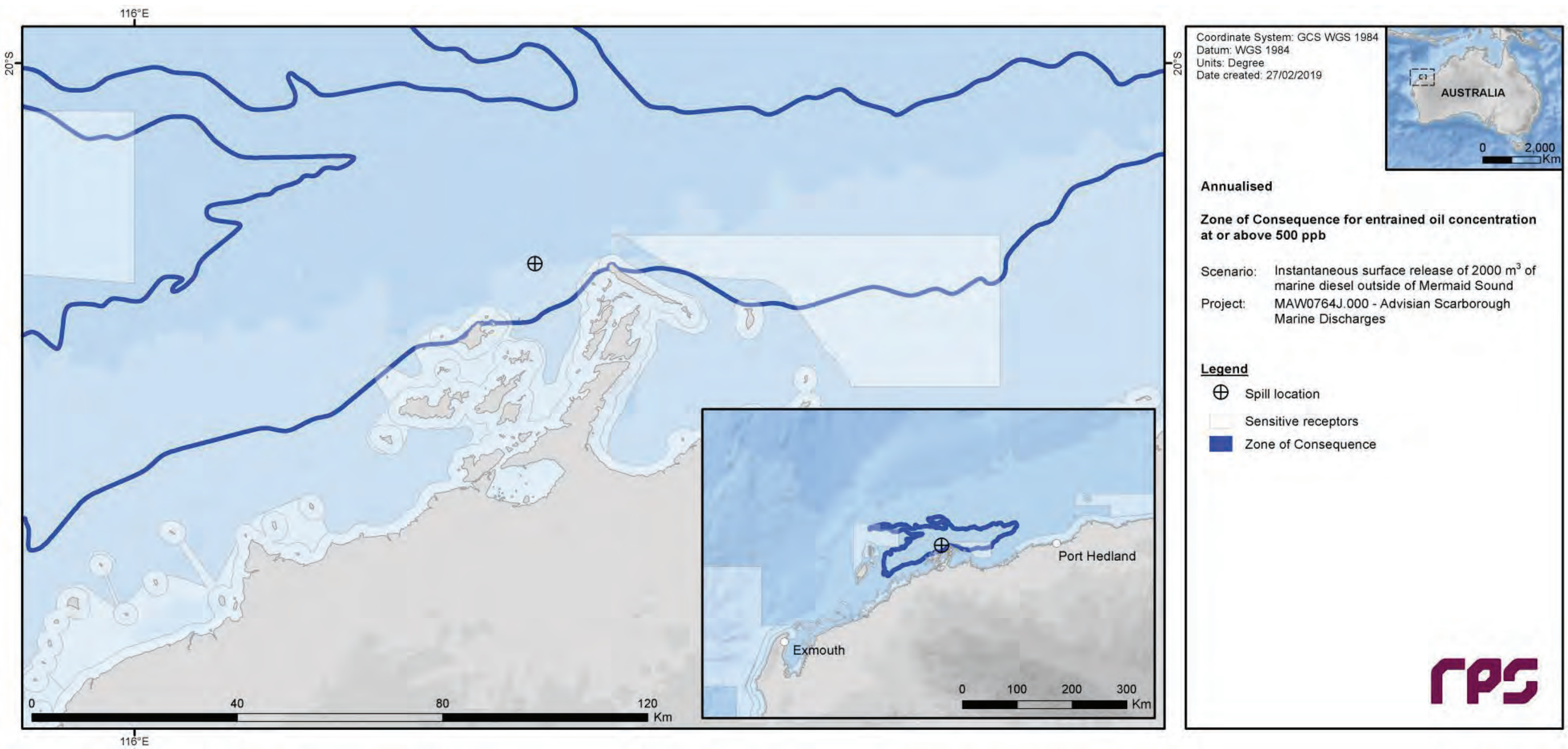



**Figure 3.18 Predicted annualised smoothed Zone of Consequence of entrained oil concentrations at or above 500 ppb resulting from an instantaneous surface release of marine diesel after a vessel collision outside Mermaid Sound.**

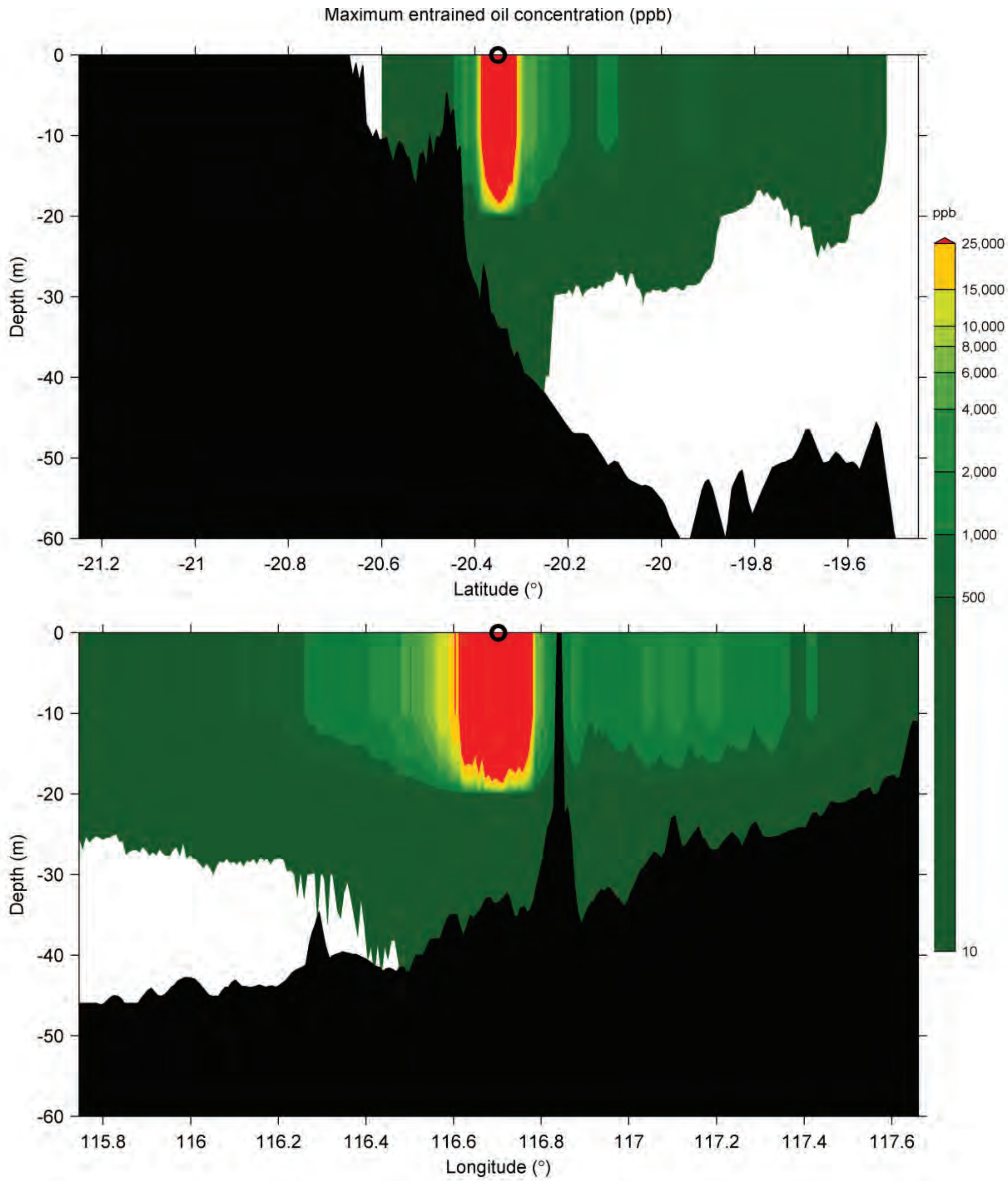



**Figure 3.19 Cross-section transects of predicted annualised maximum entrained oil concentrations for an instantaneous surface release of marine diesel after a vessel collision outside Mermaid Sound. Transect locations are shown in Figure 3.1.**

### 3.2.2.3 Dissolved Aromatic Hydrocarbons

**Table 3.3 Expected annualised dissolved aromatic hydrocarbon outcomes at sensitive receptors resulting from an instantaneous surface release of marine diesel after a vessel collision outside Mermaid Sound.**

| Receptor | Probability (%) of dissolved aromatic hydrocarbon concentration ≥500 ppb | Maximum dissolved aromatic hydrocarbon concentration (ppb) averaged over all replicate simulations | Maximum dissolved aromatic hydrocarbon concentration (ppb), at any depth, in the worst replicate simulation |
|---|---|---|---|
| Barrow Island | <1 | <1 | <1 |
| Dampier Archipelago | <1 | 27 | 366 |
| Glomar Shoals* | <1 | NC | NC |
| Montebello Islands | <1 | <1 | <1 |
| Muiron Islands MMA-WHA | <1 | NC | NC |
| Ningaloo Coast North WHA | <1 | NC | NC |
| Ningaloo RUZ | <1 | NC | NC |
| Pilbara - Middle Pilbara - Islands & Shoreline | <1 | <1 | <1 |
| Pilbara - Northern Pilbara - Islands & Shoreline | <1 | <1 | <1 |
| Pilbara Islands - Southern Island Group | <1 | NC | NC |
| Rankin Bank* | <1 | <1 | NC |
| Lowendal Islands | <1 | <1 | <1 |
| Montebello MP | <1 | <1 | 7 |
| Montebello State Marine Park | <1 | <1 | <1 |
| Muiron Islands | <1 | NC | NC |
| Dampier MP | 2 | 41 | 635 |
| Eighty Mile Beach MP | <1 | NC | NC |
| Gascoyne MP | <1 | NC | NC |
| WA Coastline | <1 | 27 | 366 |

NC: No contact to receptor predicted for specified threshold.

* Probabilities and maximum concentrations calculated at depth of submerged feature.

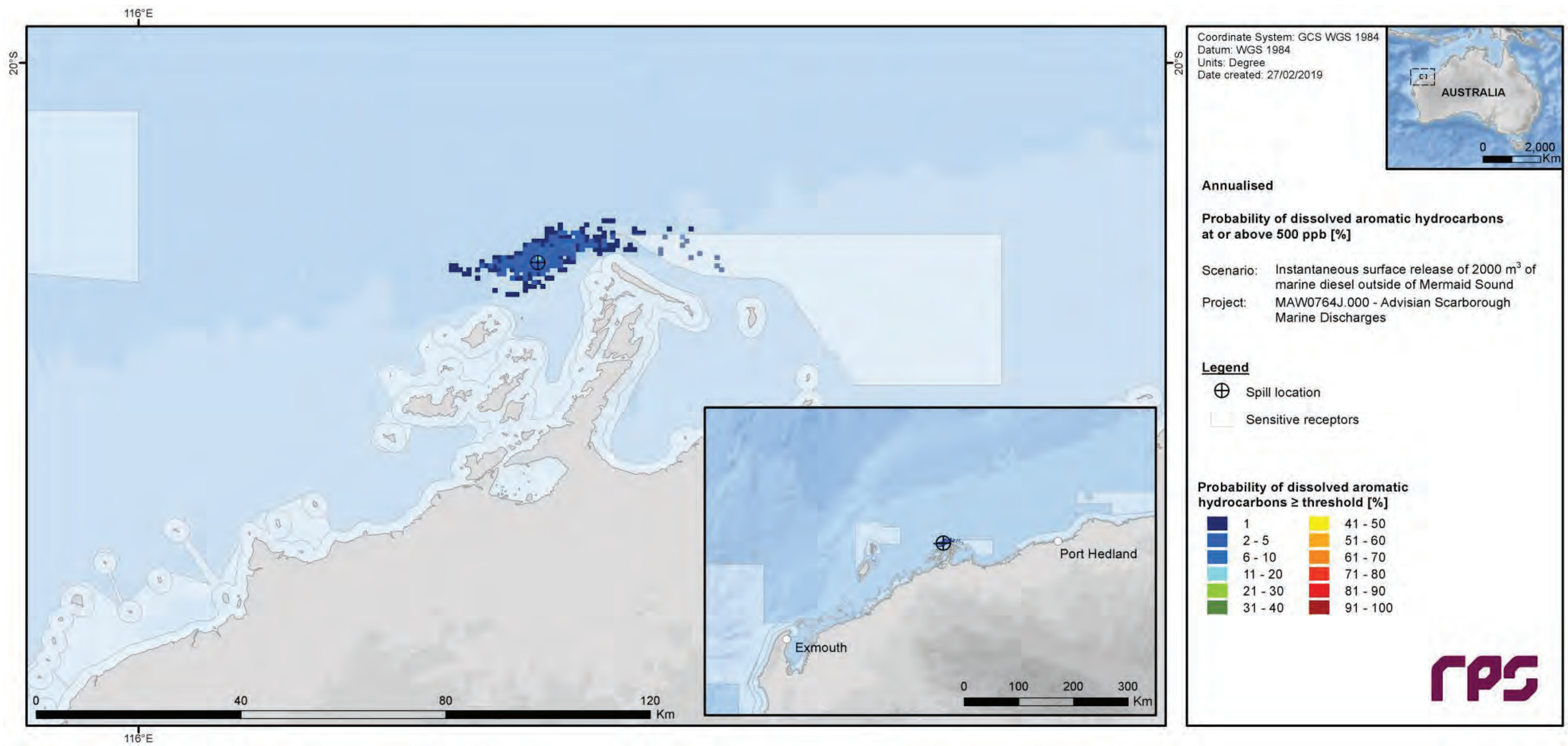



**Figure 3.20 Predicted annualised probability of dissolved aromatic hydrocarbon concentrations at or above 500 ppb resulting from an instantaneous surface release of marine diesel after a vessel collision outside Mermaid Sound.**

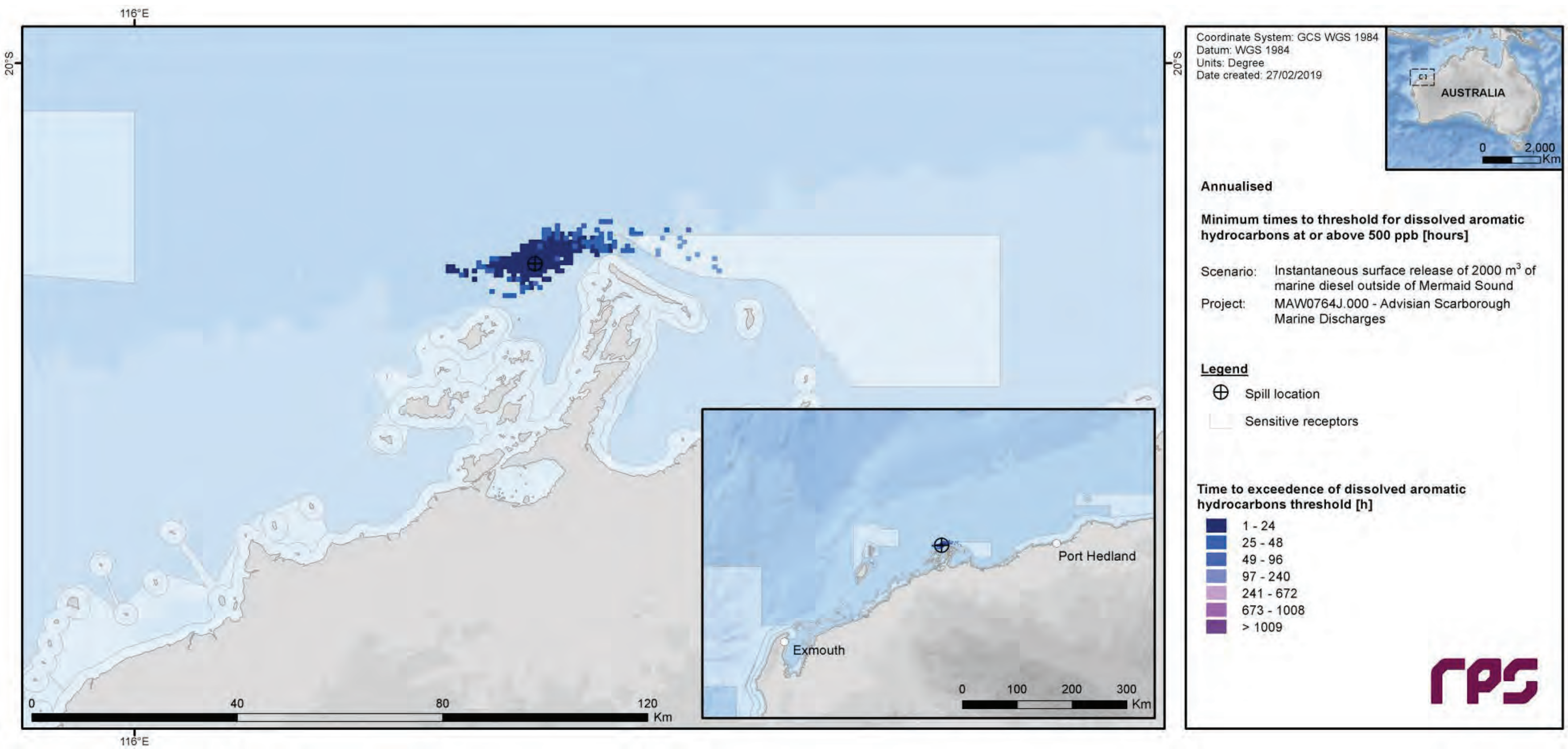



**Figure 3.21 Predicted annualised minimum times to contact by dissolved aromatic hydrocarbon concentrations at or above 500 ppb resulting from an instantaneous surface release of marine diesel after a vessel collision outside Mermaid Sound.**

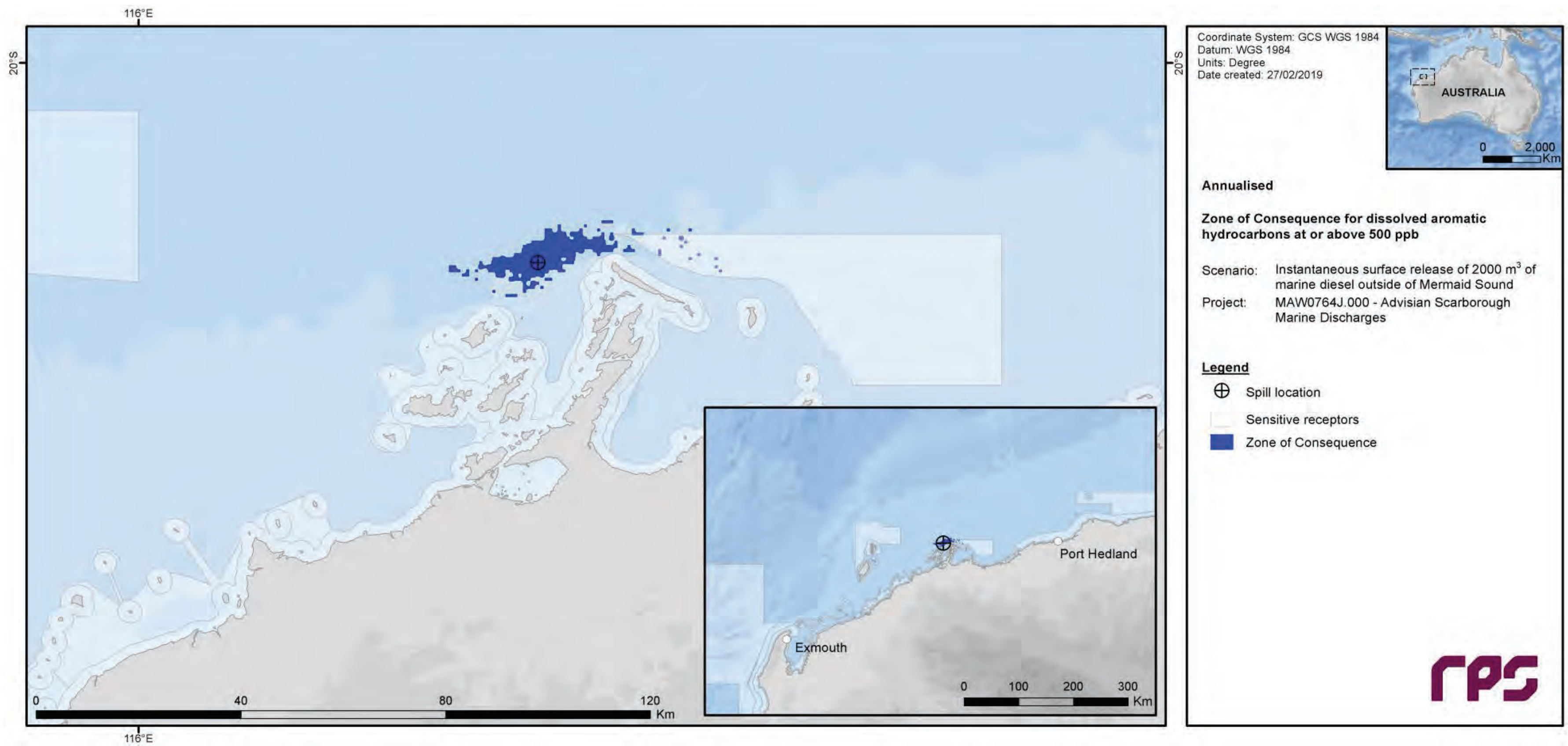



**Figure 3.22 Predicted annualised Zone of Consequence of dissolved aromatic hydrocarbon concentrations at or above 500 ppb resulting from an instantaneous surface release of marine diesel after a vessel collision outside Mermaid Sound.**

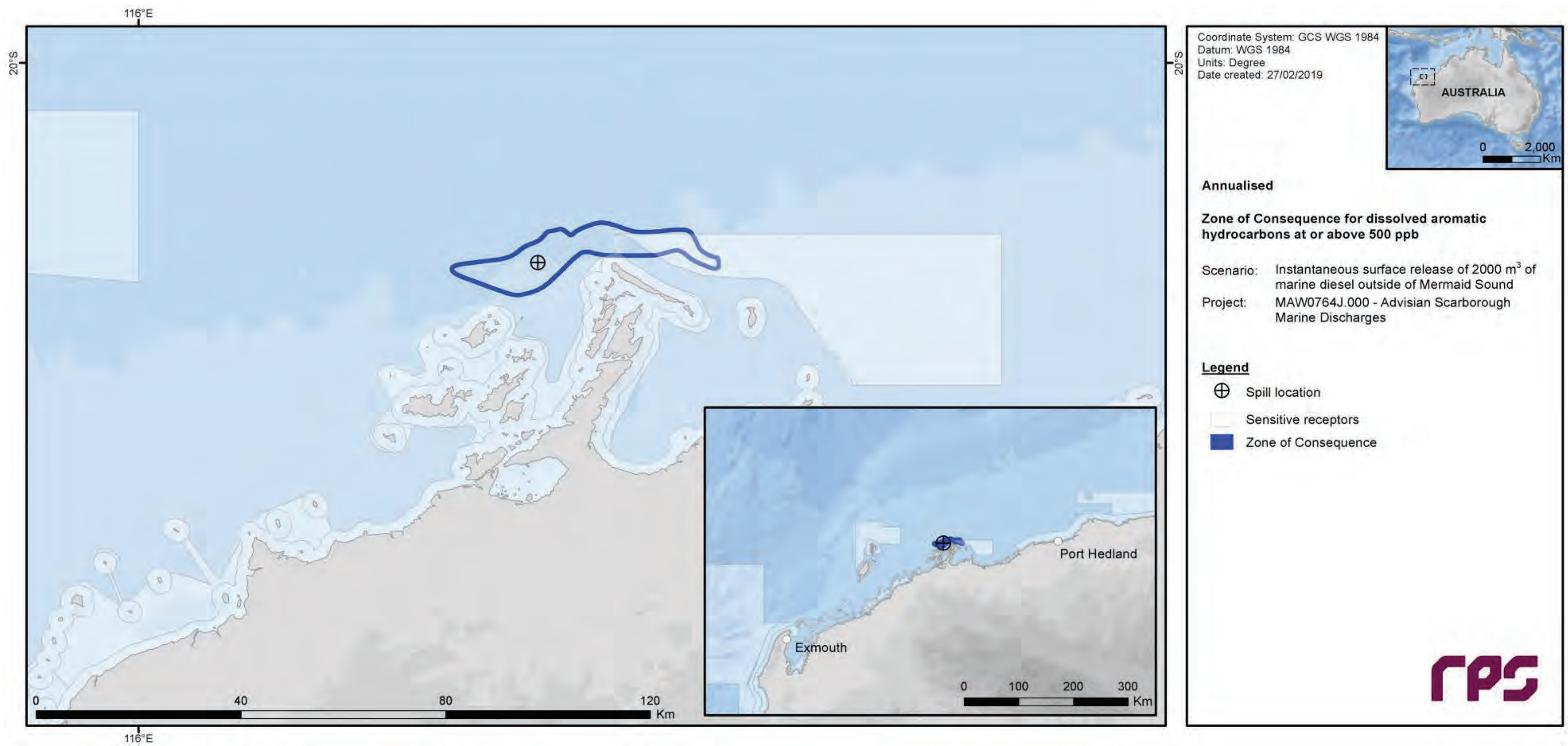



**Figure 3.23 Predicted annualised smoothed Zone of Consequence of dissolved aromatic hydrocarbon concentrations at or above 500 ppb resulting from an instantaneous surface release of marine diesel after a vessel collision outside Mermaid Sound.**

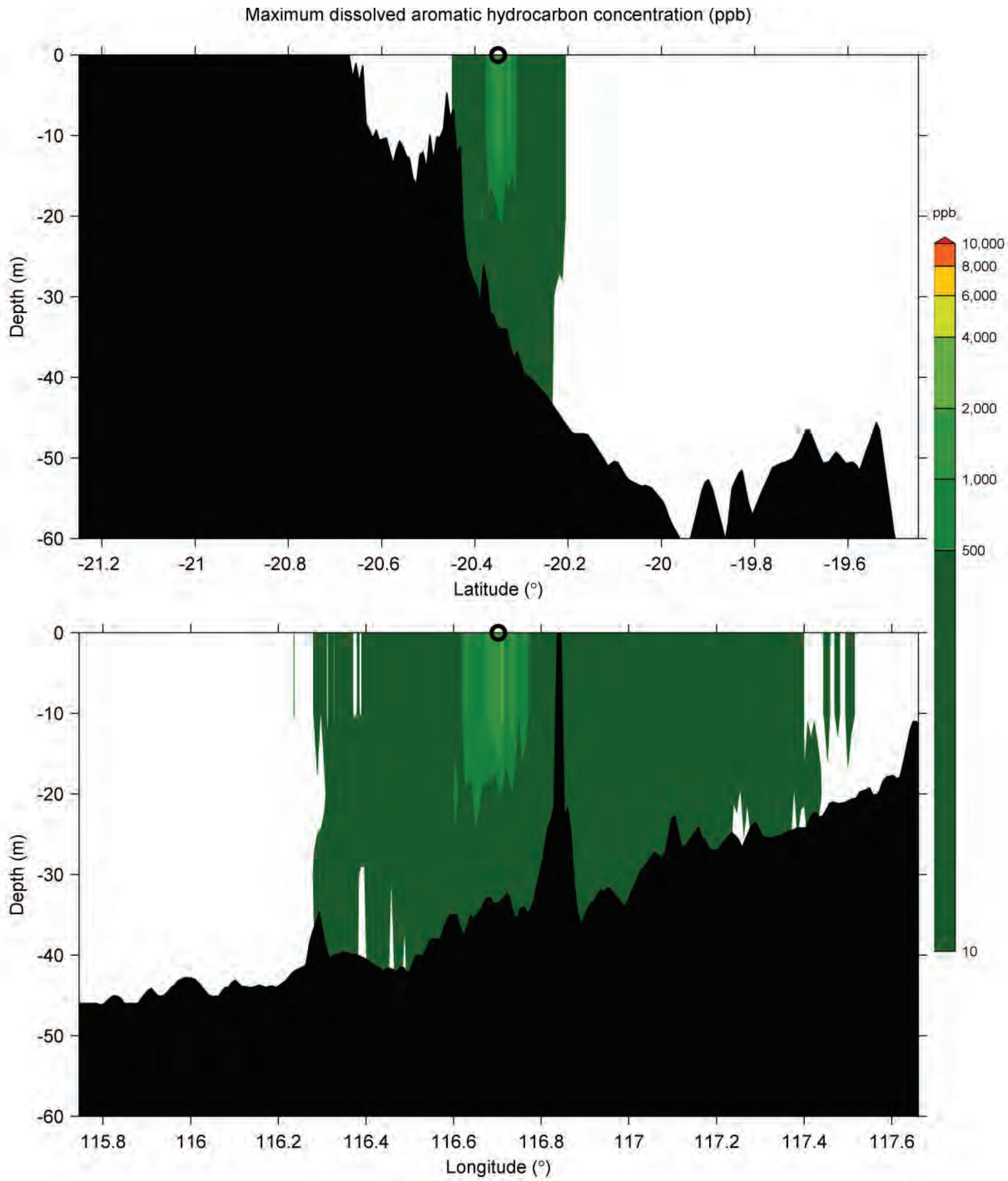



**Figure 3.24 Cross-section transects of predicted annualised maximum dissolved aromatic hydrocarbon concentrations for an instantaneous surface release of marine diesel after a vessel collision outside Mermaid Sound. Transect locations are shown in Figure 3.1.**

# 3.3 Scenario 2: Short-Term (Instantaneous) Surface Release of Marine Diesel after a Vessel Collision within Montebello Marine Park

## 3.3.1 Discussion of Results

### 3.3.1.1 Overview

This scenario investigated the probability of exposure to surrounding regions by oil resulting from a short-term (instantaneous) surface release of 2,000 $m^3$ of marine diesel within the Montebello Marine Park during operations at any time of year, with no mitigation measures applied.

Considering the discharge characteristics, the properties of the oil and its expected weathering behaviour, floating oil will be susceptible to entrainment into the wave-mixed layer under typical wind conditions. Evaporation rates will be significant, given the moderate proportion of volatile compounds in the oil (41%). The low-volatility fraction of the oil (54%) will take longer durations of the order of days to evaporate, and the residual fraction of 5% is expected to persist in the environment until degradation processes occur. Considering the spill volume, there is a low potential for dissolution of soluble aromatic compounds.

### 3.3.1.2 Floating and Shoreline Oil

The probability contour figures for floating oil indicate that concentrations equal to or greater than the 10 g/$m^2$, 50 g/$m^2$ and 100 g/$m^2$ thresholds could potentially be found, in the form of slicks, up to 39 km, 36 km and 33 km from the spill site, respectively (Figure 3.25, Figure 3.26 and Figure 3.27).

Given that the spill location lies within the Montebello MP receptor area, floating oil at concentrations equal to or greater than 100 g/$m^2$ are forecast with a probability of 100% and a minimum time to contact of less than 1 hour (Table 3.4). Probabilities of floating oil contact at the 10 g/$m^2$ threshold are forecast to be less than 1% for all other shoreline receptors.

Potential for accumulation of oil on shorelines is predicted to be low, with a maximum accumulated volume of <1 $m^3$ and a maximum local accumulated concentration on shorelines of 11 g/$m^2$ forecast at Barrow Island (Table 3.4).

The forecast annualised minimum times to contact, ZoC and smoothed ZoC for floating oil at or above the 10 g/$m^2$, 50 g/$m^2$ and 100 g/$m^2$ threshold concentrations are depicted in Figure 3.28 to Figure 3.30, Figure 3.31 to Figure 3.33 and Figure 3.34 to Figure 3.36, respectively.

### 3.3.1.3 Entrained Oil

Entrained oil at concentrations equal to or greater than the 500 ppb threshold is predicted to be found up to around 308 km from the spill site (Figure 3.37).

The Montebello MP and Muiron Islands MMA-WHA receptors are predicted to receive entrained oil concentrations at the 500 ppb threshold with probabilities of 70% and 7%, respectively (Table 3.5). The maximum entrained oil concentration is forecast as 157.0 ppm within the Montebello MP.

The forecast annualised minimum times to contact, ZoC and smoothed ZoC for entrained oil at or above the 500 ppb threshold concentration are depicted in Figure 3.38, Figure 3.39 and Figure 3.40, respectively.

The cross-sectional transects of maximum entrained oil concentrations in the vicinity of the release site show that concentrations above 25,000 ppb are expected to extend from the sea surface to depths of around 15 m (Figure 3.41).

### 3.3.1.4 Dissolved Aromatic Hydrocarbons

Dissolved aromatic hydrocarbons at concentrations equal to or greater than the 500 ppb threshold are predicted to be found up to around 85 km from the spill site (Figure 3.42).

The Montebello MP receptor is predicted to receive dissolved aromatic hydrocarbon concentrations at the 500 ppb threshold with a probability of 9% (Table 3.6). The maximum dissolved aromatic hydrocarbon concentration is forecast as 2.0 ppm within the Montebello MP.

The forecast annualised minimum times to contact, ZoC and smoothed ZoC for dissolved aromatic hydrocarbons at or above the 500 ppb threshold concentration are depicted in Figure 3.43, Figure 3.44 and Figure 3.45, respectively.

The cross-sectional transects of maximum dissolved aromatic hydrocarbon concentrations in the vicinity of the release site show that concentrations above 1,000 ppb are expected to extend from the sea surface to depths of around 15 m (Figure 3.46).

## 3.3.2 Results Tables and Figures

### 3.3.2.1 Floating and Shoreline Oil

**Table 3.4 Expected annualised floating and shoreline oil outcomes at sensitive receptors resulting from an instantaneous surface release of marine diesel after a vessel collision within Montebello Marine Park.**

| Receptor | Probability (%) of floating oil concentration ≥10 g/m² | Probability (%) of floating oil concentration ≥50 g/m² | Probability (%) of floating oil concentration ≥100 g/m² | Minimum time to receptor (hours) for floating oil at ≥10 g/m² | Minimum time to receptor (hours) for floating oil at ≥50 g/m² | Minimum time to receptor (hours) for floating oil at ≥100 g/m² | Probability (%) of shoreline oil concentration ≥100 g/m² | Probability (%) of shoreline oil concentration ≥250 g/m² | Minimum time to receptor (hours) for shoreline oil at ≥100 g/m² | Minimum time to receptor (hours) for shoreline oil at ≥250 g/m² | Maximum local accumulated concentration (g/m²) averaged over all replicate simulations | Maximum local accumulated concentration (g/m²) in the worst replicate simulation | Maximum accumulated volume (m³) along this shoreline, averaged over all replicate simulations | Maximum accumulated volume (m³) along this shoreline, in the worst replicate simulation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Argo-Rowley Terrace MP* | <1 | <1 | <1 | NC | NC | NC | NA | NA | NA | NA | NA | NA | NA | NA |
| Barrow Island | <1 | <1 | <1 | NC | NC | NC | <1 | <1 | NC | NC | 0.1 | 11 | <1 | <1 |
| Glomar Shoals* | <1 | <1 | <1 | NC | NC | NC | NA | NA | NA | NA | NA | NA | NA | NA |
| Montebello Islands | <1 | <1 | <1 | NC | NC | NC | <1 | <1 | NC | NC | <0.1 | 4.1 | <1 | <1 |
| Muiron Islands MMA-WHA | <1 | <1 | <1 | NC | NC | NC | <1 | <1 | NC | NC | <0.1 | 7.1 | <1 | <1 |
| Ningaloo Coast Middle | <1 | <1 | <1 | NC | NC | NC | <1 | <1 | NC | NC | NC | NC | NC | NC |
| Ningaloo Coast Middle WHA | <1 | <1 | <1 | NC | NC | NC | <1 | <1 | NC | NC | NC | NC | NC | NC |
| Ningaloo Coast North | <1 | <1 | <1 | NC | NC | NC | <1 | <1 | NC | NC | <0.1 | 7 | <1 | <1 |
| Ningaloo Coast North WHA | <1 | <1 | <1 | NC | NC | NC | <1 | <1 | NC | NC | <0.1 | 7 | <1 | <1 |
| Ningaloo Coast South WHA | <1 | <1 | <1 | NC | NC | NC | <1 | <1 | NC | NC | NC | NC | NC | NC |
| Ningaloo RUZ* | <1 | <1 | <1 | NC | NC | NC | NA | NA | NA | NA | NA | NA | NA | NA |
| Pilbara Islands - Southern Island Group | <1 | <1 | <1 | NC | NC | NC | <1 | <1 | NC | NC | <0.1 | 1.7 | <1 | <1 |
| Rankin Bank* | <1 | <1 | <1 | NC | NC | NC | NA | NA | NA | NA | NA | NA | NA | NA |
| Shark Bay Open Ocean Coast | <1 | <1 | <1 | NC | NC | NC | <1 | <1 | NC | NC | NC | NC | NC | NC |
| Shark Bay WHA | <1 | <1 | <1 | NC | NC | NC | <1 | <1 | NC | NC | NC | NC | NC | NC |
| Bernier & Dorre Islands | <1 | <1 | <1 | NC | NC | NC | <1 | <1 | NC | NC | NC | NC | NC | NC |
| Lowendal Islands | <1 | <1 | <1 | NC | NC | NC | <1 | <1 | NC | NC | NC | NC | NC | NC |
| Montebello MP* | 100 | 100 | 100 | 1 | 1 | 1 | NA | NA | NA | NA | NA | NA | NA | NA |
| Montebello State Marine Park | <1 | <1 | <1 | NC | NC | NC | <1 | <1 | NC | NC | <0.1 | 4.1 | <1 | <1 |
| Muiron Islands | <1 | <1 | <1 | NC | NC | NC | <1 | <1 | NC | NC | <0.1 | 7.1 | <1 | <1 |
| Gascoyne MP* | <1 | <1 | <1 | NC | NC | NC | NA | NA | NA | NA | NA | NA | NA | NA |
| WA Coastline | <1 | <1 | <1 | NC | NC | NC | <1 | <1 | NC | NC | 0.1 | 11 | <1 | <1 |

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.

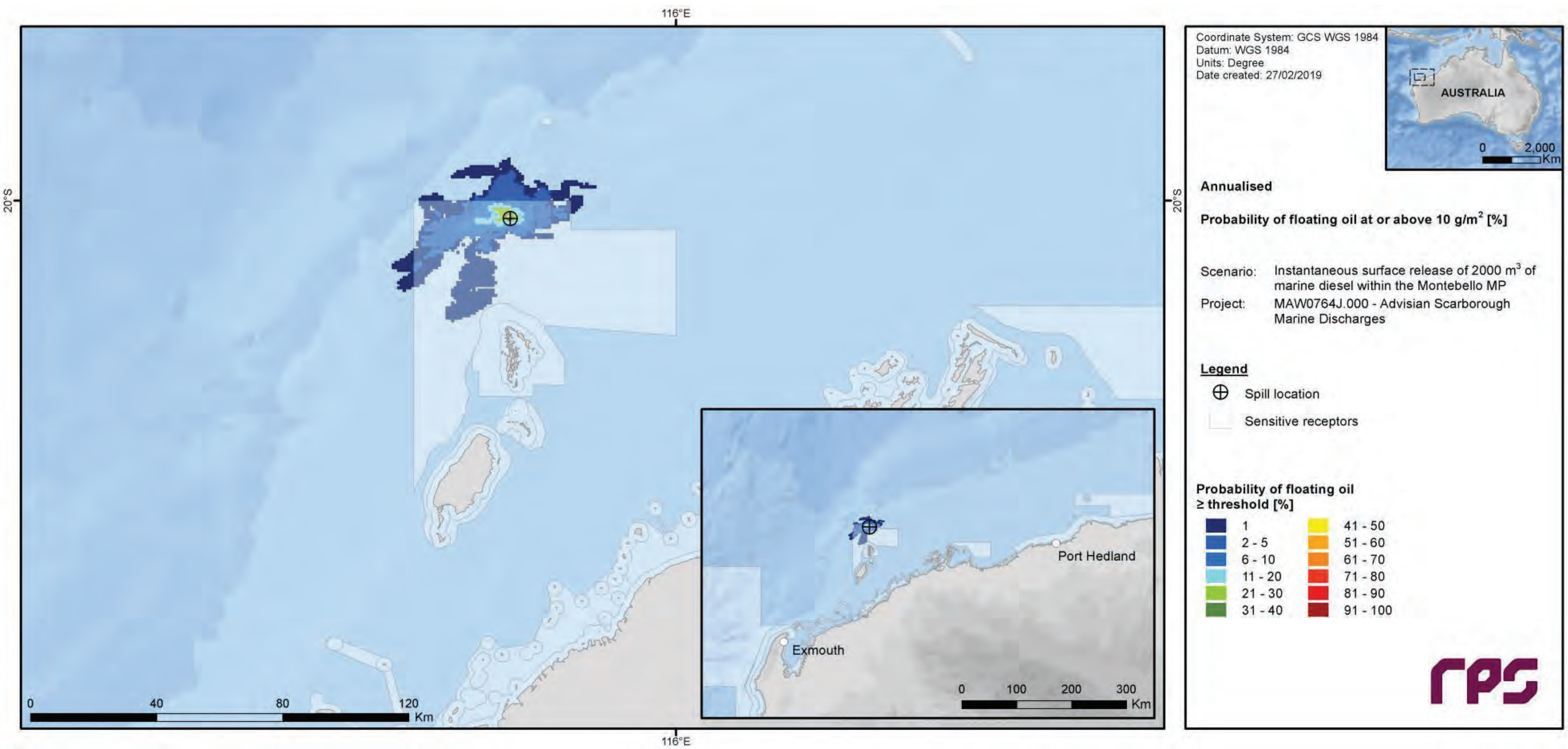



**Figure 3.25 Predicted annualised probability of floating oil concentrations at or above 10 g/m$^2$ resulting from an instantaneous surface release of marine diesel after a vessel collision within Montebello Marine Park.**

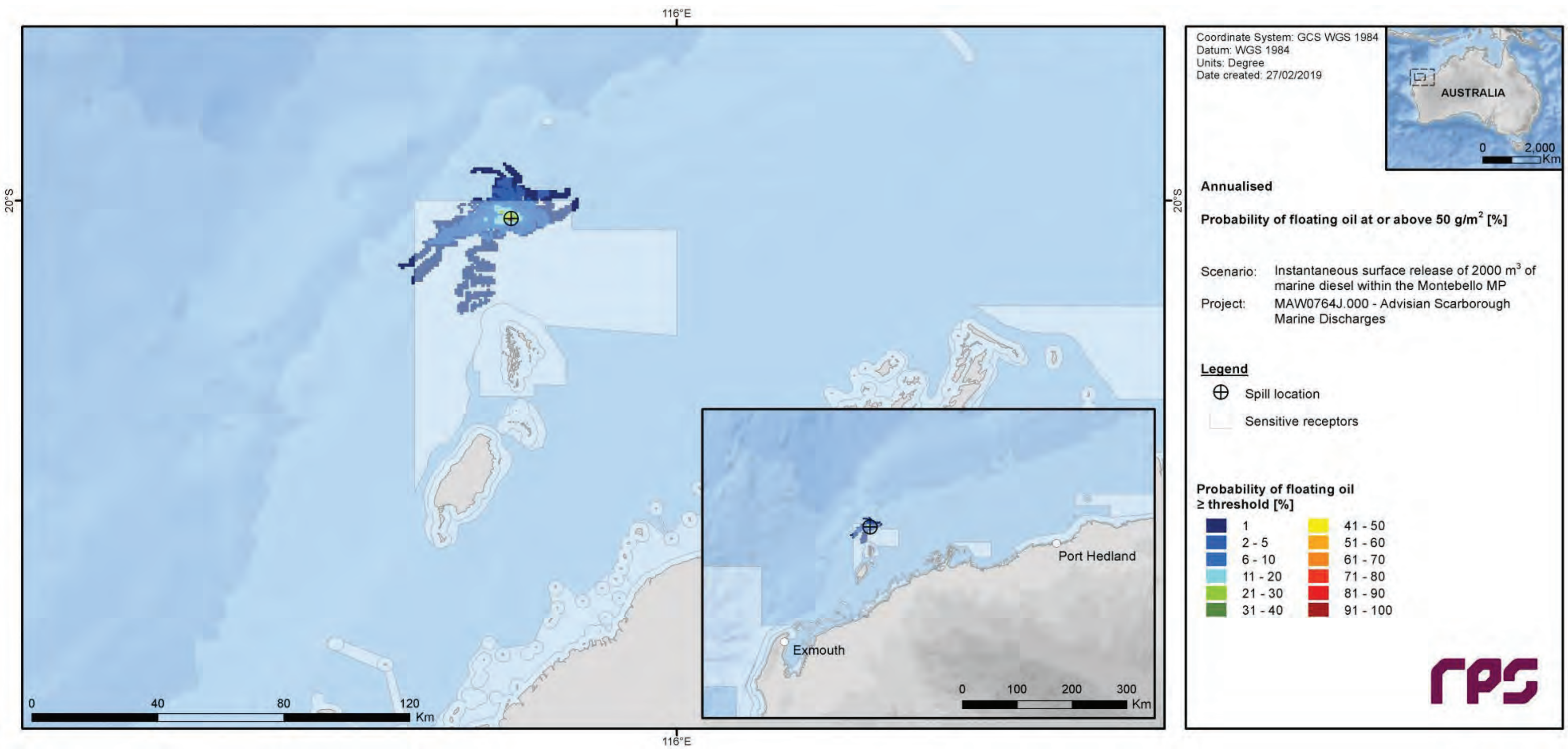



**Figure 3.26 Predicted annualised probability of floating oil concentrations at or above 50 g/m² resulting from an instantaneous surface release of marine diesel after a vessel collision within Montebello Marine Park.**

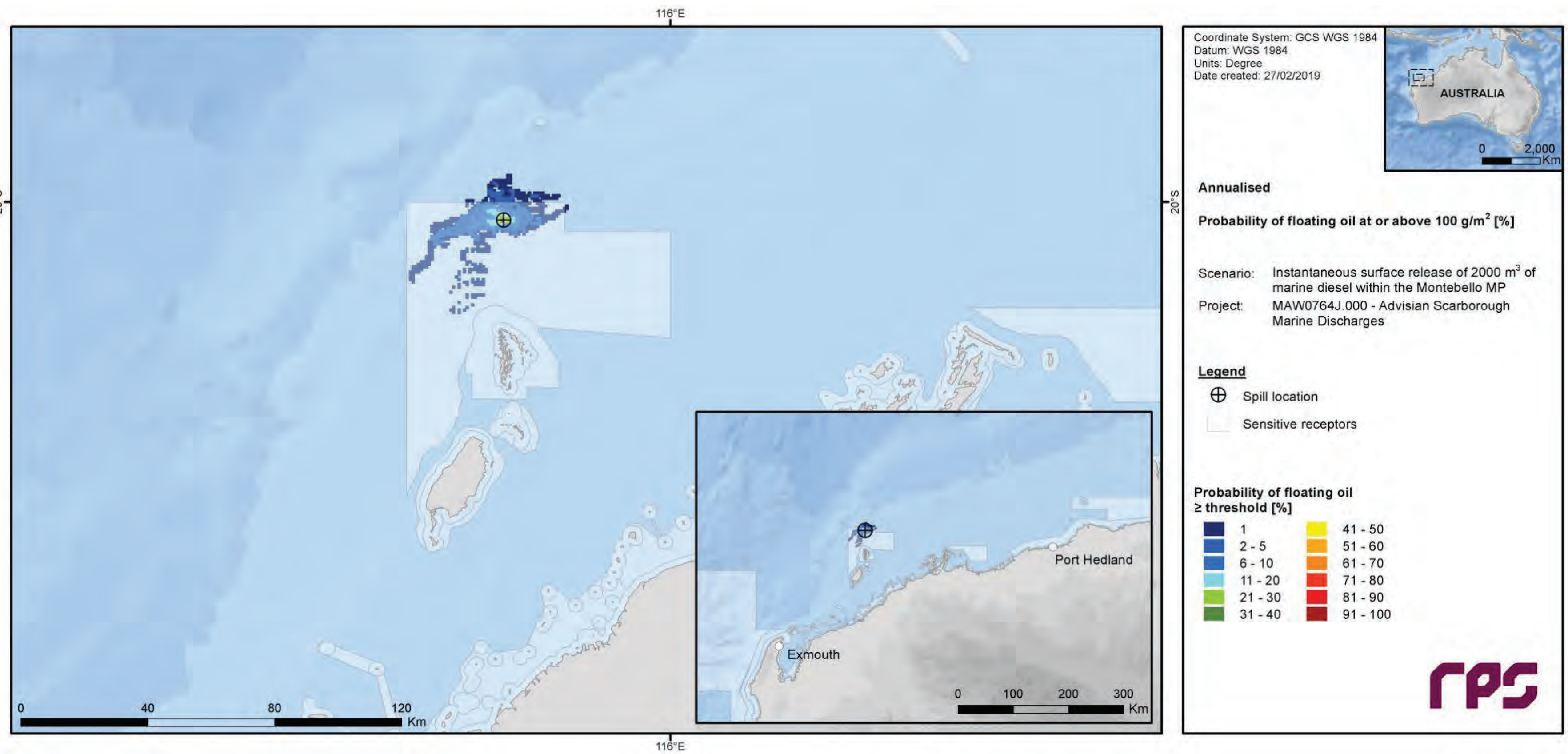



**Figure 3.27 Predicted annualised probability of floating oil concentrations at or above 100 g/m² resulting from an instantaneous surface release of marine diesel after a vessel collision within Montebello Marine Park.**

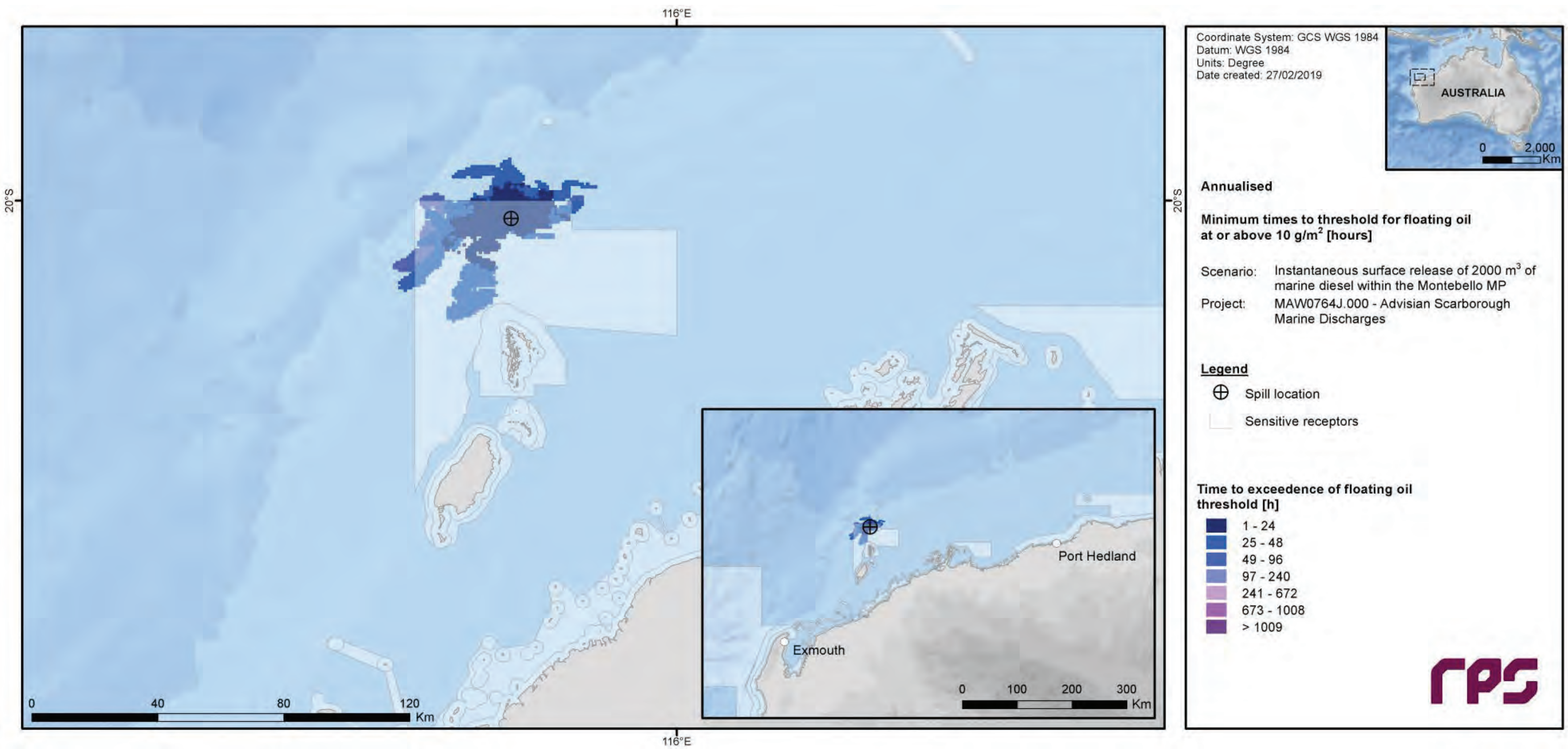



**Figure 3.28 Predicted annualised minimum times to contact by floating oil concentrations at or above 10 g/m$^2$ resulting from an instantaneous surface release of marine diesel after a vessel collision within Montebello Marine Park.**

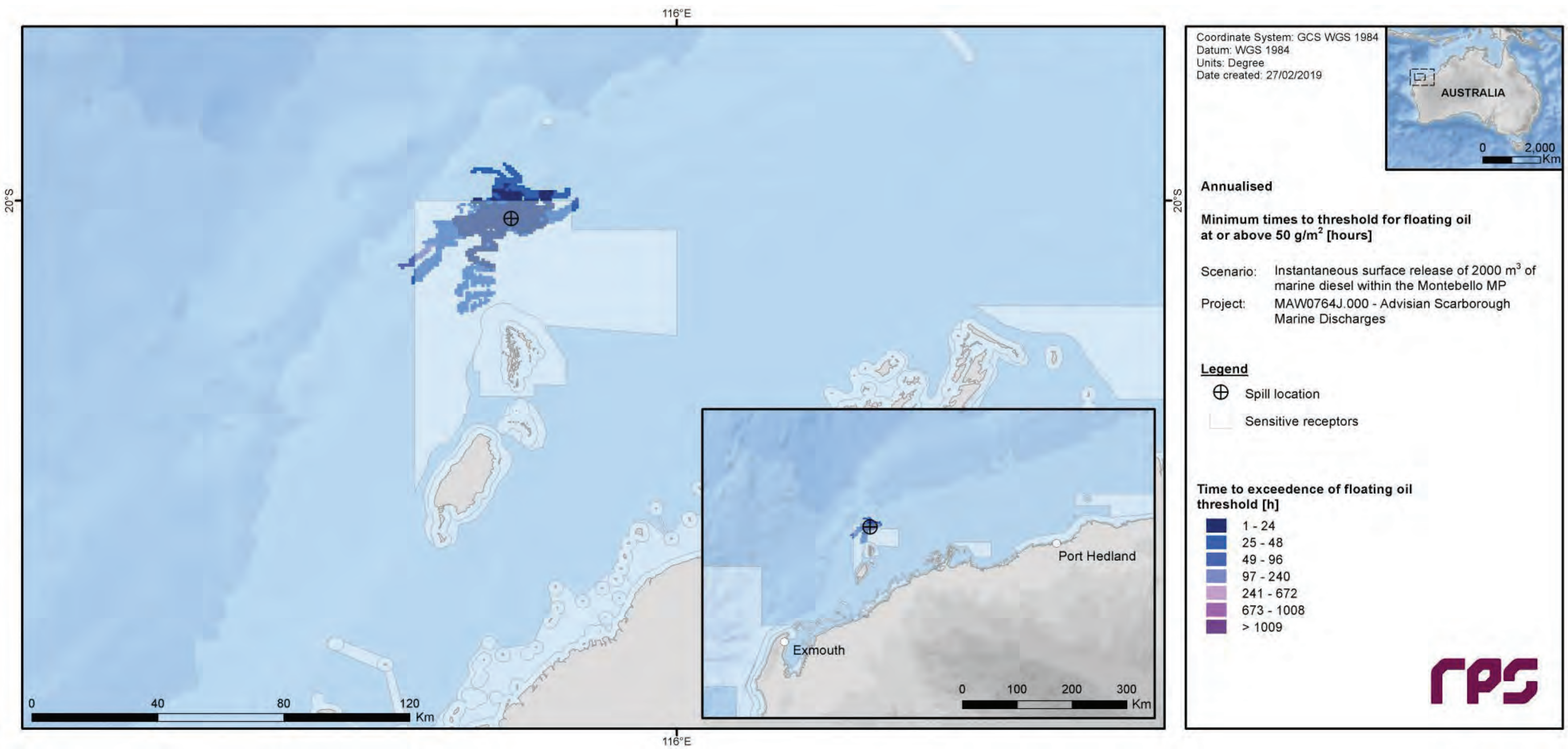



**Figure 3.29 Predicted annualised minimum times to contact by floating oil concentrations at or above 50 g/m$^2$ resulting from an instantaneous surface release of marine diesel after a vessel collision within Montebello Marine Park.**

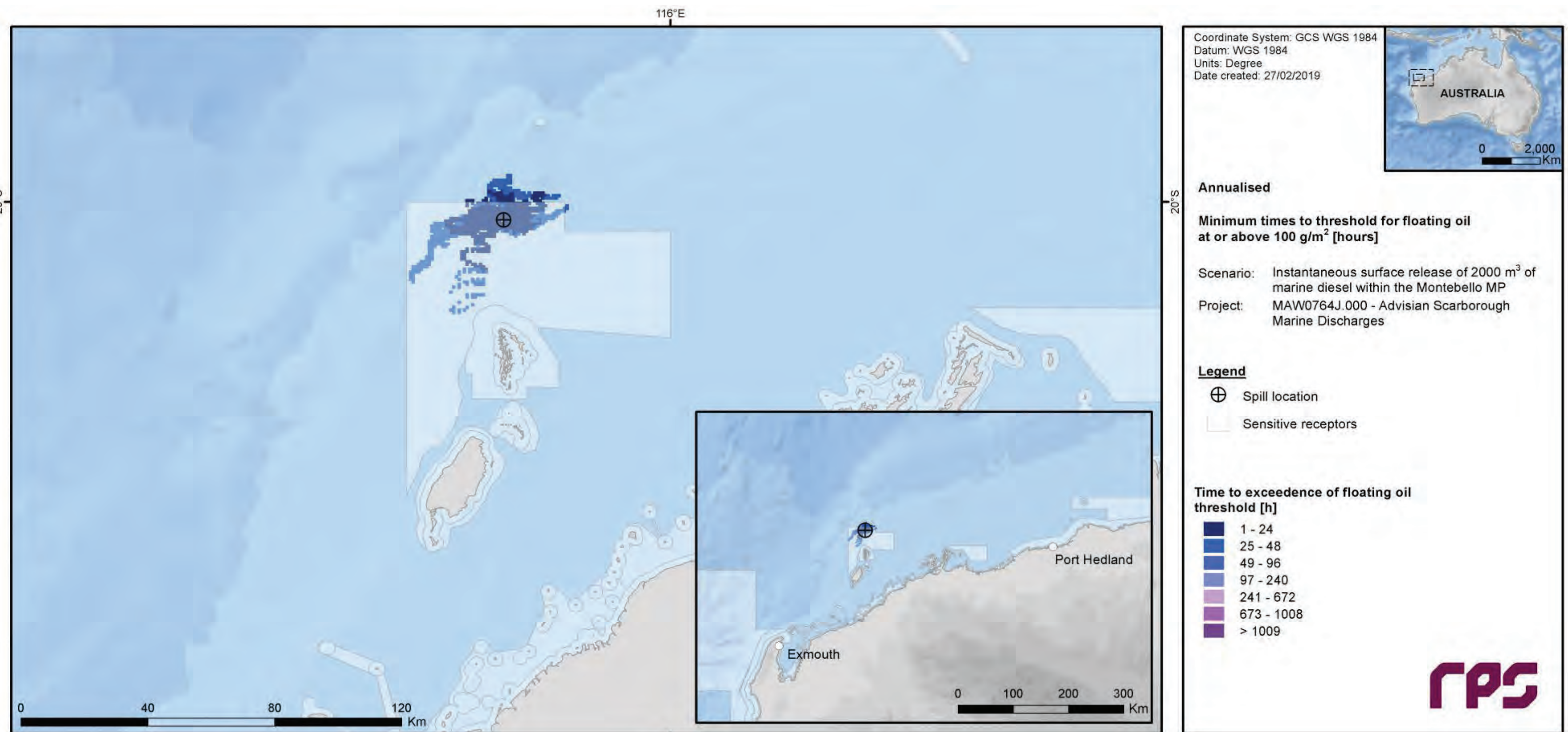



**Figure 3.30 Predicted annualised minimum times to contact by floating oil concentrations at or above 100 g/m$^2$ resulting from an instantaneous surface release of marine diesel after a vessel collision within Montebello Marine Park.**

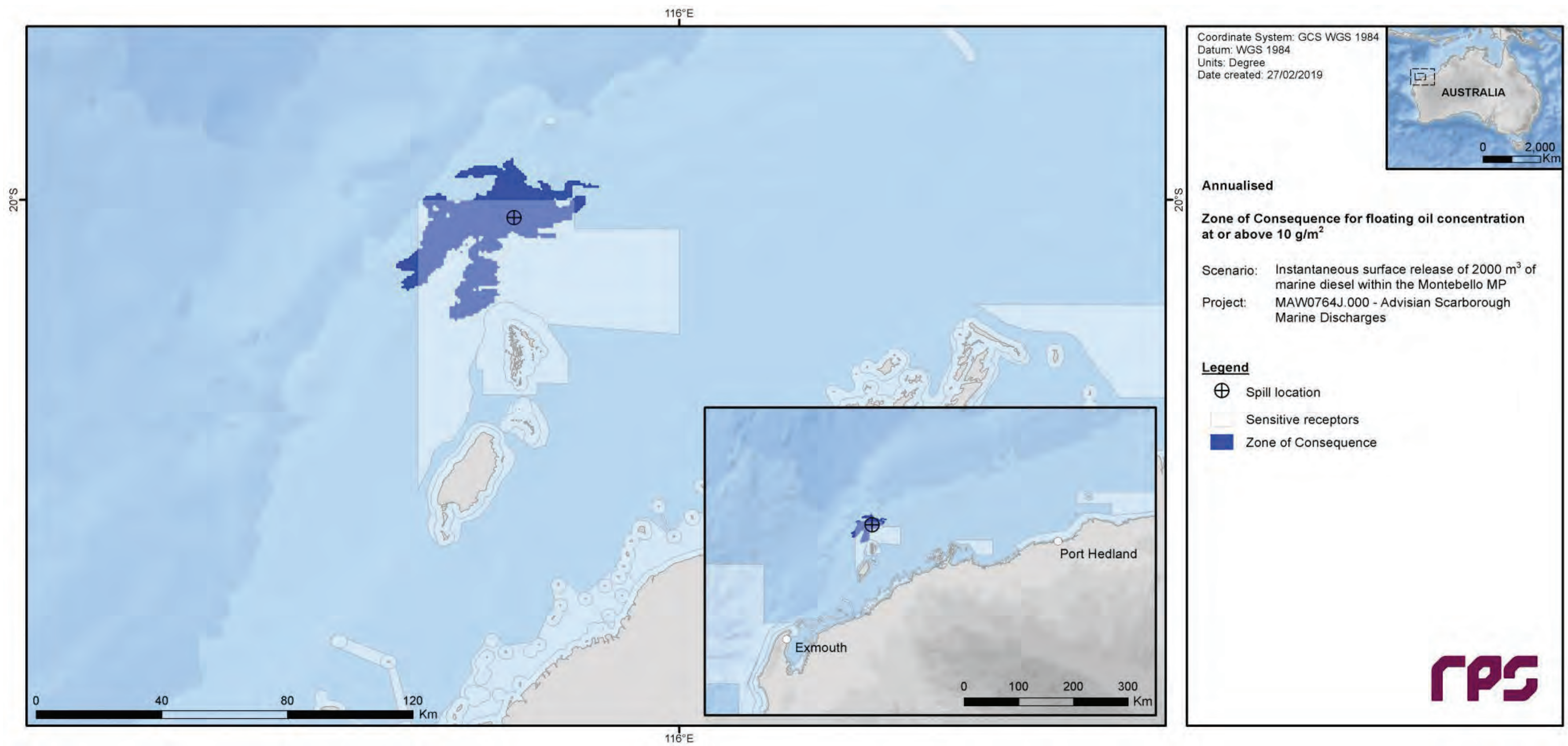



**Figure 3.31 Predicted annualised Zone of Consequence of floating oil concentrations at or above 10 g/m$^2$ resulting from an instantaneous surface release of marine diesel after a vessel collision within Montebello Marine Park.**

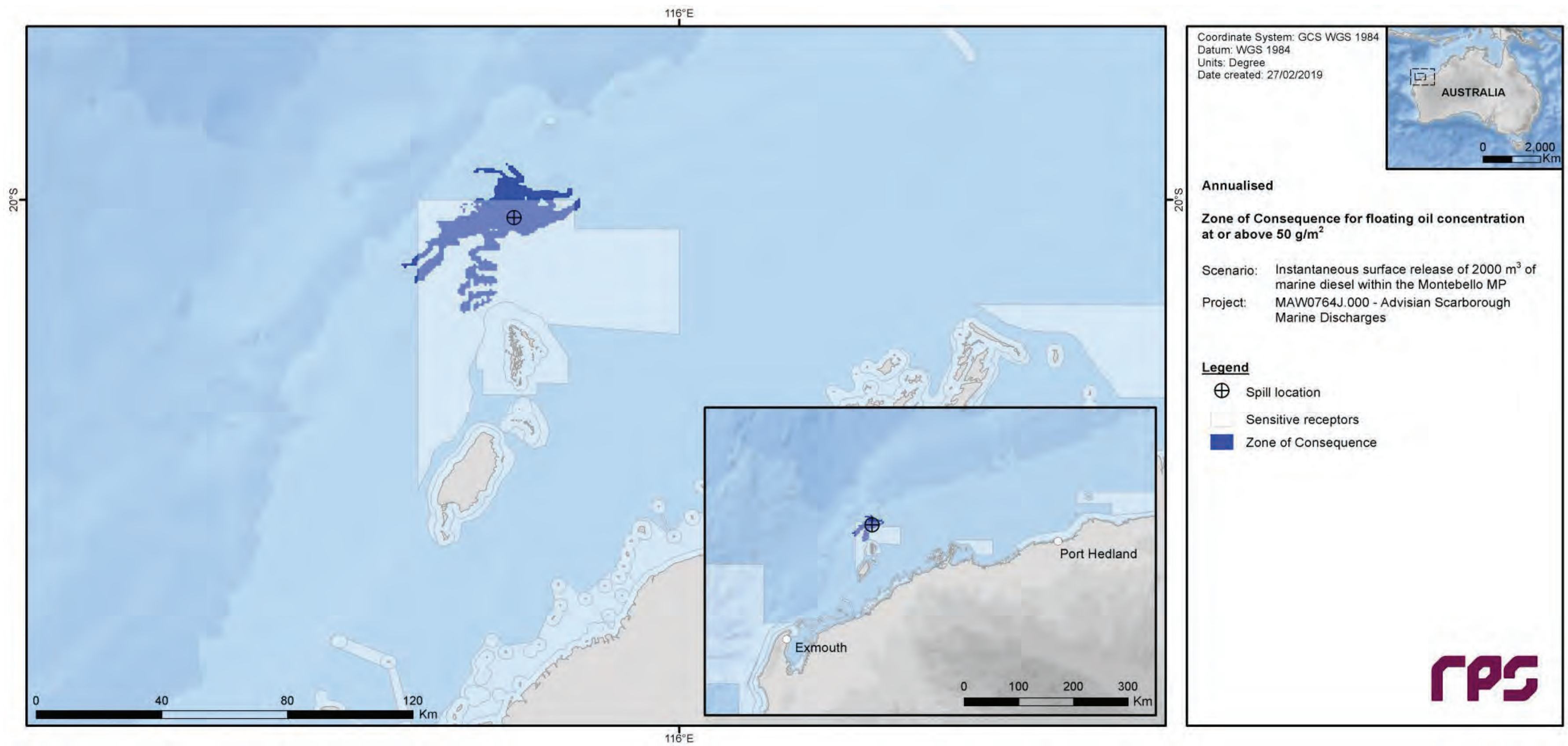



**Figure 3.32 Predicted annualised Zone of Consequence of floating oil concentrations at or above 50 g/m$^2$ resulting from an instantaneous surface release of marine diesel after a vessel collision within Montebello Marine Park.**

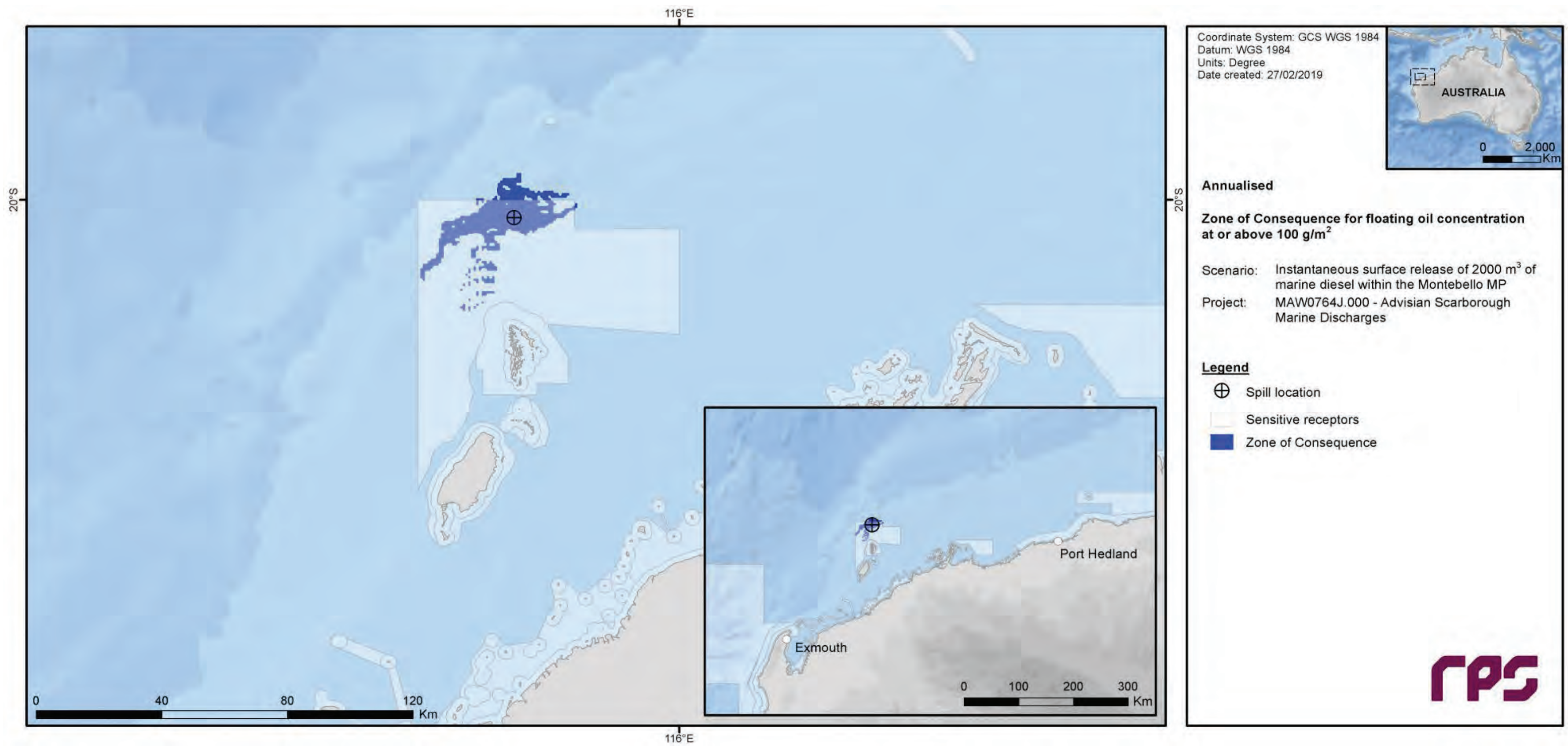



**Figure 3.33 Predicted annualised Zone of Consequence of floating oil concentrations at or above 100 g/m$^2$ resulting from an instantaneous surface release of marine diesel after a vessel collision within Montebello Marine Park.**

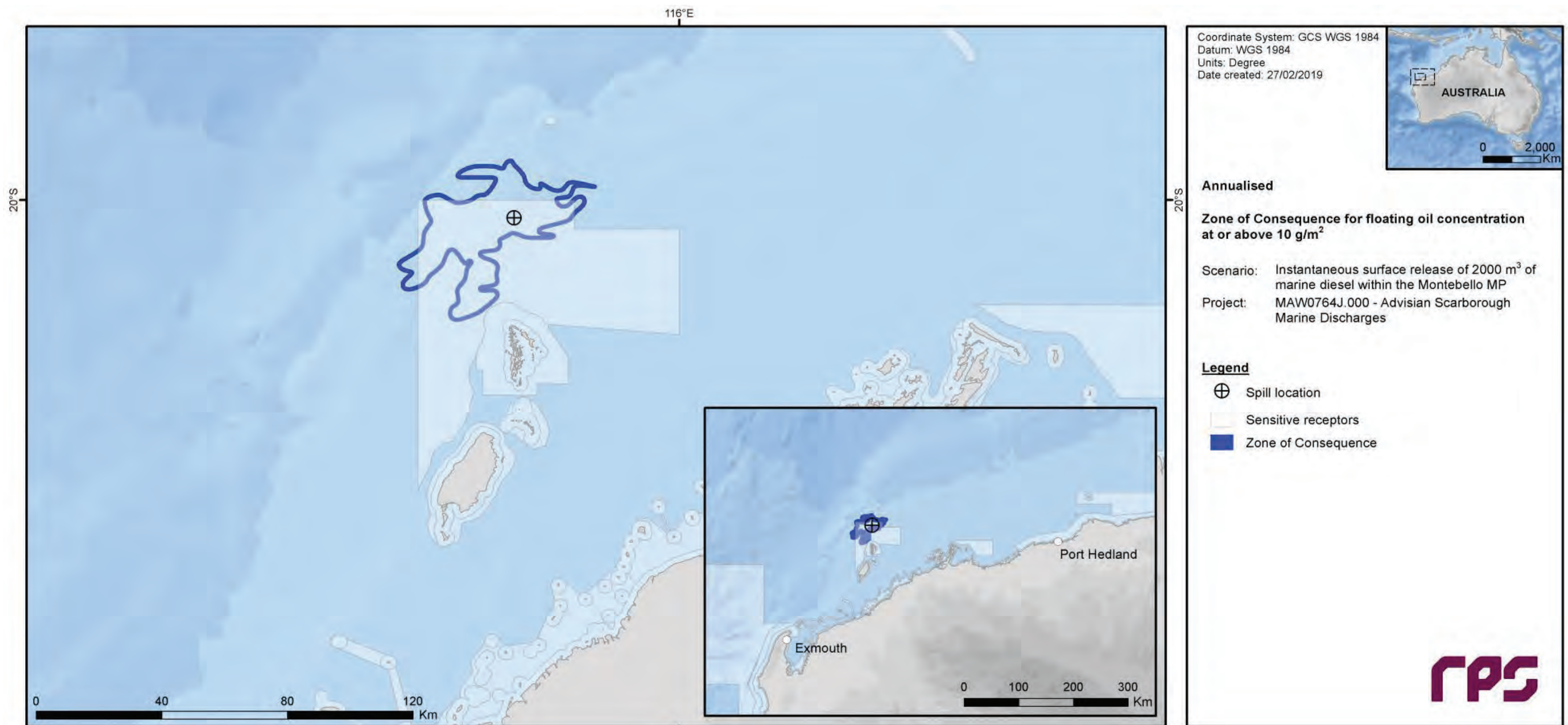



**Figure 3.34 Predicted annualised smoothed Zone of Consequence of floating oil concentrations at or above 10 g/m$^2$ resulting from an instantaneous surface release of marine diesel after a vessel collision within Montebello Marine Park.**

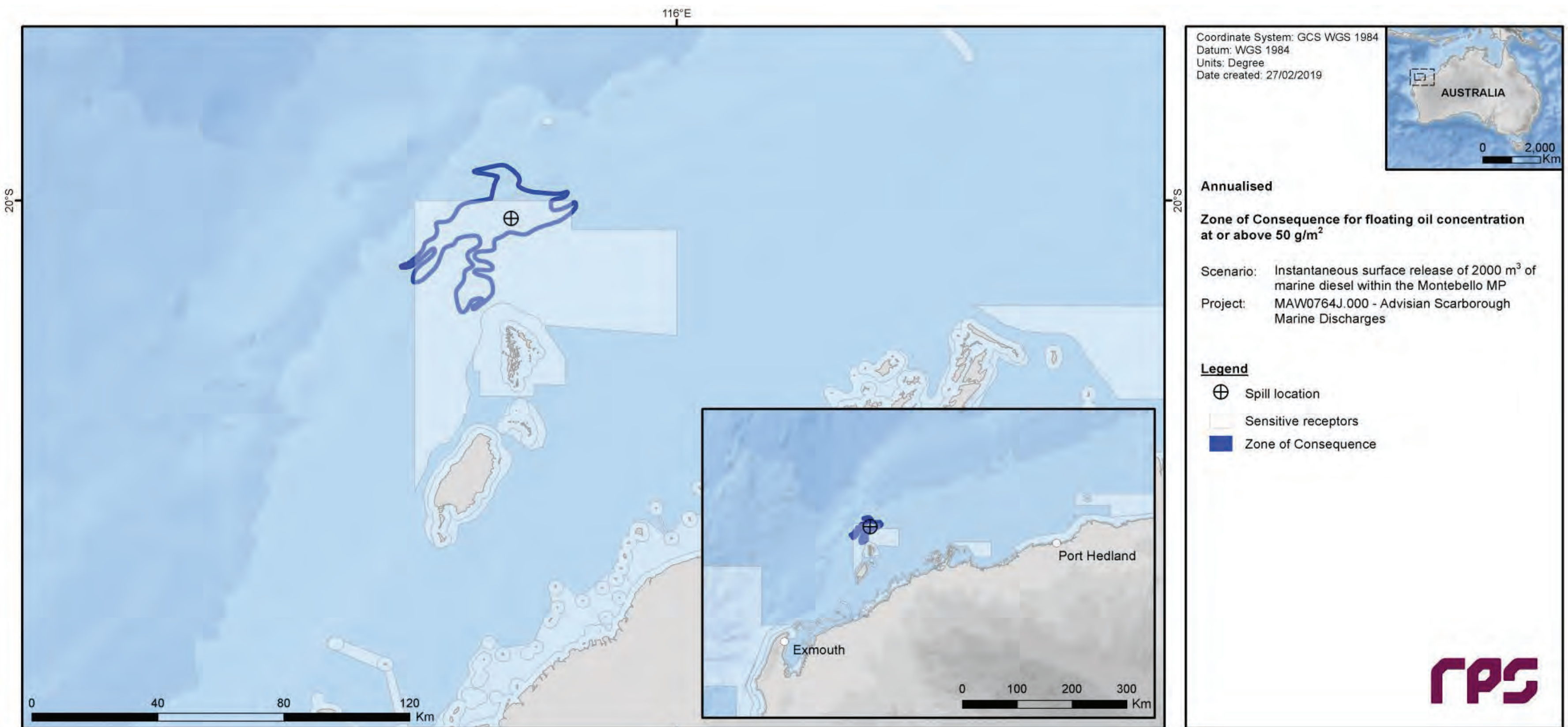



**Figure 3.35 Predicted annualised smoothed Zone of Consequence of floating oil concentrations at or above 50 g/m$^2$ resulting from an instantaneous surface release of marine diesel after a vessel collision within Montebello Marine Park.**

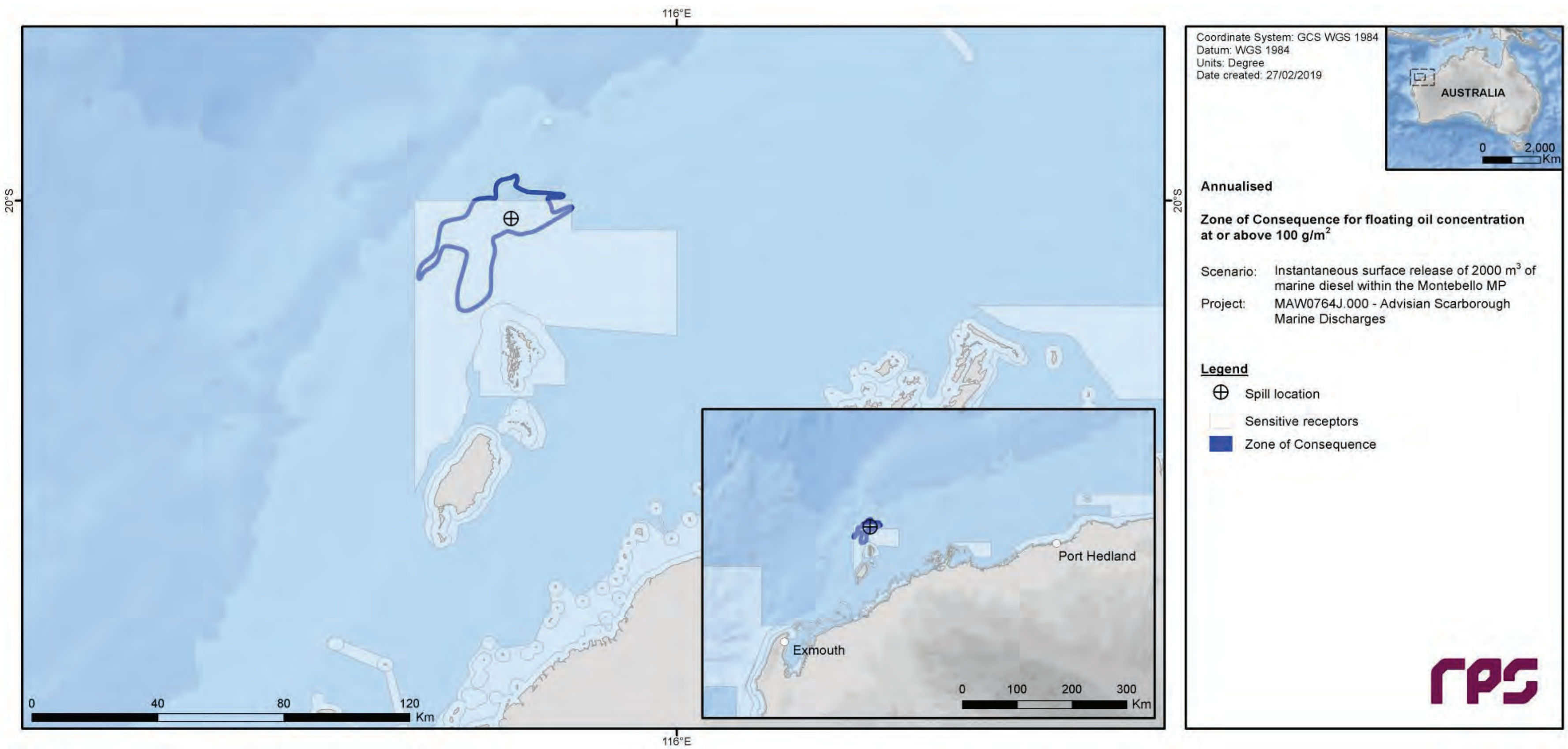



**Figure 3.36 Predicted annualised smoothed Zone of Consequence of floating oil concentrations at or above 100 g/m$^2$ resulting from an instantaneous surface release of marine diesel after a vessel collision within Montebello Marine Park.**

### 3.3.2.2 Entrained Oil

**Table 3.5 Expected annualised entrained oil outcomes at sensitive receptors resulting from an instantaneous surface release of marine diesel after a vessel collision within Montebello Marine Park.**

| Receptor | Probability (%) of entrained oil concentration ≥500 ppb | Minimum time to receptor (hours) for entrained oil at ≥500 ppb | Maximum entrained oil concentration (ppb) averaged over all replicate simulations | Maximum entrained oil concentration (ppb), at any depth, in the worst replicate simulation |
|---|---|---|---|---|
| Argo-Rowley Terrace MP | <1 | NC | 2 | 109 |
| Barrow Island | 1 | 88 | 55 | 4,225 |
| Glomar Shoals* | <1 | 389 | 9 | 8 |
| Montebello Islands | 2 | 212 | 28 | 963 |
| Muiron Islands MMA-WHA | 7 | 183 | 100 | 2,392 |
| Ningaloo Coast Middle | <1 | NC | 3 | 228 |
| Ningaloo Coast Middle WHA | <1 | NC | 7 | 472 |
| Ningaloo Coast North | 1 | 314 | 24 | 690 |
| Ningaloo Coast North WHA | 4 | 223 | 66 | 2,438 |
| Ningaloo Coast South WHA | <1 | NC | <1 | 51 |
| Ningaloo RUZ | 4 | 223 | 66 | 2,438 |
| Pilbara Islands - Southern Island Group | 2 | 171 | 45 | 2,536 |
| Rankin Bank* | <1 | 101 | 78 | 193 |
| Shark Bay Open Ocean Coast | <1 | NC | 2 | 153 |
| Shark Bay WHA | <1 | NC | 2 | 153 |
| Bernier & Dorre Islands | <1 | NC | 2 | 156 |
| Lowendal Islands | 1 | 164 | 8 | 639 |
| Montebello MP | 70 | 1 | 14,381 | 156,954 |
| Montebello State Marine Park | 4 | 85 | 95 | 4,577 |
| Muiron Islands | 5 | 185 | 78 | 1,676 |
| Gascoyne MP | 2 | 339 | 36 | 836 |
| WA Coastline | 5 | 93 | 71 | 3,381 |

NC: No contact to receptor predicted for specified threshold.

* Probabilities and maximum concentrations calculated at depth of submerged feature.

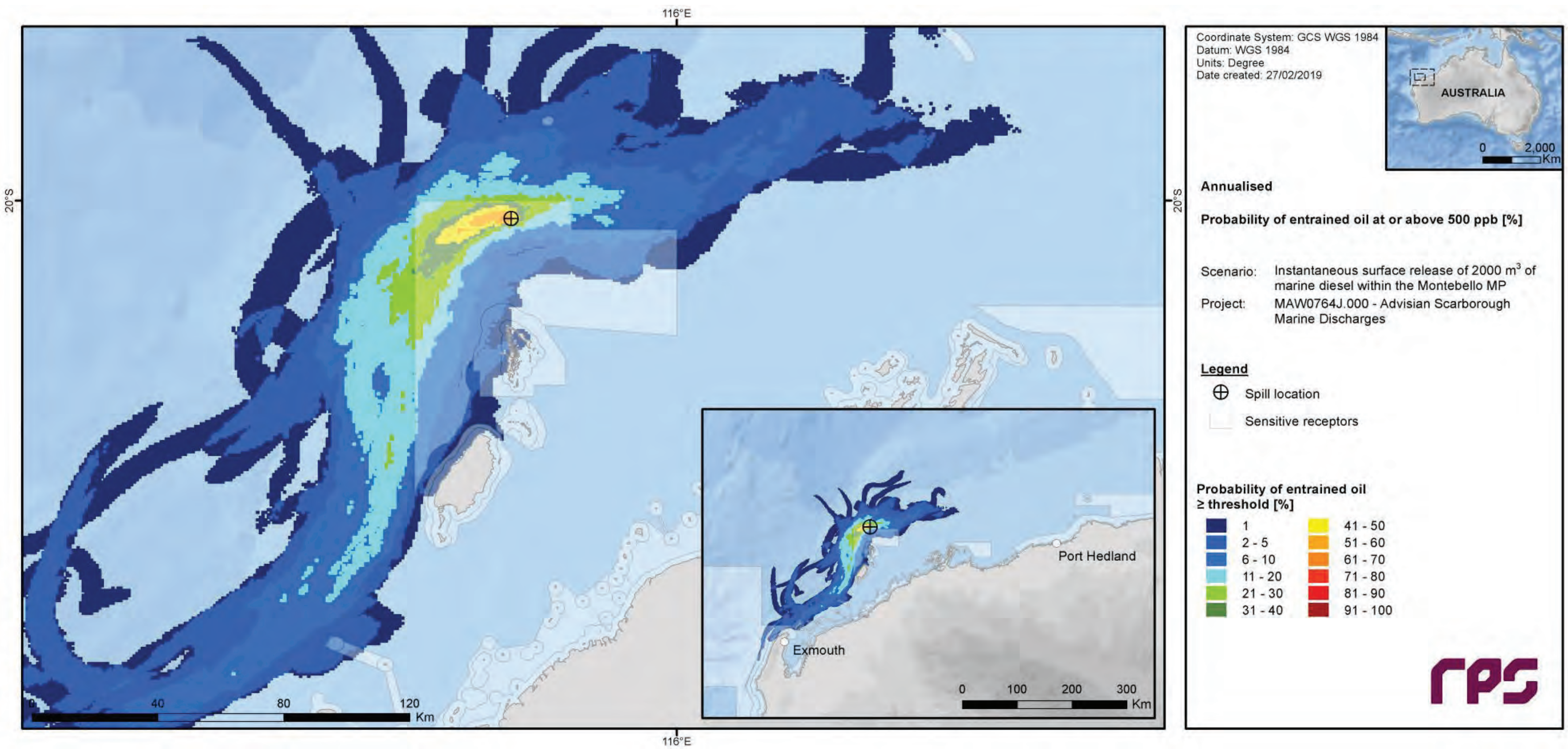



**Figure 3.37 Predicted annualised probability of entrained oil concentrations at or above 500 ppb resulting from an instantaneous surface release of marine diesel after a vessel collision within Montebello Marine Park.**

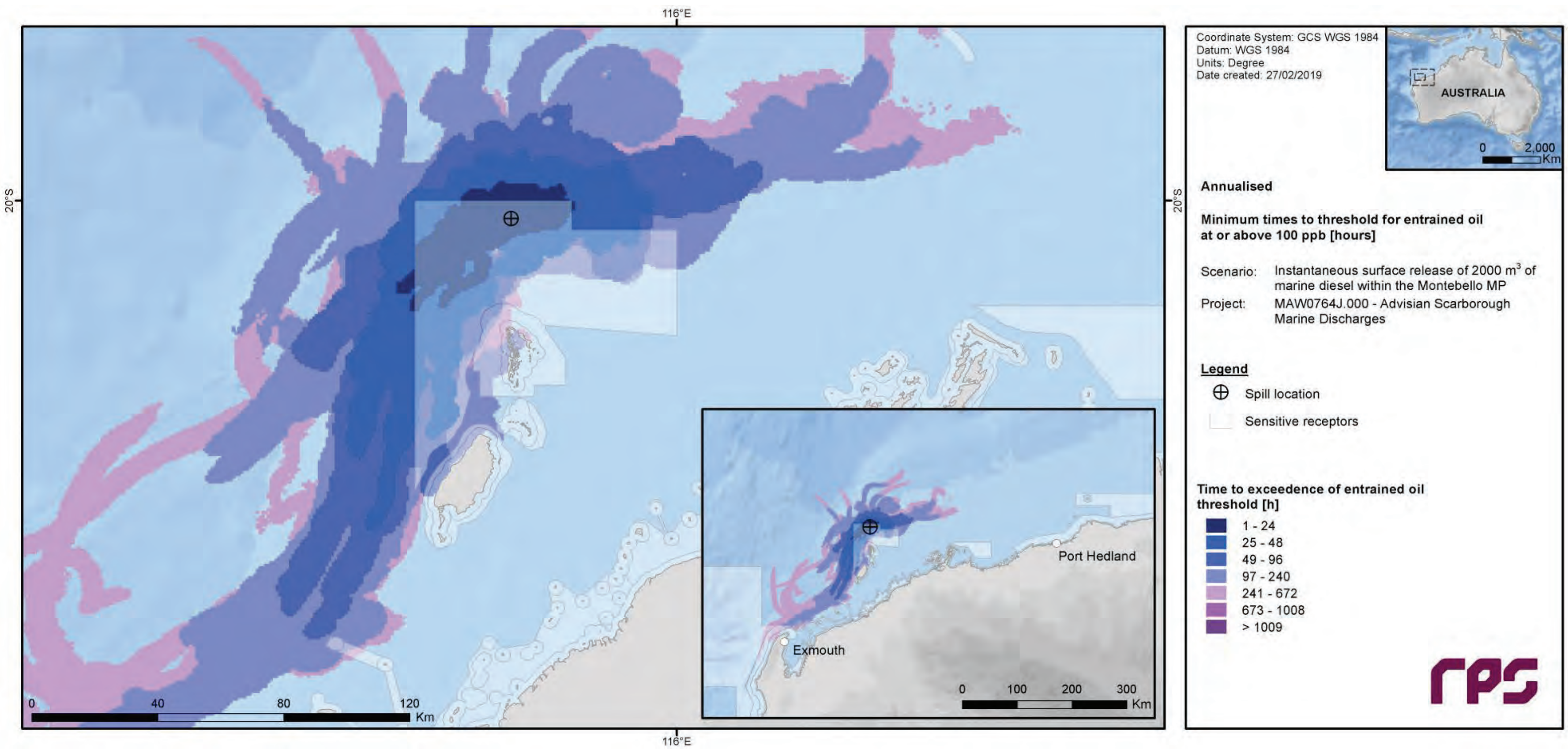



**Figure 3.38 Predicted annualised minimum times to contact by entrained oil concentrations at or above 500 ppb resulting from an instantaneous surface release of marine diesel after a vessel collision within Montebello Marine Park.**

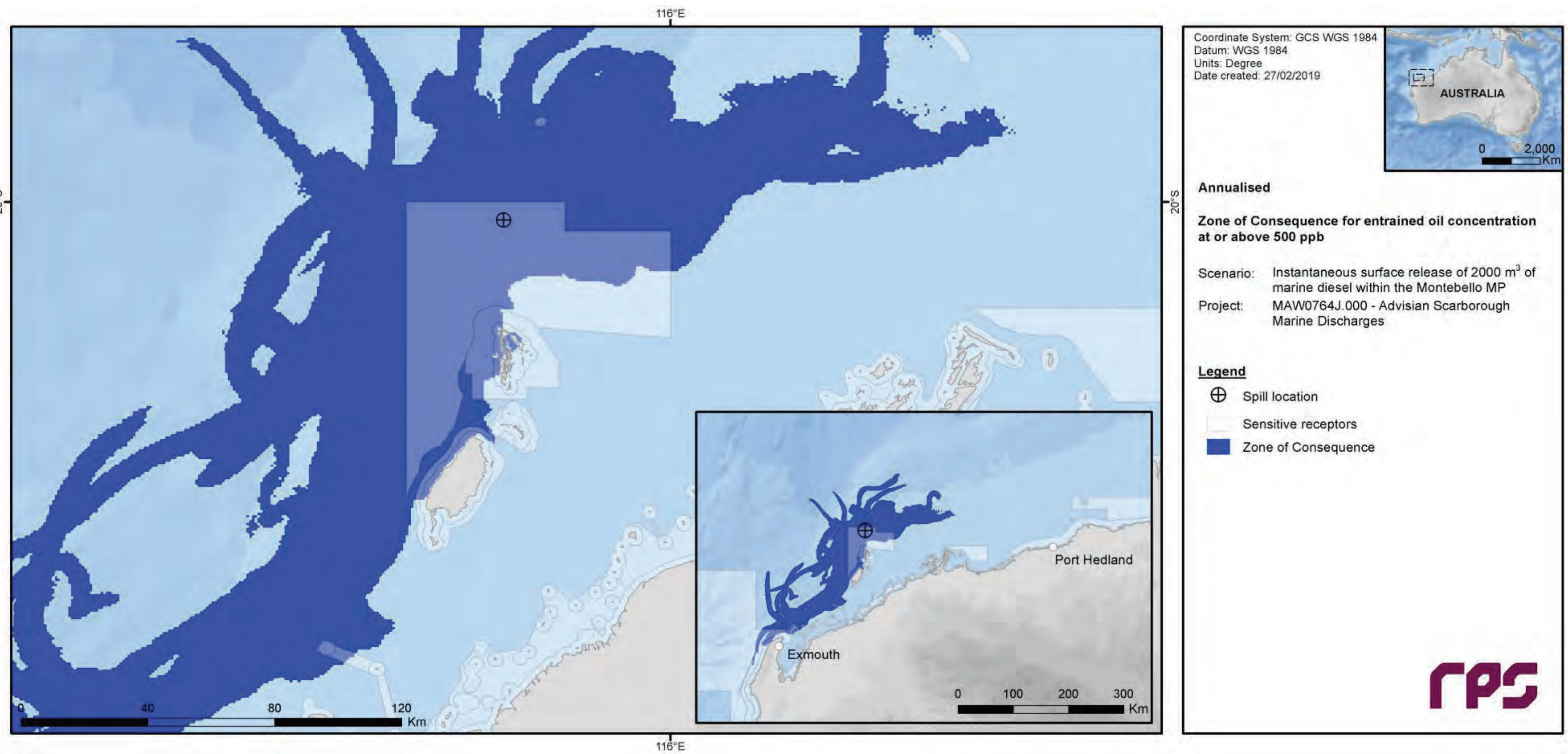



**Figure 3.39 Predicted annualised Zone of Consequence of entrained oil concentrations at or above 500 ppb resulting from an instantaneous surface release of marine diesel after a vessel collision within Montebello Marine Park.**

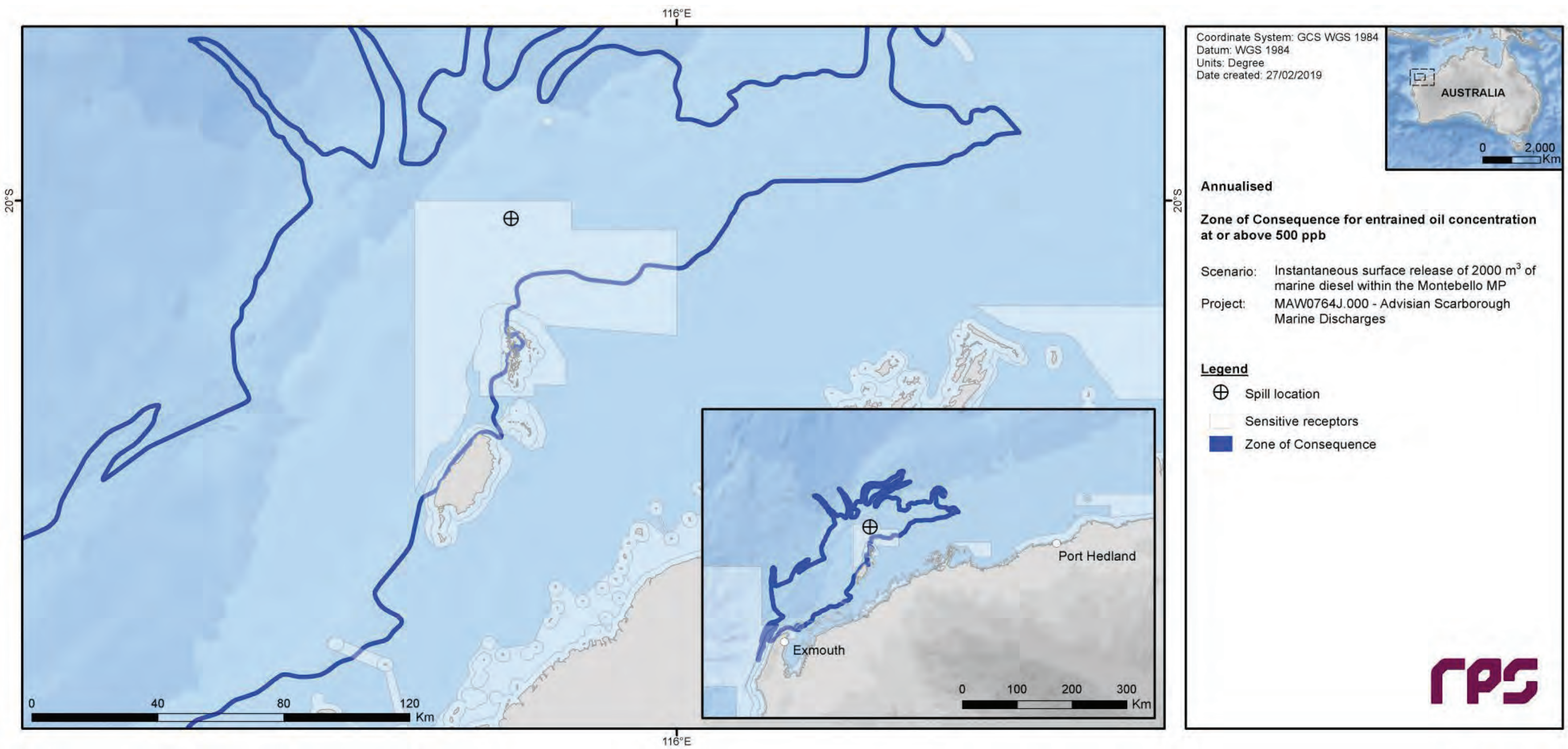



**Figure 3.40 Predicted annualised smoothed Zone of Consequence of entrained oil concentrations at or above 500 ppb resulting from an instantaneous surface release of marine diesel after a vessel collision within Montebello Marine Park.**

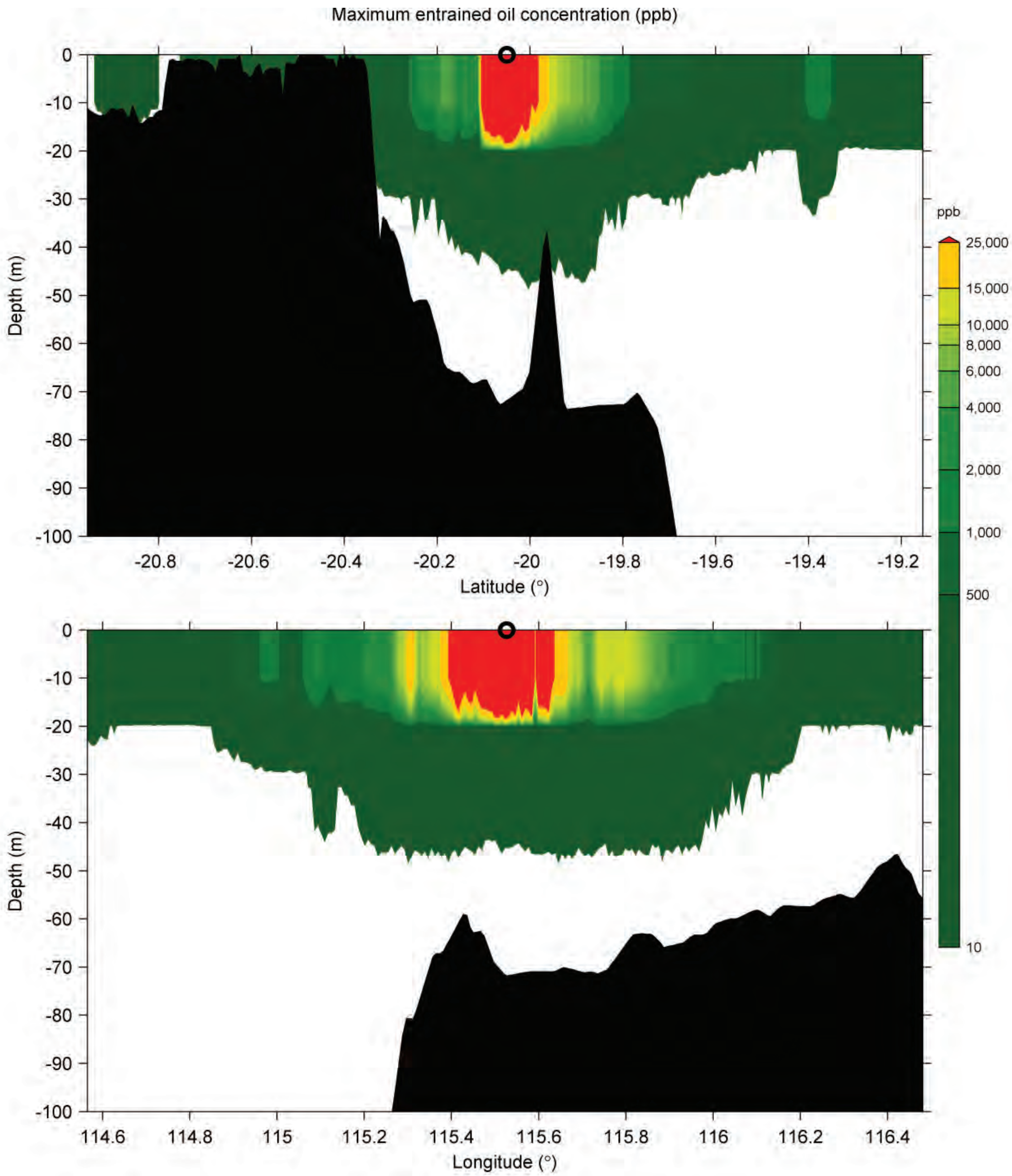



**Figure 3.41 Cross-section transects of predicted annualised maximum entrained oil concentrations for an instantaneous surface release of marine diesel after a vessel collision within Montebello Marine Park. Transect locations are shown in Figure 3.1.**

### 3.3.2.3 Dissolved Aromatic Hydrocarbons

**Table 3.6 Expected annualised dissolved aromatic hydrocarbon outcomes at sensitive receptors resulting from an instantaneous surface release of marine diesel after a vessel collision within Montebello Marine Park.**

| Receptor | Probability (%) of dissolved aromatic hydrocarbon concentration ≥500 ppb | Maximum dissolved aromatic hydrocarbon concentration (ppb) averaged over all replicate simulations | Maximum dissolved aromatic hydrocarbon concentration (ppb), at any depth, in the worst replicate simulation |
|---|---|---|---|
| Argo-Rowley Terrace MP | <1 | NC | NC |
| Barrow Island | <1 | 3 | 200 |
| Glomar Shoals* | <1 | <1 | <1 |
| Montebello Islands | <1 | <1 | 56 |
| Muiron Islands MMA-WHA | <1 | <1 | 29 |
| Ningaloo Coast Middle | <1 | <1 | 2 |
| Ningaloo Coast Middle WHA | <1 | <1 | 2 |
| Ningaloo Coast North | <1 | <1 | 10 |
| Ningaloo Coast North WHA | <1 | <1 | 47 |
| Ningaloo Coast South WHA | <1 | <1 | <1 |
| Ningaloo RUZ | <1 | <1 | 47 |
| Pilbara Islands - Southern Island Group | <1 | <1 | 25 |
| Rankin Bank* | <1 | 2 | 69 |
| Shark Bay Open Ocean Coast | <1 | NC | NC |
| Shark Bay WHA | <1 | NC | NC |
| Bernier & Dorre Islands | <1 | NC | NC |
| Lowendal Islands | <1 | <1 | 3 |
| Montebello MP | 9 | 154 | 1,990 |
| Montebello State Marine Park | <1 | 2 | 108 |
| Muiron Islands | <1 | <1 | 26 |
| Gascoyne MP | <1 | <1 | 23 |
| WA Coastline | <1 | <1 | 97 |

NC: No contact to receptor predicted for specified threshold.

* Probabilities and maximum concentrations calculated at depth of submerged feature.

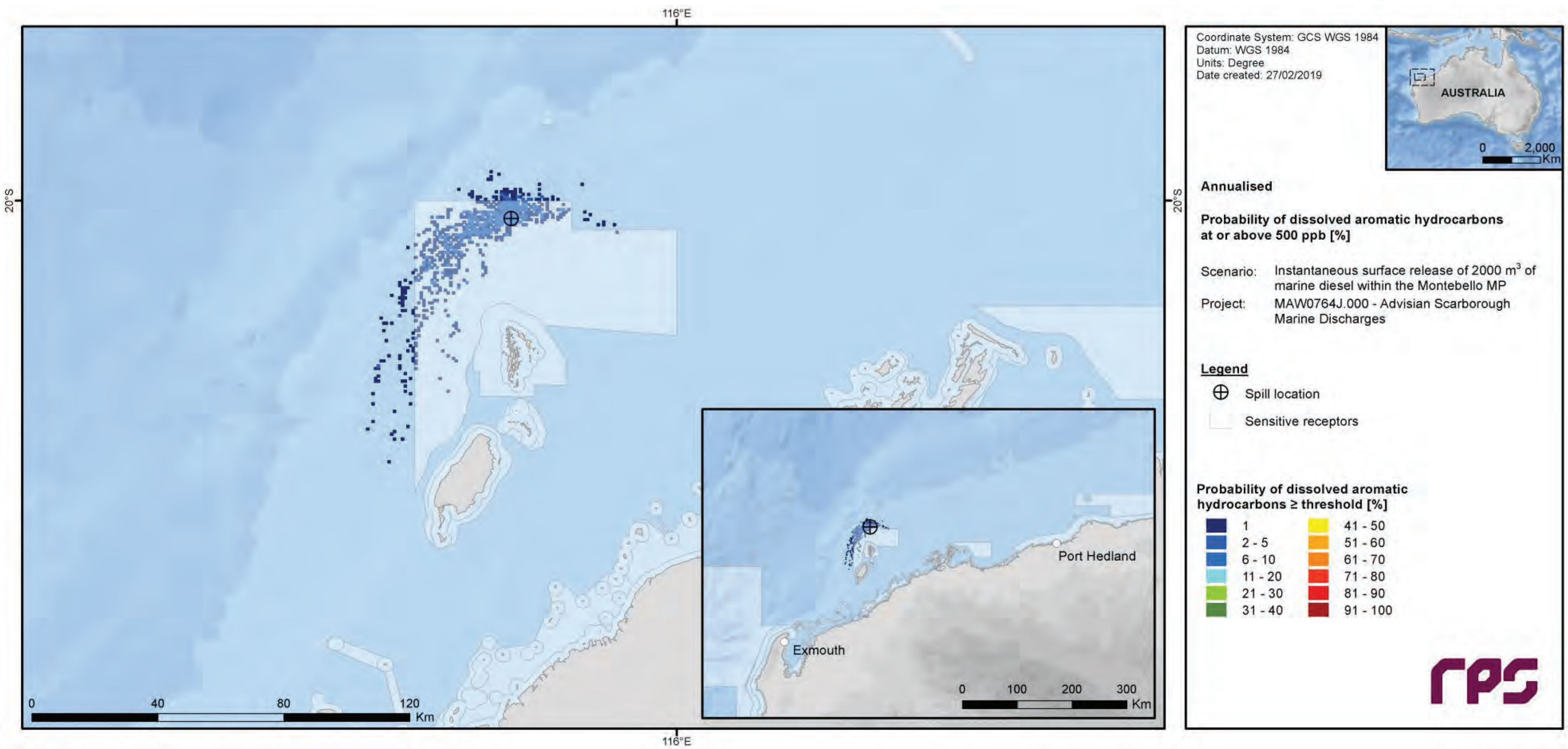



**Figure 3.42 Predicted annualised probability of dissolved aromatic hydrocarbon concentrations at or above 500 ppb resulting from an instantaneous surface release of marine diesel after a vessel collision within Montebello Marine Park.**

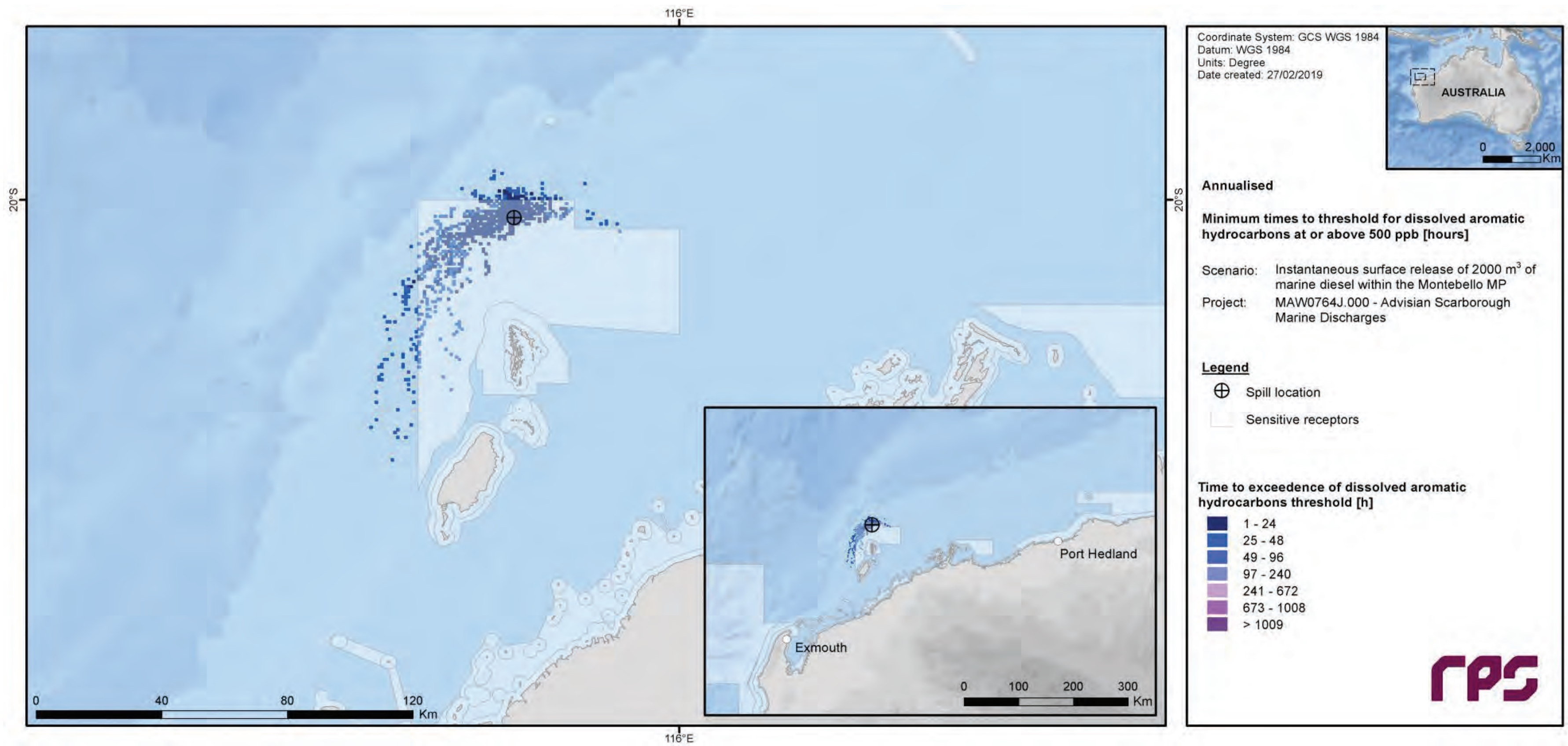



**Figure 3.43 Predicted annualised minimum times to contact by dissolved aromatic hydrocarbon concentrations at or above 500 ppb resulting from an instantaneous surface release of marine diesel after a vessel collision within Montebello Marine Park.**

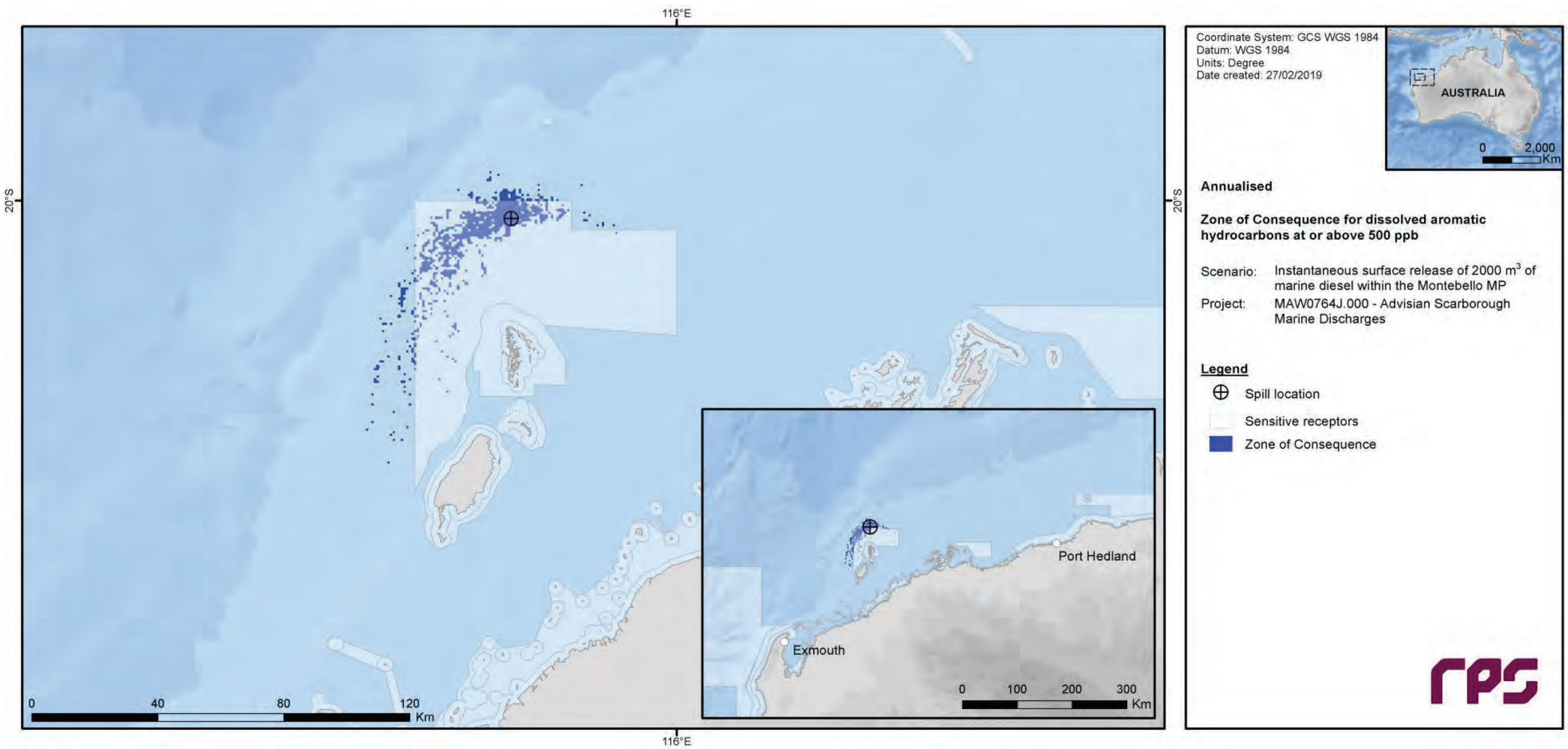



**Figure 3.44 Predicted annualised Zone of Consequence of dissolved aromatic hydrocarbon concentrations at or above 500 ppb resulting from an instantaneous surface release of marine diesel after a vessel collision within Montebello Marine Park.**

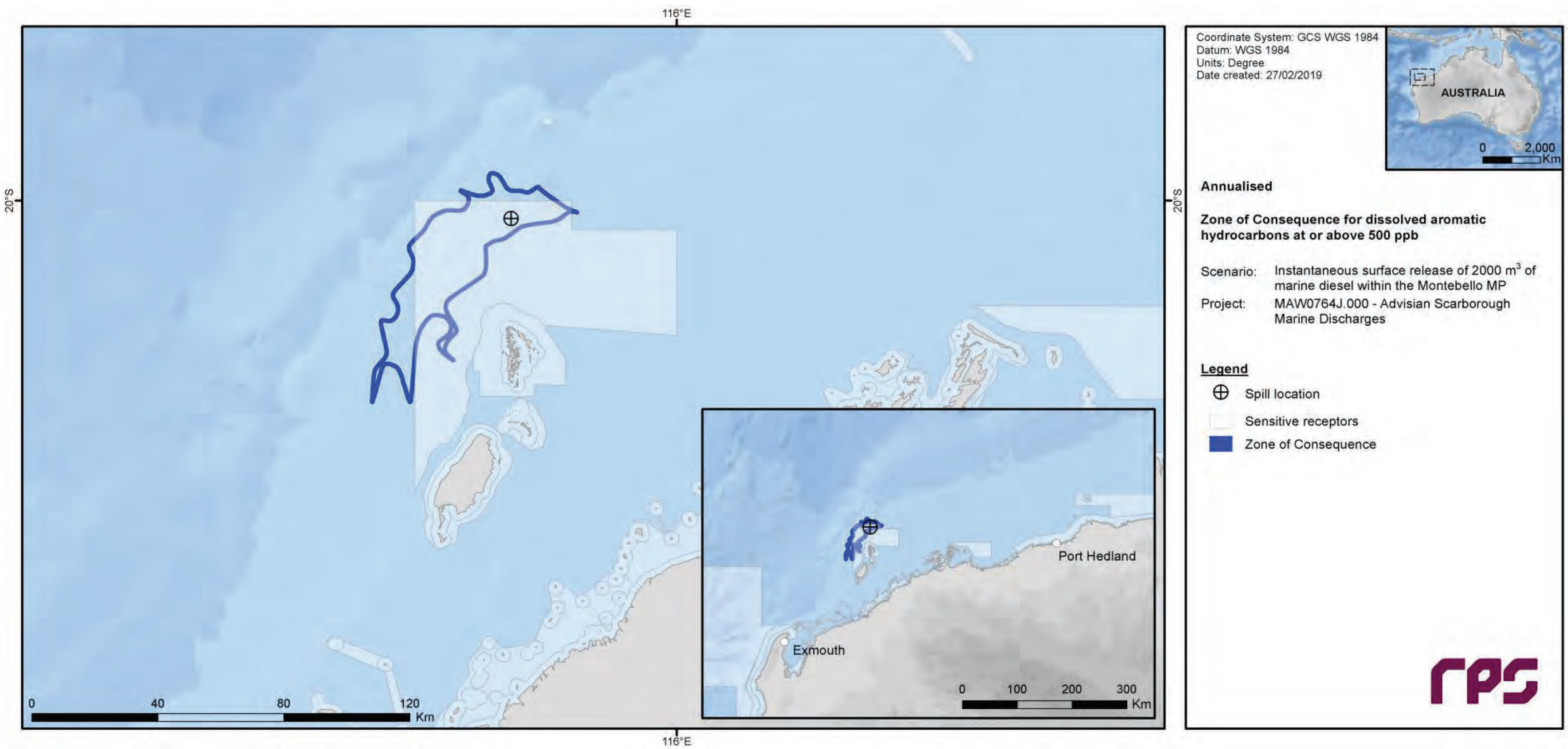



**Figure 3.45 Predicted annualised smoothed Zone of Consequence of dissolved aromatic hydrocarbon concentrations at or above 500 ppb resulting from an instantaneous surface release of marine diesel after a vessel collision within Montebello Marine Park.**

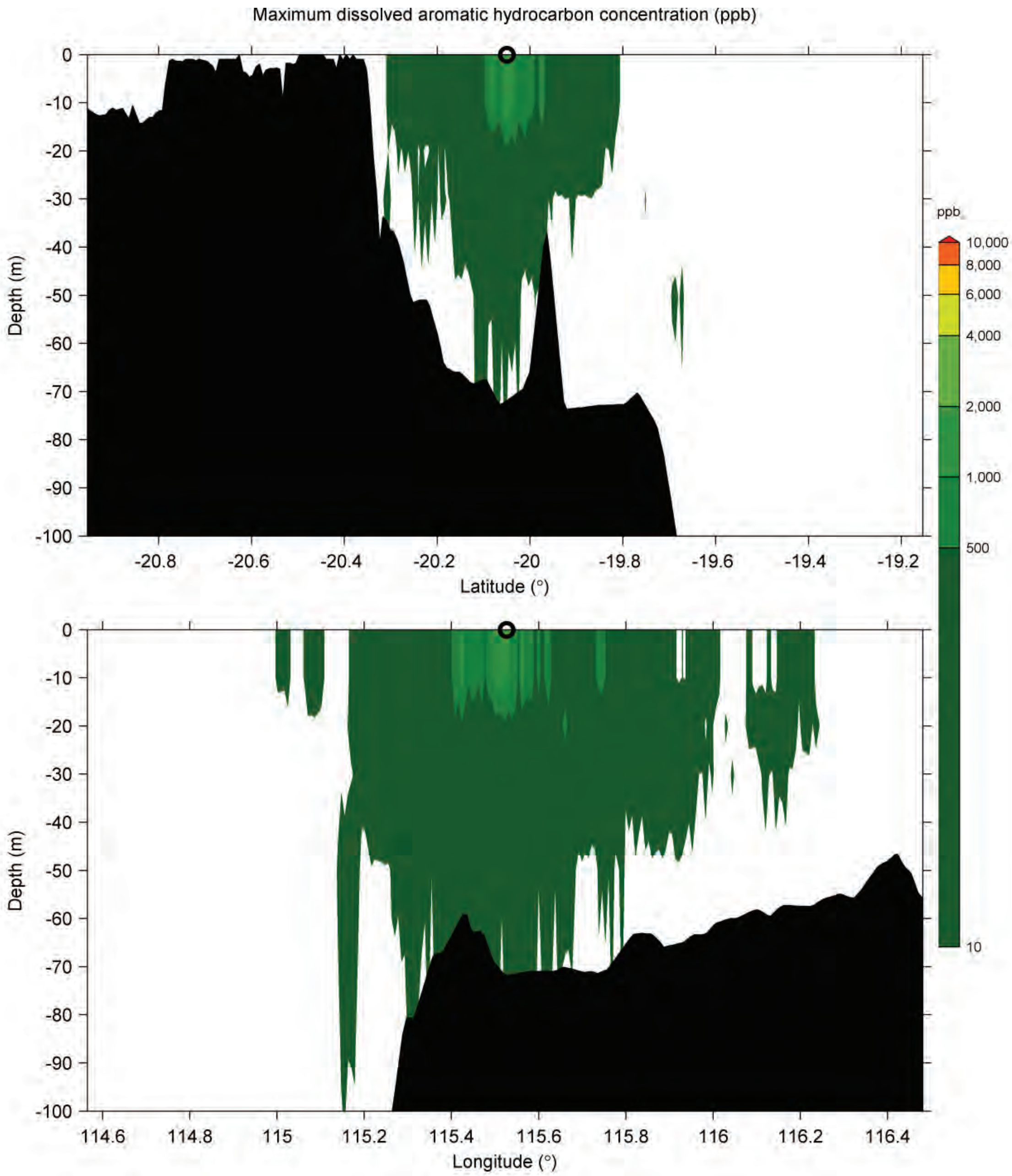



**Figure 3.46 Cross-section transects of predicted annualised maximum dissolved aromatic hydrocarbon concentrations for an instantaneous surface release of marine diesel after a vessel collision within Montebello Marine Park. Transect locations are shown in Figure 3.1.**

## 3.4 Scenario 3: Short-Term (Instantaneous) Surface Release of Marine Diesel after a Vessel Collision at the FPU Location

### 3.4.1 Discussion of Results

#### 3.4.1.1 Overview

This scenario investigated the probability of exposure to surrounding regions by oil resulting from a short-term (instantaneous) surface release of 2,000 $m^3$ of marine diesel at the FPU location during operations at any time of year, with no mitigation measures applied.

Considering the discharge characteristics, the properties of the oil and its expected weathering behaviour, floating oil will be susceptible to entrainment into the wave-mixed layer under typical wind conditions. Evaporation rates will be significant, given the moderate proportion of volatile compounds in the oil (41%). The low-volatility fraction of the oil (54%) will take longer durations of the order of days to evaporate, and the residual fraction of 5% is expected to persist in the environment until degradation processes occur. Considering the spill volume, there is a low potential for dissolution of soluble aromatic compounds.

#### 3.4.1.2 Floating and Shoreline Oil

The probability contour figures for floating oil indicate that concentrations equal to or greater than the 10 g/$m^2$, 50 g/$m^2$ and 100 g/$m^2$ thresholds could potentially be found, in the form of slicks, up to 113 km, 60 km and 58 km from the spill site, respectively (Figure 3.47, Figure 3.48 and Figure 3.49).

No shoreline receptors are predicted to be contacted by floating oil concentrations at any of the assessed thresholds (Table 3.7). Floating oil at the 10 g/$m^2$ threshold is predicted to arrive at the surface waters of the Gascoyne MP receptor with a probability of 1% after 64 hours.

No accumulation of oil on shorelines is predicted (Table 3.7).

The forecast annualised minimum times to contact, ZoC and smoothed ZoC for floating oil at or above the 10 g/$m^2$, 50 g/$m^2$ and 100 g/$m^2$ threshold concentrations are depicted in Figure 3.50 to Figure 3.52, Figure 3.53 to Figure 3.55 and Figure 3.56 to Figure 3.58, respectively.

#### 3.4.1.3 Entrained Oil

Entrained oil at concentrations equal to or greater than the 500 ppb threshold is predicted to be found up to around 476 km from the spill site (Figure 3.59).

The Gascoyne MP is predicted to receive entrained oil concentrations at the 500 ppb threshold with a probability of 8% (Table 3.8). The maximum entrained oil concentration is forecast as 7.2 ppm within the Gascoyne MP.

The forecast annualised minimum times to contact, ZoC and smoothed ZoC for entrained oil at or above the 500 ppb threshold concentration are depicted in Figure 3.60, Figure 3.61 and Figure 3.62, respectively.

The cross-sectional transects of maximum entrained oil concentrations in the vicinity of the release site show that concentrations above 25,000 ppb are expected to extend from the sea surface to depths of around 15 m (Figure 3.63).

#### 3.4.1.4 Dissolved Aromatic Hydrocarbons

Dissolved aromatic hydrocarbons at concentrations equal to or greater than the 500 ppb threshold are predicted to be found up to around 74 km from the spill site (Figure 3.64).

No receptors are predicted to receive dissolved aromatic hydrocarbon concentrations at the 500 ppb threshold (Table 3.9). The maximum dissolved aromatic hydrocarbon concentration is forecast as 462 ppb within the Gascoyne MP.

The forecast annualised minimum times to contact, ZoC and smoothed ZoC for dissolved aromatic hydrocarbons at or above the 500 ppb threshold concentration are depicted in Figure 3.65, Figure 3.66 and Figure 3.67, respectively.

The cross-sectional transects of maximum dissolved aromatic hydrocarbon concentrations in the vicinity of the release site show that concentrations above 1,000 ppb are expected to extend from the sea surface to depths of around 15 m (Figure 3.68).

## 3.4.2 Results Tables and Figures

### 3.4.2.1 Floating and Shoreline Oil

**Table 3.7 Expected annualised floating and shoreline oil outcomes at sensitive receptors resulting from an instantaneous surface release of marine diesel after a vessel collision at the FPU location.**

| Receptor | Probability (%) of floating oil concentration ≥10 g/m² | Probability (%) of floating oil concentration ≥50 g/m² | Probability (%) of floating oil concentration ≥100 g/m² | Minimum time to receptor (hours) for floating oil at ≥10 g/m² | Minimum time to receptor (hours) for floating oil at ≥50 g/m² | Minimum time to receptor (hours) for floating oil at ≥100 g/m² | Probability (%) of shoreline oil concentration ≥100 g/m² | Probability (%) of shoreline oil concentration ≥250 g/m² | Minimum time to receptor (hours) for shoreline oil at ≥100 g/m² | Minimum time to receptor (hours) for shoreline oil at ≥250 g/m² | Maximum local accumulated concentration (g/m²) averaged over all replicate simulations | Maximum local accumulated concentration (g/m²) in the worst replicate simulation | Maximum accumulated volume (m³) along this shoreline, averaged over all replicate simulations | Maximum accumulated volume (m³) along this shoreline, in the worst replicate simulation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ningaloo Coast North WHA | <1 | <1 | <1 | NC | NC | NC | <1 | <1 | NC | NC | NC | NC | NC | NC |
| Ningaloo RUZ* | <1 | <1 | <1 | NC | NC | NC | NA | NA | NA | NA | NA | NA | NA | NA |
| Abrolhos Islands MP* | <1 | <1 | <1 | NC | NC | NC | NA | NA | NA | NA | NA | NA | NA | NA |
| Carnarvon Canyon MP* | <1 | <1 | <1 | NC | NC | NC | NA | NA | NA | NA | NA | NA | NA | NA |
| Gascoyne MP* | 1 | <1 | <1 | 64 | NC | NC | 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.

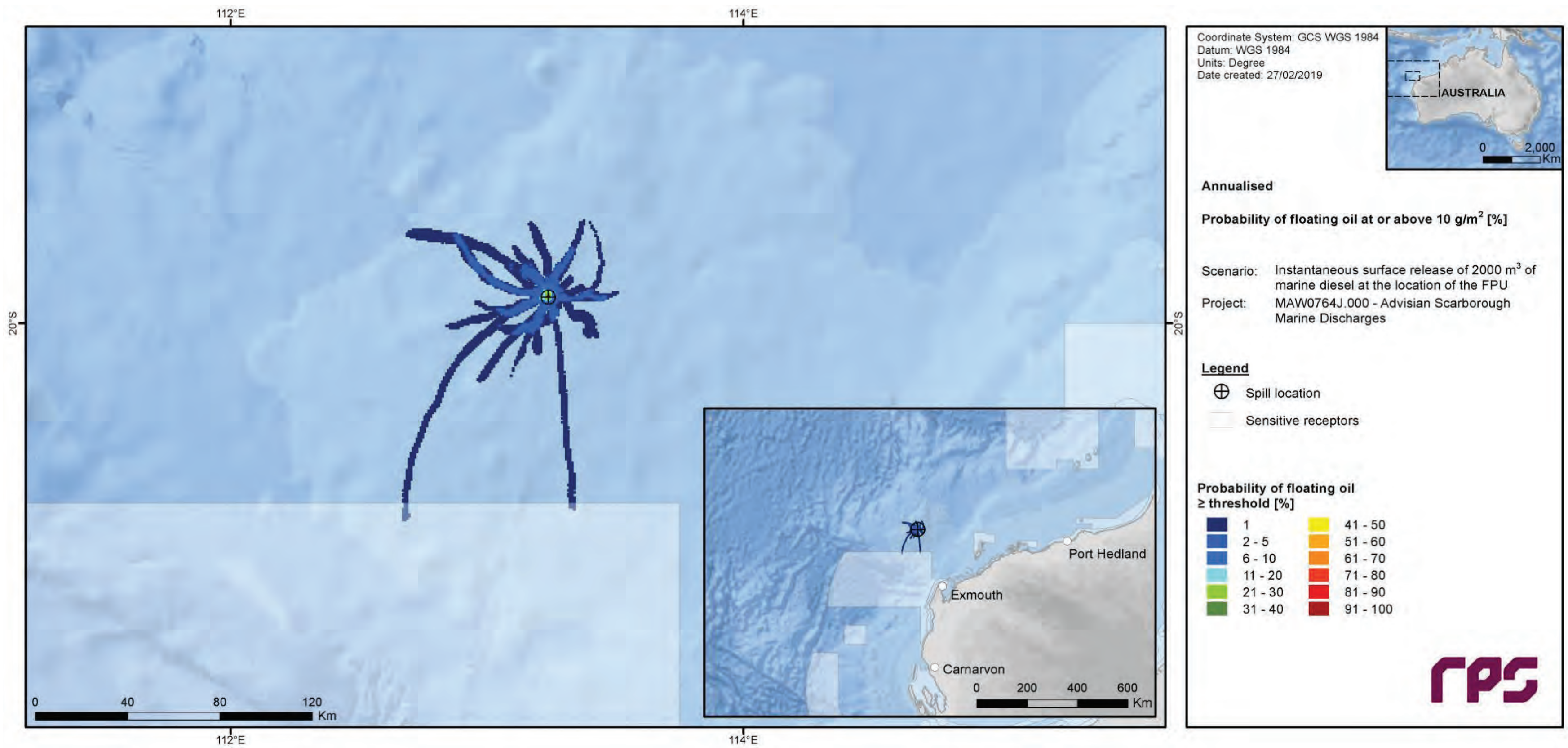



**Figure 3.47** **Predicted annualised probability of floating oil concentrations at or above 10 g/m$^2$ resulting from an instantaneous surface release of marine diesel after a vessel collision at the FPU location.**

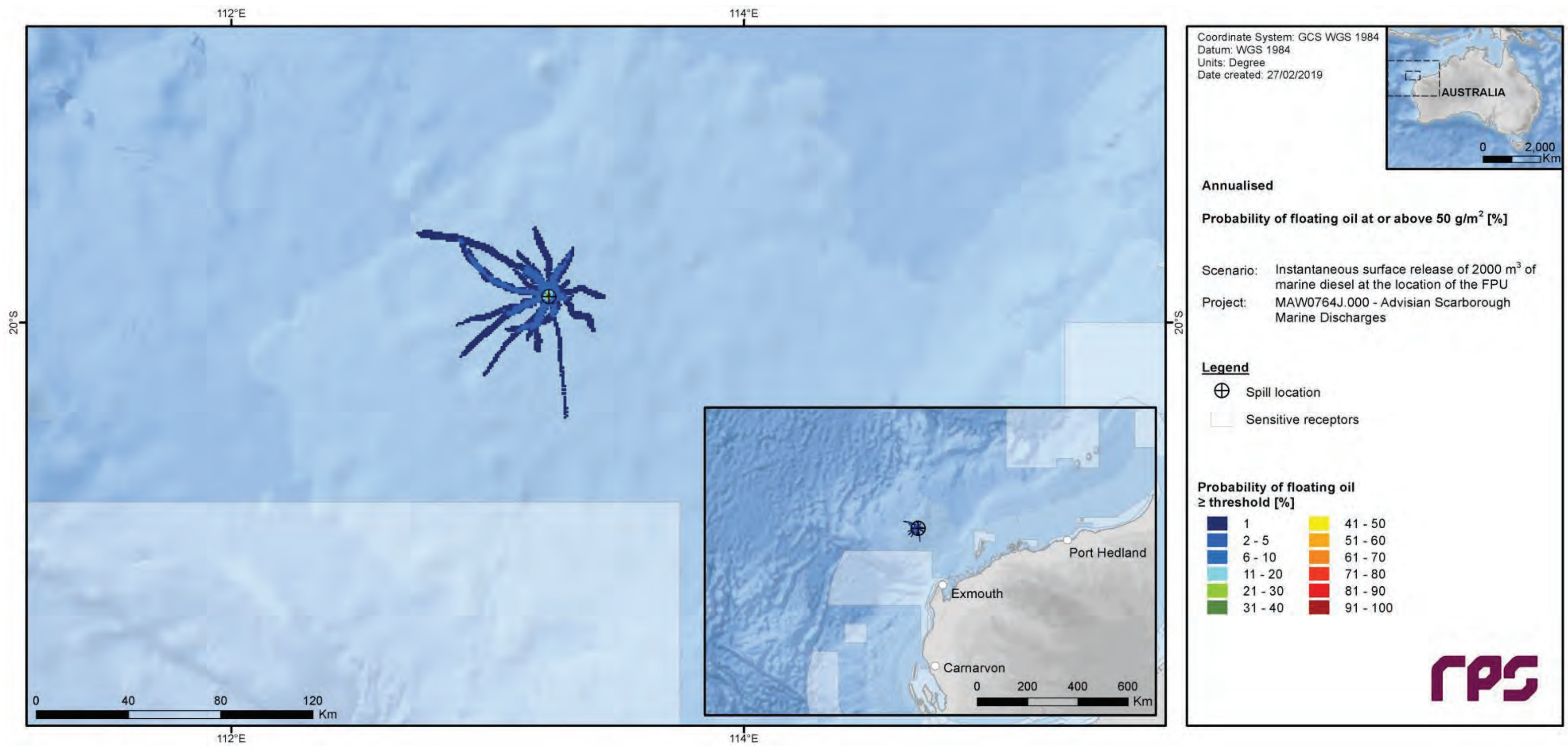



**Figure 3.48 Predicted annualised probability of floating oil concentrations at or above 50 g/m$^2$ resulting from an instantaneous surface release of marine diesel after a vessel collision at the FPU location.**

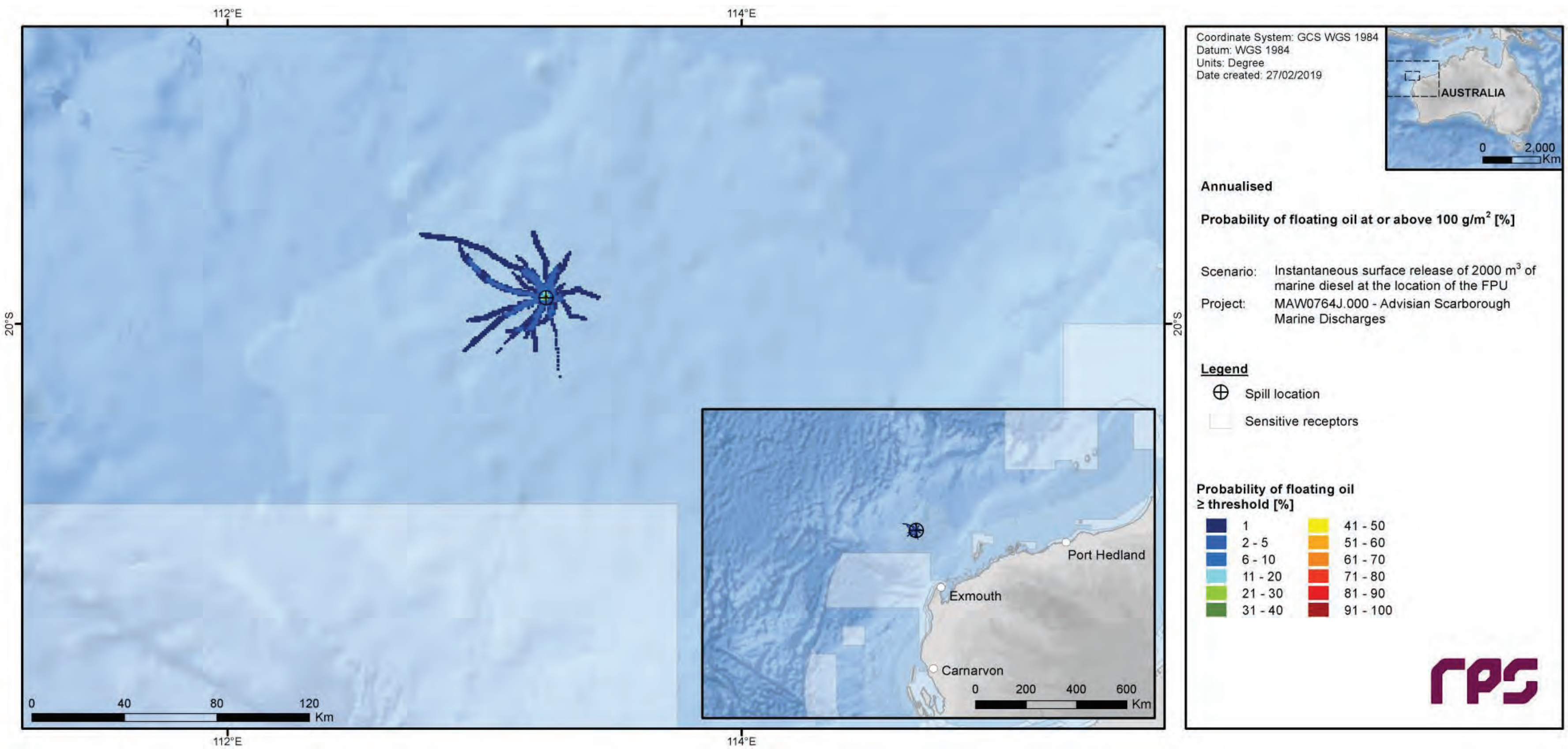



**Figure 3.49 Predicted annualised probability of floating oil concentrations at or above 100 g/m$^2$ resulting from an instantaneous surface release of marine diesel after a vessel collision at the FPU location.**

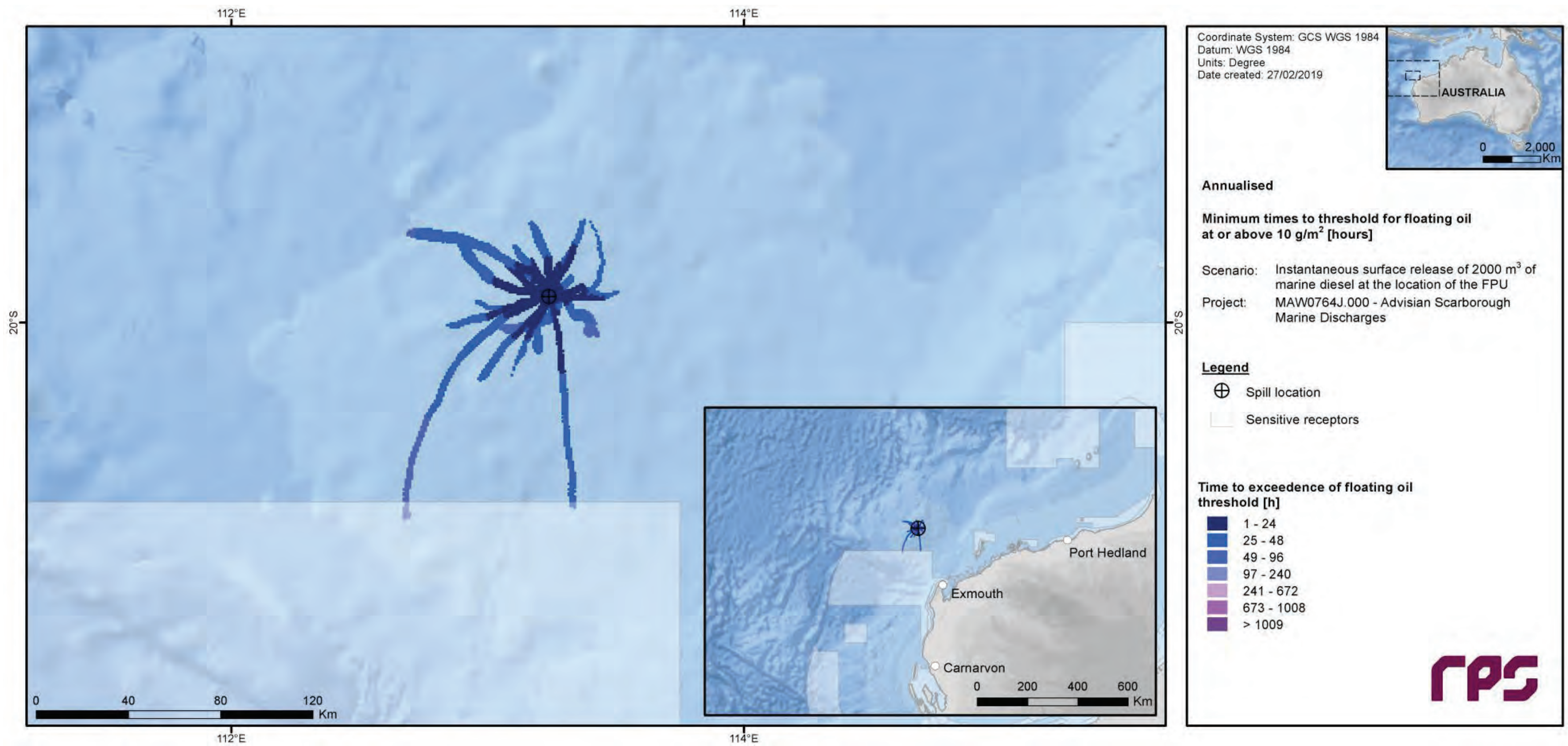



**Figure 3.50 Predicted annualised minimum times to contact by floating oil concentrations at or above 10 g/m$^2$ resulting from an instantaneous surface release of marine diesel after a vessel collision at the FPU location.**

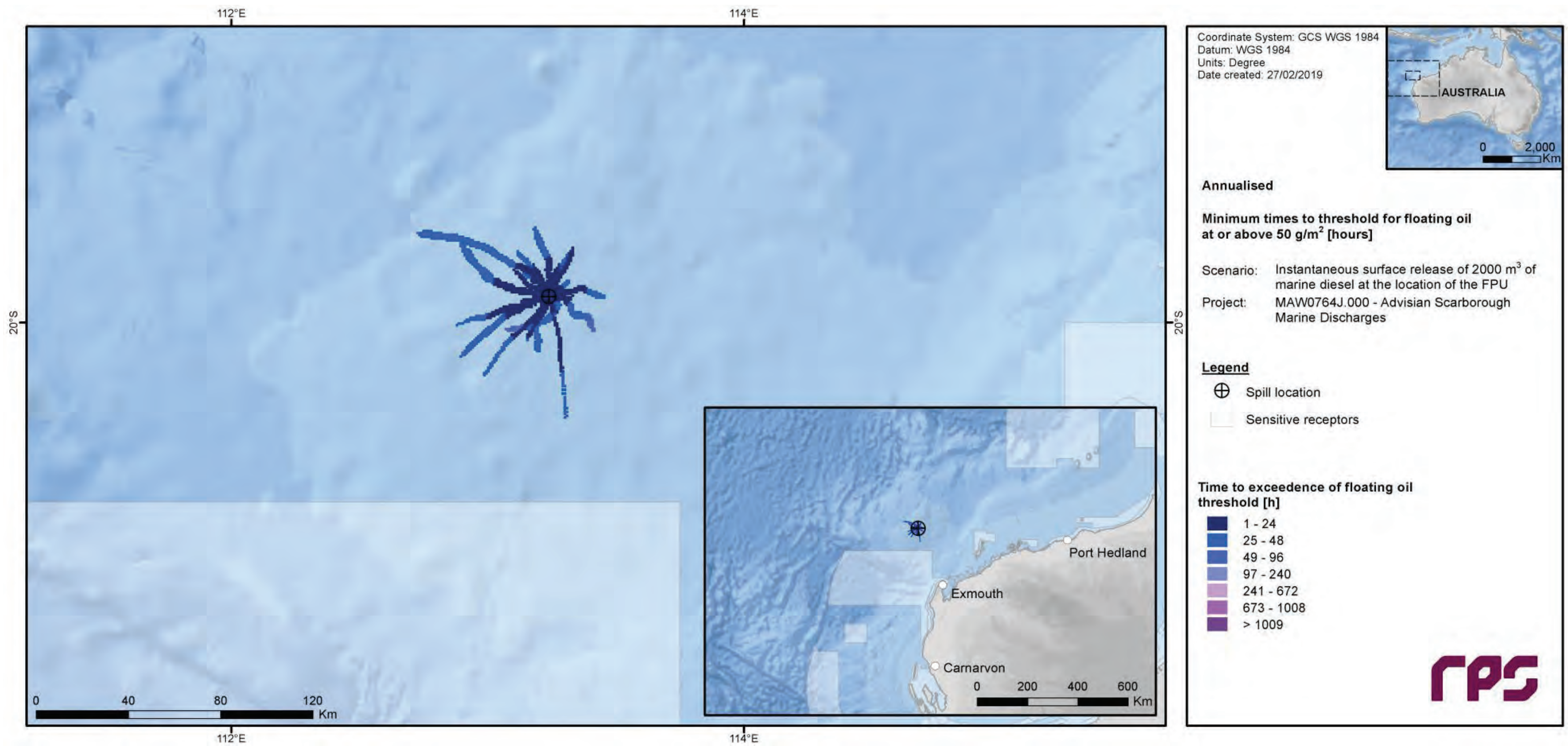



**Figure 3.51 Predicted annualised minimum times to contact by floating oil concentrations at or above 50 g/m$^2$ resulting from an instantaneous surface release of marine diesel after a vessel collision at the FPU location.**

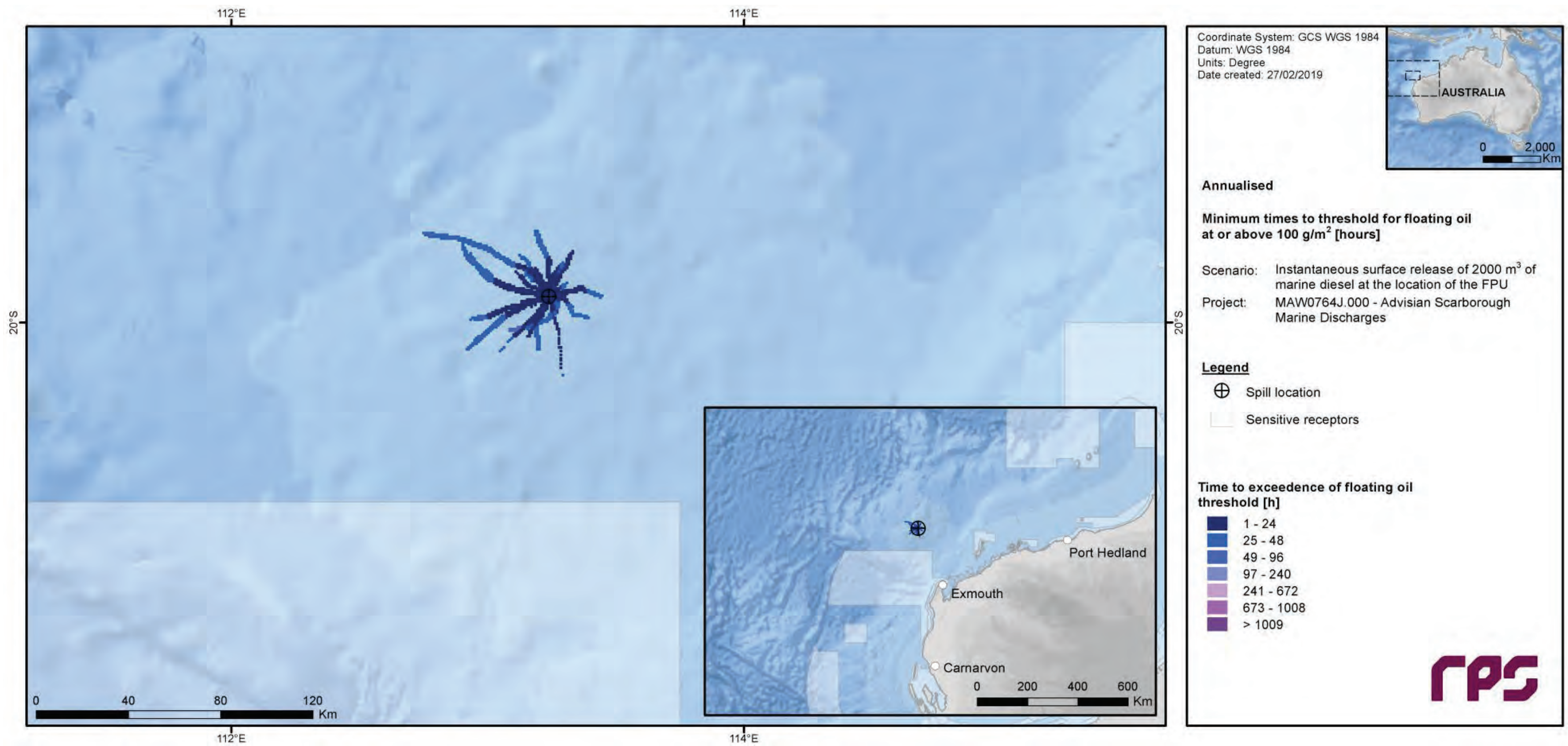



**Figure 3.52 Predicted annualised minimum times to contact by floating oil concentrations at or above 100 g/m$^2$ resulting from an instantaneous surface release of marine diesel after a vessel collision at the FPU location.**

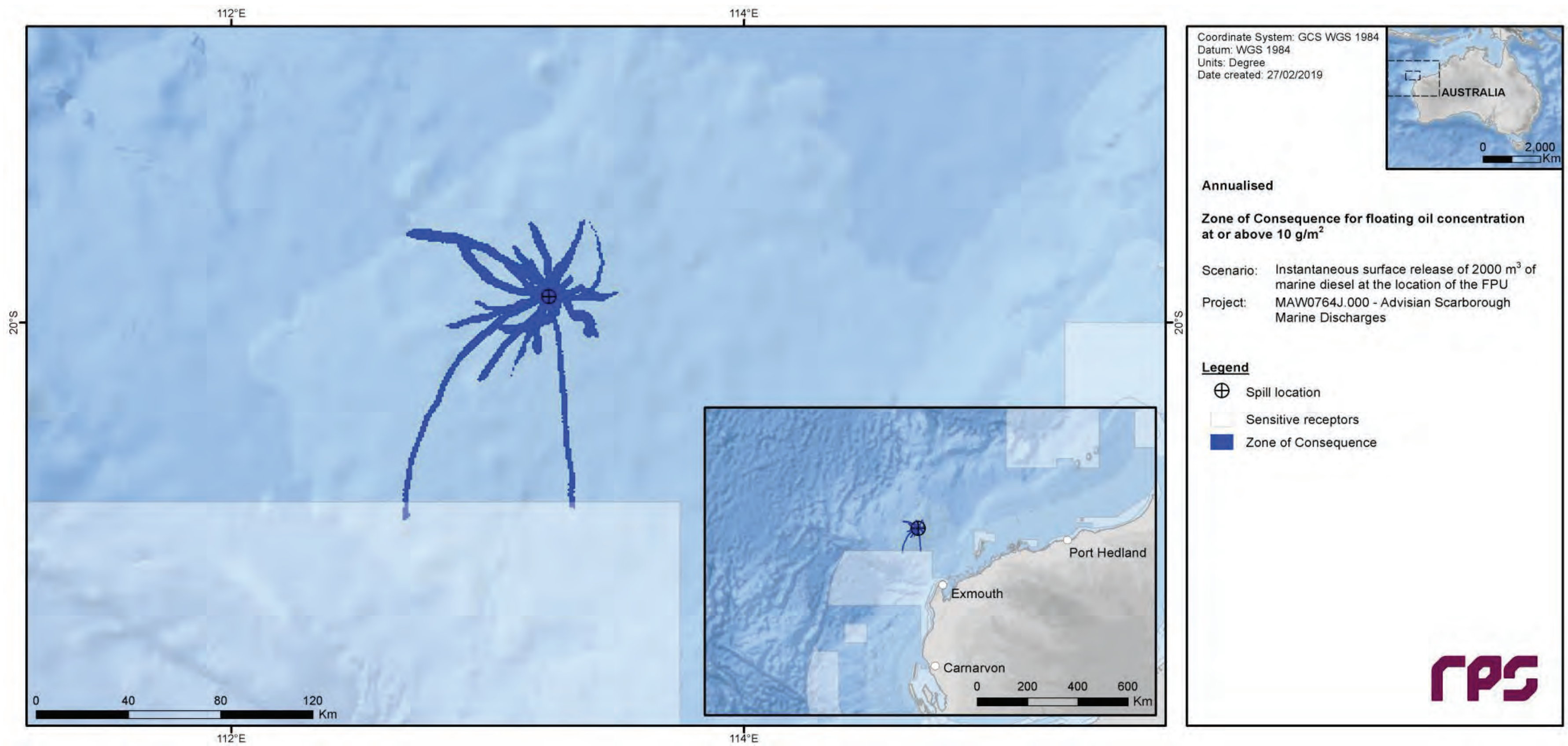



**Figure 3.53 Predicted annualised Zone of Consequence of floating oil concentrations at or above 10 g/m$^2$ resulting from an instantaneous surface release of marine diesel after a vessel collision at the FPU location.**

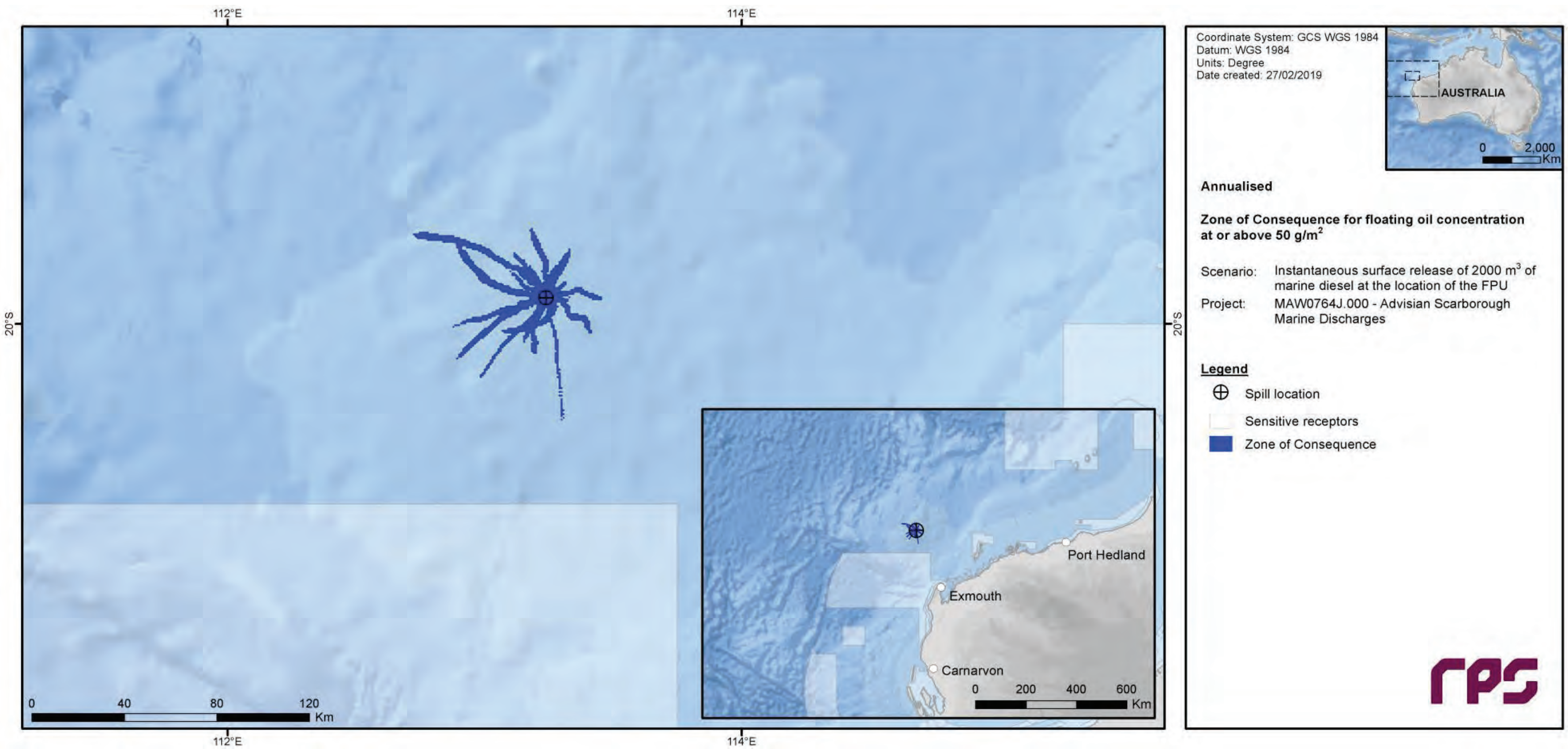



**Figure 3.54 Predicted annualised Zone of Consequence of floating oil concentrations at or above 50 g/m$^2$ resulting from an instantaneous surface release of marine diesel after a vessel collision at the FPU location.**

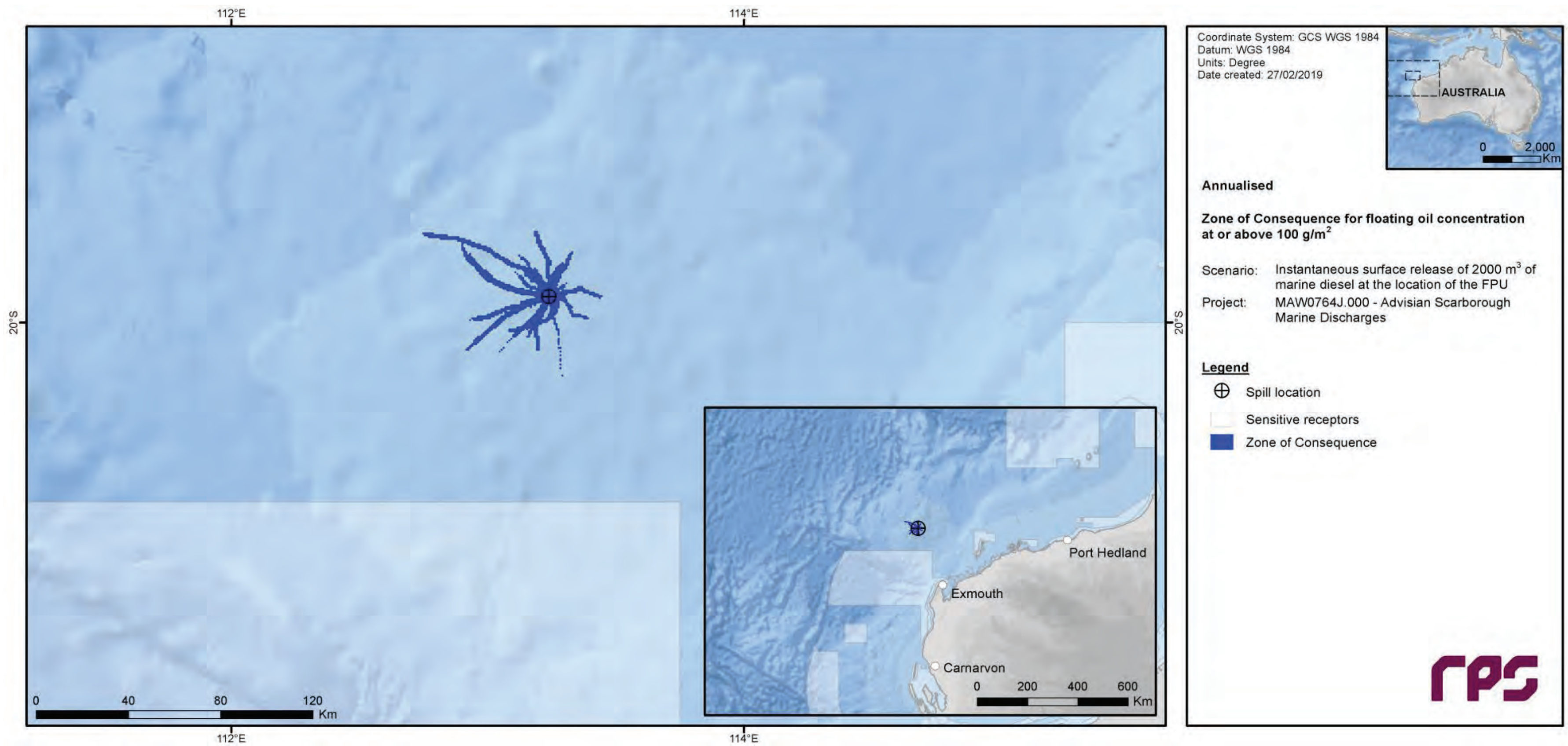



**Figure 3.55 Predicted annualised Zone of Consequence of floating oil concentrations at or above 100 g/m$^2$ resulting from an instantaneous surface release of marine diesel after a vessel collision at the FPU location.**

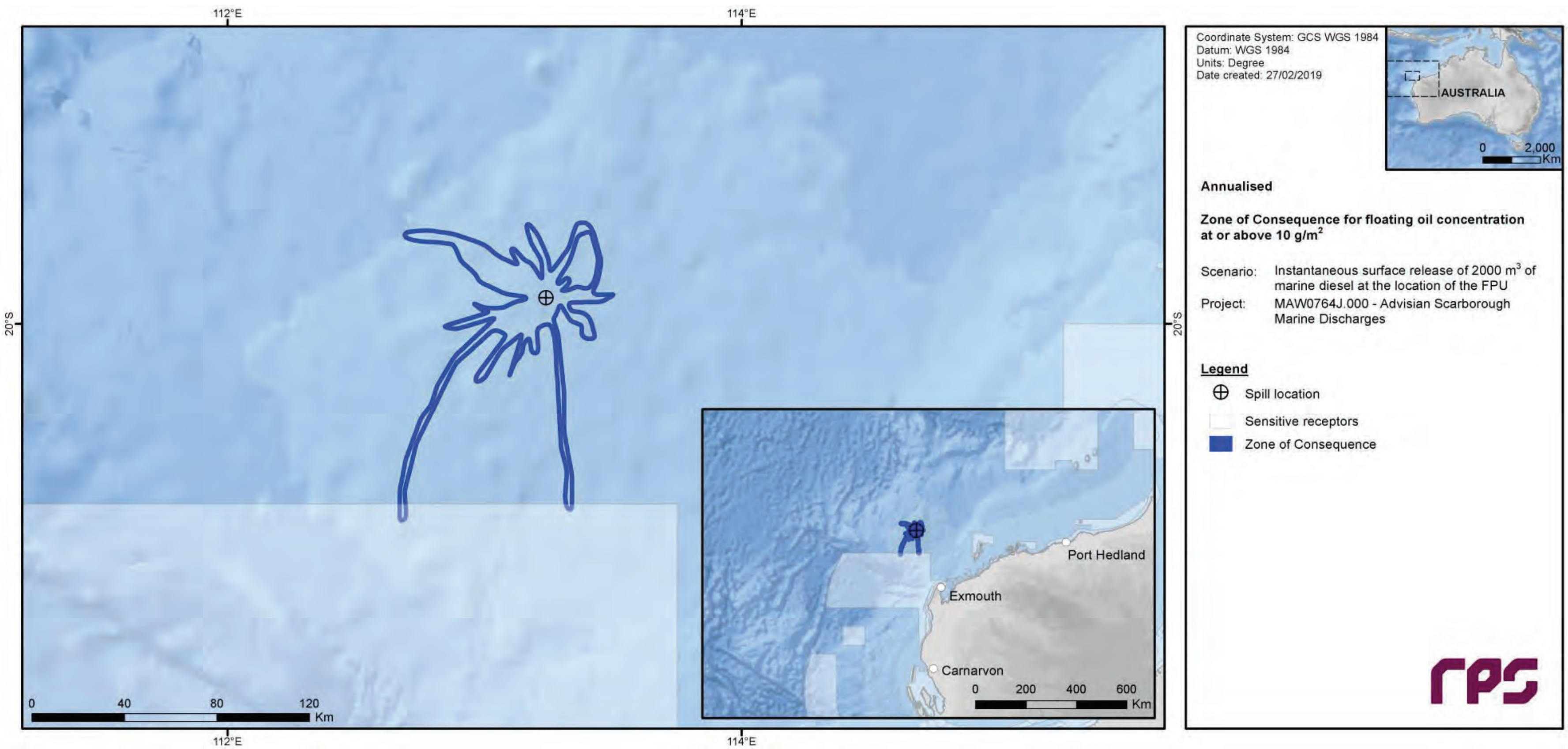



**Figure 3.56 Predicted annualised smoothed Zone of Consequence of floating oil concentrations at or above 10 g/m$^2$ resulting from an instantaneous surface release of marine diesel after a vessel collision at the FPU location.**

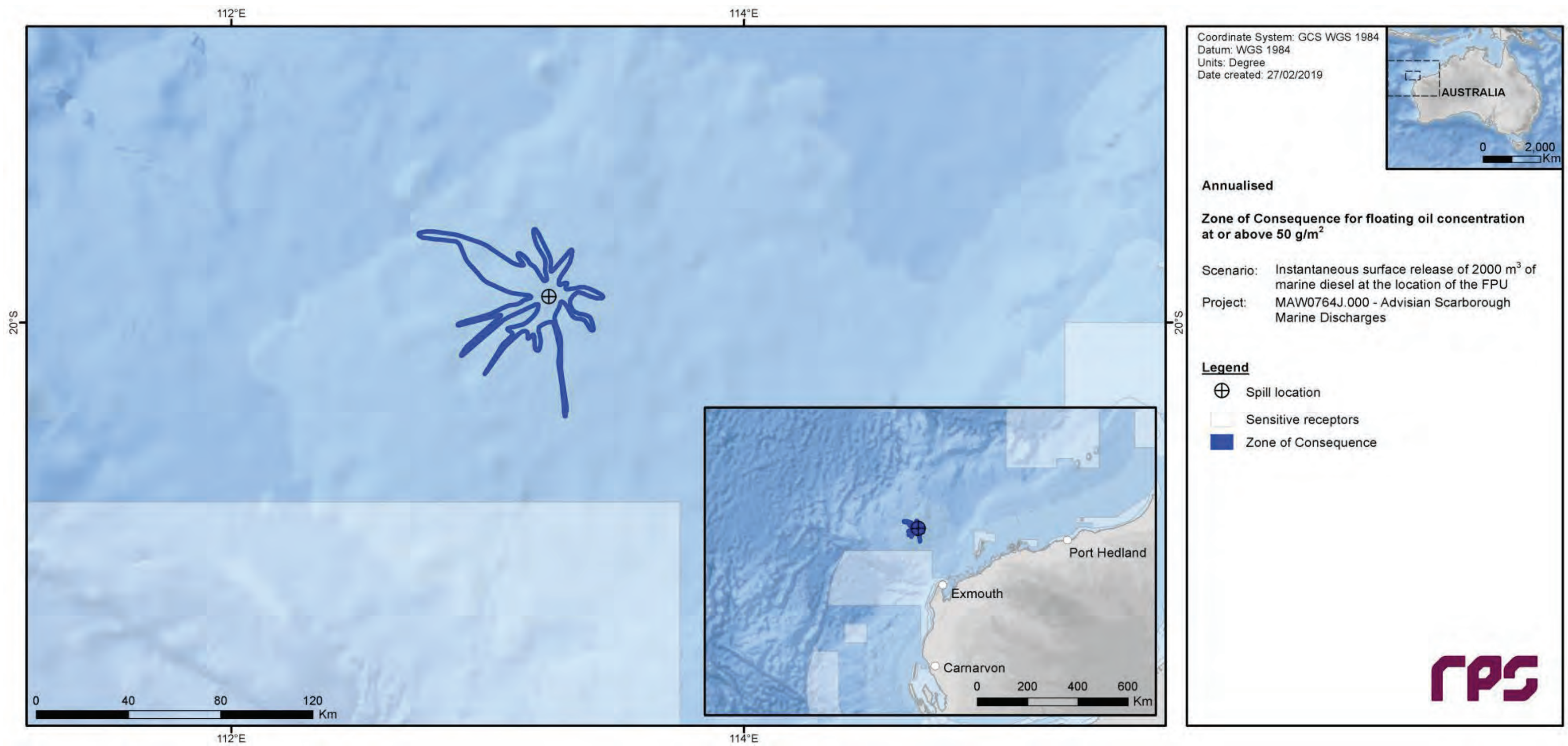



**Figure 3.57 Predicted annualised smoothed Zone of Consequence of floating oil concentrations at or above 50 g/m$^2$ resulting from an instantaneous surface release of marine diesel after a vessel collision at the FPU location.**

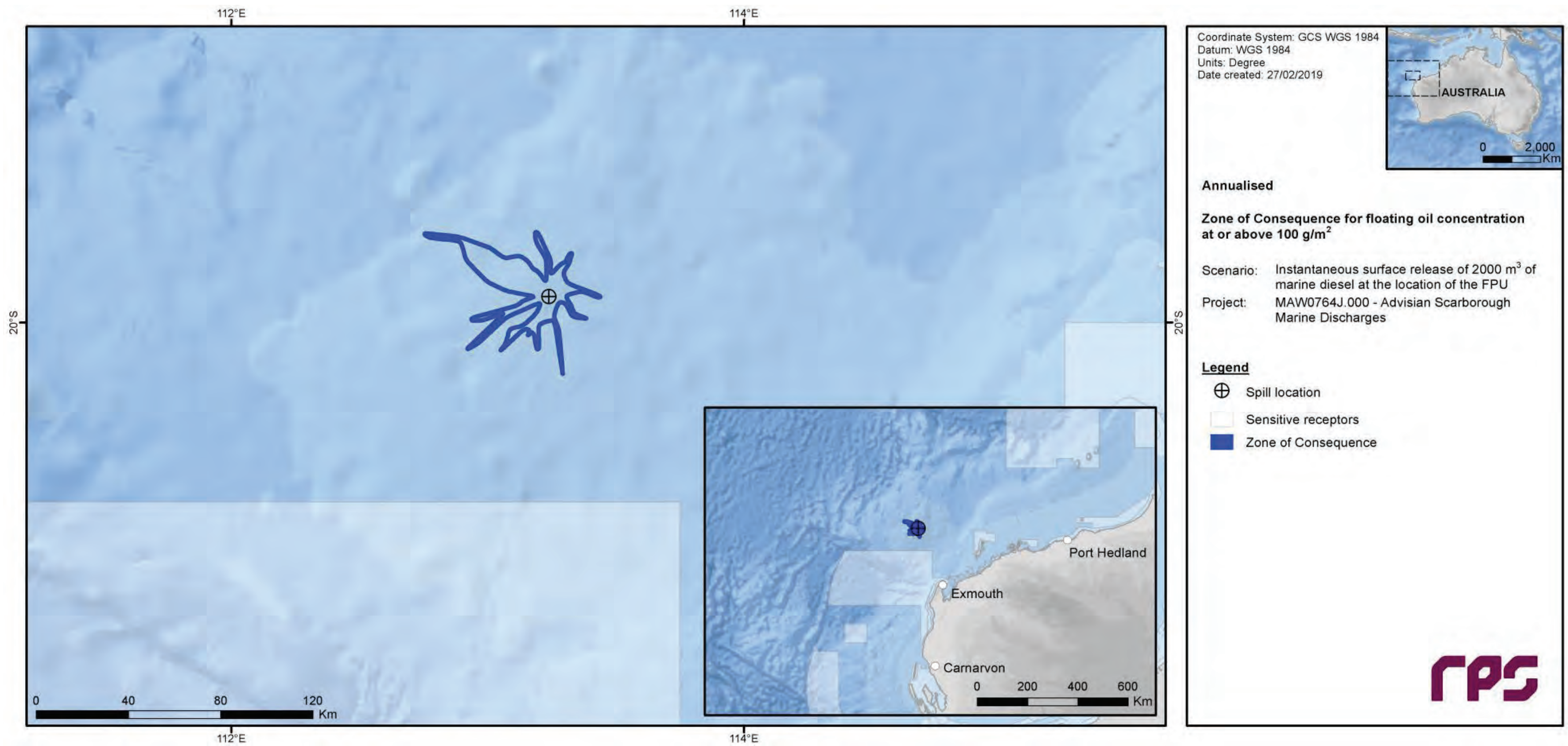



**Figure 3.58 Predicted annualised smoothed Zone of Consequence of floating oil concentrations at or above 100 g/m$^2$ resulting from an instantaneous surface release of marine diesel after a vessel collision at the FPU location.**

#### 3.4.2.2 Entrained Oil

**Table 3.8 Expected annualised entrained oil outcomes at sensitive receptors resulting from an instantaneous surface release of marine diesel after a vessel collision at the FPU location.**

| Receptor | Probability (%) of entrained oil concentration ≥500 ppb | Minimum time to receptor (hours) for entrained oil at ≥500 ppb | Maximum entrained oil concentration (ppb) averaged over all replicate simulations | Maximum entrained oil concentration (ppb), at any depth, in the worst replicate simulation |
|---|---|---|---|---|
| Ningaloo Coast North WHA | <1 | NC | <1 | 52 |
| Ningaloo RUZ | <1 | NC | <1 | 52 |
| Abrolhos Islands MP | <1 | NC | 2 | 167 |
| Carnarvon Canyon MP | <1 | NC | 3 | 196 |
| Gascoyne MP | 8 | 62 | 185 | 7,236 |

NC: No contact to receptor predicted for specified threshold.

* Probabilities and maximum concentrations calculated at depth of submerged feature.

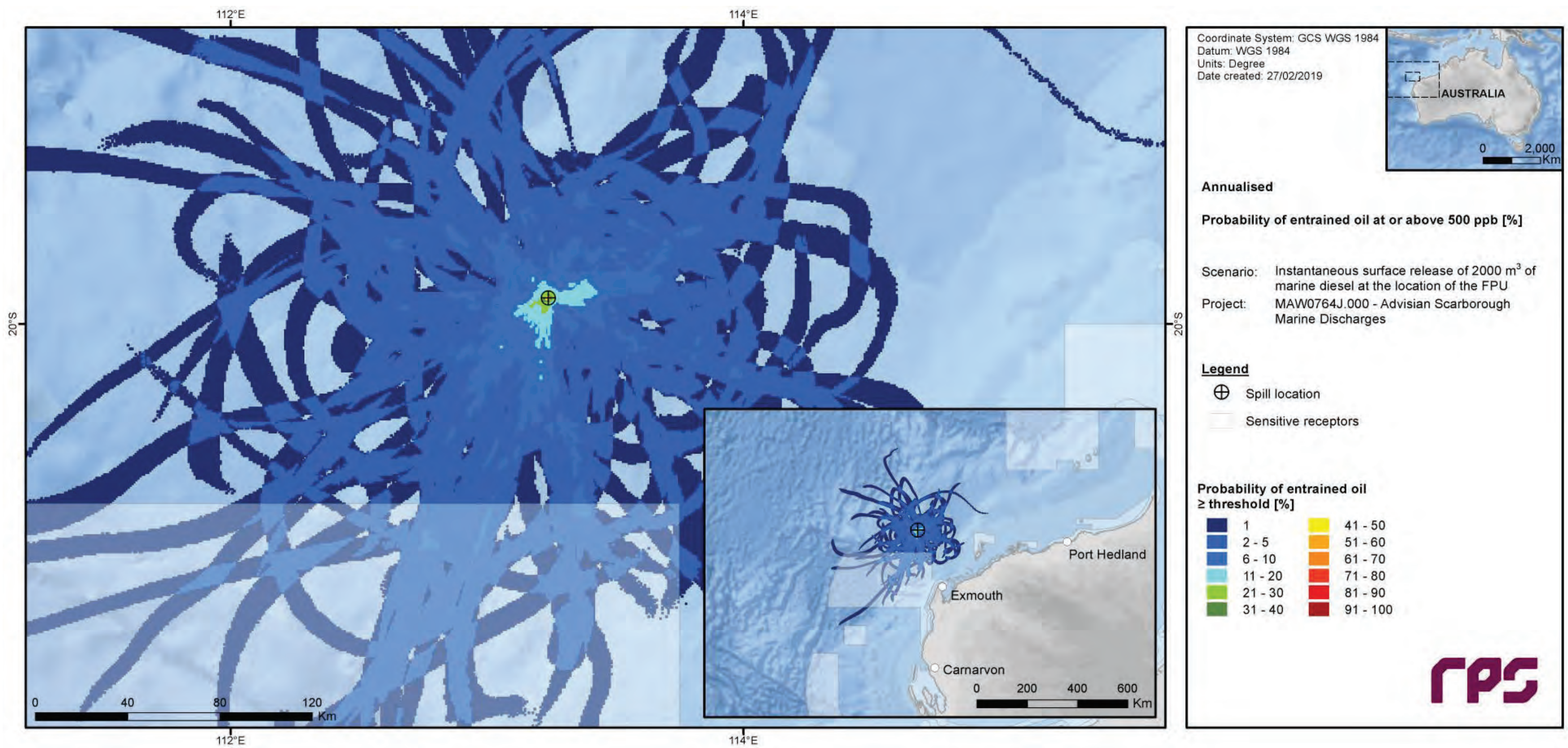



**Figure 3.59 Predicted annualised probability of entrained oil concentrations at or above 500 ppb resulting from an instantaneous surface release of marine diesel after a vessel collision at the FPU location.**

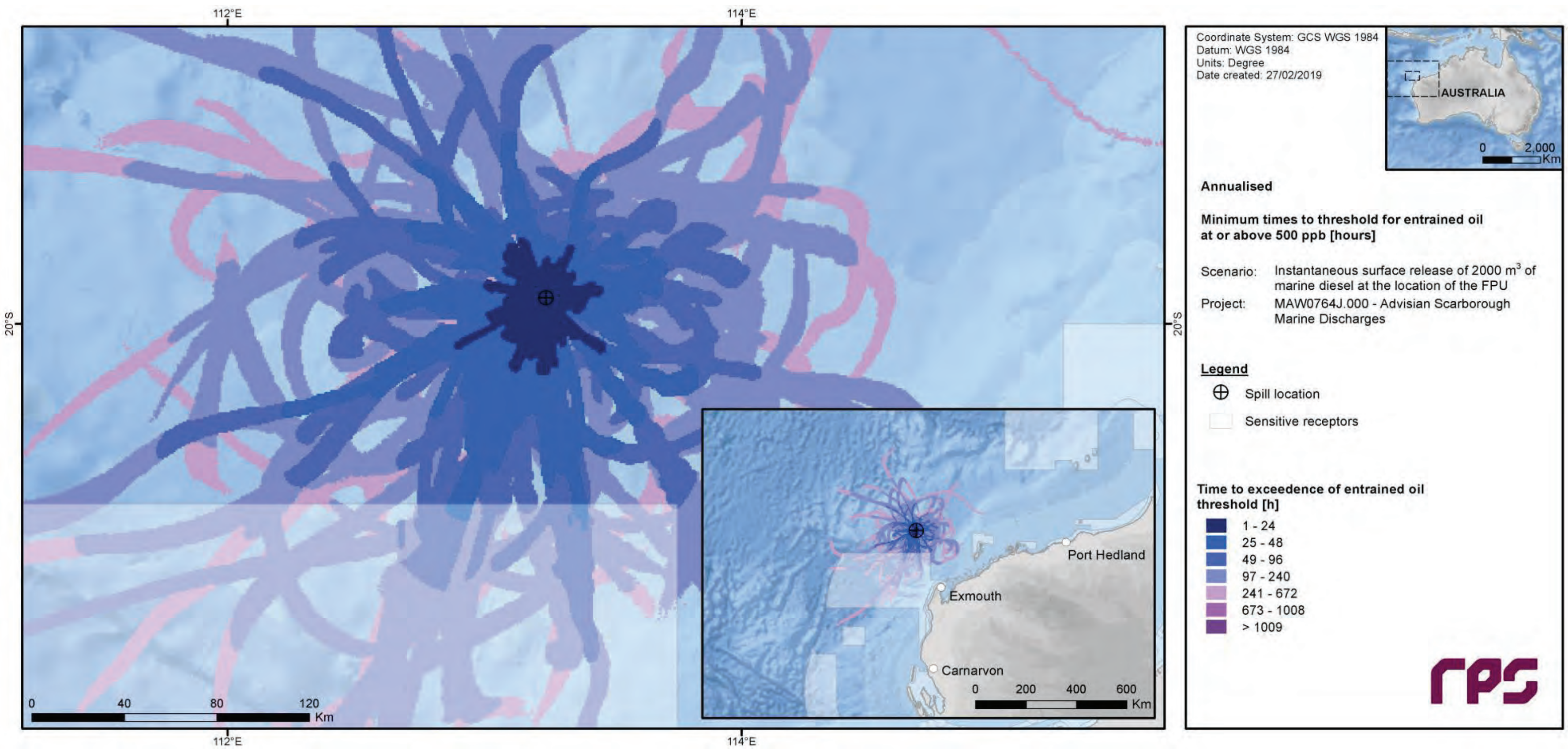



**Figure 3.60 Predicted annualised minimum times to contact by entrained oil concentrations at or above 500 ppb resulting from an instantaneous surface release of marine diesel after a vessel collision at the FPU location.**

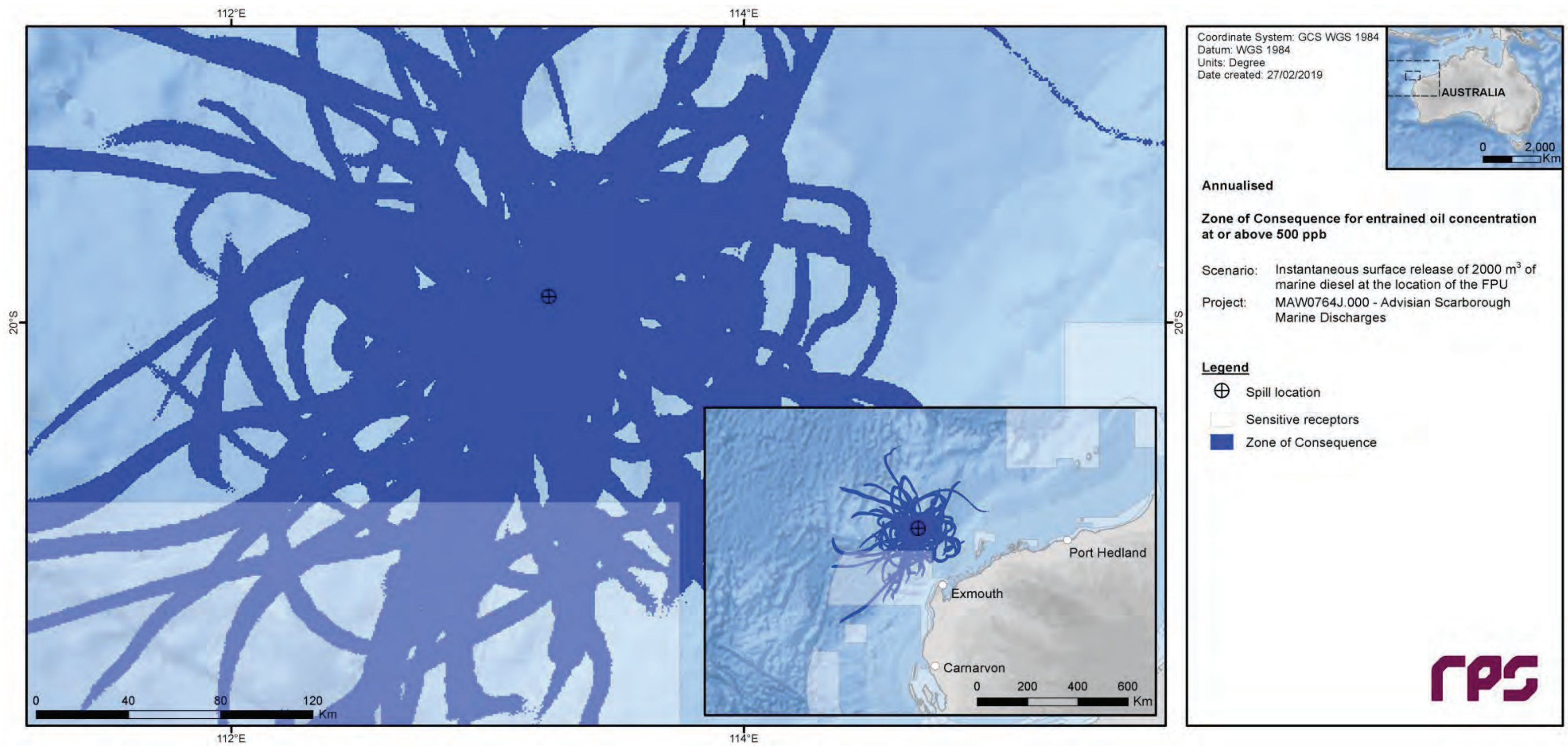



**Figure 3.61 Predicted annualised Zone of Consequence of entrained oil concentrations at or above 500 ppb resulting from an instantaneous surface release of marine diesel after a vessel collision at the FPU location.**

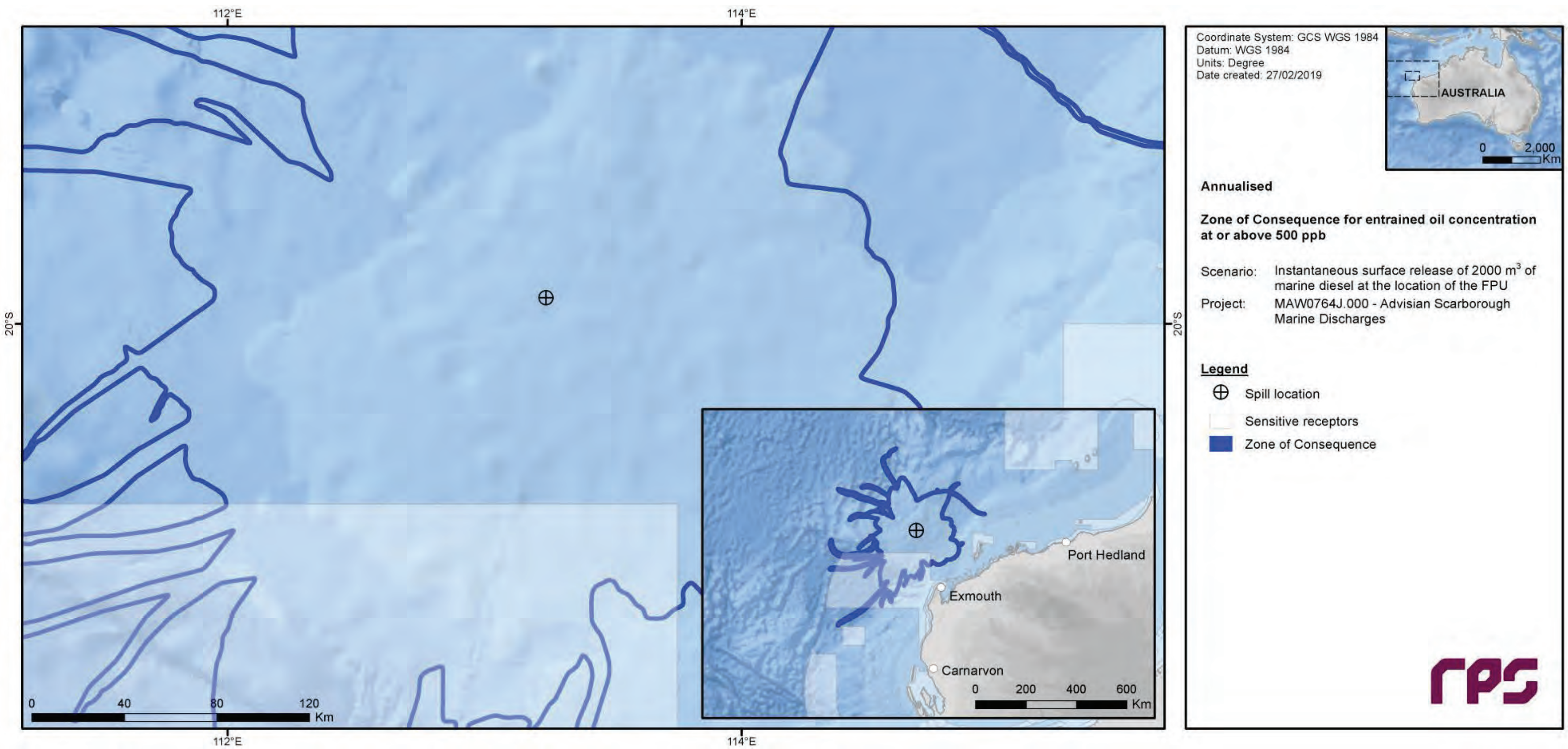



**Figure 3.62 Predicted annualised smoothed Zone of Consequence of entrained oil concentrations at or above 500 ppb resulting from an instantaneous surface release of marine diesel after a vessel collision at the FPU location.**

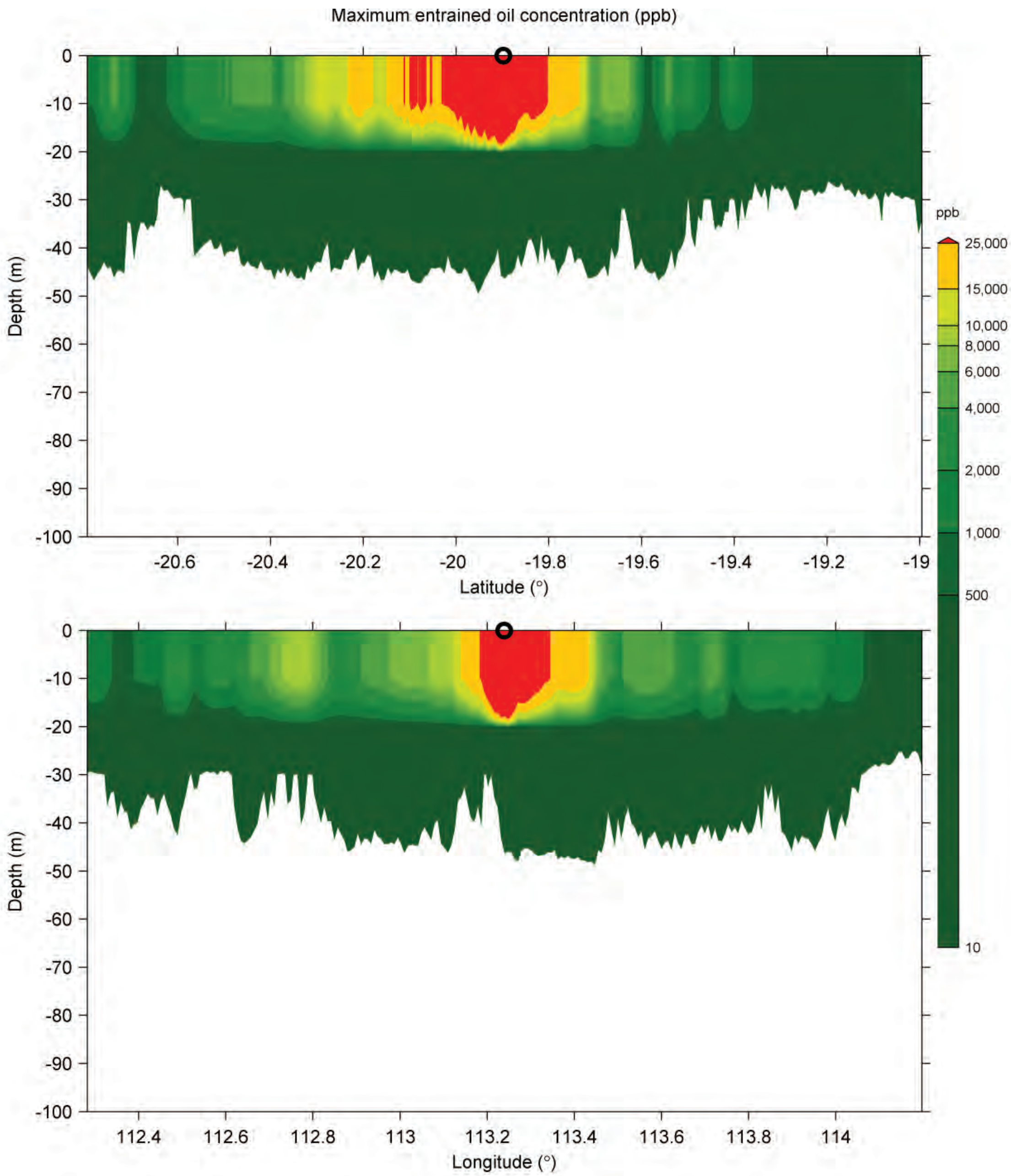



**Figure 3.63 Cross-section transects of predicted annualised maximum entrained oil concentrations for an instantaneous surface release of marine diesel after a vessel collision at the FPU location. Transect locations are shown in Figure 3.1.**

#### 3.4.2.3 Dissolved Aromatic Hydrocarbons

**Table 3.9 Expected annualised dissolved aromatic hydrocarbon outcomes at sensitive receptors resulting from an instantaneous surface release of marine diesel after a vessel collision at the FPU location.**

| Receptor | Probability (%) of dissolved aromatic hydrocarbon concentration ≥500 ppb | Maximum dissolved aromatic hydrocarbon concentration (ppb) averaged over all replicate simulations | Maximum dissolved aromatic hydrocarbon concentration (ppb), at any depth, in the worst replicate simulation |
|---|---|---|---|
| Ningaloo Coast North WHA | <1 | <1 | 2 |
| Ningaloo RUZ | <1 | <1 | 3 |
| Abrolhos Islands MP | <1 | <1 | <1 |
| Carnarvon Canyon MP | <1 | <1 | 6 |
| Gascoyne MP | <1 | 6 | 462 |

NC: No contact to receptor predicted for specified threshold.

* Probabilities and maximum concentrations calculated at depth of submerged feature.

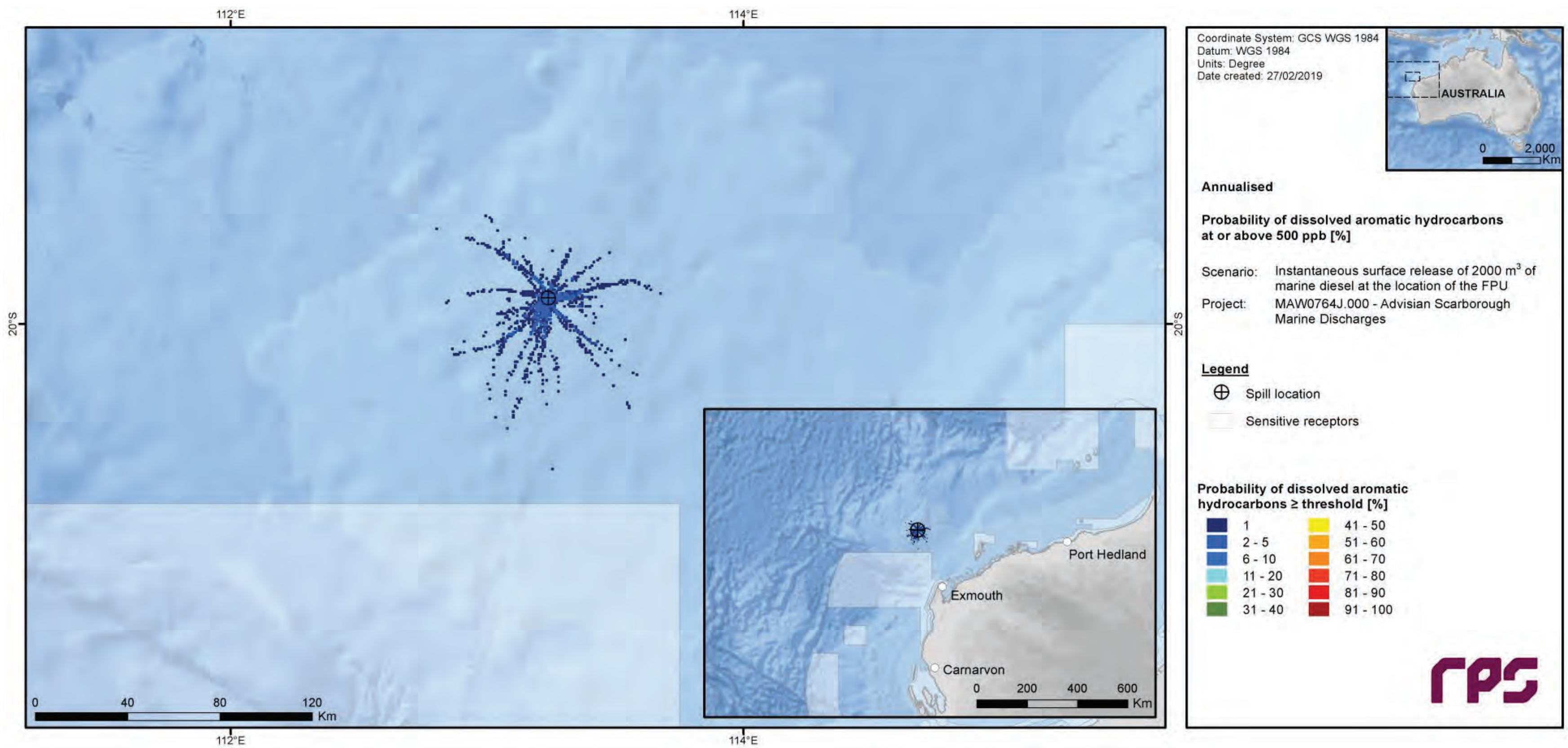



**Figure 3.64 Predicted annualised probability of dissolved aromatic hydrocarbon concentrations at or above 500 ppb resulting from an instantaneous surface release of marine diesel after a vessel collision at the FPU location.**

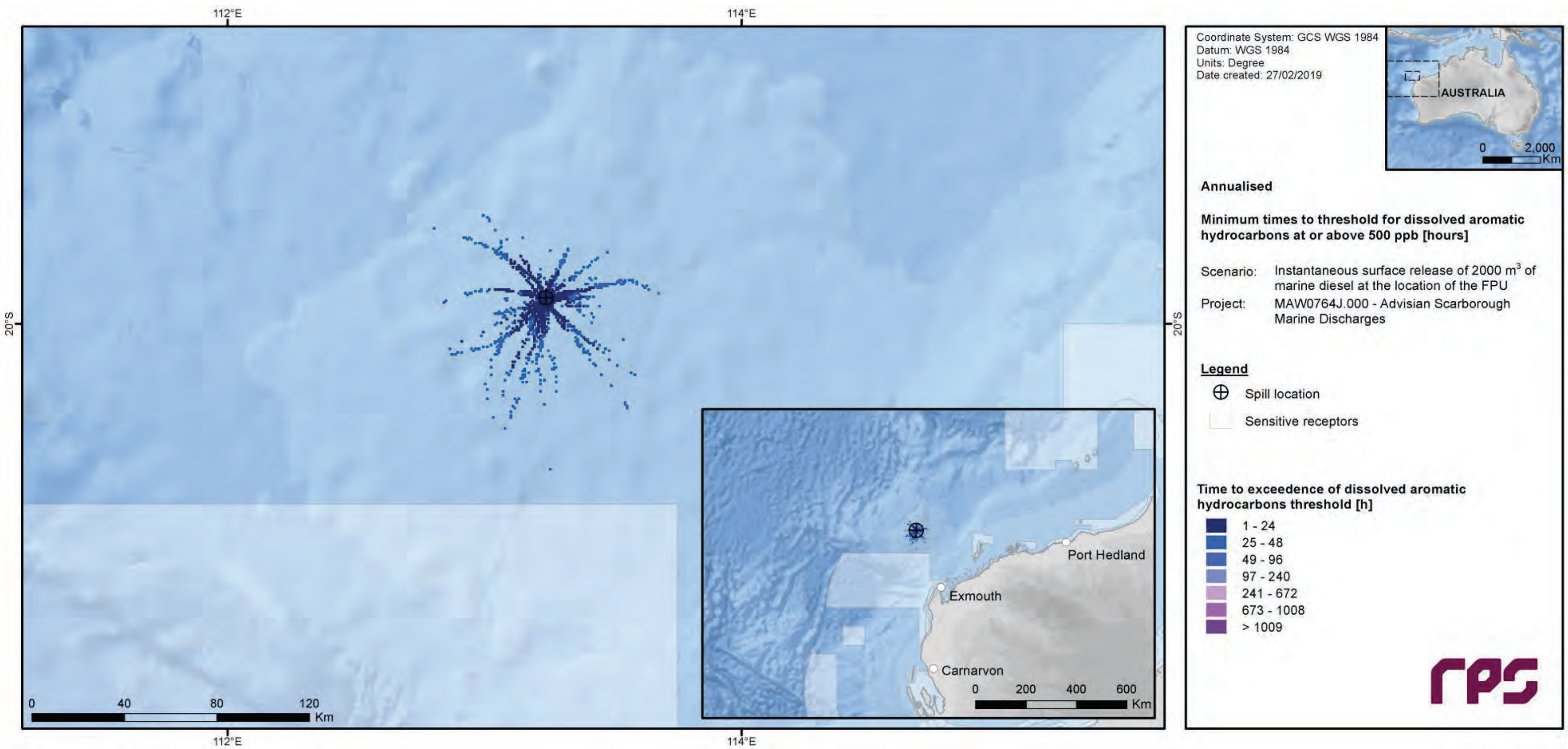



**Figure 3.65 Predicted annualised minimum times to contact by dissolved aromatic hydrocarbon concentrations at or above 500 ppb resulting from an instantaneous surface release of marine diesel after a vessel collision at the FPU location.**

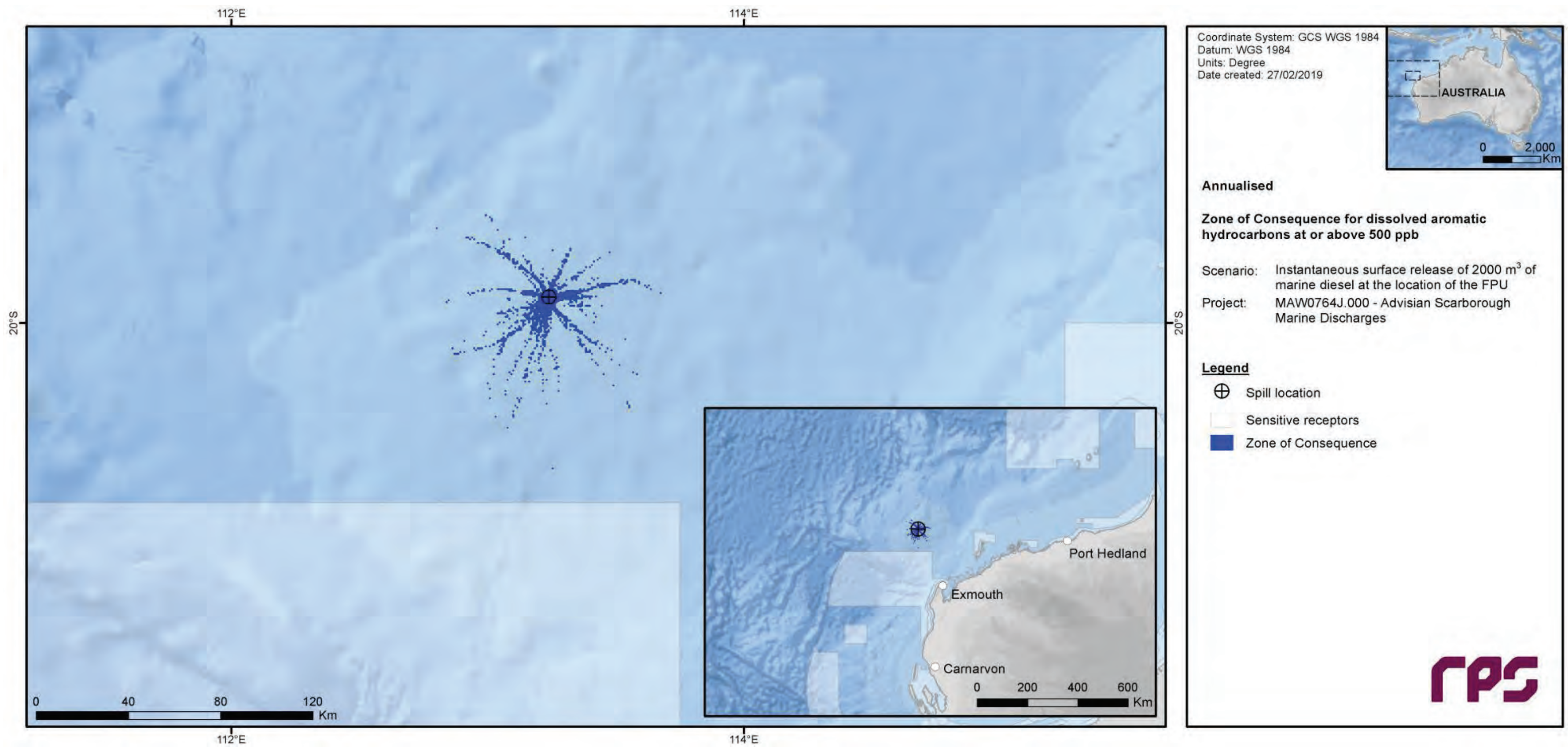



**Figure 3.66** **Predicted annualised Zone of Consequence of dissolved aromatic hydrocarbon concentrations at or above 500 ppb resulting from an instantaneous surface release of marine diesel after a vessel collision at the FPU location.**

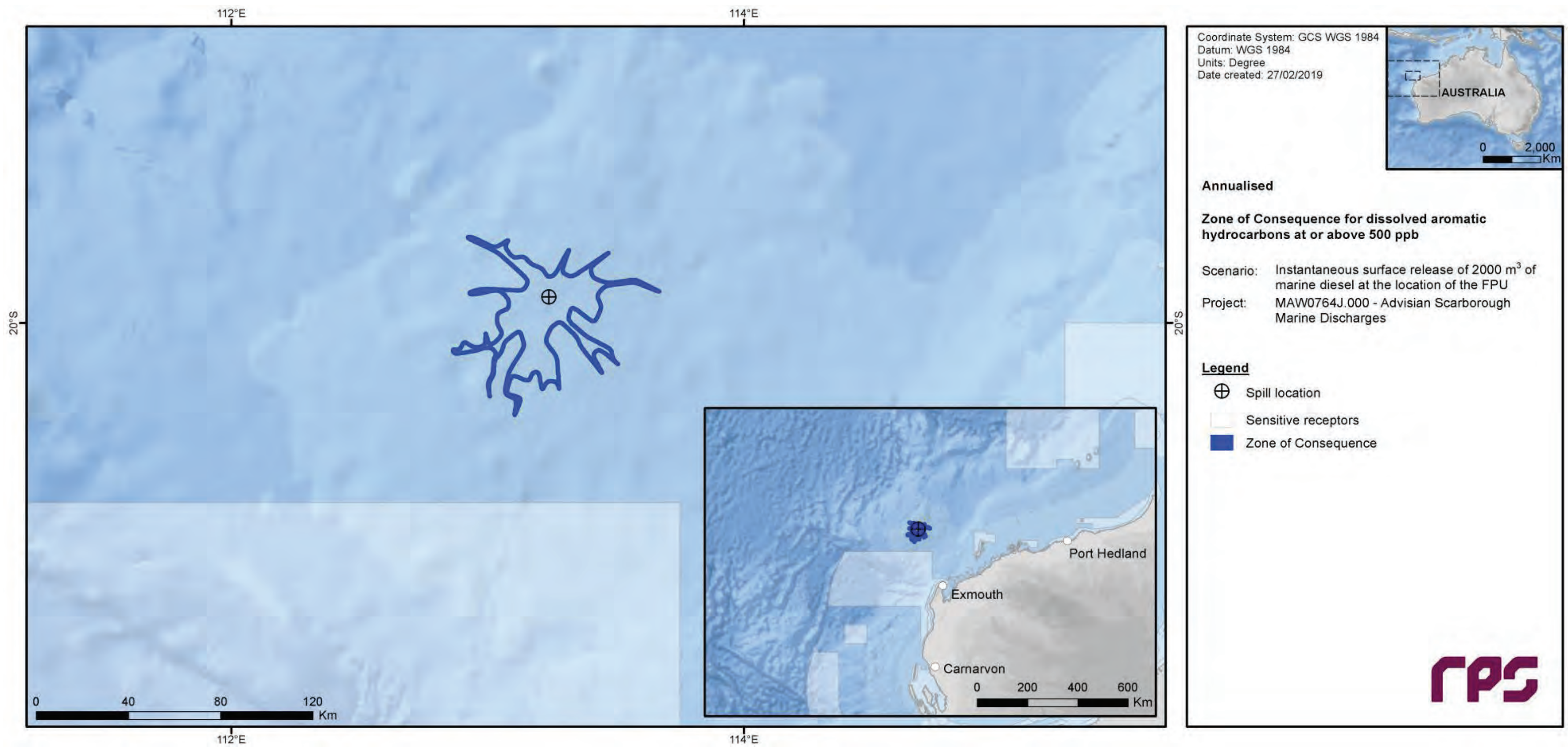



**Figure 3.67 Predicted annualised smoothed Zone of Consequence of dissolved aromatic hydrocarbon concentrations at or above 500 ppb resulting from an instantaneous surface release of marine diesel after a vessel collision at the FPU location.**

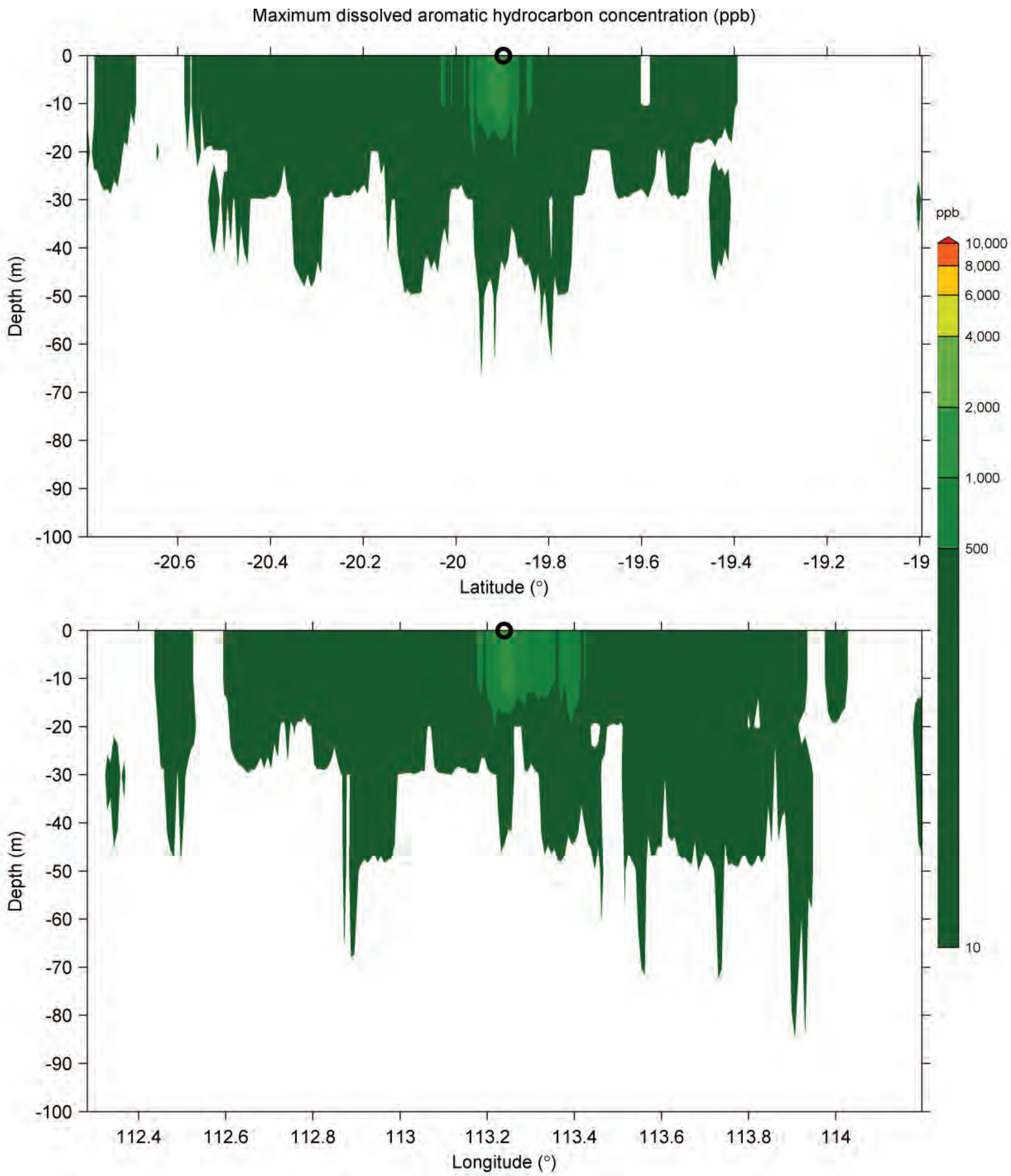



**Figure 3.68 Cross-section transects of predicted annualised maximum dissolved aromatic hydrocarbon concentrations for an instantaneous surface release of marine diesel after a vessel collision at the FPU location. Transect locations are shown in Figure 3.1.**

# 4 DETERMINISTIC ASSESSMENT RESULTS

## 4.1 Overview

For each scenario, deterministic model runs of interest were selected from the stochastic set of replicate simulations according to the following criteria:

- Maximum distance in a south-westerly direction from the release site reached by entrained oil (at a threshold of 500 ppb);
- Maximum total area covered by entrained oil (at a threshold of 500 ppb) over the course of a simulation.

A time series compilation of figures from each deterministic replicate simulation (i.e. a single spill event) for each scenario is presented in the following sections. Each of the figure compilations includes areal exposure at discrete time intervals during the simulation.

## 4.2 Scenario 1: Short-Term (Instantaneous) Surface Release of Marine Diesel after a Vessel Collision outside Mermaid Sound

### 4.2.1 Simulation with Maximal South-Westerly Extent of Entrained Oil at the 500 ppb Threshold

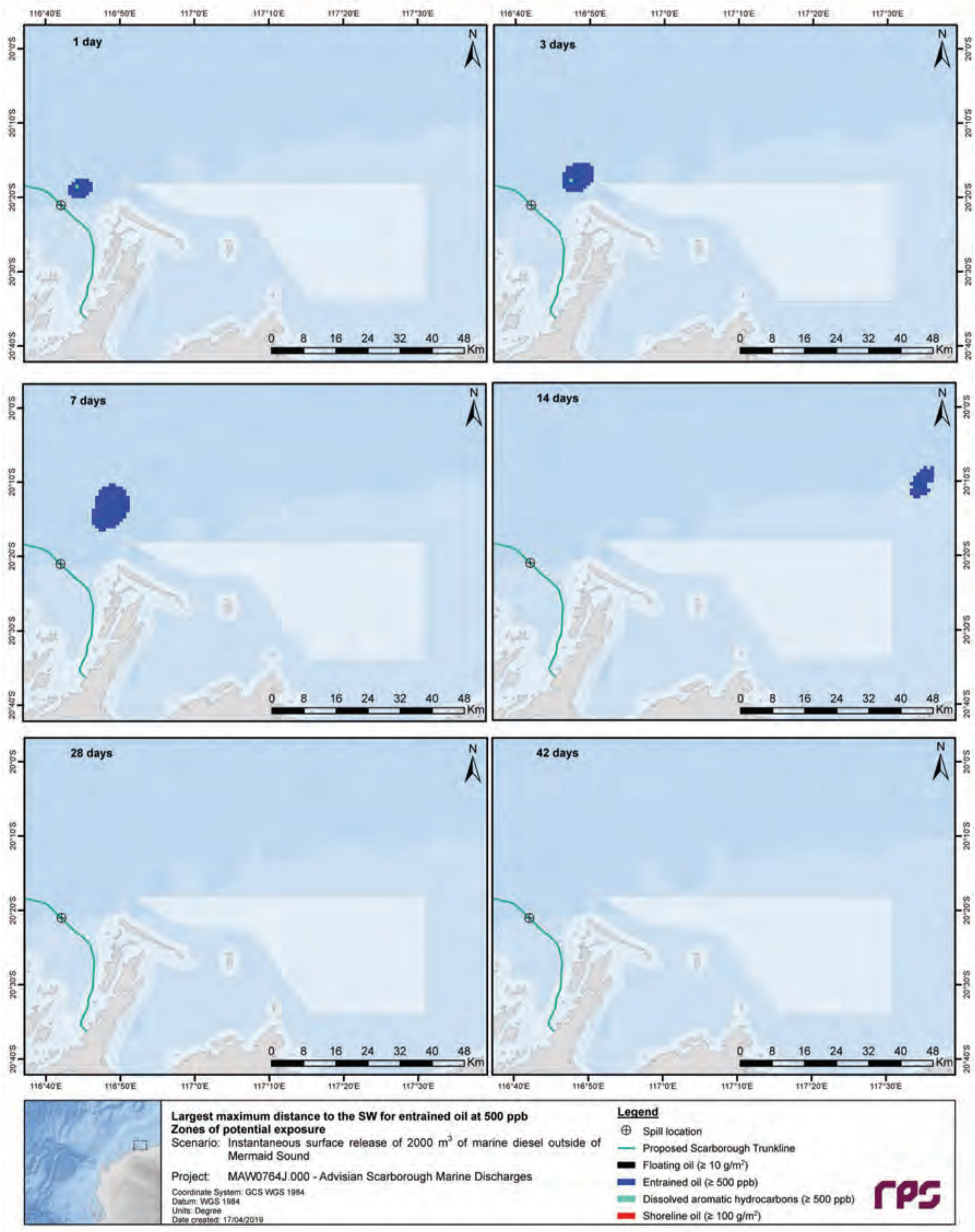



**Figure 4.1** **Time-varying areal extent of potential exposure at defined floating oil, entrained oil, dissolved aromatic hydrocarbon and shoreline oil threshold concentrations, resulting from an instantaneous surface release of marine diesel after a vessel collision outside Mermaid Sound, for the replicate simulation where entrained oil at the 500 ppb threshold is forecast to reach the greatest distance in a south-westerly direction from the release site.**

### 4.2.2 Simulation with Maximal Overall Swept Area of Entrained Oil at the 500 ppb Threshold

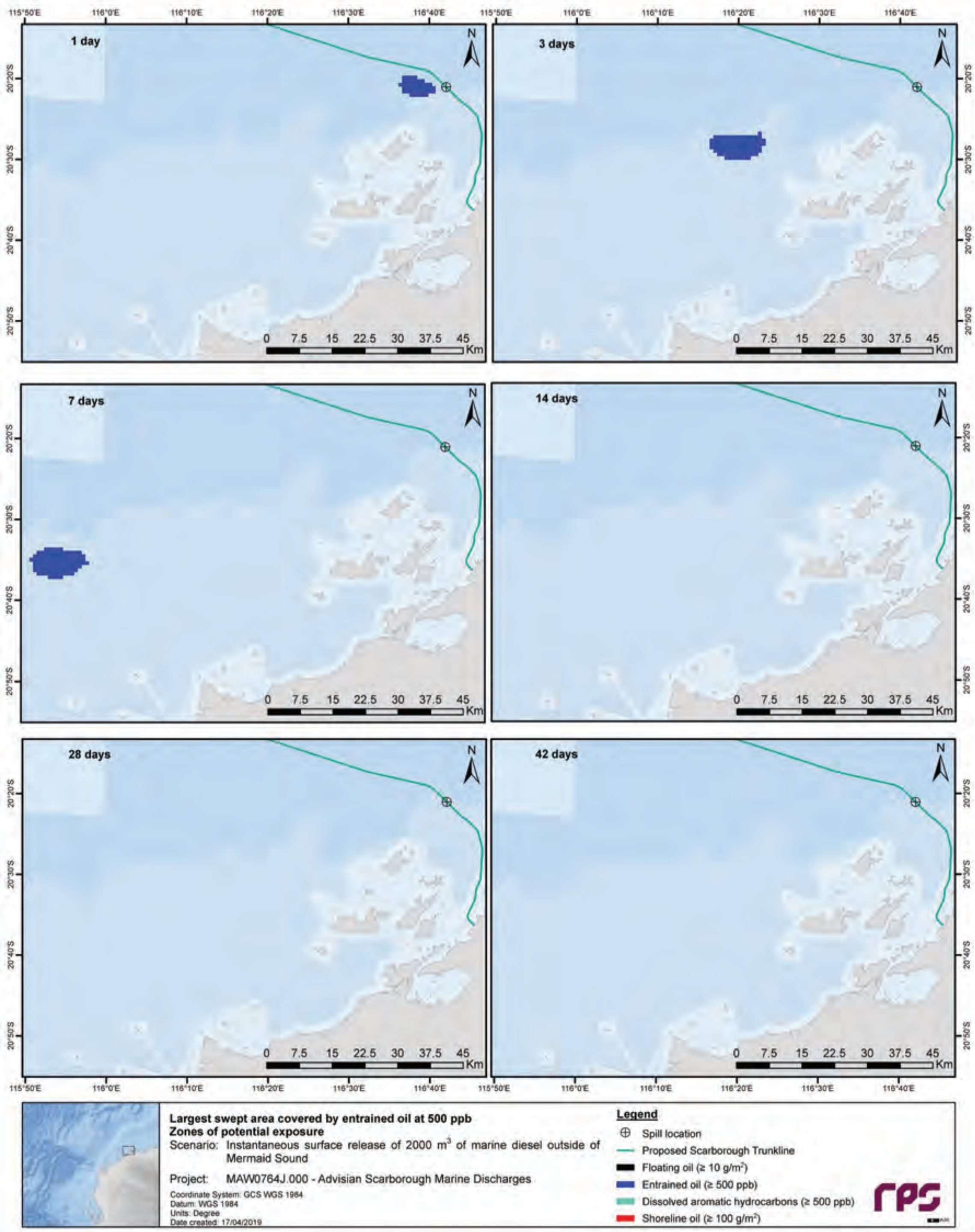



**Figure 4.2** Time-varying areal extent of potential exposure at defined floating oil, entrained oil, dissolved aromatic hydrocarbon and shoreline oil threshold concentrations, resulting from an instantaneous surface release of marine diesel after a vessel collision outside Mermaid Sound, for the replicate simulation where entrained oil at the 500 ppb threshold is forecast to cover the greatest total area over the course of a simulation.

## 4.3 Scenario 2: Short-Term (Instantaneous) Surface Release of Marine Diesel after a Vessel Collision within Montebello Marine Park

### 4.3.1 Simulation with Maximal South-Westerly Extent of Entrained Oil at the 500 ppb Threshold

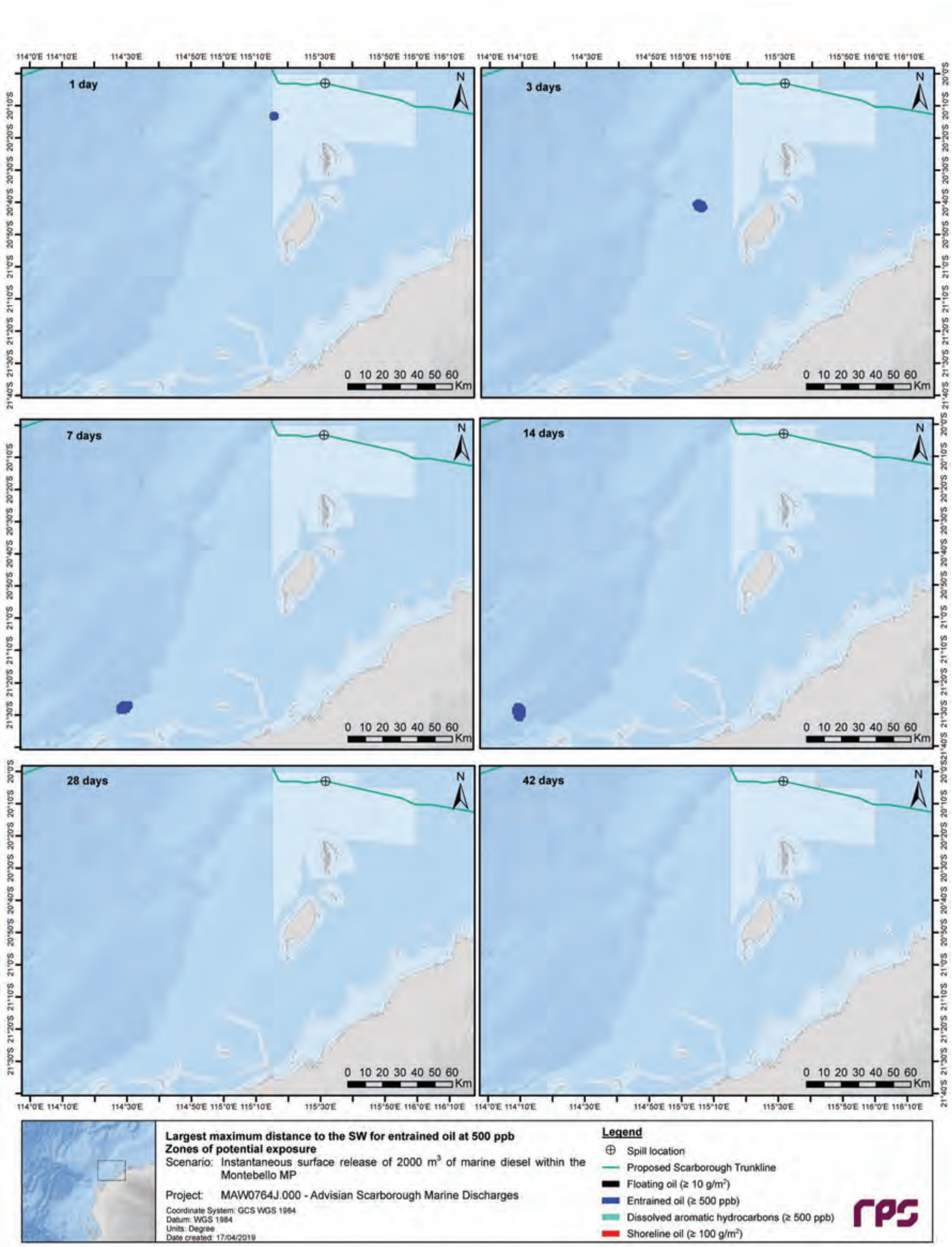



**Figure 4.3** **Time-varying areal extent of potential exposure at defined floating oil, entrained oil, dissolved aromatic hydrocarbon and shoreline oil threshold concentrations, resulting from an instantaneous surface release of marine diesel after a vessel collision within Montebello Marine Park, for the replicate simulation where entrained oil at the 500 ppb threshold is forecast to reach the greatest distance in a south-westerly direction from the release site.**

### 4.3.2 Simulation with Maximal Overall Swept Area of Entrained Oil at the 500 ppb Threshold

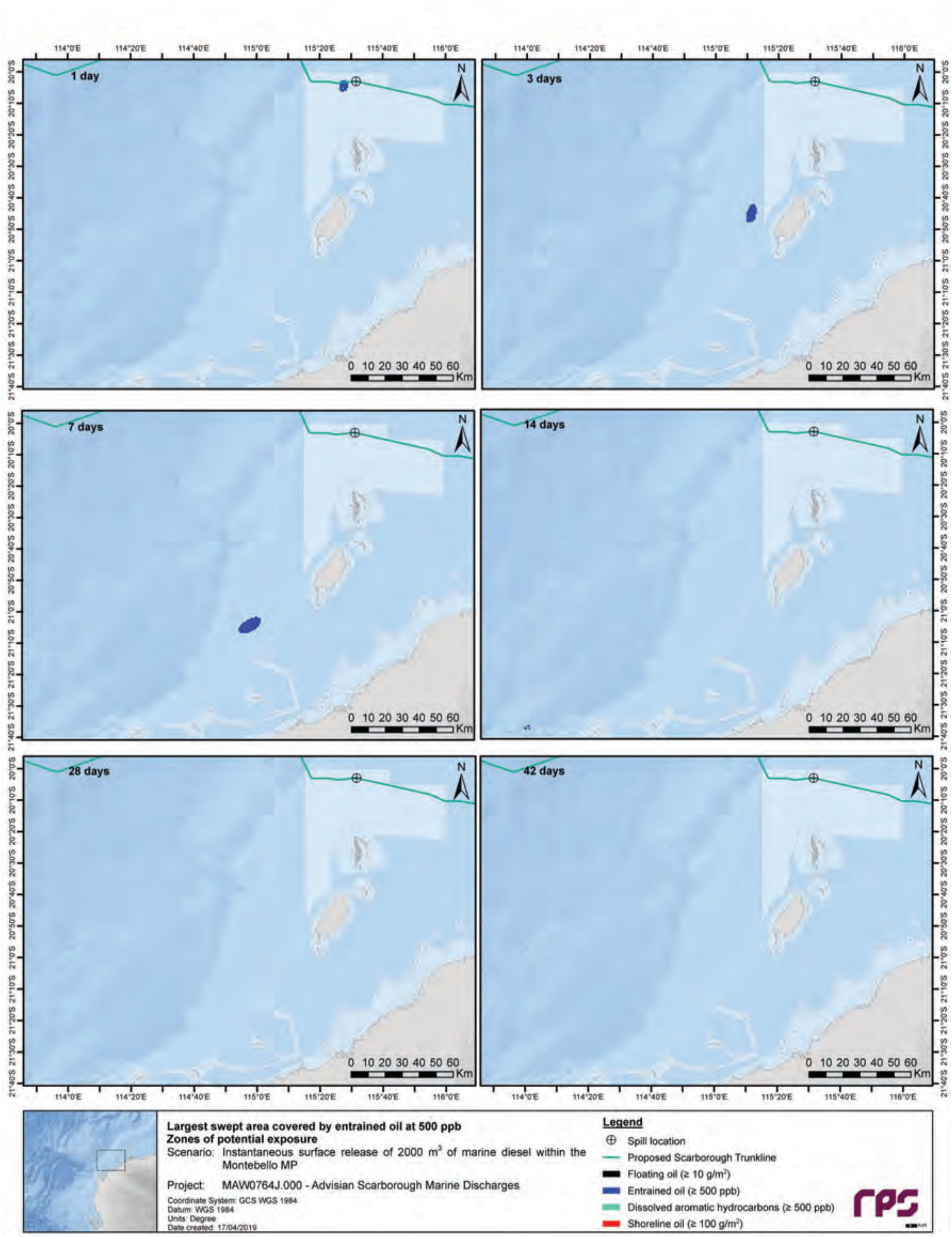



**Figure 4.4** **Time-varying areal extent of potential exposure at defined floating oil, entrained oil, dissolved aromatic hydrocarbon and shoreline oil threshold concentrations, resulting from an instantaneous surface release of marine diesel after a vessel collision within Montebello Marine Park, for the replicate simulation where entrained oil at the 500 ppb threshold is forecast to cover the greatest total area over the course of a simulation.**

## 4.4 Scenario 3: Short-Term (Instantaneous) Surface Release of Marine Diesel after a Vessel Collision at the FPU Location

### 4.4.1 Simulation with Maximal South-Westerly Extent of Entrained Oil at the 500 ppb Threshold

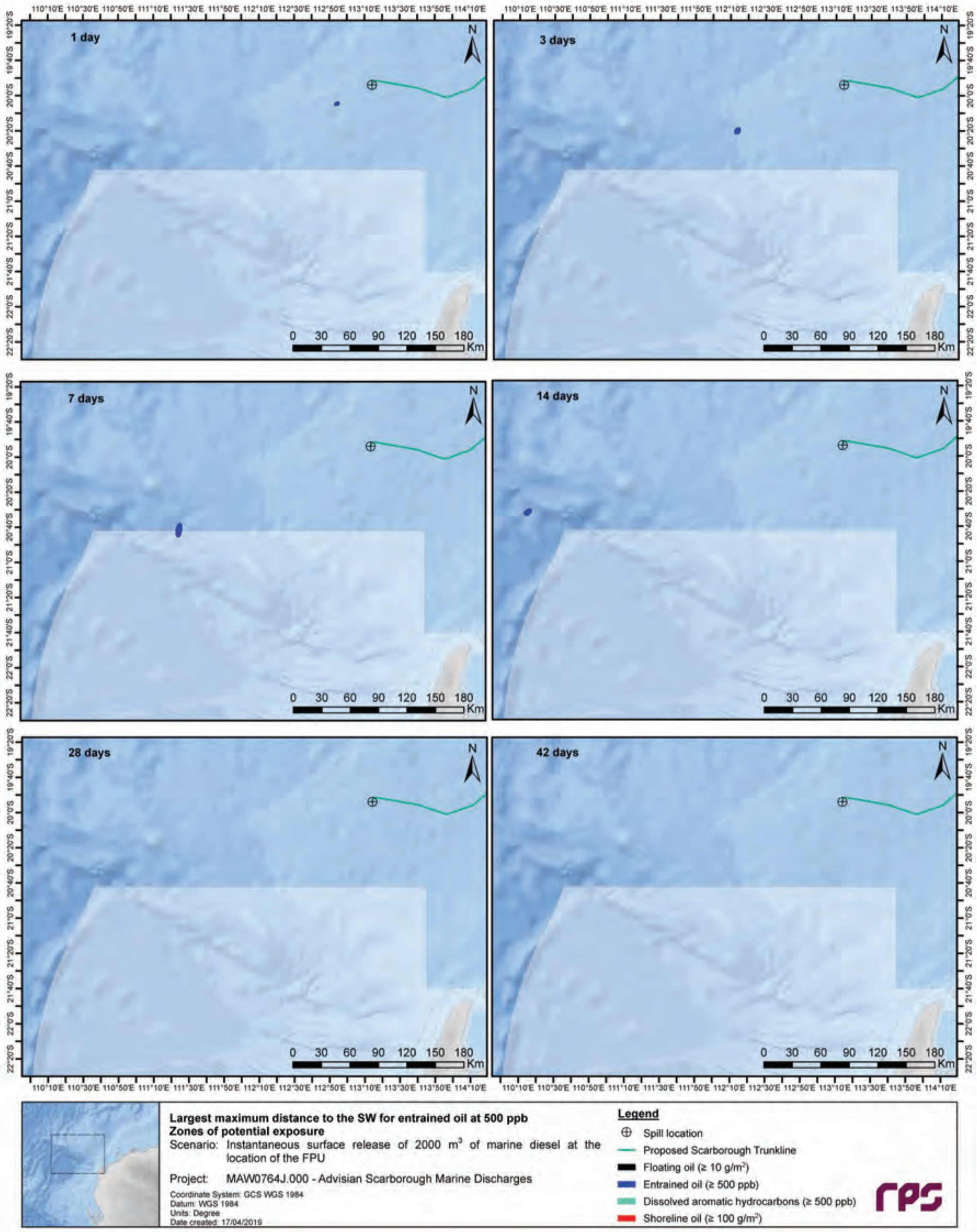



**Figure 4.5** **Time-varying areal extent of potential exposure at defined floating oil, entrained oil, dissolved aromatic hydrocarbon and shoreline oil threshold concentrations, resulting from an instantaneous surface release of marine diesel after a vessel collision at the FPU location, for the replicate simulation where entrained oil at the 500 ppb threshold is forecast to reach the greatest distance in a south-westerly direction from the release site.**

### 4.4.2 Simulation with Maximal Overall Swept Area of Entrained Oil at the 500 ppb Threshold

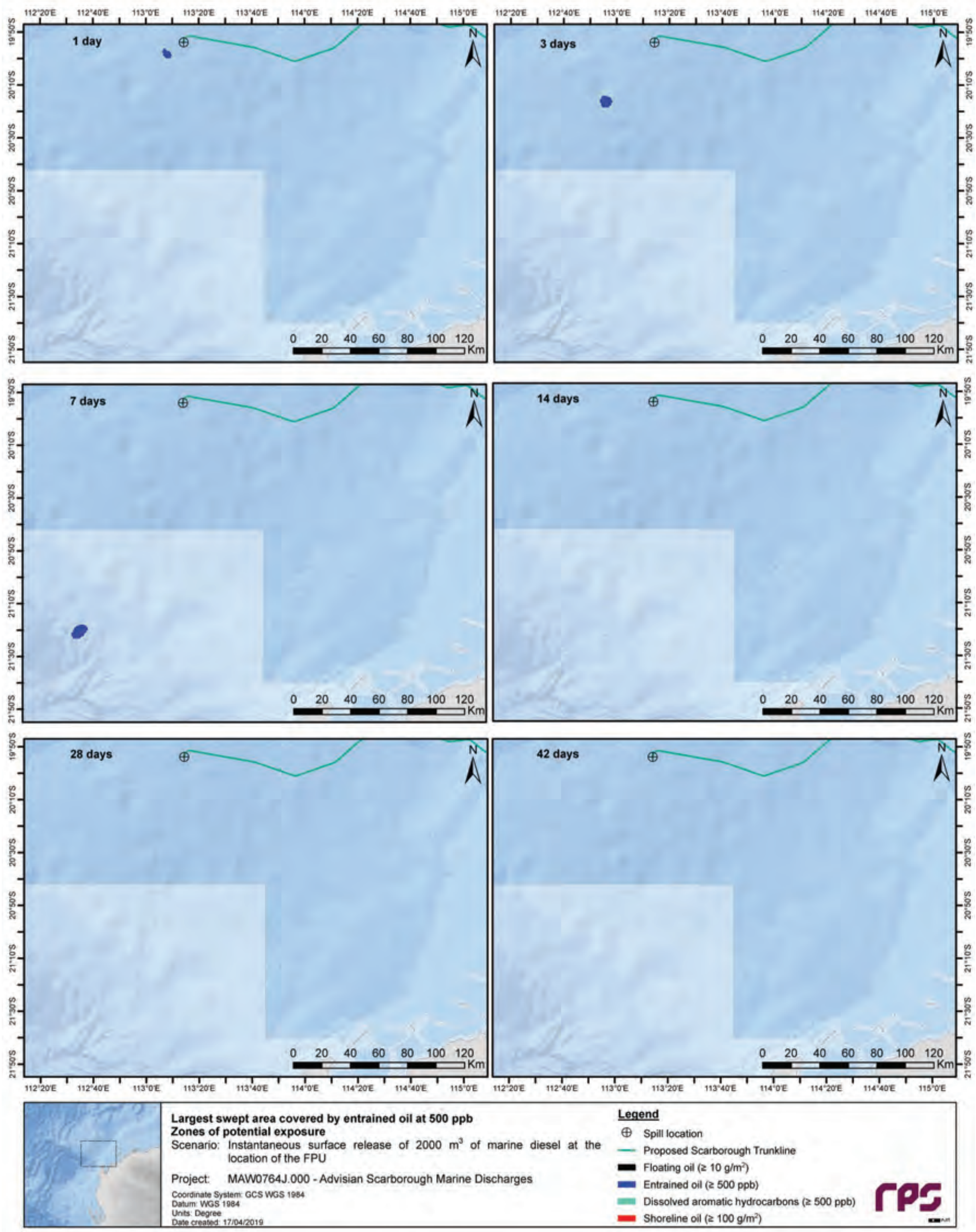



**Figure 4.6** **Time-varying areal extent of potential exposure at defined floating oil, entrained oil, dissolved aromatic hydrocarbon and shoreline oil threshold concentrations, resulting from an instantaneous surface release of marine diesel after a vessel collision at the FPU location, for the replicate simulation where entrained oil at the 500 ppb threshold is forecast to cover the greatest total area over the course of a simulation.**

# 5 CONCLUSIONS

The main findings of this study are as follows:

## Metocean Influences

- Tidal flows will have a significant influence on the trajectory of any oil spilled at the modelled release sites, irrespective of the seasonal conditions.
- Large-scale drift currents will have a significant influence on the trajectory of any oil spilled at the modelled release sites, irrespective of the seasonal conditions. The prevailing drift currents will determine the trajectory of oil that is entrained beneath the water surface.
- Interactions with the prevailing wind will provide additional variation in the trajectory of spilled oil.
- Due to the location of the hypothetical spill site and the dominance of tidal flows, the coastal areas predicted to be most likely to be impacted by spilled oil are those bordering Mermaid Sound and its numerous passages.

## Oil Characteristics and Weathering Behaviour

- Marine diesel is a mixture of volatile and persistent hydrocarbons with low percentages of highly volatile and residual components. If exposed to the atmosphere, around 41% of the mass would be expected to evaporate in around 24 hours, another 54% within a few days, and the remaining 5% would be expected to persist in the marine environment until decayed. The influence of entrainment will regulate the degree of mass retention in the environment.
- During the surface release, floating oil will be susceptible to entrainment into the wave-mixed layer under typical wind conditions. Evaporation rates will be significant, given the moderate proportion of volatile compounds in the oil (41%). The low-volatility fraction of the oil (54%) will take longer durations of the order of days to evaporate, and the residual fraction of 5% is expected to persist in the environment until degradation processes occur. Considering the spill volume, there is a low potential for dissolution of soluble aromatic compounds.

## Summary of Stochastic Assessment Results

### Scenario 1: Short-Term (Instantaneous) Surface Release of Marine Diesel after a Vessel Collision outside Mermaid Sound

- Floating oil at concentrations equal to or greater than the 10 g/m$^2$, 50 g/m$^2$ and 100 g/m$^2$ thresholds could potentially be found up to 29 km, 21 km and 18 km from the spill site, respectively.
- The Dampier Archipelago shoreline receptor is predicted to be contacted by floating oil concentrations at the 10 g/m$^2$ threshold with a probability of 2% and a minimum time to contact of 27 hours.
- Potential for accumulation of oil on shorelines is predicted to be low, with a maximum accumulated volume and concentration of 3 m$^3$ and 156 g/m$^2$, respectively, forecast at the Dampier Archipelago.
- Entrained oil at concentrations equal to or greater than the 500 ppb threshold is predicted to be found up to around 163 km from the spill site.
- The Dampier MP and Dampier Archipelago receptors are predicted to receive entrained oil concentrations at the 500 ppb threshold with probabilities of 44% and 23%, respectively.

- The maximum entrained oil concentration forecast for any receptor is predicted as 10.9 ppm within the Dampier Archipelago.
- Dissolved aromatic hydrocarbons at concentrations equal to or greater than the 500 ppb threshold are predicted to be found up to around 34 km from the spill site.
- The Dampier MP is predicted to receive dissolved aromatic hydrocarbon concentrations at the 500 ppb threshold with a probability of 2%.
- The maximum dissolved aromatic hydrocarbon concentration forecast for any receptor is predicted as 635 ppb within the Dampier MP.

## Scenario 2: Short-Term (Instantaneous) Surface Release of Marine Diesel after a Vessel Collision within Montebello Marine Park

- Floating oil at concentrations equal to or greater than the 10 g/m$^2$, 50 g/m$^2$ and 100 g/m$^2$ thresholds could potentially be found up to 39 km, 36 km and 33 km from the spill site, respectively.
- Given that the spill location lies within the Montebello MP receptor area, floating oil at concentrations equal to or greater than 100 g/m$^2$ are forecast with a probability of 100% and a minimum time to contact of less than 1 hour.
- Potential for accumulation of oil on shorelines is predicted to be low, with a maximum accumulated volume and concentration of <1 m$^3$ and 1 g/m$^2$, respectively, forecast at Barrow Island.
- Entrained oil at concentrations equal to or greater than the 500 ppb threshold is predicted to be found up to around 308 km from the spill site.
- The Montebello MP and Muiron Islands MMA-WHA receptors are predicted to receive entrained oil concentrations at the 500 ppb threshold with probabilities of 70% and 7%, respectively.
- The maximum entrained oil concentration forecast for any receptor is predicted as 157.0 ppm within the Montebello MP.
- Dissolved aromatic hydrocarbons at concentrations equal to or greater than the 500 ppb threshold are predicted to be found up to around 85 km from the spill site.
- The Montebello MP is predicted to receive dissolved aromatic hydrocarbon concentrations at the 500 ppb threshold with a probability of 2%.
- The maximum dissolved aromatic hydrocarbon concentration forecast for any receptor is predicted as 2.0 ppm within the Montebello MP.

## Scenario 3: Short-Term (Instantaneous) Surface Release of Marine Diesel after a Vessel Collision at the FPU Location

- Floating oil at concentrations equal to or greater than the 10 g/m$^2$, 50 g/m$^2$ and 100 g/m$^2$ thresholds could potentially be found up to 113 km, 60 km and 58 km from the spill site, respectively.
- No shoreline receptors are predicted to be contacted by floating oil concentrations at any of the assessed thresholds.
- No accumulation of oil on shorelines is predicted.
- Entrained oil at concentrations equal to or greater than the 500 ppb threshold is predicted to be found up to around 476 km from the spill site.

- The Gascoyne MP receptor is predicted to receive entrained oil concentrations at the 500 ppb threshold with a probability of 8%.
- The maximum entrained oil concentration forecast for any receptor is predicted as 7.2 ppm within the Gascoyne MP.
- Dissolved aromatic hydrocarbons at concentrations equal to or greater than the 500 ppb threshold are predicted to be found up to around 74 km from the spill site.
- No receptors are predicted to receive dissolved aromatic hydrocarbon concentrations at the 500 ppb threshold.
- The maximum dissolved aromatic hydrocarbon concentration forecast for any receptor is predicted as 462 ppb within the Gascoyne MP.

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# Appendix J

## Scarborough Development Dredged Sediment Dispersion Modelling

# SCARBOROUGH DEVELOPMENT DREDGED SEDIMENT DISPERSION MODELLING

## Report

MAW0753J
Scarborough Development
Dredged Sediment
Dispersion Modelling
Rev 4
07 June 2019

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# 1 INTRODUCTION

## 1.1 Background

RPS was commissioned by Advisian Pty Ltd (Advisian), on behalf of Woodside Energy Ltd (Woodside), to undertake sediment dispersion modelling of dredging, disposal and backfill operations associated with the development of Scarborough, in support of the State and Commonwealth referrals and an Offshore Project Proposal to NOPSEMA. The Scarborough gas field is located within offshore permit WA-1-R.

Dredging, disposal and backfill operations along the Scarborough pipeline route, from the mainland of the Burrup Peninsula outwards to a chainage of KP50, are proposed as part of the project (Figure 1.1).

RPS has conducted sediment dispersion modelling to quantify the potential magnitude, intensity and spatial distribution of suspended sediment concentrations (SSC) and sedimentation that would be expected for the dredging, disposal and backfill operations proposed for the development of Scarborough. The predicted outcomes are to be used to inform the assessment of the potential for influence or impact upon water quality and benthic habitats in the region.

This technical report contains a summary of the sediment fate model inputs, methodologies and assumptions, and the model outcomes following analysis of specified threshold criteria.

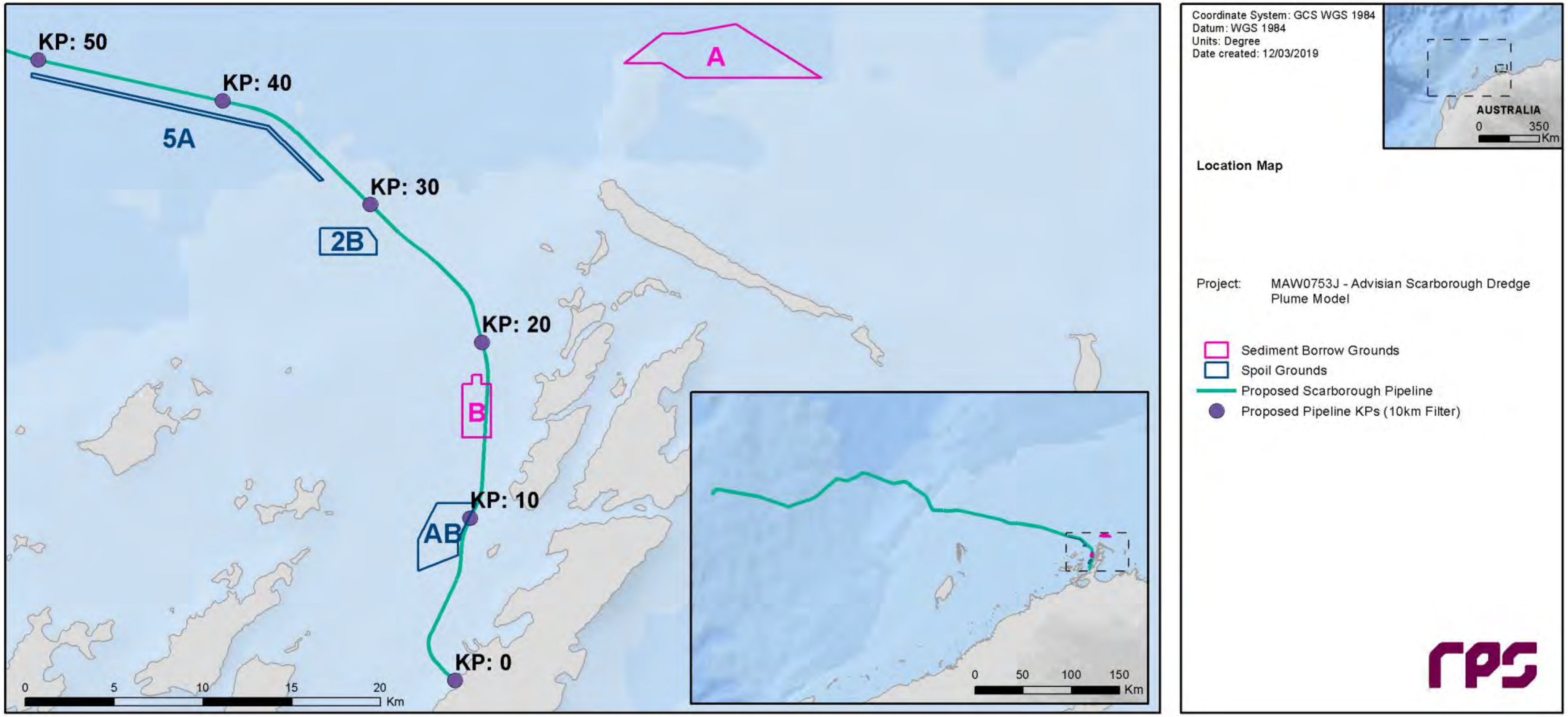


**Figure 1.1** **Route of the inner sections (KP0 to KP50) of the proposed Scarborough pipeline on the North West Shelf of Australia, and locations of the existing spoil grounds (AB, 2B and 5A) and sediment borrow grounds (A and B) that will be utilised during disposal and backfill activities.**

## 1.2 Modelling Scope

RPS was commissioned to conduct sediment dispersion modelling for the following activities:

- Dredging of sediment along the pipeline route and disposal of dredged sediment at three nominated spoil grounds;
- Dredging of the borrow ground and backfill and stabilisation of the pipeline.

The scope of work required to complete the sediment dispersion modelling included:

1. Hydrodynamic Modelling.
    a. An initial assessment of the existing D-FLOW hydrodynamic model framework in the Mermaid Sound region determined that refinements were necessary to suit the requirements of this scope of work. Reconfiguration of the model was conducted, followed by re-validation of the model predictions against available measurements of water levels and currents for the same validation period as utilised previously.
    b. Two years (2016-2017) of hydrodynamic simulation data was produced for use as input to the sediment dispersion model.
2. Wave Modelling.
    a. An initial assessment of the existing D-WAVE wave model framework in the Mermaid Sound region determined that refinements were necessary to suit the requirements of this scope of work. Reconfiguration of the model was conducted, followed by re-validation of the model predictions against available predictions from an operational RPS model for the same validation period as utilised previously.
    b. Two years (2016-2017) of wave simulation data was produced for use as input to the sediment dispersion model.
3. Sediment Dispersion Modelling.
    a. Inputs for the dredging program were prepared for the DREDGEMAP model, accounting for all potential concurrent sources of sediment characterised by location, intensity, particle size distribution, vertical distribution in the water column, and levels of cohesivity.
    b. Four dredging, disposal and backfill scenarios were simulated: (i) dredging commencing in winter including an offshore borrow ground; (ii) dredging commencing in winter including an inshore borrow ground; (iii) dredging commencing in summer including an offshore borrow ground; (iv) dredging commencing in summer including an inshore borrow ground.
    c. Simulation outputs from each separate dredging, disposal and backfill activity were post-processed, combined and analysed to determine outcomes including zones of impact and influence for each scenario based on specified threshold criteria.
    d. Key model outcomes were provided as spatial datasets in GIS shapefile format.
4. Reporting. A technical report detailing the sediment fate model inputs, methodologies, assumptions and model outcomes following analysis of specified threshold criteria was provided.

## 1.3 Definitions of Relevant Terms and Abbreviations

**BHD:**

Backhoe Dredge. A pontoon equipped with a hydraulic excavator. The pontoon is stabilised and secured by three spuds. The excavator uses a large arm fitted with a bucket to excavate material from the seabed and discharge it into (typically) a split hopper barge moored alongside. BHDs are mainly used for dredging or breaking up the sedimentary rock below a layer of unconsolidated sediments, or for dredging in areas inaccessible to larger self-propelled vessels.

**Dewatering:**

Draining of excess water from a split hopper barge using its drainage system.

**Overflow:**

Excess water and suspended solids that leave a TSHD hopper and are discharged to the water column via a weir and discharge pipe located at the base of the vessel.

**Resuspension:**

Removal of deposited material from the seabed to the water column as a result of natural or artificial agitation.

**Sedimentation rate:**

Rate of sediment accumulation on the seabed following deposition of SSC from the water column.

**Side-dump vessel:**

Self-propelled vessel that is capable of transporting and installing a variety of different sizes of rock. Large cranes of fall pipes are used to dump rocks from the vessels to the seabed.

**Split hopper barge:**

Vessel with a large open hold used to load and transport dredged material. The unloading is performed by splitting the two halves of the hull to release the material towards the seabed.

**SSC:**

Suspended Solids Concentration (or Suspended Sediment Concentration). The concentration of sediment material in the water column following natural or artificial resuspension from the seabed.

**TSHD:**

Trailer Suction Hopper Dredge. A self-propelled vessel with one or two suction tubes/arms, equipped with drag-heads that are lowered to the seabed and trailed over the bottom. The vessel has a powerful pump system that sucks up a mixture of sediment and water and discharges it in the hopper (hold) of the vessel. TSHDs are mainly used for dredging loose and soft soils such as sand, gravel, silt or clay.

# 2 HYDRODYNAMIC AND WAVE MODELLING

## 2.1 Overview

Modelling of the potential sediment dispersion from the dredging, disposal and backfill activities associated with the development of Scarborough required temporal and spatial representation of the hydrodynamic and wave conditions within the project area. A hydrodynamic and wave model framework for the Mermaid Sound area was constructed, calibrated and validated for a past marine modelling study of dredge spoil stability and navigation for Woodside (RPS, 2016). This model framework has been refined for the Scarborough scope of work and is described in the following sections.

The hydrodynamic and wave modelling for the project was conducted using the Delft3D suite of software. The Delft3D suite is a fully integrated computer software package composed of several modules (e.g. flow, waves, sediment, water quality, and ecology) grouped around a common interface. This software suite has been developed to carry out studies with a multi-disciplinary approach and multi-dimensional calculations (e.g. 2-D and 3-D) for a range of systems, such as oceanic, coastal, estuarine and river environments. It can simulate the interaction of flows, waves, sediment transport, morphological developments, water quality and aquatic ecology. Specific modules of the Delft3D suite are referenced in this report, following the convention of the software developers, with the suffix D- (e.g. D-FLOW for the Delft3D Hydrodynamics module and D-WAVE for the Delft3D Spectral Wave module).

The Delft3D suite has been developed by Deltares, an independent institute for applied research on water with over 30 years of experience in modelling aquatic systems (http://www.deltares.nl/en). The Delft3D suite of models adheres to the International Association for Hydro-Environment Engineering and Research guidelines for documenting the validity of computational modelling software, closely replicating an array of analytical, laboratory, schematic and real-world data.

The configuration of the current and wave models is in line with recommendations of best practice for sediment dispersion modelling in Western Australia as outlined by WAMSI Dredging Science Node guidance (Sun *et al.*, 2016). Inclusion of mesoscale ocean currents is recommended, as these currents have a significant influence on the net drift of suspended material over the time scales of dredging operations (days to weeks) and are therefore important to predictions of sediment transport. The use of three-dimensional current modelling with a series of interconnected grids of progressively finer resolution is also recommended, as are coupling of the current and wave models and validation of current predictions against measured data.

## 2.2 Hydrodynamic Model (D-FLOW)

### 2.2.1 Model Description

To simulate the hydrodynamics within Mermaid Sound and the surrounding area, a three-dimensional model with accurate representations of the bathymetry, bottom roughness and spatially-varying wind stress was utilised for the region. The model framework was developed through the combination of a large-scale regional model with smaller refined regions, or sub-domains.

The D-FLOW model is ideally suited to represent the hydrodynamics of complex coastal waters, including regions where the tidal range creates large intertidal zones and where buoyancy processes are important. RPS has applied the model for numerous studies in the region.

D-FLOW is a multi-dimensional (2-D or 3-D) hydrodynamic (and transport) simulation program which calculates non-steady flow and transport phenomena that result from tidal, meteorological and baroclinic forcing on a rectilinear or a curvilinear, boundary-fitted grid. In three-dimensional simulations, the vertical grid can be defined following the sigma-coordinate approach, where the local water depth is divided into a series of layers with thickness at a set proportion of the depth.

D-FLOW allows for the establishment of a series of interconnected (two-way, dynamically-nested) curvilinear grids of varying resolution; a technique referred to as “domain decomposition”. This allows for the generation of a series of grids with progressively increasing spatial resolution, down to an appropriate scale for accurate resolution of the hydrodynamics associated with features such as dredged channels. The main advantage of domain decomposition over traditional one-way, or static, nesting systems is that the model domains interact seamlessly, allowing transport and feedback between the regions of different scales. The ability to dynamically couple multiple model domains offers a flexible framework for hydrodynamic model development. This modelling method was applied in this study.

Inputs to the model, as discussed in the following sections, included:

- Bathymetry of the study area, including shipping channels, islands, and adjacent features. The wetting and drying of the intertidal zones was simulated in applicable areas.
- Boundary elevation forcing data.
- Spatially-varying surface wind and pressure data.

### 2.2.2 Bathymetry and Domain Definition

The hydrodynamic model was established over the domain shown in Figure 2.1. Accurate bathymetry is a significant factor in development of a model framework required to resolve highly variable wave and current conditions. The bathymetry was developed using data provided by Woodside and supplemented with data from Geoscience Australia and the C-MAP electronic chart database where relevant and required.

The composite bathymetric data was interpolated onto the D-FLOW Cartesian grid. The resultant bathymetry is shown in Figure 2.2. The extent and shape of the model coastline will change as water levels rise and fall with tidal movements due to the inclusion of wetting and drying within the model system.

The vertical grid of the model comprised five layers of varying thickness, depending on location, throughout the domain. Five layers was found to be enough to resolve the circulation and provide suitable bed level currents, without overly compromising model performance. As the model was set up as a proportional sigma-grid in the vertical dimension, these layers therefore represented a terrain-following arrangement with a layer thickness of 20% of the total local water depth.

To offset the computational effort required for a large, multi-layered model domain, and to achieve adequate horizontal and temporal resolution, a multiple-grid (domain-decomposition) strategy was applied using three sub-domains of varying horizontal grid cell size (Figure 2.1 and Figure 2.2). Horizontal resolutions within each sub-domain were 250 m for the Mermaid Sound region from Enderby Island to Legendre Island (sub-grid 2), 500 m for the intermediate region (sub-grid 1) and 2 km for the outer domain (sub-grid 0).

Each sub-domain is an individual hydrodynamic model simulated in parallel with the others, with dynamic coupling at the shared boundaries between sub-domains. The outermost sub-domain captured large-scale oceanographic phenomena which progressively fed into the finer-resolution domains representing the area of interest. The resolution of the innermost sub-domain was specified after assessment of the requirement to adequately resolve the variation in current fields, and in turn the sediment dynamics.

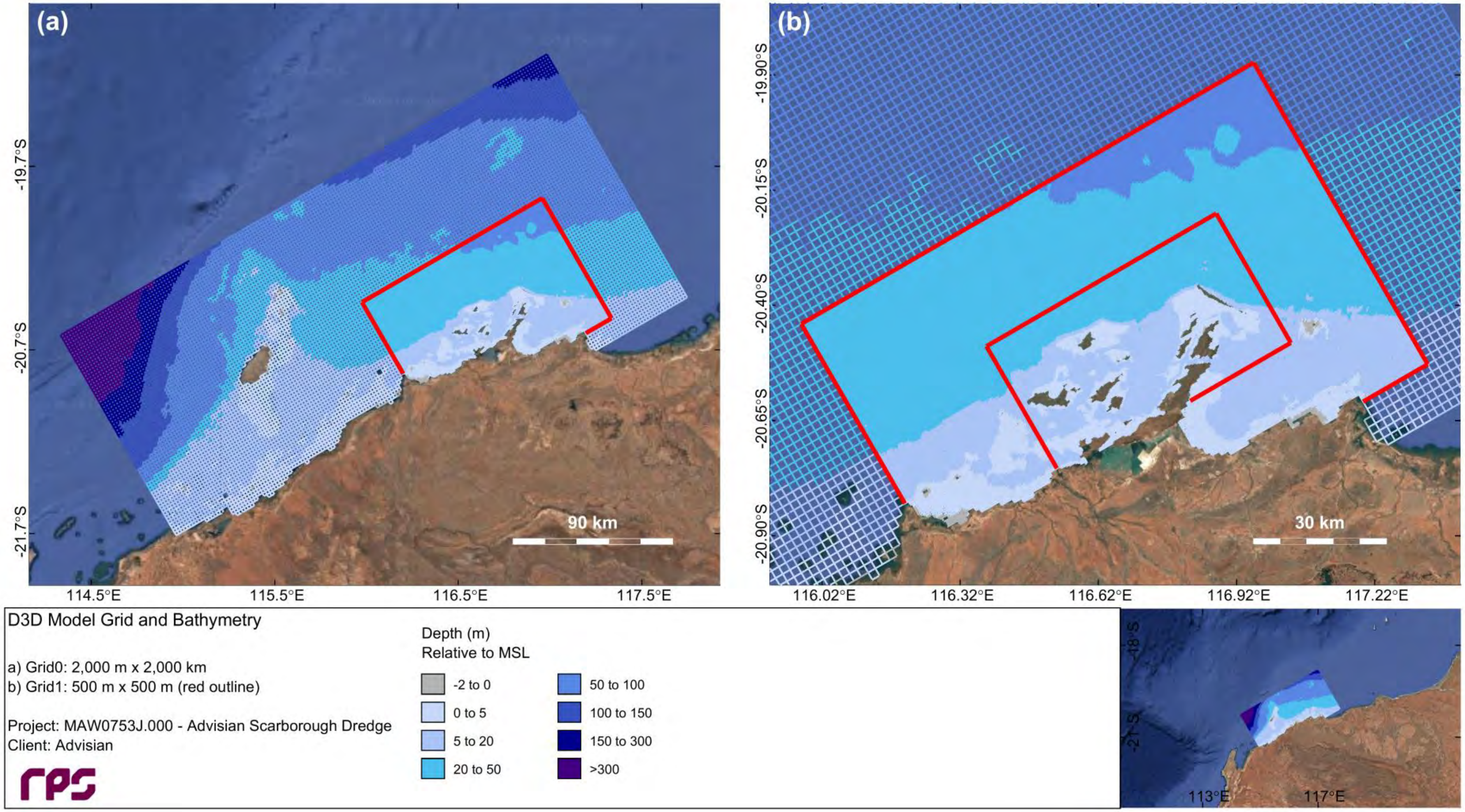


**Figure 2.1 Model grid setup showing the domain-decomposition scheme applied, highlighting the two outermost grids.**

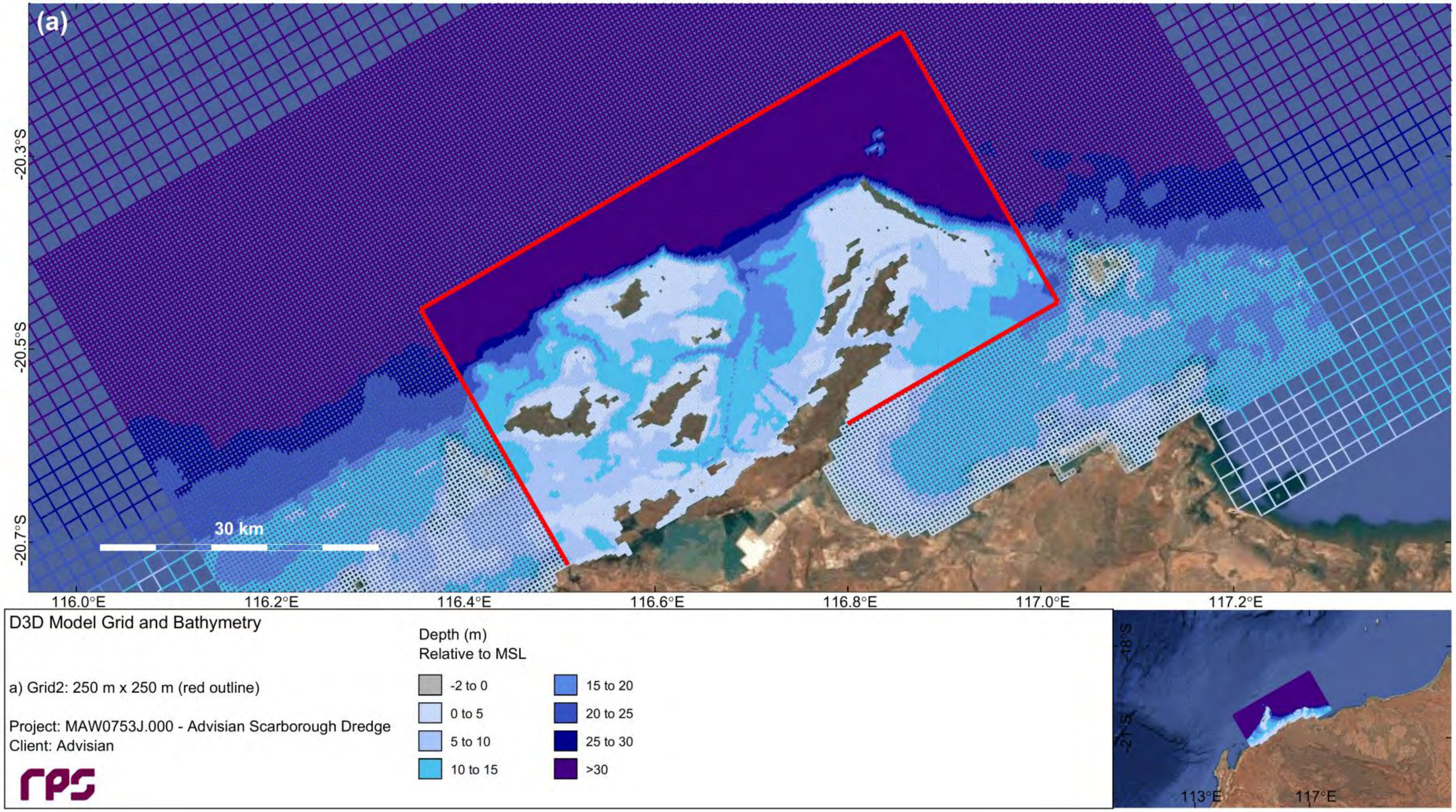


**Figure 2.2 Model grid setup showing the domain-decomposition scheme applied, highlighting the innermost grid.**

### 2.2.3 Boundary and Initial Conditions

#### 2.2.3.1 Overview

As the hydrodynamics in the study area are controlled primarily by tidal flows and wind forcing, these processes were explicitly included in the developed model.

The model was forced on the open boundaries of the outer sub-domain with time series of water elevation obtained for the chosen simulation period. Spatially-varying wind speed and wind direction data was used to force the model across the entire domain.

#### 2.2.3.2 Water Elevation

Water elevations at hourly intervals were obtained from the TPXO8.0 database, which is the most recent iteration of a global model of ocean tides derived from measurements of sea-surface topography by the TOPEX/Poseidon satellite-borne radar altimeters. Tides are provided as complex amplitudes of earth-relative sea-surface elevation for eight primary ($M_2$, $S_2$, $N_2$, $K_2$, $K_1$, $O_1$, $P_1$, $Q_1$), two long-period ($M_f$, $M_m$) and three non-linear ($M_4$, $MS_4$, $MN_4$) harmonic constituents at a spatial resolution of 0.25°.

The tidal sea level data was augmented with non-tidal sea level elevation data from the global Hybrid Coordinate Ocean Model (HYCOM; Bleck, 2002; Chassignet *et al.*, 2003; Halliwell, 2004), created by the USA's National Ocean Partnership Program (NOPP) as part of the Global Ocean Data Assimilation Experiment (GODAE). The HYCOM model is a three-dimensional model that assimilates observations of sea surface temperature, sea surface salinity and surface height, obtained by satellite instrumentation, along with atmospheric forcing conditions from atmospheric models to predict drift currents generated by such forces as wind shear, density, 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 than non-hybrid models. The model has global coverage with a horizontal resolution of 1/12$^{th}$ of a degree (~7 km at mid-latitudes) and a temporal resolution of 24 hours.

#### 2.2.3.3 Wind Forcing

Spatially-variable wind data was sourced from the Global Data Assimilation System (GDAS), which is used by the National Centers for Environmental Prediction (NCEP) Global Forecast System (GFS) model to place observations into a gridded model space for the purpose of starting, or initializing, weather forecasts with observed data. The GFS Forecasts model variant used has a horizontal resolution of 1/12$^{th}$ of a degree and a temporal resolution of 6 hours (NCEP, 2016).

### 2.2.4 Model Validation

#### 2.2.4.1 Comparison of Modelled and Measured Water Elevation

Validation of the water level changes predicted by the D-FLOW hydrodynamic model configuration was provided through comparisons to independent predictions from the XTide tidal constituent database (Flater, 1998). Comparison of model tidal amplitudes with the XTide database showed strong agreement (Figure 2.3), with slight overprediction of tidal amplitudes at some stations. Time series comparisons for two tide stations situated at locations that are relevant to this study also showed good agreement (Figure 2.4).

In general, a consistent match is observed between water elevations calculated by the D-FLOW model and those predicted by XTide (Figure 2.4). Both the amplitude and phase of the semidiurnal tidal signal are clearly reproduced at each station, as is the timing of the spring-neap cycle. The D-FLOW model slightly overpredicts high tides and underpredicts low tides, which indicates there was a small difference between the datums used to compare these different data sets rather than actual amplitude differences.

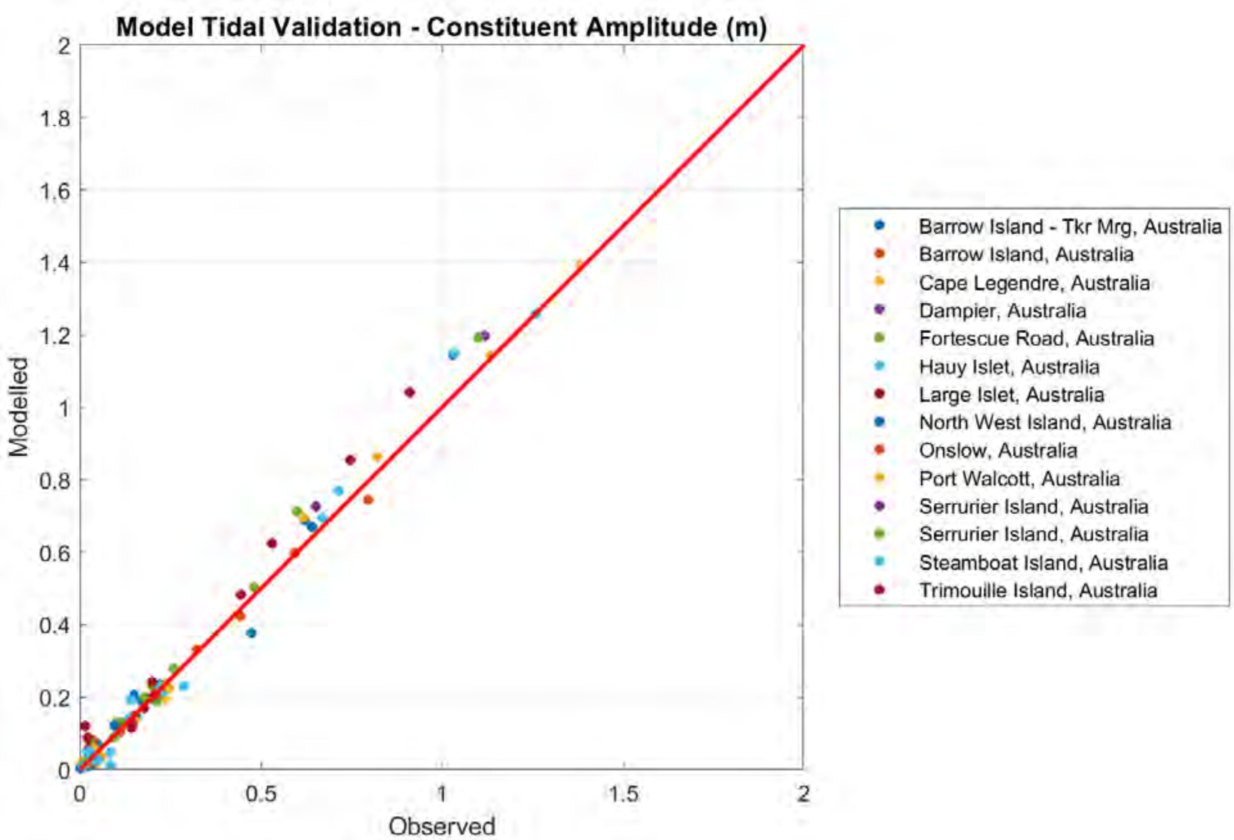


**Figure 2.3 Comparison of tidal amplitudes from the D-FLOW hydrodynamic model (y-axis) with those from the XTide database (x-axis) at 14 stations located within the model domain.**

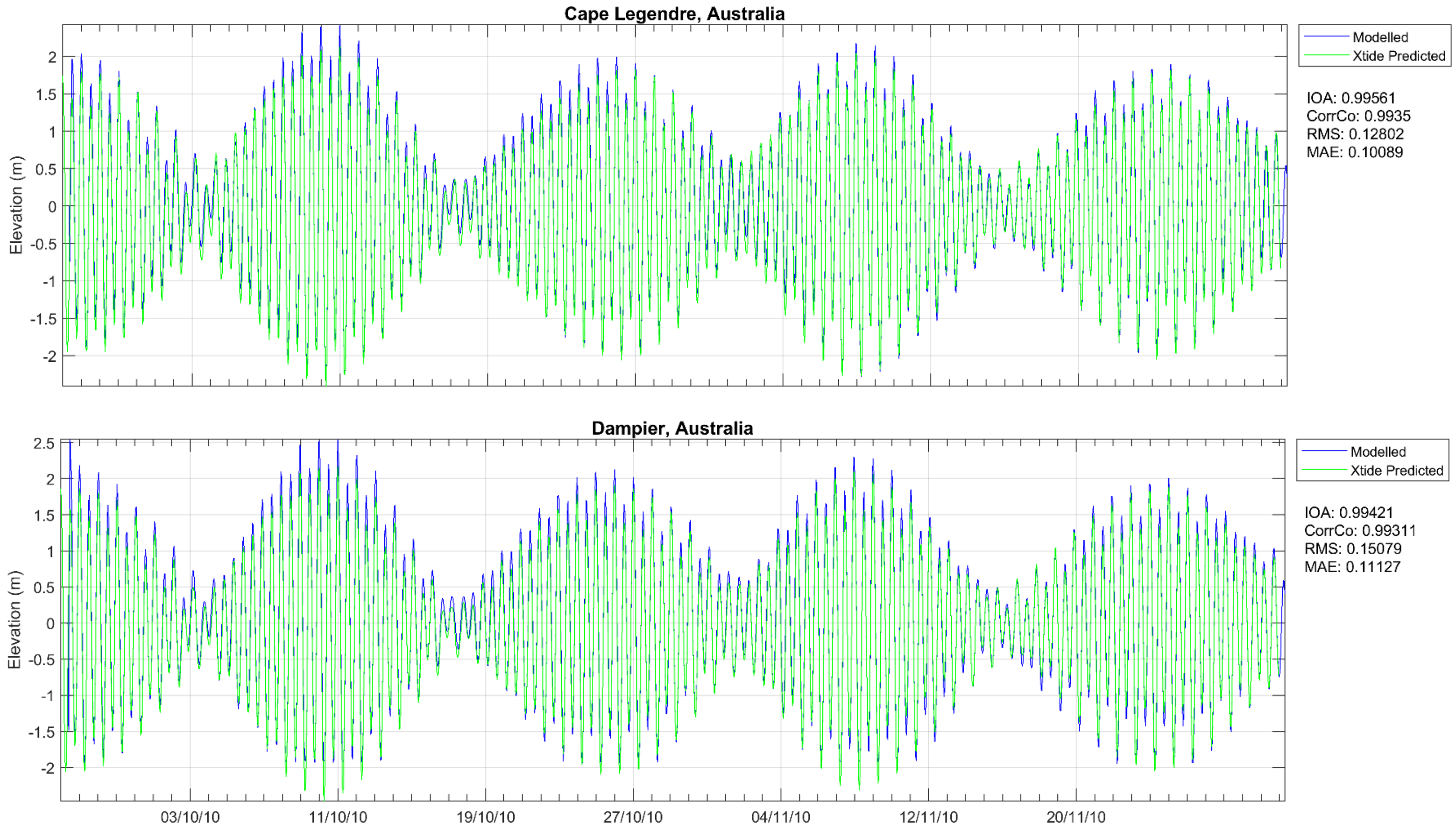


**Figure 2.4** **Comparisons of water elevations predicted by the D-FLOW hydrodynamic model (blue line) with those predicted by the XTide database (green line) over the validation period of October-November 2010 at two selected station locations.**

#### 2.2.4.2 Comparison of Modelled and Measured Currents

Validation of the model-predicted currents was conducted for a spring/neap tide period during October and November 2010 by comparing the model results to measured data from the Woodside LNG Channel AWAC that was located within Mermaid Sound (116.738° E, 20.561° S) in water depth of approximately 12 m. Comparisons of current speed and direction at a depth interval representative of the mid-water column are provided in Figure 2.5.

Overall, the comparison indicates that the model provides a good prediction of tidal currents at the comparison site. There was a minor mismatch in the phase of the tidal oscillations, with a slight lag apparent in the modelled data. However, this lag was not evident in the XTide water level comparisons (Figure 2.4).

The amplitudes of the modelled and measured current fluctuations were generally well-matched, but there were some spikes in the measured data that were not reproduced. These spikes in the measured data, assuming they were not instrument errors, may have been caused by local-scale events related to wind-driven currents. These events are difficult to reproduce in the model because the horizontal grid scale of the model in this region is 250 m. The GFS wind driving the model can be less accurate close to the coast when sea breeze effects are dominant. The inability of the model to reproduce some spikes observed in the measured data might be explained by inaccuracies in the NCEP wind data near to the Woodside LNG Channel AWAC location.

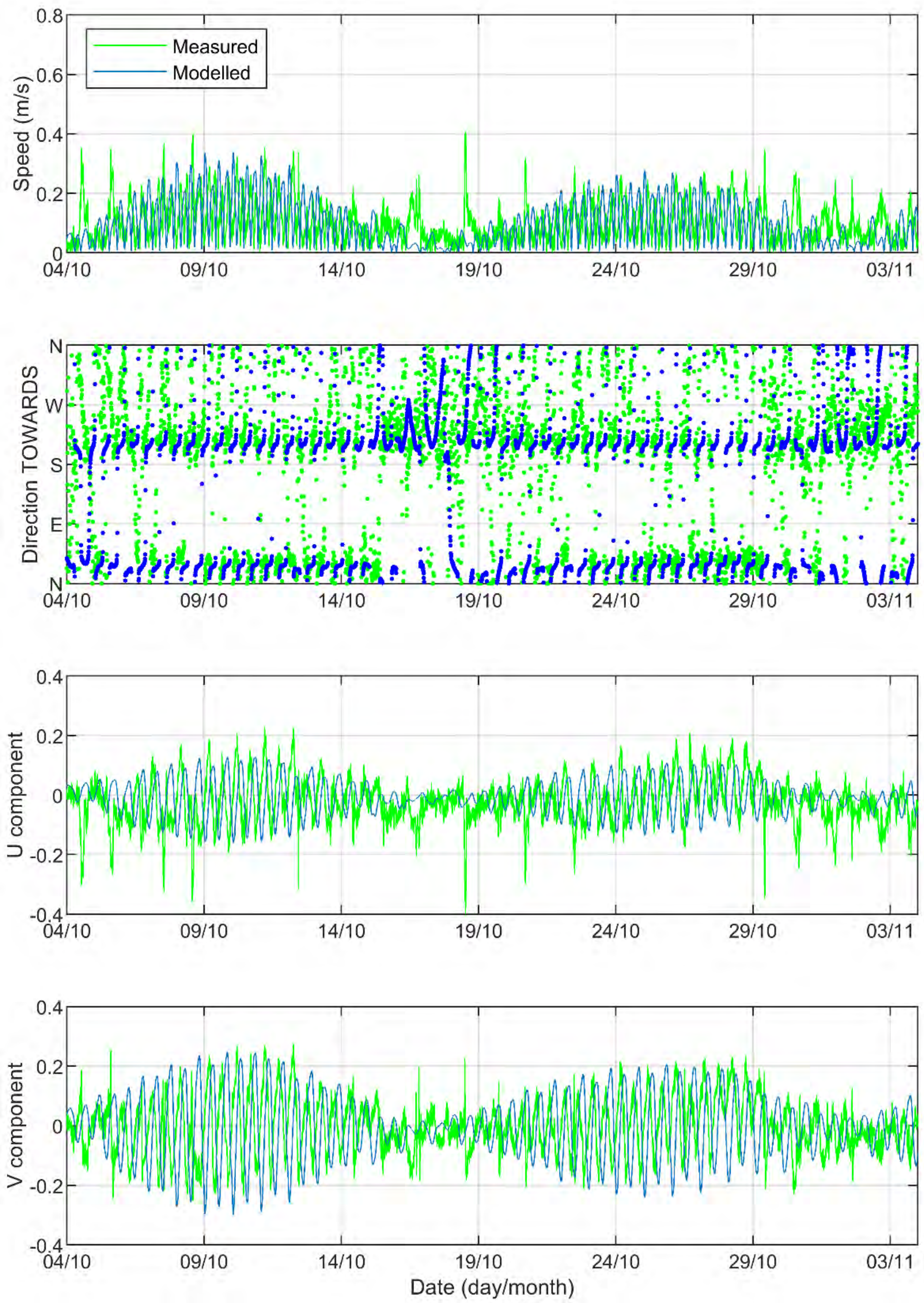


**Figure 2.5** **Comparisons of modelled (blue line) and measured (green line) currents for a mid-water column depth interval at the Woodside LNG Channel AWAC location during the 2010 validation period.**

## 2.3 Wave Model (D-WAVE)

### 2.3.1 Model Description

Reliable forecasting for the fate of fine sediments in the study location, which is a wave-exposed coastal region, required the input of wave spectra information to calculate the shear-stress and orbital velocities imposed by waves which will affect the settlement and re-suspension of fine material that is initially suspended by dredging and related operations. D-WAVE is a variant of the well-known SWAN wave model that has been customised for compatibility with the Delft3D software suite.

The D-WAVE model is a spectral phase-averaging wave model originally developed by the Delft University of Technology. D-WAVE, a third-generation model based on the energy balance equation, is a numerical model for simulating realistic estimates of wave parameters in coastal areas for given wind, bottom and current conditions.

D-WAVE includes algorithms for the following wave propagation processes: propagation through geographic space; refraction and shoaling due to bottom and current variations; blocking and reflections by opposing currents; and transmission through or blockage by obstacles. The model also accounts for dissipation effects due to white-capping, bottom friction and wave breaking as well as non-linear wave-wave interactions. D-WAVE is fully spectral (in all directions and frequencies) and computes the evolution of wind waves in coastal regions with shallow water depths and ambient currents.

RPS has successfully applied D-WAVE in many studies in the region, including ambient condition modelling in Mermaid Sound and dredging fate projects in the wider Pilbara region.

### 2.3.2 Model Implementation

The D-WAVE model was developed to cover the same grid regions defined by the hydrodynamic model (Figure 2.1 and Figure 2.2). The bathymetry and wind data input to the wave model was the same as used for the hydrodynamic model. Time-varying water level information for each grid node in the wave model was provided by the output of the hydrodynamic model. The boundary data to represent swells imposed from a distance was sourced from the WAVEWATCH III 0.5° model, operated by the National Oceanic and Atmospheric Administration (NOAA) (NOAA, 2018).

The wave model was run in a coupled mode with the hydrodynamic model for the years of 2016 and 2017. The model results were independently validated by comparison to other modelled wave data for the Mermaid Sound region that is held internally by RPS.

# 3 SEDIMENT FATE MODELLING

## 3.1 General Approach

Estimates for the three-dimensional distribution of sediments suspended by dredging, disposal and backfill operations have been derived for the full duration of the pipeline dredging and backfill program using numerical modelling. The approach of modelling dredging operations in full and in three dimensions is in line with best practice for sediment dispersion modelling in Western Australia as outlined by WAMSI Dredging Science Node guidance (Sun *et al.*, 2016).

This modelling relied upon specification of sediment discharges over time for each of the expected sources of sediment suspension, and predicted the evolution of the combined sediment plumes via current transport, dispersion, sinking and sedimentation. The model allowed for the subsequent resuspension of settling sediments due to the erosive effects of currents and waves. Thus, the fate of sediments was assessed beyond their initial settling.

Forcing was provided using predictions of three-dimensional current fields and two-dimensional wave fields for the study area, which are described in Section 2.

## 3.2 Model Description

Modelling of the dispersion of suspended sediment resulting from the various dredging, disposal and backfill operations was undertaken using an advanced sediment fate model, Suspended Sediment FATE (SSFATE), operating within the RPS DREDGEMAP model framework. This model computes the advection, dispersion, differential sinking, settlement and resuspension of sediment particles. The model can be used to represent inputs from a wide range of suspension sources, producing predictions of sediment fate both over the short-term (minutes to days following a discharge source) and longer term (days to years following a discharge source).

SSFATE allows the three-dimensional predictions of SSC and seabed sedimentation to be assessed against allowable exposure thresholds. Sedimentation thresholds often relate to burial depths or rates, while SSC thresholds are usually more complicated, involving tiered exposure duration and intensities. As a result, assessing the project-generated sediment distributions against these thresholds in both three-dimensional space and time is a computationally intensive task. A variety of SSC threshold formulations have recently been applied in Western Australian coastal waters and at present there are no general guidelines.

SSFATE is a computer model originally developed jointly by the US Army Corps of Engineers (USACE) Engineer Research and Development Center (ERDC) and RPS to estimate SSC generated in the water column and deposition patterns generated due to dredging operations in a current-dominated environment, such as a river (Johnson *et al.*, 2000; Swanson *et al.*, 2000, 2004). RPS has significantly enhanced the capability of SSFATE to allow the prediction of sediment fate in marine and coastal environments where wave forcing becomes important for reworking the distribution of sediments (Swanson *et al.*, 2007).

SSFATE is formulated to simulate far-field effects (~25 m or larger scale) in which the mean transport and turbulence associated with ambient currents are dominant over the initial turbulence generated at the discharge point. A five-class particle-based model predicts the transport and dispersion of the suspended material. The classes include the 0-130 µm range of sediment grain sizes that typically result in plumes. Heavier sediments tend to settle very rapidly, remain more stable over time and are not relevant over the longer durations (>1 hour) and larger spatial scales (>25 m) of interest here. Table 3.1 shows the standard material classes used in SSFATE for suspended sediment.

**Table 3.1 Material size classes used in SSFATE.**

| Material Class Description | Particle Size Range (µm) |
|---|---|
| Clay | <7 |
| Fine Silt | 8-34 |
| Coarse Silt | 35-74 |
| Fine Sand | 75-130 |
| Coarse Sand | >130 |

Particle advection is calculated using three-dimensional current fields, obtained from hydrodynamic modelling, thus the model can account for vertical changes in the currents within the water column. For example, as particles sink towards the seabed they will tend to be moved at slower speeds due to the slowing of currents by friction at the seabed. Particle diffusion is assumed to follow a random walk process using a Lagrangian approach of calculating transport, which uses a grid-less space to remove limitations of grid resolution, artefacts due to grid boundaries, and also maintain a high degree of mass conservation.

Following release into the model space, the sediment cloud evolves according to the following processes:

- Advection due to the three-dimensional current field.
- Diffusion by a random walk model with the mass diffusion rate specified, ideally, from measurements at the site. As particles represent an ensemble of real particles, each particle in the model has an associated Gaussian distribution governed by particle age and the mass diffusion properties of the surrounding water.
- Settlement or sinking of the sediment due to buoyancy forces. Settlement rates are determined from the particle class sizes and include allowance for flocculation and other concentration-dependent behaviour, following the model of Teeter (2000).
- Potential deposition to the seabed determined using a model that couples the deposition across particle classes (Teeter, 2000). The likelihood and rate of deposition depends on the shear stress at the seabed. High shear inhibits deposition, and in some cases excludes it altogether with sediment remaining in suspension. The model allows for partial deposition of individual particles according to a practical deposition rate, thereby allowing the bulk sediment mass to be represented by fewer particles.
- Potential resuspension from the seabed, if previously deposited, at a rate governed by exceedance of a shear stress threshold at the seabed due to the combined action of waves and currents. Different thresholds are applied for resuspension depending upon the size of the particle and the duration of sedimentation, based on empirical studies that have demonstrated that newly-settled sediments will have higher water content and are more easily resuspended by lower shear stresses (Swanson *et al.*, 2007). The resuspension flux calculation also accounts for armouring of fine particles within the interstitial spaces of larger particles. Thus, the model can indicate whether deposits will stabilise or continue to erode over time given the shear forces that occur at the site. Resuspended material is released back into the water column to be affected by the processes defined above.

SSFATE formulations and proof of performance have been documented in a series of USACE Dredging Operations and Environmental Research (DOER) Program technical notes (Johnson *et al.*, 2000; Swanson *et al.*, 2000), and published in the peer-reviewed literature (Andersen *et al.*, 2001; Swanson *et al.*, 2004; Swanson *et al.*, 2007). SSFATE has been applied and validated by RPS against observations of sedimentation and suspended sediments at multiple locations in Australia, notably Cockburn Sound for Fremantle Ports and Mermaid Sound for the LNG Foundation Project dredging program.

## 3.3 Model Limitations

There are inherent limitations to the accuracy of numerical models. The possible sources of uncertainty within the modelling conducted for the sediment fate assessment of the Scarborough development include:

- *The equations and algorithms applied in the model*. The formulations included in the model, as discussed in Section 3.2, were selected to achieve the best possible representation of the relevant processes and have been proven to be valid over a range of projects.
- *The accuracy of the physical (current and wave) inputs to the model*. Current and wave forcing inputs were provided from validated three-dimensional hydrodynamic and wave models created and customised for the study area. The accuracy of these models is suitable, as good correlations with field measurements and independent model predictions have been achieved, with the uncertainties minimised and quantifiable. The hydrodynamic and wave models are described in Section 2. It should be noted that the model inputs are a hindcast of past metocean conditions; the overall trends reflected in this data will be broadly reflected in future conditions, but conditions on any given day during the actual dredging operations may be quite different.
- *The accuracy of dredge methodology inputs to the model*. Specification of the proposed dredge and disposal methodologies was provided by Woodside after consultation with the dredging contractors that may be engaged to perform the work. Any assumptions made to achieve a realistic representation of the dredging and disposal activities are outlined in Section 3.5 and were based on extensive past project experience.
- *The accuracy of the material properties input to the model*. Geotechnical information obtained during previous site investigations for the LNG Foundation Project was provided by Woodside (Woodside, 2018b) and is discussed in Section 3.6. From this data, the properties of the in situ material to be dredged are reasonably well-known. However, it is not possible to determine how the material properties will be changed by the action of the dredge and the mixing of the material with seawater in the process of pumping it to the hopper. Therefore, assumptions were made in the model with regard to the material that is released into the water column from dredging and the material properties of the sediments that are to be placed at the spoil grounds.
- *The accuracy of the dredging and disposal sediment source terms input to the model*. The source definition in the model is flexible and can be applied to any sediment source by specifying the time-varying flux rate, particle size distribution (PSD) and vertical profile in the water column. This information will be specific to the equipment used and the material encountered at the site, and therefore can only be determined with confidence from a pilot study at the site or field measurements during dredging. In the absence of such data, assumptions were made with regard to these parameters. The assumptions are outlined in Section 3.7 and were based on literature review, including the recent WAMSI Dredging Science Node reports, and extensive past project experience.

The major sources of uncertainty for the sediment fate modelling are the modelled dredging methodology and sediment source inputs to the model. The assumptions made were based on literature review and experience, and aimed to give a good representation of the sources of suspended sediment that will result from the proposed dredging, disposal and backfill activities. However, as there were uncertainties in the inputs to the model, the results should be considered as indicative of the expected ranges in magnitude and distribution of suspended sediments and sedimentation, rather than an exact prediction.

## 3.4 Model Domain and Bathymetry

The DREDGEMAP model domain established for the Scarborough dredging works extended approximately 95 km north-south by 115 km east-west (Figure 3.1). The model grid covers the section of the Western Australian coastline from Regnard Bay, south of West Intercourse Island, to Point Samson in the east. The offshore boundaries of the domain were imposed at a reasonable distance from the proposed dredging areas, to allow potential sediment drift patterns in offshore directions to be adequately captured.

This region lies within the model domain of the Delft3D hydrodynamic and wave models that provide the current and wave inputs to DREDGEMAP (see Section 2). A grid resolution of 100 m by 100 m was selected to ensure that existing features in the domain, including the many bays, islands and passages of the Dampier Archipelago, were adequately defined.

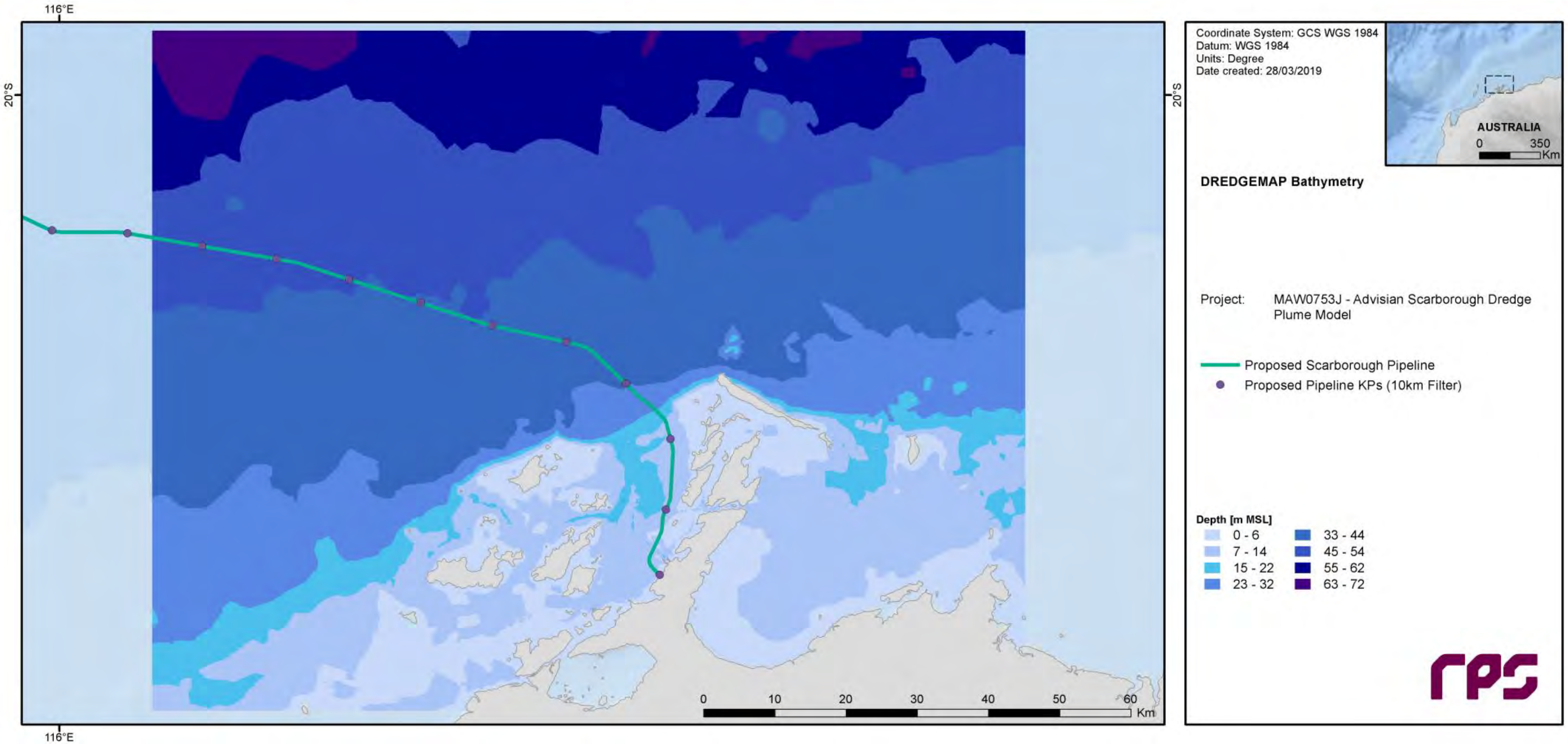


**Figure 3.1 DREDGEMAP model domain and bathymetry (m MSL).**

## 3.5 Dredging Project Description and Model Operational Assumptions

### 3.5.1 Overview

Information outlining the proposed dredging, disposal and backfill operations for the development of Scarborough has been drawn from the Scope of Work document (Advisian, 2018), subsequent email discussions, and input data provided by Woodside and its potential dredging contractors. At the time of commencement of modelling, the collated information represented the best available data with regard to geotechnical properties of the project areas, the dredging and construction methodologies expected to be used within these areas, and the typical characteristics of vessels that may be engaged for the work.

The operations modelled have been broken into two phases with four main activities:

- Phase 1 (Dredging):
  - Dredging of sediment along the pipeline route;
  - Disposal of dredged sediment at three nominated spoil grounds.
- Phase 2 (Backfilling):
  - Dredging of the borrow ground;
  - Backfill and stabilisation of the pipeline.

The pipeline route, spoil grounds and borrow grounds will cover State and Commonwealth Waters (Figure 1.1).

The following sections outline the details of the operations for each of these activities and highlight any assumptions that were made.

### 3.5.2 Methods and Equipment

#### 3.5.2.1 Pipeline Route Dredging

The material to be dredged from the pipeline route will consist mainly of marine sediments (approximately 3.8 $Mm^3$) and marine sediment/coarse material mix (approximately 0.2 $Mm^3$).

The dredging operations for the pipeline route have been divided into ten sections as outlined in Table 3.2, with seven of these sections requiring dredging. The dredging in each of the seven sections was assumed to be completed with either a backhoe dredge (BHD) or a trailing suction hopper dredge (TSHD). Typically, a TSHD will dredge unconsolidated sediments and a BHD will dredge sedimentary rock, and the quantities of each material type assumed in this case are detailed in Section 3.5.3. The assumed BHD bucket size was in the range of 20 $m^3$ (rock) to 30 $m^3$ (general purpose), while the TSHD hopper size was assumed to be 12,000 $m^3$ (filled 98% to capacity). It has been specified that overflow of fines from the TSHD hopper and dewatering of the split hopper barges that accompany the BHD will be permitted.

The estimated cycle times for dredging within each pipeline section where the BHD will operate are presented in Table 3.3, and those for each pipeline section where the TSHD will operate are presented in Table 3.4 (Woodside, 2018a).

The potential for sediment mobilisation by TSHD propeller-wash effects has been considered along all relevant pipeline sections. This has been done using supplied data on vessel characteristics, and local depth and seabed composition. For the purposes of the modelling assessment, the relevant specifications were as follows:

- Vessel draft: 10.0 m loaded and 6.0 m empty.
- Number of propellers: 2 (ducted).
- Diameter of propellers: 4.0 m.
- Thrust power: 5,800 kW per propeller.

**Table 3.2 Provisional outline of proposed pipeline dredging and disposal activities.**

| Pipeline Zone | Pipeline Location | Vessel | Task Description | Disposal Location |
|---|---|---|---|---|
| PRE1 | KP0.1 – KP0.6 | BHD & barges | Dredging of a 3.5 m deep trench. Dredging of pre-treated sediment if required. | AB |
| PRE2 | KP0.6 – KP3.6 | BHD & barges and TSHD | Dredging of a 3.5-4.0 m deep trench. | AB |
| PRE3 | KP3.6 – KP4.6 | TSHD | Clearing out of a pre-excavated trench across the NWS Shipping Channel. | AB |
| PRE4 | KP4.6 – KP6.2 | BHD & barges and TSHD | Dredging of a 3.0 m deep trench. | AB |
| PRE5 | KP6.2 – KP11.0 | N/A | No dredging. | N/A |
| PRE6 | KP11.0 – KP18.4 | TSHD | Dredging of a 2.0-3.0 m deep trench. | 2B |
| PRE7 | KP18.4 – KP19.3 | N/A | No dredging. | N/A |
| PRE8 | KP19.3 – KP21.3 | TSHD | Dredging of a 2.5-3.0 m deep trench. | 2B |
| PRE9 | KP21.3 – KP24.4 | N/A | No dredging. | N/A |
| PRE10 | KP24.4 – KP50.0 | TSHD | Dredging of a 2.5-3.5 m trench along sections with unconsolidated sediment. | 5A |

**Table 3.3 Estimated cycle times for each pipeline section where the BHD will be operating.**

| Pipeline Zone | Non-Dewatering Time (min) | Dewatering Time (min) | Disposal Time (min) | Sailing Time (min) | Total Cycle Time (min) |
|---|---|---|---|---|---|
| PRE1 | 90 | 360 | 20 | 84 | 464 |
| PRE2 | 160 | 640 | 20 | 72 | 732 |
| PRE4 | 160 | 640 | 20 | 48 | 708 |

**Table 3.4 Estimated cycle times for each pipeline section where the TSHD will be operating.**

| Pipeline Zone | Non-Overflow Time (min) | Overflow Time (min) | Disposal Time (min) | Sailing Time (min) | Total Cycle Time (min) |
|---|---|---|---|---|---|
| PRE2 | 45 | 210 | 20 | 77 | 352 |
| PRE3 | 45 | 210 | 20 | 64 | 339 |
| PRE4 | 45 | 210 | 20 | 58 | 333 |
| PRE6 | 45 | 210 | 20 | 102 | 377 |
| PRE8 | 45 | 210 | 20 | 83 | 358 |
| PRE10 | 45 | 210 | 20 | 40 | 315 |

#### 3.5.2.2 Spoil Ground Disposal

As outlined in Table 3.2, it was assumed that all material dredged by the BHD will be placed into a waiting split hopper barge and transported to the offshore disposal areas, while all material dredged by the TSHD will be transported directly to the offshore disposal areas.

It was assumed that the BHD will be accompanied by two split hopper barges, assumed to be approximately 3,800 $m^3$ in capacity, to be used for disposal of dredged material. Material discharges from the split hopper barges were assumed to occur between depths of 5.8 m and 1.5 m below mean sea level.

The TSHD hopper doors, from which discharge will occur, were assumed to be opened at a depth of 12.75 m below sea level. The modelled vessel draft will be reduced as spoil is discharged to a minimum depth of 8.75 m below sea level when empty.

The split hopper barges will be pushed or towed by a harbour tug. The potential for sediment mobilisation by tug propeller-wash effects has been considered along all relevant pipeline sections. This has been done using supplied data on vessel characteristics, and local depth and seabed composition. For the purposes of the modelling assessment, the relevant specifications were as follows:

- Vessel draft: 4.5 m (tug).
- Number of propellers: 2 (ducted).
- Diameter of propellers: 2.5 m.
- Thrust power: 1,850 kW per propeller.

The allocations of dredge spoil from each pipeline section to each spoil ground are shown in Table 3.5. It was assumed that the broad aim of the spoil disposal patterns will be to evenly distribute the total volume of allocated material across the entire spoil ground area by the conclusion of all activities, so the spacing of individual disposal operations (which are restricted to a comparatively small area within the spoil ground) was designed to achieve this.

Table 3.5 Anticipated spoil ground allocations of dredge volumes from each pipeline section.

| Spoil Ground | Pipeline Zone | Spoil Volume ($m^3$) | Spoil Ground Area ($m^2$) | Theoretical Thickness (m) |
|---|---|---|---|---|
| AB | PRE1-4 | 501,832 | 4,000,000 | 0.13 |
| 2B | PRE6 & 8 | 424,677 | 2,600,000 | 0.16 |
| 5A | PRE10 | 943,032 | 3,200,000 | 0.29 |

### 3.5.2.3 Borrow Ground Dredging

Dredging of backfill material from the borrow ground locations will consist of the removal of approximately 2 $Mm^3$ of sandy sediments with a low proportion of fines.

It was assumed that dredging of the borrow grounds will be conducted using a TSHD, with two options modelled. For Option A all material will be dredged from borrow ground A, and for Option B all material will be dredged from borrow ground B (Figure 1.1). The TSHD hopper size was assumed to be 9,700 $m^3$ (filled at a rate of approximately 90 $m^3$/min). It has been specified that overflow of fines from the TSHD hopper will be permitted.

The estimated cycle times for TSHD dredging within the borrow grounds and placement of material within each pipeline section are presented in Table 3.6 (Woodside, 2018a).

The pipeline route runs through the eastern edge of borrow ground B. Although the dredging and backfill activities are obviously not coincident in time, it has been assumed that dredging of backfill material will be restricted to approximately the western three-quarters of the borrow ground to avoid disturbing the previously-dredged pipeline route.

The potential for sediment mobilisation by TSHD propeller-wash effects has been considered in both borrow grounds. This has been done using supplied data on vessel characteristics, and local depth and seabed composition. For the purposes of the modelling assessment, the relevant specifications were as follows:

- Vessel draft: 10.0 m loaded and 6.0 m empty.
- Number of propellers: 2 (ducted).
- Diameter of propellers: 4.0 m.
- Thrust power: 5,800 kW per propeller.

Table 3.6 Estimated cycle times for each pipeline section where the TSHD will be placing material dredged from the borrow grounds.

| Pipeline Zone | Non-Overflow Time (min) | Overflow Time (min) | Placement Time (min) | Sailing Time (min) | Total Cycle Time (min) |
|---|---|---|---|---|---|
| POST2 | 30 | 74 | 107 | 46 | 257 |
| POST4 | 30 | 74 | 107 | 46 | 257 |
| POST6 | 30 | 74 | 107 | 53 | 264 |
| POST8 | 30 | 74 | 107 | 53 | 264 |
| POST10 | 30 | 74 | 107 | 58 | 269 |

### 3.5.2.4 Pipeline Route Backfill

The backfill operations for the pipeline route have been divided into ten sections as outlined in Table 3.7. It was assumed that rock backfill will be placed by a side-dump vessel and sand backfill will be placed by a TSHD.

The side-dump vessel was assumed to have a capacity of 4,500 tonnes with an average installation rate of approximately 2,250 tonnes/hr, with rock dumped from a fixed height at the sea surface. The TSHD hopper size was assumed to be 9,700 $m^3$ (emptied at a rate of approximately 90 $m^3$/min), with sand discharged through the suction pipe at an elevation of approximately 5 m above the pipeline.

The potential for sediment mobilisation by TSHD and side-dump vessel propeller-wash effects has been considered along the relevant pipeline sections. This has been done using supplied data on vessel characteristics, and local depth and seabed composition. For the purposes of the modelling assessment, the relevant specifications were as follows:

- Vessel draft:
  - 10.0 m loaded and 6.0 m empty (TSHD).
  - 4.8 m loaded (side-dump vessel).
- Number of propellers:
  - 2 (ducted; TSHD).
  - 2+2 (ducted; side-dump vessel).
- Diameter of propellers:
  - 4.0 m (TSHD).
  - 2.5 m (side-dump vessel).
- Thrust power:
  - 5,800 kW per propeller (TSHD).
  - 2 x 1,250 kW and 2 x 1,000 kW (side-dump vessel).

**Table 3.7 Provisional outline of proposed pipeline backfill and stabilisation activities.**

| Pipeline Zone | Pipeline Location | Vessel | Task Description | Borrow Location |
|---|---|---|---|---|
| POST1 | KP0.1 – KP0.6 | Side-dump vessel | Rock backfill (1.2-2.0 m cover over top of pipe). | Rock from the Nickol Bay Quarry. |
| POST2 | KP0.6 – KP3.6 | TSHD | Sand backfill (≥3.0 m cover over top of pipe). | Sand from the borrow grounds indicated in Figure 1.1. |
| POST3 | KP3.6 – KP4.6 | Side-dump vessel | Rock backfill (2.0 m cover over top of pipe). | Rock from the Nickol Bay Quarry. |
| POST4 | KP4.6 – KP6.2 | TSHD | Sand backfill (1.7-2.5 m cover over top of pipe). | Sand from the borrow grounds indicated in Figure 1.1. |
| POST5 | KP6.2 – KP11.0 | Side-dump vessel | No cover rock berm (flush to top of pipe). | Rock from the Nickol Bay Quarry. |
| POST6 | KP11.0 – KP18.4 | TSHD | Sand backfill (0.8-1.7 m cover over top of pipe). | Sand from the borrow grounds indicated in Figure 1.1. |
| POST7 | KP18.4 – KP19.3 | Side-dump vessel | No cover rock berm (flush to top of pipe). | Rock from the Nickol Bay Quarry. |
| POST8 | KP19.3 – KP21.3 | TSHD | Sand backfill (1.2-1.7 m cover over top of pipe). | Sand from the borrow grounds indicated in Figure 1.1. |
| POST9 | KP21.3 – KP24.4 | Side-dump vessel | No cover rock berm (flush to top of pipe). | Rock from the Nickol Bay Quarry. |
| POST10 | KP24.4 – KP50.0 | TSHD | Sand backfill (0.7-1.7 m cover over top of pipe). | Sand from the borrow grounds indicated in Figure 1.1. |

### 3.5.3 Quantities and Production Rates

For dredging of each section along the pipeline route, the proposed dredge depths, quantities for each material type, and production rates for each material type were specified for input to the modelling (Table 3.8). The table has two material categories, defined as “soft” (unconsolidated sediments) and “moderate” (calcareous sedimentary rock). It is understood that no “hard” material (andesite igneous rock) will be present due to its removal during capital dredging activities for the LNG Foundation Project (Woodside, 2018b).

For sand backfill of each relevant section along the pipeline route, which involves dredging of one of the two potential borrow grounds, the proposed quantities and production rates for each material type were specified for input to the modelling (Table 3.9). The sole material category within the borrow grounds was assumed to be unconsolidated sediments (“soft” material). It was also assumed that production rates for dredging at each potential borrow ground were identical.

For rock backfill section where rock is to be placed, quantities for each material category were specified (Table 3.10).

It is understood that:

- The estimated material quantities were based on the latest surveyed bathymetry and a geotechnical model incorporating existing geotechnical data;
- The estimated production rates were based on the material type and equipment that may be used for dredging;
- The estimated production rates were average values inclusive of expected downtime estimates.

**Table 3.8 Modelled dredge depths, quantities of material type, and production rates by material type for dredging of each pipeline section.**

| Pipeline Zone | Dredge Depth (m CD) | Dredged Quantities ($m^3$) | | | Production Rates ($m^3$/week) | |
|---|---|---|---|---|---|---|
| | Target | Soft Material | Moderate Material | Total | Soft Material | Moderate Material |
| PRE1 | +4.3 / -5.5 | 13,811 | 10,131 | 23,942 | 40-60,000 | 15-20,000 |
| PRE2 | -13.1 / -11.1 | 216,995 | 21,256 | 238,251 | 175-225,000 | 15-20,000 |
| PRE3 | -10.7 / -18.6 | 131,992 | - | 131,992 | 175-225,000 | - |
| PRE4 | -9.7 / -11.3 | 87,890 | 19,760 | 107,650 | 175-225,000 | 15-20,000 |
| PRE6 | -13.0 / -16.0 | 349,334 | - | 349,334 | 175-225,000 | - |
| PRE8 | -14.4 / -17.7 | 75,343 | - | 75,343 | 175-225,000 | - |
| PRE10 | -24.0 / -44.9 | 943,032 | - | 943,032 | 175-225,000 | - |
| | **Totals** | **1,818,397** | **51,147** | **1,869,544** | - | - |

**Table 3.9 Modelled quantities of material type and production rates by material type for dredging of sand backfill material for each pipeline section from the borrow grounds.**

| Pipeline Zone | Dredged/Backfill Quantities ($m^3$) | Production Rates ($m^3$/week) |
|---|---|---|
| | Soft Material | Soft Material |
| POST2 | 159,992 | 325,000 |
| POST4 | 80,394 | 325,000 |
| POST6 | 349,334 | 325,000 |
| POST8 | 75,343 | 325,000 |
| POST10 | 943,032 | 325,000 |
| **Totals** | **1,608,095** | **-** |

**Table 3.10 Modelled quantities of material type for placement of rock backfill material within each pipeline section.**

| Pipeline Zone | Backfill Quantities ($m^3$) | | |
|---|---|---|---|
| | Material Category 1 | Material Category 2 | Total |
| POST1 | 4,577 | 5,399 | 9,976 |
| POST3 | 8,395 | 21,979 | 30,374 |
| POST5 | 6,384 | 10,032 | 16,416 |
| POST7 | 2,170 | 3,410 | 5,580 |
| POST9 | 4,270 | 6,710 | 10,980 |
| **Totals** | **25,896** | **47,530** | **73,426** |

### 3.5.4 Schedules

For dredging of each section along the pipeline route, the proposed duration and sequencing of operations has been specified for input to the modelling (Table 3.11). The table has two material categories, as described in Section 3.5.3.

The sequence of dredging has been assumed to start in zone PRE1 and proceed consecutively to zone PRE10. Modelling of each section involves a series of dredging and related disposal activities. Allocations of spoil material from each pipeline section to each of the three spoil grounds are outlined in Table 3.2.

For backfill of each section along the pipeline route, the proposed duration and sequencing of operations has been specified for input to the modelling (Table 3.12). The table has two material categories, as described in Section 3.5.3.

The sequence of backfilling has been assumed to involve completing all sand backfill tasks (proceeding consecutively from zone POST2 to zone POST10) and then completing all rock backfill tasks (proceeding consecutively from zone POST1 to zone POST9). Modelling of each section involves a series of dredging and related backfill activities. For the pipeline sections where rock backfill will be placed, no associated borrow ground dredging will occur.

**Table 3.11 Modelled durations of dredging and disposal operations by material type for each pipeline section.**

| Pipeline Zone | Duration of Operations (weeks) | | |
|---|---|---|---|
| | Material Category 1 | Material Category 2 | Total |
| PRE1 | 0.3 | 0.6 | 0.9 |
| PRE2 | 0.9 | 1.2 | 2.1 |
| PRE3 | 0.5 | - | 0.5 |
| PRE4 | 0.4 | 1.1 | 1.5 |
| PRE6 | 1.4 | - | 1.4 |
| PRE8 | 0.3 | - | 0.3 |
| PRE10 | 3.8 | - | 3.8 |
| **Totals** | **7.6** | **2.9** | **10.5** |

**Table 3.12 Modelled durations of dredging and backfill operations by material type for each pipeline section.**

| Pipeline Zone | Duration of Operations (weeks) | | |
|---|---|---|---|
| | Material Category 1 | Material Category 2 | Total |
| POST1 | 0.2 | 0.2 | 0.4 |
| POST2 | 1.0 | 0.0 | 1.0 |
| POST3 | 0.3 | 0.9 | 1.2 |
| POST4 | 0.5 | 0.0 | 0.5 |
| POST5 | 0.3 | 0.4 | 0.7 |
| POST6 | 2.0 | 0.0 | 2.0 |
| POST7 | 0.1 | 0.1 | 0.2 |
| POST8 | 0.5 | 0.0 | 0.5 |
| POST9 | 0.2 | 0.3 | 0.5 |
| POST10 | 6.0 | 0.0 | 6.0 |
| **Totals** | **11.1** | **1.9** | **13.0** |

### 3.5.5 Scenario Summary

The provisional schedule for the dredging works indicates a July 2021 start for dredging of the pipeline route followed by a December 2021 start for backfill and stabilisation works. Analysis of wind data in the region from 1993-2017 has shown that the period of 2016-2017 is likely to be representative of typical conditions. The dredge modelling simulations were conducted using hydrodynamic and wave data drawn from this period, with nominal start dates for model simulation purposes being chosen as 1st July 2016 (winter) and 1st January 2017 (summer).

A summary of the scenarios that were modelled is as follows:

- Dredging works to commence on 1st July 2016 (winter start):
  - Option A: dredging of backfill material from borrow ground A (Scenario 1A).
    - TSHD dredging and disposal operations were programmed to occur between 1st July 2016 and 21st August 2016.
    - BHD dredging and disposal operations were programmed to occur between 21st August 2016 and 10th September 2016.
    - A simulation run-on period was assumed to occur between 10th September 2016 and 1st December 2016. Sediments suspended in the water column during previous operations were subject to settlement and progressively-reducing levels of resuspension during this time.
    - TSHD dredging and sand backfill operations were programmed to occur between 1st December 2016 and 9th February 2017.
    - Side-dump vessel rock backfill operations were programmed to occur between 9th February 2017 and 2nd March 2017.

- A further simulation run-on period was assumed to occur between 2nd March 2017 and 30th April 2017. Sediments suspended in the water column during previous operations were subject to settlement and progressively-reducing levels of resuspension during this time.

  - Option B: dredging of backfill material from borrow ground B (Scenario 1B).
    - Sequence of operations as per Option A, but with the use of the alternate borrow ground.

- Dredging works to commence on 1st January 2017 (summer start):
  - Option A: dredging of backfill material from borrow ground A (Scenario 2A).
    - TSHD dredging and disposal operations were programmed to occur between 1st January 2017 and 21st February 2017.
    - BHD dredging and disposal operations were programmed to occur between 21st February 2017 and 13th March 2017.
    - A simulation run-on period was assumed to occur between 13th March 2017 and 1st June 2017. Sediments suspended in the water column during previous operations were subject to settlement and progressively-reducing levels of resuspension during this time.
    - TSHD dredging and sand backfill operations were programmed to occur between 1st June 2017 and 10th August 2017.
    - Side-dump vessel rock backfill operations were programmed to occur between 10th August 2017 and 31st August 2017.
    - A further simulation run-on period was assumed to occur between 31st August 2017 and 31st October 2017. Sediments suspended in the water column during previous operations were subject to settlement and progressively-reducing levels of resuspension during this time.
  - Option B: dredging of backfill material from borrow ground B (Scenario 2B).
    - Sequence of operations as per Option A, but with the use of the alternate borrow ground.

The outcomes of the summer-start and winter-start scenarios have been analysed and presented separately, for comparison, in Section 5. The outcomes of each borrow ground dredging option have also been analysed and presented separately for each of the two seasonal scenarios.

## 3.6 Geotechnical Information

The dredged material from the pipeline route will consist mainly of marine sediments (approximately 3.8 $Mm^3$) and marine sediment/coarse material mix (approximately 0.2 $Mm^3$). The backfill material to be dredged from the borrow ground locations will consist of the removal of 2 $Mm^3$ of sandy sediments with a low proportion of fines.

The critical geotechnical information required as input to the modelling is PSD data for the sediments to be dredged along the pipeline route, for the sediments to be dredged from the borrow grounds and for the quarry-rock material.

This data has been specified (Woodside, 2018b) for the dredging and sand backfill operations relating to each pipeline section. The resultant PSDs for each pipeline section have been redistributed to match the material size classes used in the DREDGEMAP model, as shown in Table 3.13, Table 3.14 and Table 3.15.

For the rock backfill operations, in the absence of grading information it has been conservatively assumed that the fraction of material within the quarry rubble classified as “fines” in this context (diameters less than 100 mm) will be 5% of the total volume. From experience, this is a typical upper limit for the “fines” fraction of well-graded limestone rubble, with the breakdown of this figure into smaller size classes usually unknown. Although the most conservative approach would be to further assume that all of the “fines” material is potentially available for resuspension into the water column, the assumed PSD has been heavily slanted towards the least-mobile coarse sand (>130 µm) category to account for the typically minimal proportion of the finest material categories. The chosen PSD is shown in Table 3.16.

The PSD data for borrow ground A can be characterised mainly as coarse sand with a low fines fraction, with coarseness and layer thickness increasing towards the eastern part of the borrow ground. For modelling purposes, PSDs measured close to the proposed trunkline route between KP30 and KP50 have been used. These PSDs consider a medium sand with higher fines content and are thus considered conservative.

The PSD data for borrow ground B is aligned with measured PSDs close to the proposed trunkline route between KP14 and KP19. For backfill purposes, a material with a PSD curve showing a $d_{10}$ > 100 µm and a $d_{50}$ > 300 µm is required to ensure the long-term stability of the pipeline. Borrow ground B is expected to have a substantially lower yield of acceptable material for trench backfill use.

In addition to PSD information, data and assumptions relating to the dry bulk density of the material to be dredged from the pipeline route and borrow grounds, and of the quarry-rock material, was used as input to the modelling. A typical average dry bulk density value of 2,150 kg/m$^3$ was assumed.

**Table 3.13 In situ PSDs broken down into DREDGEMAP material classes for each pipeline section to be dredged, derived from available geotechnical information.**

| Sediment Grain Size Class | Size Range (µm) | Zone PRE1 (%) | Zone PRE2 (%) | Zone PRE3 (%) | Zone PRE4 (%) | Zone PRE6 (%) | Zone PRE8 (%) | Zone PRE10 (%) |
|---|---|---|---|---|---|---|---|---|
| Clay | <7 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 (<KP16.5) 1.0 (>KP16.5) | 1.0 | 8.0 (<KP30) 2.5 (>KP30) |
| Fine Silt | 8-34 | 14.0 | 14.0 | 14.0 | 14.0 | 14.0 (<KP16.5) 1.0 (>KP16.5) | 1.0 | 12.0 (<KP30) 2.5 (>KP30) |
| Coarse Silt | 35-74 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 (<KP16.5) 4.0 (>KP16.5) | 4.0 | 14.0 (<KP30) 10.0 (>KP30) |
| Fine Sand | 75-130 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 (<KP16.5) 2.0 (>KP16.5) | 2.0 | 14.0 (<KP30) 15.0 (>KP30) |
| Coarse Sand | >130 | 40.0 | 40.0 | 40.0 | 40.0 | 40.0 (<KP16.5) 92.0 (>KP16.5) | 92.0 | 52.0 (<KP30) 70.0 (>KP30) |

Table 3.14 In situ PSDs broken down into DREDGEMAP material classes for the sand backfill material of each pipeline section if it were dredged from borrow ground A, derived from available geotechnical information.

| Sediment Grain Size Class | Size Range (µm) | Zone POST2 (%) | Zone POST4 (%) | Zone POST6 (%) | Zone POST8 (%) | Zone POST10 (%) |
|---|---|---|---|---|---|---|
| Clay | <7 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 |
| Fine Silt | 8-34 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 |
| Coarse Silt | 35-74 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 |
| Fine Sand | 75-130 | 15.0 | 15.0 | 15.0 | 15.0 | 15.0 |
| Coarse Sand | >130 | 70.0 | 70.0 | 70.0 | 70.0 | 70.0 |

Table 3.15 In situ PSDs broken down into DREDGEMAP material classes for the sand backfill material of each pipeline section if it were dredged from borrow ground B, derived from available geotechnical information.

| Sediment Grain Size Class | Size Range (µm) | Zone POST2 (%) | Zone POST4 (%) | Zone POST6 (%) | Zone POST8 (%) | Zone POST10 (%) |
|---|---|---|---|---|---|---|
| Clay | <7 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Fine Silt | 8-34 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Coarse Silt | 35-74 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 |
| Fine Sand | 75-130 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 |
| Coarse Sand | >130 | 92.0 | 92.0 | 92.0 | 92.0 | 92.0 |

Table 3.16 In situ PSDs broken down into DREDGEMAP material classes for the rock backfill material of each pipeline section, assumed as typical values for well-graded limestone rubble.

| Sediment Grain Size Class | Size Range (µm) | Zone POST1 (%) | Zone POST3 (%) | Zone POST5 (%) | Zone POST7 (%) | Zone POST9 (%) |
|---|---|---|---|---|---|---|
| Clay | <7 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Fine Silt | 8-34 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Coarse Silt | 35-74 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Fine Sand | 75-130 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Coarse Sand | >130 | 98.0 | 98.0 | 98.0 | 98.0 | 98.0 |

# 3.7 Model Sediment Sources

## 3.7.1 Overview

To accurately represent the pipeline dredging, disposal and backfill operations in DREDGEMAP, a range of information was defined for the proposed operations, including dredge, disposal and backfill methodology, production rates, sediment/rock types and quantities (see Section 3.5). It is evident that there will be seven different sources of suspended sediment plumes during dredging, disposal and backfill operations, which can be broadly defined as:

- Direct suspension of material from the BHD bucket, from grabbing and lifting unconsolidated sediments and sedimentary rock through the water column, accounting for periods of no-dewatering and dewatering from the split hopper barge;
- Disposal of sediment and rock excavated by the BHD from split hopper barges to the nominated spoil grounds;
- Direct suspension of material by the TSHD during dredging of unconsolidated sediments, accounting for no-overflow and overflow periods;
- Disposal of sediment dredged by the TSHD to the nominated spoil grounds;
- Indirect suspension of material due to the propeller wash of the BHD barge tug and TSHD while dredging;
- Suspension of material during backfill activities, via TSHD, using sediments dredged from the borrow ground;
- Suspension of material during backfill activities, via side-dump vessel, using rock from onshore quarries.

Each of these sources of suspended sediment plumes will vary in strength and persistence depending on the nature of the operations. In the DREDGEMAP model, each source is defined by specifying the time-varying flux rate, PSD and vertical profile in the water column. The following sections outline how the information provided has been used to represent the dredging operations in the model and explain any assumptions that have been made to supplement the available information.

## 3.7.2 Representation of BHD Dredging

A BHD will be used to excavate all unconsolidated sediments and sedimentary rock material from zone PRE1, and all sedimentary rock material from zones PRE2 and PRE4 (following TSHD dredging of unconsolidated sediments in these zones). The BHD will use a large excavator arm fitted with an open bucket of (nominally) 20-30 $m^3$ capacity. The excavator will lift material in the bucket and deliver it to one of two waiting split hopper barges – assumed for the purposes of modelling to be 3,800 $m^3$ in capacity – for transport to spoil ground AB for disposal.

Sources of sediment suspension from this type of operation include:

- Disturbance of the seabed sediments by the excavator bucket;
- Dewatering of the split hopper barge, resulting in the discharge of water and entrained sediments.

Past observations have shown that material is suspended due to the initial grab at the seabed. Further suspension is generated as sediment spills from the bucket as it is lifted through the water column. Spillage of water and sediment also occurs as the bucket breaks free of the water surface and drains freely. Only sediments <130 μm in diameter are considered “lost” (i.e. suspended into the water column), because the coarser material spilled from the bucket while being lifted to the surface will fall immediately to the bottom where it will be re-dredged during subsequent grabs. As such, the distribution of material suspended by the bucket spillage is assumed to be distributed across the four smaller sediment size classes in the model.

For the dredging of the unconsolidated sediments during periods with no dewatering from the barge, the PSD used in the model is based on PSDs from nearby boreholes (see Section 3.6), with the proportion >130 µm removed and the remaining distribution normalised to 100% by scaling up the proportions in the four remaining size classes (Table 3.17). The same PSD is used for the sedimentary rock component, assuming that due to the excavation action of the BHD the rock will break down into similar proportions of fines. Because the dredging action of the excavator involves no cutting or hydraulic pumping, this is a conservative assumption. During dewatering periods, an increase in the rate of release of fine sediments, and hence initial turbidity, is observed (Anchor Environmental, 2003). The water released during dewatering of the barge contains a high proportion of fines because the coarse material settles rapidly in the barge while the fine material remains in suspension. After the barge begins dewatering, a PSD heavily weighted towards finer particles has been assumed based on previous field measurements of hopper barge dewatering at Geraldton Port (OPR, 2010), with the proportion >75 µm removed and the remaining distribution normalised to 100% by scaling up the proportions in the three remaining size classes (Table 3.18).

Table 3.19 shows the assumed vertical distribution of the suspended material during the BHD operations while the barge is not dewatering. The distribution is higher at the seabed and water surface, to represent the larger loss rate of material during the initial grab and as the bucket breaks free of the water column. After the barge begins dewatering, a uniform distribution of sediments throughout the water column, between the hull depth and the seabed, has been assumed to represent a continuous stream of material being discharged from the barge (Table 3.20).

**Table 3.17 Assumed PSDs of sediments initially suspended into the water column during BHD dredging operations along the pipeline route while the barge is not dewatering.**

| Sediment Grain Size Class | Size Range (µm) | PSD (%) for Sediment and Sedimentary Rock Removal – Zone PRE1 | PSD (%) for Sedimentary Rock Removal – Zone PRE2 | PSD (%) for Sedimentary Rock Removal – Zone PRE4 |
|---|---|---|---|---|
| Clay | <7 | 16.7 | 16.7 | 16.7 |
| Fine Silt | 8-34 | 23.3 | 23.3 | 23.3 |
| Coarse Silt | 35-74 | 26.7 | 26.7 | 26.7 |
| Fine Sand | 75-130 | 33.3 | 33.3 | 33.3 |
| Coarse Sand | >130 | 0.0 | 0.0 | 0.0 |

**Table 3.18 Assumed PSDs of sediments initially suspended into the water column during BHD dredging operations along the pipeline route while the barge is dewatering.**

| Sediment Grain Size Class | Size Range (µm) | PSD (%) for Sediment and Sedimentary Rock Removal – Zone PRE1 | PSD (%) for Sedimentary Rock Removal – Zone PRE2 | PSD (%) for Sedimentary Rock Removal – Zone PRE4 |
|---|---|---|---|---|
| Clay | <7 | 43.0 | 43.0 | 43.0 |
| Fine Silt | 8-34 | 30.2 | 30.2 | 30.2 |
| Coarse Silt | 35-74 | 26.8 | 26.8 | 26.8 |
| Fine Sand | 75-130 | 0.0 | 0.0 | 0.0 |
| Coarse Sand | >130 | 0.0 | 0.0 | 0.0 |

**Table 3.19 Assumed vertical distribution of sediments initially suspended into the water column during BHD dredging operations along the pipeline route while the barge is not dewatering.**

| Elevation | Example Elevation (m ASB) – 10 m Water Depth | Vertical Distribution (%) of Sediments |
|---|---|---|
| Surface/water depth | 10.0 | 23.0 |
| 0.8 x water depth | 8.0 | 16.0 |
| 0.5 x water depth | 5.0 | 14.0 |
| 0.3 x water depth | 3.0 | 19.0 |
| 0.1 x water depth | 1.0 | 28.0 |

**Table 3.20 Assumed vertical distribution of sediments initially suspended into the water column during BHD dredging operations along the pipeline route while the barge is dewatering.**

| Elevation | Example Elevation (m ASB) – 10 m Water Depth and 5.8 m Hull Depth | Vertical Distribution (%) of Sediments |
|---|---|---|
| Hopper hull elevation | 4.2 | 20.0 |
| 0.75 x hull elevation | 3.2 | 20.0 |
| 0.50 x hull elevation | 2.1 | 20.0 |
| 0.25 x hull elevation | 1.0 | 20.0 |
| 0.50 m (ASB) | 0.5 | 20.0 |

Loss rates from similar operations are known to vary based on such factors as the size and type of bucket (i.e. open or closed), nature of the seabed material, presence of debris, current speed and depth of water, as well as the care of the operator (Hayes & Wu, 2001; Anchor Environmental, 2003). Reported rates compared by Anchor Environmental (2003) varied from 0.1% to 10%, with a mean of 2.1%. In the absence of measurements for the specific situation and equipment, the mean of 2.1% of production rate is assumed for all BHD operations during periods with no dewatering, and a rate of 2.4% of production rate is assumed for all BHD operations during dewatering periods. The latter value is in line with the overflow rate calculated for the TSHD hopper overflow (see Section 3.7.4).

### 3.7.3 Representation of Disposal of BHD-Dredged Material

All material dredged by the BHD will be placed into one of two waiting 3,800 $m^3$ split hopper barges and transported (by harbour tug) to spoil ground AB for disposal. This material will include all unconsolidated sediments and sedimentary rock material from zone PRE1, and all sedimentary rock material from zones PRE2 and PRE4.

For the disposal of the unconsolidated sediments dredged by BHD, the PSD used in the model is based on PSDs from nearby boreholes (see Section 3.6). The same PSD is used for the sedimentary rock component, assuming that due to the excavation action of the BHD the rock will break down into similar proportions of fines. Because the dredging action of the excavator involves no cutting or hydraulic pumping, this is a conservative assumption. This PSD is adjusted by removal of the component treated as suspended during dredging (see Section 3.7.2), but as this represents only 2.1% of the mass for the minor components, the modified PSD is not significantly different to the in situ PSD (Table 3.21).

Once at the AB spoil ground, the split hopper barge will open to release the sediments from the bottom of the hull at a depth of approximately 5.8 m below sea level. Previous observations of sediment dumping from hopper vessels (e.g. CSMW, 2005) have shown that there is an initial rapid descent of solids, with the heavy particles tending to entrain lighter particles, followed by a billowing of lighter components back into the water column after contact with the seabed (Figure 3.2). A proportion of the lighter components will also remain suspended and may be trapped by density layers, if present.

Because simulations in this study focused on the far-field fate of sediment particles due to transport and sinking after the initial dump phase, simulations were run with the initial vertical distribution specified to represent the post-collision phase for a case where a high proportion of the sediments are resuspended after collision with the seabed. To represent this, an assumed vertical distribution for the sediments (Table 3.22) has been specified following published information from previous hopper disposal operations (CSMW, 2005; NEPA, 2001). This vertical distribution, with the majority of the material input near the seabed and only 7% of the material released in the upper half of the water column, is in line with values quoted in the recent literature review by Mills & Kemps (2016), which found that sediment resuspension from individual dredged material disposal events was generally less than 10% of the disposed material load.

It is estimated that 95-99% of the bulk load deposits directly onto the seabed in a typical case, with the remainder released into the water column (CSMW, 2005, NEPA, 2001). It is difficult to find other definitive source values in the literature, but a value of 5% of each load agrees well with past experience and appears to be a conservative estimate based on the values quoted above. Accordingly, 5% of each hopper load was placed in suspension in the water column in the sediment fate model.

In addition to the proportion of material immediately suspended in the water column, disposal from the barge will result in the stockpiling of sediment as a mound on the seabed that will be subject to resuspension by tidal and wave forces. Because fine sediments in the deposited mass may be subject to ongoing resuspension and dispersion over time, it was necessary to specify the deposits as a further source of sediment potentially subject to resuspension. For this purpose, it was assumed that 5% of the deposited mass – representing the upper surface layer – would be subject to resuspension. It should be noted that the model maintains a mass balance estimate of the remaining sediment of each size class within each grid cell to derive an estimate of the median particle size in the surface-layer sediments. In turn, the potential for ongoing resuspension of fines is calculated. In this way, the model represents the increased armouring of sediments as the average particle size increases.

The disposal time for the barge material within each dredge cycle was assumed to be 20 minutes (Table 3.3). The disposal location within spoil ground AB was varied for each dredge cycle in a randomised manner, with the ultimate aim of ensuring an even distribution of dredged material within the spoil ground by the conclusion of all activities.

**Table 3.21 Assumed PSDs of sediments initially suspended into the water column during split hopper barge disposal operations at spoil ground AB.**

| Sediment Grain Size Class | Size Range (µm) | PSD (%) for Sediment and Sedimentary Rock Disposal – Zone PRE1 | PSD (%) for Sedimentary Rock Disposal – Zone PRE2 | PSD (%) for Sedimentary Rock Disposal – Zone PRE4 |
|---|---|---|---|---|
| Clay | <7 | 9.7 | 9.7 | 9.7 |
| Fine Silt | 8-34 | 13.5 | 13.5 | 13.5 |
| Coarse Silt | 35-74 | 15.4 | 15.4 | 15.4 |
| Fine Sand | 75-130 | 19.3 | 19.3 | 19.3 |
| Coarse Sand | >130 | 42.1 | 42.1 | 42.1 |

**Table 3.22 Assumed vertical distribution of sediments initially suspended into the water column during split hopper barge disposal operations at spoil ground AB.**

| Elevation | Example Elevation (m ASB) – 10 m Water Depth | Vertical Distribution (%) of Sediments |
|---|---|---|
| Surface/water depth | 10.0 | 2.0 |
| 0.6 x water depth | 6.0 | 5.0 |
| 0.4 x water depth | 4.0 | 15.0 |
| 0.15 x water depth | 1.5 | 35.0 |
| 0.1 x water depth | 1.0 | 43.0 |

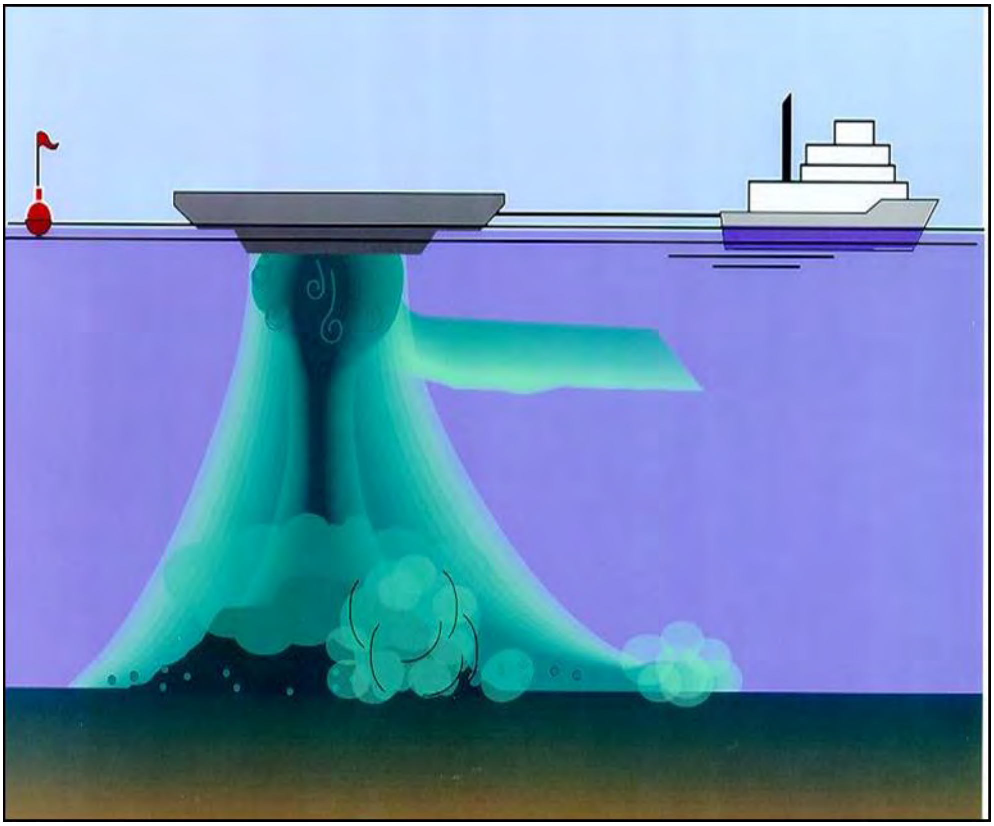

Figure 3.2 **Conceptual diagram showing the general behaviour of sediments dumped from a split hopper barge and the vertical distribution of material set up by entrainment and billowing (source: ASA, 2004).**

### 3.7.4 Representation of TSHD Dredging

A TSHD will be used to excavate all unconsolidated sediments from zones PRE2, PRE3 and PRE4 with disposal at spoil ground AB, zones PRE6 and PRE8 with disposal at spoil ground 2B, and zone PRE10 with disposal at spoil ground 5A. A smaller TSHD will be used to dredge backfill material from the borrow grounds, with disposal along the pipeline route. For the purposes of modelling, the capacities of the TSHDs to be used for dredging of the pipeline route and borrow grounds were assumed as 12,000 $m^3$ and 9,700 $m^3$, respectively.

TSHD vessels remove sediments by dragging a large drag-head over the seabed and drawing up the disturbed sediment by hydraulic suction. Sources of sediment suspension from this type of operation include:

- Hydraulic disturbance of the seabed sediments by the trailing arm;
- Propeller-wash generated as the vessel manoeuvres;
- Overflow of the on-board hoppers, resulting in the discharge of water and entrained sediments.

The characteristics of each of these sources vary greatly due to a wide range of factors (USACE, 2008) making the generalisation of source terms difficult. It appears however, that the overflow source term is dominant, being typically an order of magnitude greater than the drag-head and propeller-wash terms.

For the dredging of the unconsolidated sediments during periods with no overflow, the PSDs used in the model are based on PSDs from nearby boreholes (see Section 3.6). The PSDs applied to dredging along the pipeline route and within the borrow grounds are shown in Table 3.23 and Table 3.25, respectively. During overflow periods, an increase in the rate of release of fine sediments, and hence initial turbidity, is observed (Anchor Environmental, 2003). The overflow water contains a high proportion of fines because the coarse material settles rapidly in the hopper while the fine material remains in suspension. After the hopper begins overflowing, PSDs heavily weighted towards finer particles has been assumed based on previous field measurements of hopper barge overflow at Geraldton Port (OPR, 2010), with the proportion >75 µm removed and the remaining distribution normalised to 100% by scaling up the proportions in the three remaining size classes. The PSDs applied to dredging along the pipeline route and within the borrow grounds are shown in Table 3.24 and Table 3.26, respectively.

Table 3.27 shows the assumed vertical distribution of the suspended material during the TSHD operations while the hopper is not overflowing. The distribution is concentrated near the seabed and decreases in intensity towards the surface, to represent the disturbance of seabed material by the drag-head and propeller-wash effects (HR Wallingford, 2003). After the hopper begins overflowing, a uniform distribution of sediments throughout the water column, between the hull depth and the seabed, has been assumed to represent a continuous stream of material being discharged from the hopper (Table 3.28). This is consistent with measured ADCP profiles presented by Hitchcock & Bell (2004), which show a reasonably even distribution of sediment through the water column during hopper overflow.

**Table 3.23 Assumed PSDs of sediments initially suspended into the water column during TSHD dredging operations along the pipeline route while the hopper <u>is not</u> overflowing.**

| Sediment Grain Size Class | Size Range (µm) | PSD (%) for Sediment Removal – Zone PRE2 | PSD (%) for Sediment Removal – Zone PRE3 | PSD (%) for Sediment Removal – Zone PRE4 | PSD (%) for Sediment Removal – Zone PRE6 | PSD (%) for Sediment Removal – Zone PRE8 | PSD (%) for Sediment Removal – Zone PRE10 |
|---|---|---|---|---|---|---|---|
| Clay | <7 | 10.0 | 10.0 | 10.0 | 10.0 (<KP16.5) 1.0 (>KP16.5) | 1.0 | 8.0 (<KP30) 2.5 (>KP30) |
| Fine Silt | 8-34 | 14.0 | 14.0 | 14.0 | 14.0 (<KP16.5) 1.0 (>KP16.5) | 1.0 | 12.0 (<KP30) 2.5 (>KP30) |
| Coarse Silt | 35-74 | 16.0 | 16.0 | 16.0 | 16.0 (<KP16.5) 4.0 (>KP16.5) | 4.0 | 14.0 (<KP30) 10.0 (>KP30) |
| Fine Sand | 75-130 | 20.0 | 20.0 | 20.0 | 20.0 (<KP16.5) 2.0 (>KP16.5) | 2.0 | 14.0 (<KP30) 15.0 (>KP30) |
| Coarse Sand | >130 | 40.0 | 40.0 | 40.0 | 40.0 (<KP16.5) 92.0 (>KP16.5) | 92.0 | 52.0 (<KP30) 70.0 (>KP30) |

Table 3.24 Assumed PSDs of sediments initially suspended into the water column during TSHD dredging operations along the pipeline route while the hopper is overflowing.

| Sediment Grain Size Class | Size Range (µm) | PSD (%) for Sediment Removal – Zone PRE2 | PSD (%) for Sediment Removal – Zone PRE3 | PSD (%) for Sediment Removal – Zone PRE4 | PSD (%) for Sediment Removal – Zone PRE6 | PSD (%) for Sediment Removal – Zone PRE8 | PSD (%) for Sediment Removal – Zone PRE10 |
|---|---|---|---|---|---|---|---|
| Clay | <7 | 43.0 | 43.0 | 43.0 | 43.0 (<KP16.5) 52.7 (>KP16.5) | 52.7 | 52.7 (<KP30) 44.3 (>KP30) |
| Fine Silt | 8-34 | 30.2 | 30.2 | 30.2 | 30.2 (<KP16.5) 26.4 (>KP16.5) | 26.4 | 26.4 (<KP30) 29.8 (>KP30) |
| Coarse Silt | 35-74 | 26.8 | 26.8 | 26.8 | 26.8 (<KP16.5) 20.9 (>KP16.5) | 20.9 | 20.9 (<KP30) 25.9 (>KP30) |
| Fine Sand | 75-130 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Coarse Sand | >130 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

Table 3.25 Assumed PSDs of sediments initially suspended into the water column during TSHD dredging operations at borrow grounds A and B while the hopper is not overflowing.

| Sediment Grain Size Class | Size Range (µm) | PSD (%) for Sediment Removal – Borrow Ground A | PSD (%) for Sediment Removal – Borrow Ground B |
|---|---|---|---|
| Clay | <7 | 2.5 | 1.0 |
| Fine Silt | 7-34 | 2.5 | 1.0 |
| Coarse Silt | 35-74 | 10.0 | 4.0 |
| Fine Sand | 75-130 | 15.0 | 2.0 |
| Coarse Sand | >130 | 70.0 | 92.0 |

Table 3.26 Assumed PSDs of sediments initially suspended into the water column during TSHD dredging operations at borrow grounds A and B while the hopper is overflowing.

| Sediment Grain Size Class | Size Range (µm) | PSD (%) for Sediment Removal – Borrow Ground A | PSD (%) for Sediment Removal – Borrow Ground B |
|---|---|---|---|
| Clay | <7 | 49.2 | 52.7 |
| Fine Silt | 7-34 | 25.5 | 26.4 |
| Coarse Silt | 35-74 | 25.3 | 20.9 |
| Fine Sand | 75-130 | 0.0 | 0.0 |
| Coarse Sand | >130 | 0.0 | 0.0 |

**Table 3.27 Assumed vertical distribution of sediments initially suspended into the water column during TSHD dredging operations along the pipeline route and at borrow grounds A and B while the hopper is not overflowing.**

| Elevation | Example Elevation (m ASB) – 30 m Water Depth | Vertical Distribution (%) of Sediments |
|---|---|---|
| 10.0 m (ASB) | 10.0 | 5.0 |
| 7.0 m (ASB) | 7.0 | 15.0 |
| 3.0 m (ASB) | 3.0 | 20.0 |
| 2.0 m (ASB) | 2.0 | 40.0 |
| 1.0 m (ASB) | 1.0 | 20.0 |

**Table 3.28 Assumed vertical distribution of sediments initially suspended into the water column during TSHD dredging operations along the pipeline route and at borrow grounds A and B while the hopper is overflowing.**

| Elevation | Example Elevation (m ASB) – 30 m Water Depth and 10 m Hull Depth | Vertical Distribution (%) of Sediments |
|---|---|---|
| Hopper hull elevation | 20.0 | 20.0 |
| 0.75 x hull elevation | 15.0 | 20.0 |
| 0.50 x hull elevation | 10.0 | 20.0 |
| 0.25 x hull elevation | 5.0 | 20.0 |
| 0.50 m (ASB) | 0.5 | 20.0 |

The resuspension of sediment when the TSHD hopper is not overflowing was estimated by combining the drag-head and propeller-wash terms. The propeller-wash component typically dominates the drag-head component, but both sources were assessed. Propeller wash generation was estimated by applying a model of the bed-induced shear stress from the larger of the TSHD vessels (12,000 $m^3$ capacity) over the range of under-keel clearances expected during the dredging operations.

Field measurements of drag-head-induced sediment suspension was reported by Coastline Surveys Ltd (CSL, 1999). The inferred production rate was less than 1 kg/s and it was concluded that, generally, drag-head production is small in comparison to the quantity of sediment released via overflow. Given the above, a loss rate of 0.6% of the gross production rate, representing a combined sediment flux due to losses from the drag-head and propeller-wash, was assumed when the TSHD is not overflowing. This rate is within the range of values (less than 1%) summarised in a review of contemporary practice conducted as part of the WAMSI Dredging Science Node by Kemps & Masini (2017).

The resuspension of sediment when the TSHD hopper is overflowing was estimated based on measurements taken of the concentrations within overflowing waters, which are generally less than 10,000 mg/L adjacent to the hopper (Hitchcock & Bell, 2004). Typical values appear to be in the 5,000-6,000 mg/L range, which correlate well with data drawn from other Western Australian projects that cannot be cited here for reasons of confidentiality. A conservative hopper overflow concentration of 10,000 mg/L was assumed for this study, which – when balanced with the expected pumping and loading rates of the dredge – resulted in a source estimate of 2.4% of the gross production rate. This flux rate is a conservative rate compared to the range of published measurements from TSHD operations (0.1-5.0%; Hayes & Wu, 2001) and is within the range of values used in modelling studies (0.3-9.8%) outlined in a review of contemporary practice by Kemps & Masini (2017).

### 3.7.5 Representation of Disposal of TSHD-Dredged Material

All material dredged by the TSHD along the pipeline route will be transported to spoil ground AB, 2B or 5A (as appropriate) for disposal. This material will include all unconsolidated sediments from zones PRE2, PRE3, PRE4, PRE6, PRE8 and PRE10.

For the disposal of the unconsolidated sediments dredged by TSHD, the PSDs used in the model are based on PSDs from nearby boreholes (see Section 3.6). These PSDs are adjusted by removal of the component treated as suspended during dredging along the pipeline route (see Section 3.7.4), but as this represents only between 0.6% and 2.4% (averaged value depending on the relative contributions of overflow and non-overflow periods to the overall mass flux) of the mass for the minor components, the modified PSDs are not significantly different to the in situ PSDs (Table 3.29).

Once at the appropriate spoil ground, the hopper will open to release the sediments from the bottom of the hull at a depth of approximately 12.75 m below sea level. Previous observations of sediment dumping from hopper vessels (e.g. CSMW, 2005) have shown that there is an initial rapid descent of solids, with the heavy particles tending to entrain lighter particles, followed by a billowing of lighter components back into the water column after contact with the seabed (Figure 3.3). A proportion of the lighter components will also remain suspended and may be trapped by density layers, if present.

Because simulations in this study focused on the far-field fate of sediment particles due to transport and sinking after the initial dump phase, simulations were run with the initial vertical distribution specified to represent the post-collision phase for a case where a high proportion of the sediments are resuspended after collision with the seabed. To represent this, an assumed vertical distribution for the sediments (Table 3.30) has been specified following published information from previous hopper disposal operations (CSMW, 2005; NEPA, 2001). This vertical distribution, with the majority of the material input near the seabed and only 15% of the material released at hull depth or above, is in line with values quoted in the recent literature review by Mills & Kemps (2016), which found that sediment resuspension from individual dredged material disposal events was generally less than 10% of the disposed material load.

It is estimated that 95-99% of the bulk load deposits directly onto the seabed in a typical case, with the remainder released into the water column (CSMW, 2005, NEPA, 2001). It is difficult to find other definitive source values in the literature, but a value of 5% of each load agrees well with past experience and appears to be a conservative estimate based on the values quoted above. Accordingly, 5% of each hopper load was placed in suspension in the water column in the sediment fate model.

In addition to the proportion of material immediately suspended in the water column, disposal from the hopper will result in the stockpiling of sediment as a mound on the seabed that will be subject to resuspension by tidal and wave forces. Because fine sediments in the deposited mass may be subject to ongoing resuspension and dispersion over time, it was necessary to specify the deposits as a further source of sediment potentially subject to resuspension. For this purpose, it was assumed that 5% of the deposited mass – representing the upper surface layer – would be subject to resuspension. It should be noted that the model maintains a mass balance estimate of the remaining sediment of each size class within each grid cell to derive an estimate of the median particle size in the surface-layer sediments. In turn, the potential for ongoing resuspension of fines is calculated. In this way, the model represents the increased armouring of sediments as the average particle size increases.

The disposal time for the hopper material within each dredge cycle was assumed to be 20 minutes (Table 3.4). The disposal location within the relevant spoil ground was varied for each dredge cycle in a randomised manner, with the ultimate aim of ensuring an even distribution of dredged material within each spoil ground by the conclusion of all activities (Table 3.5).

**Table 3.29 Assumed PSDs of sediments initially suspended into the water column during TSHD hopper disposal operations at spoil grounds AB, 2B and 5A.**

| Sediment Grain Size Class | Size Range (µm) | PSD (%) for Sediment Disposal – Zone PRE2 | PSD (%) for Sediment Disposal – Zone PRE3 | PSD (%) for Sediment Disposal – Zone PRE4 | PSD (%) for Sediment Disposal – Zone PRE6 | PSD (%) for Sediment Disposal – Zone PRE8 | PSD (%) for Sediment Disposal – Zone PRE10 |
|---|---|---|---|---|---|---|---|
| Clay | <7 | 9.0 | 9.0 | 9.0 | 9.0 (<KP16.5) 0.0 (>KP16.5) | 0.0 | 0.0 (<KP30) 6.9 (>KP30) |
| Fine Silt | 8-34 | 13.3 | 13.3 | 13.3 | 13.3 (<KP16.5) 0.1 (>KP16.5) | 0.1 | 0.1 (<KP30) 11.3 (>KP30) |
| Coarse Silt | 35-74 | 15.3 | 15.3 | 15.3 | 15.3 (<KP16.5) 3.5 (>KP16.5) | 3.5 | 3.5 (<KP30) 13.4 (>KP30) |
| Fine Sand | 75-130 | 20.0 | 20.0 | 20.0 | 20.0 (<KP16.5) 2.0 (>KP16.5) | 2.0 | 2.0 (<KP30) 14.0 (>KP30) |
| Coarse Sand | >130 | 42.4 | 42.4 | 42.4 | 42.4 (<KP16.5) 94.4 (>KP16.5) | 94.4 | 94.4 (<KP30) 54.4 (>KP30) |

**Table 3.30 Assumed vertical distribution of sediments initially suspended into the water column during TSHD hopper disposal operations at spoil grounds AB, 2B and 5A.**

| Elevation | Example Elevation (m ASB) – 20 m Water Depth and 12.75 m Hull Depth | Vertical Distribution (%) of Sediments |
|---|---|---|
| Surface/water depth | 20.0 | 5.0 |
| Hopper hull elevation | 7.5 | 10.0 |
| 0.75 x hull elevation | 5.6 | 20.0 |
| 0.50 x hull elevation | 3.8 | 30.0 |
| 0.25 x hull elevation | 1.9 | 35.0 |

### 3.7.6 Representation of BHD Barge Tug/TSHD Propeller Wash

Modelling of sediment suspended by propeller-induced motion at the seabed was conducted to estimate likely sediment concentrations generated by the TSHD and harbour tug propellers while manoeuvring during dredging operations. A specialised numerical model developed by RPS, named PROPMAP, was used to estimate a time- and space-varying rate of sediment flux from the seabed due to the thrust imposed by each vessel's propellers at the seabed level behind the moving vessel. The model uses characteristics of the vessel of interest to estimate the three-dimensional thrust-field generated by the propellers. This thrust-field is then combined with the grain size and degree of cohesion of the seabed sediments, and the varying under-keel clearance along the typical vessel paths, to calculate variations in the suspended sediment flux from the seabed in time and space.

The following details were used as input to PROPMAP to calculate variable rates of sediment flux from the seabed due to propeller-wash effects:

- Vessel tracks and speeds;
- Vessel draft, engine power and propeller size;
- Bathymetry along the vessel tracks;
- Grain size distributions of the sediment, defining the proportions of clay and silt along the vessel tracks.

The calculation steps applied by PROPMAP at discrete intervals along each vessel path were as follows:

- Based on the vessel's engine power and propeller size, determine the propeller-induced velocity profile;
- Based on the vessel's draft and the local bathymetry, determine the intersection of the thrust-field with the seabed and find the thrust imposed on it;
- Based on the velocity of water flow at the seabed, calculate the shear stress acting on it;
- Based on the calculated shear stress, and the sediment grain size and cohesiveness, calculate a theoretical erosion flux (mass per unit time) for seabed sediment.

Propeller-induced velocity profiles were calculated using empirical expressions from Blaauw & van de Kaa (1978). Thrust at the seabed will depend upon the level of the bed, which will intersect as a plane (Figure 3.3). For an under-keel clearance of 1 m, a velocity field exceeding 5 m/s would intersect the bed in this example, while at a clearance of 4 m the bed velocity would be reduced to <2 m/s. The influence of this thrust will vary with the sediment grain size. Consequently, outcomes will be sensitive to the magnitude of the thrust, the under-keel clearance and the PSD of the bed.

Sediment erosion flux was estimated from the derived velocity field using the empirical formulations of van Rijn (1989). The sediment flux component attributable to propeller wash was found to be depth-limited for areas where the under-keel clearance was less than 3 m, assuming a fully-loaded vessel (maximum draft). Simulations over deeper areas, including the areas where vessels would transit to the spoil grounds, indicated that flux would be minimal (compared to other sources) and representative of short-lived suspension of the surface-layer sediments followed by rapid settlement. This settlement time was estimated to be shorter than the simulation output time-step. Propeller-wash was found to be more significant in the shallow areas and would be greater over sediments previously suspended by dredging.

These findings were used to inform the definition of the sediment flux rates during TSHD dredging operations (see Section 3.7.4).

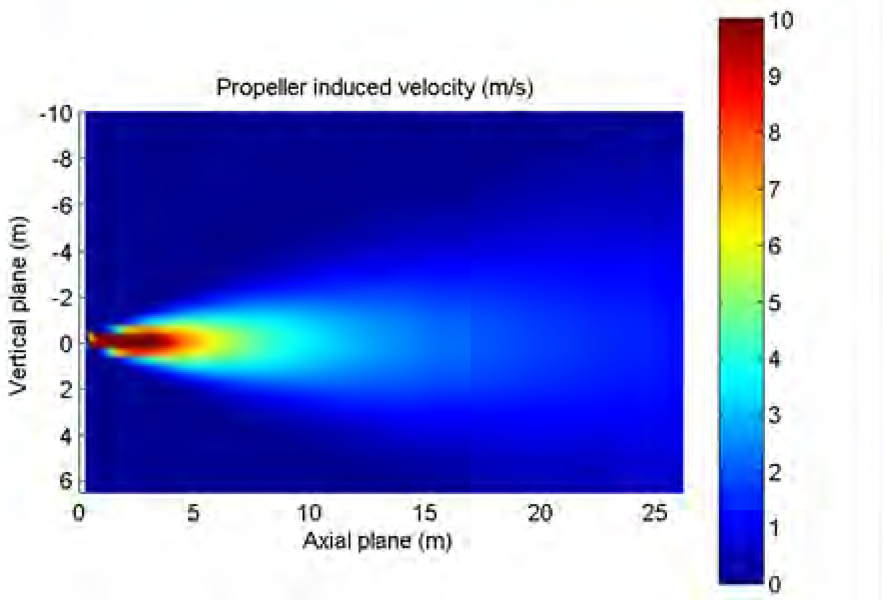


**Figure 3.3 Two-dimensional view of a propeller-induced velocity profile.**

In summary, propeller-wash effects were considered: (i) along each pipeline section during dredging; (ii) between each pipeline section and the spoil grounds during dredging; and (iii) between borrow ground B and each pipeline section during backfilling. For borrow ground A, and the waters between it and the pipeline, propeller-wash effects are not relevant due to the greater water depths.

In the absence of definitive information relating to the seabed composition of the areas traversed by the barge tug or TSHD between the pipeline and the spoil grounds (or traversed by the TSHD between borrow ground B and the pipeline), for simplicity the seabed composition was assumed to be described by the PSD of the area from which the vessel began its journey.

### 3.7.7 Representation of TSHD Backfill

All material dredged by the TSHD within the borrow grounds will be transported to sections POST2, POST4, POST6, POST8 and POST10 of the pipeline route for placement.

For the backfill of the pipeline using unconsolidated sediments dredged by TSHD, the PSDs used in the model are based on PSDs from nearby boreholes (see Section 3.6). These PSDs are adjusted by removal of the component treated as suspended during dredging within the borrow grounds (see Section 3.7.4), but as this represents only between 0.6% and 2.4% (averaged value depending on the relative contributions of overflow and non-overflow periods to the overall mass flux) of the mass for the minor components, the modified PSDs are not significantly different to the in situ PSDs (Table 3.31). It has been assumed, conservatively, that all sediment dredged from the borrow grounds is available for use as backfill material.

Once at the appropriate location, the TSHD suction pipe will discharge material at an elevation of approximately 5 m above the pipeline. Sediment release from the suction pipe will occur as a jet of slurry that will have an initial rapid descent of solids followed by a billowing of lighter components back into the water column after contact with the seabed/pipeline (Swanson *et al.*, 2004). The plume that results from disposal of a jet of slurry from a pipe is typically concentrated near the seabed, with most of the material within 3 m of the bottom, and lower concentrations extend up towards the surface (Figure 3.4). Table 3.32 shows the assumed vertical distribution of the suspended material for the TSHD backfill source.

It is estimated that 95-99% of the bulk load deposits directly onto the seabed in a typical case, with the remainder released into the water column (CSMW, 2005, NEPA, 2001). It is difficult to find other definitive source values in the literature, and no site-specific sampling has been conducted for TSHD backfill placement operations, but a value of 5% of each load agrees well with past experience and appears to be a conservative estimate based on the values quoted above. Accordingly, 5% of each hopper load was placed in suspension in the water column in the sediment fate model.

The placement time for the hopper material within each dredge cycle was assumed to be 107 minutes (Table 3.6).

**Table 3.31 Assumed PSDs of sediments initially suspended into the water column during TSHD backfill operations using material dredged at borrow grounds A and B.**

| Sediment Grain Size Class | Size Range (µm) | PSD (%) for Sediment Backfill – Borrow Ground A | PSD (%) for Sediment Backfill – Borrow Ground B |
|---|---|---|---|
| Clay | <7 | 1.3 | 0.0 |
| Fine Silt | 7-34 | 1.9 | 0.1 |
| Coarse Silt | 35-74 | 9.4 | 3.5 |
| Fine Sand | 75-130 | 15.0 | 2.0 |
| Coarse Sand | >130 | 72.4 | 94.4 |

**Table 3.32 Assumed vertical distribution of sediments initially suspended into the water column during TSHD backfill operations using material dredged at borrow grounds A and B.**

| Elevation | Example Elevation (m ASB) – 20 m Water Depth and 5 m Pipe Elevation | Vertical Distribution (%) of Sediments |
|---|---|---|
| Surface/water depth | 20.0 | 5.0 |
| Suction pipe elevation | 5.0 | 10.0 |
| 0.75 x pipe elevation | 3.8 | 15.0 |
| 0.50 x pipe elevation | 2.5 | 20.0 |
| 0.25 x pipe elevation | 1.3 | 50.0 |

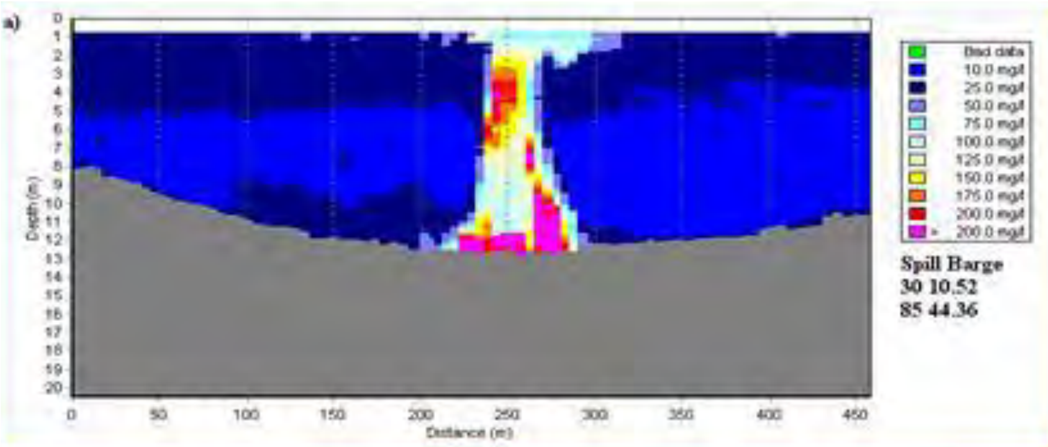


**Figure 3.4 Example of a vertical cross-section through a typical open-water discharge plume from a spreader barge pipe (source: Swanson *et al.*, 2004).**

### 3.7.8 Representation of Side-Dump Vessel Backfill

Rock material from an onshore quarry source will be transported by a side-dump vessel to sections POST1, POST3, POST5, POST7 and POST9 of the pipeline route for placement.

Based on previous project experience, quarry rock used for breakwater core construction or pipeline armouring typically contains around 5% material with diameters less than 100 mm. Therefore, a conservative loss rate of 5% of the total volume of dumped rock material was applied in the modelling. Based on material testing from previous projects, the volume of quarried core/rock material less than 130 µm in size is typically even lower, in the order of 2%. Table 3.33 (equivalent to Table 3.16) presents the PSD that was applied in the modelling of the rock backfill source. The composition of the material is dominated by coarse sand and larger particles, with the 2% of finer material assumed to be evenly spread over the four smaller material classes. Although coarse sand material will be initially suspended in the water column, it will not be available for resuspension once it settles.

Because the rock backfill material will be dumped from the deck of the vessel, it will move through the whole water column as it falls to the seabed. Therefore, a uniform vertical distribution of suspended material in the water column has been assumed (Table 3.34).

The placement time for the rock material within each cycle was assumed to be 120 minutes (Woodside, 2018a). Other than an increased placement time, the operational cycle is assumed to be equivalent to that for TSHD backfill operations outlined in Table 3.6.

**Table 3.33 Assumed PSDs of sediments initially suspended into the water column during side-dump vessel backfill operations using material from an onshore quarry.**

| Sediment Grain Size Class | Size Range (µm) | PSD (%) for Rock Backfill |
|---|---|---|
| Clay | <7 | 0.5 |
| Fine Silt | 7-34 | 0.5 |
| Coarse Silt | 35-74 | 0.5 |
| Fine Sand | 75-130 | 0.5 |
| Coarse Sand | >130 | 98.0 |

**Table 3.34 Assumed vertical distribution of sediments initially suspended into the water column during side-dump vessel backfill operations using material from an onshore quarry.**

| Elevation | Example Elevation (m ASB) – 10 m Water Depth | Vertical Distribution (%) of Sediments |
|---|---|---|
| Surface/water depth | 10.0 | 20.0 |
| 0.8 x water depth | 8.0 | 20.0 |
| 0.6 x water depth | 6.0 | 20.0 |
| 0.4 x water depth | 4.0 | 20.0 |
| 0.2 x water depth | 2.0 | 20.0 |

### 3.7.9 Summary of Source Rates and Volumes

For each source of suspended sediment plumes during dredging, disposal and backfill operations, as described in the preceding sections, Table 3.35 summaries the associated loss rates and approximate volumes of suspended sediment expected. The volumes assigned to the respective non-overflow and overflow periods for TSHD dredging, and non-dewatering and dewatering periods for BHD dredging, are based on the modelled cycle times detailed in Table 3.3, Table 3.4 and Table 3.6.

A total of approximately 246,230 m$^3$ of sediment is expected to be initially suspended in the water column over the course of the modelled program. This volume represents approximately 6.9% of the in situ dredged (and quarry) volume. If all deposited material assumed to be available for potential resuspension following spoil ground disposal operations is actually resuspended, a total of 339,076 m$^3$ of sediment will be suspended in the water column over the program duration; this will represent approximately 9.5% of the in situ dredged (and quarry) volume.

**Table 3.35 Summary of sediment sources applied in the model.**

| Phase | Operation | Source Rate (% Production Rate) | Dredged Volume ($m^3$) | Suspended Volume ($m^3$) |
|---|---|---|---|---|
| Pipeline dredging | BHD excavator bucket | 2.1 | 51,147 | 215 |
| | BHD excavator bucket + dewatering from barge | 2.4 | | 982 |
| | Disposal from hopper barge | 5 (water column)<br>5 (seabed; *potential*) | | 2,557<br>*2,557* |
| | TSHD drag-head + propeller-wash | 0.6 | 1,818,397 | 1,925 |
| | TSHD drag-head + propeller-wash + overflow | 2.4 | | 35,940 |
| | Disposal from TSHD | 5 (water column)<br>5 (seabed; *potential*) | | 90,920<br>*90,920* |
| Pipeline backfilling | TSHD drag-head + propeller-wash | 0.6 | 1,608,095 | 2,783 |
| | TSHD drag-head + propeller-wash + overflow | 2.4 | | 27,461 |
| | Placement from TSHD | 5 | | 80,405 |
| | Placement from side-dump vessel | 5 | 73,426 | 3,671 |
| | | **Totals** | **3,551,065** | **246,229**<br>***339,076*** |

# 4 ENVIRONMENTAL THRESHOLD ANALYSIS

## 4.1 Overview

Predictions of SSC for each scenario were assessed against a series of water quality thresholds to categorise the modelled outcomes into management zones of influence and impact, defined with regard to environmental sensitivities in the study region. These thresholds, and the technical justification which followed guidance from the WAMSI Dredging Science Node, were supplied to RPS by Advisian (MScience, 2019). Thresholds were selected for benthic habitats on the basis of past and present mapping of communities in the project area.

Thresholds for three management zones – a Zone of Influence (ZoI), a Zone of Moderate Impact (ZoMI) and a Zone of High Impact (ZoHI) – were defined. The criteria associated with each management zone also varied across three ecological zones, which were broadly defined based on past studies of these areas. The ecological zones are named as follows, with reference to the pipeline chainages shown in Figure 1.1, and with the spatial extents agreed for this study shown in Figure 4.1:

- Offshore: the pipeline area beyond KP25, and generally all areas north of a boundary line containing Rosemary Island, Legendre Island and Delambre Island.
- Zone B: the pipeline area between KP8 and KP25, adjacent coral and macroalgae habitats within Mermaid Sound, and generally all coral, macroalgae and mixed community habitats between Dolphin Island and Bezout Island.
- Zone A: the pipeline area between the shoreline and KP8, adjacent macroalgae and mangrove habitats within Mermaid Sound, and generally all mangrove, marsh and seagrass habitats between Nickol Bay and Point Samson.

Thresholds for coral habitats within Zone B were developed with the aid of data collected during a previous dredging campaign at Barrow Island, which is considered a similar habitat. Water quality within Zone A is more turbid, and coral communities are comprised of more sediment-tolerant or resilient species. Offshore habitats are not likely to contain corals.

In developing the thresholds, it was assumed that benthic communities around Spoil Ground 2B and Borrow Ground A (see Figure 1.1) will be sparse and made up largely of sponges and filter feeders without corals.

## 4.2 Baseline Water Quality

Water quality data collected during the LNG Foundation Project over the period of 2007 to 2010 (MScience, 2010) demonstrated that turbidity at sites within the Zone A and Zone B management areas was raised by 0.7 NTU and 0.3 NTU, respectively, as a result of dredging activities. Subtraction of these dredge-induced values across the 2007-2010 data set yielded a set of baseline turbidity measurements.

Table 4.1 presents the mean and 80$^{th}$-percentile SSC values calculated from the background turbidity measurements in each zone. For the purposes of threshold assessment, it has been assumed that the summer season comprises the period of November to March and the winter season contains the months of April to October.

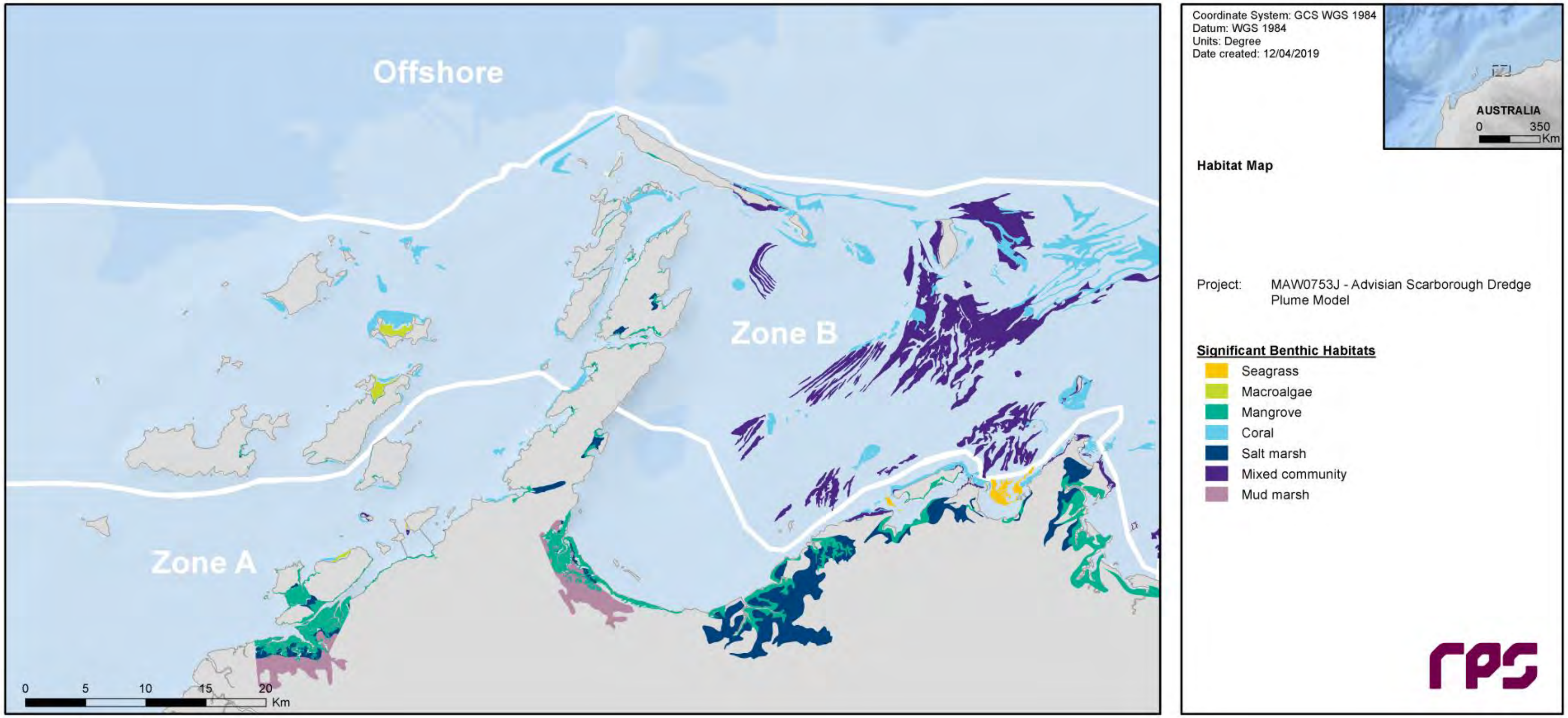


**Figure 4.1 Delineation of the proposed ecological zones (Zone A, Zone B and Offshore) in the context of known habitat areas and types. Thresholds used to define the management zones will vary in magnitude between the ecological zones.**

**Table 4.1 Baseline mean and 80th percentile SSC values calculated from measurements undertaken during the LNG Foundation Project (2007-2010), categorised into summer and winter seasons for each of the three ecological zones.**

| Ecological Zone | Season | Mean SSC (mg/L) | 80th Percentile SSC (mg/L) |
|---|---|---|---|
| A | Summer | 4.1 | 5.0 |
| | Winter | 1.8 | 2.3 |
| B | Summer | 2.5 | 2.7 |
| | Winter | 1.2 | 1.6 |
| Offshore | Summer | 1.8 | 1.8 |
| | Winter | 0.6 | 0.9 |

## 4.3 Zone of Influence (ZoI)

The ZoI is defined as "*a zone where impacts to water quality will be detectable but below a level causing detectable impacts to biota*" (MScience, 2019). This is generally considered equivalent to the area around dredging activities where a plume may be visible to the naked eye.

The ZoI threshold will be exceeded at any point within the model domain where dredging is forecast to increase the depth-averaged concentration of SSC (specifically the contribution attributable to dredging activities) by a level greater than the seasonal 80th percentile baseline SSC over a 24-hour average period.

Table 4.2 presents the threshold SSC values used to define the extents of the ZoI. A background SSC value appropriate for each ecological zone and month of the year was added to the dredge-induced SSC predictions from the sediment fate model prior to evaluation of the thresholds.

Potential exceedances of the threshold were evaluated over the duration of each dredge scenario by calculating a rolling 24-hour average of SSC concentrations in each model grid cell and checking for breaches as this time-window progressed through the data set at hourly increments (the temporal resolution of the data set). If the 24-hour average SSC concentration exceeds the threshold value at any time, even if only on one occasion, the model grid cell is included in the ZoI area. With each scenario spanning a period of ten months, ZoI threshold checks were undertaken for more than 7,000 time steps. This approach allowed an increased opportunity to detect threshold exceedance events, compared with that afforded by the alternative method of simply analysing each unique 24-hour sequence in turn (i.e. with no temporal overlap) from the start to the end of the data set.

Typically, averaging discrete data points over an arbitrary time period will serve to reduce the influence of transient spikes in concentration, thereby reducing the possibility of spurious exceedances. More rarely, a transient concentration spike of sufficient magnitude to skew the rolling average to an above-threshold state may result in exceedances being recorded for a longer period than will be the case in reality. Generally, applying a time-average to a data set for the purposes of threshold analysis will result in a smaller zone of effect than if instantaneous data is evaluated. This methodology also has a strong connection to critical exposure times for benthic habitats or species of concern in the project area.

**Table 4.2 Background, dredge-excess and threshold SSC values used as the criteria to define the ZoI outer boundary within each ecological zone.**

| Ecological Zone | Season | Time-Averaged Period (hours) | Background SSC (mg/L) [a] | Dredge-Excess SSC (mg/L) [b] | Threshold SSC (mg/L) [c] |
|---|---|---|---|---|---|
| A | Summer | 24 | 4.1 | 5.0 | 9.1 |
| | Winter | 24 | 1.8 | 2.3 | 4.1 |
| B | Summer | 24 | 2.5 | 2.7 | 5.2 |
| | Winter | 24 | 1.2 | 1.6 | 2.8 |
| Offshore | Summer | 24 | 1.8 | 1.8 | 3.6 |
| | Winter | 24 | 0.6 | 0.9 | 1.5 |

[a] Background values are equivalent to 'Mean SSC' values in Table 4.1.

[b] Dredge-excess values are equivalent to '80$^{th}$ Percentile SSC' values in Table 4.1.

[c] Threshold values are the sum of background and dredge-excess values.

## 4.4 Zone of Moderate Impact (ZoMI)

The ZoMI is defined as "*a zone where impacts are sub-lethal or lethal but recoverable (in terms of the community) within a five-year period*" (MScience, 2019).

The ZoMI threshold will be exceeded at any point within the model domain where dredging is forecast to increase the depth-averaged concentration of SSC to a level sufficient to trigger impacts to $EC_{10}$ (10% Effect Concentration or 10% Inhibition) or to cause bleaching through loss of light or sedimentation.

Thresholds chosen to indicate a transition between the ZoI and ZoMI areas are largely based on the 'possible mortality' thresholds of Fisher *et al.* (2019). These thresholds are based on analysis of water quality and coral monitoring data collected during a previous dredging project at Barrow Island, where coral communities exist in clear, near-oceanic conditions. Distinctions must be made between the thresholds most appropriate for each ecological zone.

Within the offshore zone, only thresholds of relevance to sponges and filter feeders are appropriate because corals, seagrasses and macroalgae are not known to form significant communities. A threshold relating to an $LC_{10}$ (10% Lethal Concentration) effect on filter feeder-sponge habitats over a 28-day exposure period was selected (Pineda *et al.*, 2017).

For Zone B, coral communities experience similar conditions to those monitored at Barrow Island and the moderate-impact thresholds of Fisher *et al.* (2019) for coral/mixed benthos communities were deemed to be appropriate (MScience, 2019).

For Zone A, coral communities experience more turbid conditions and are more tolerant of elevated SSC levels and lowered light levels than their neighbours in Zone B due to adaptation and a different mix of species. To account for this greater tolerance, the moderate-impact thresholds in Zone A were defined as those of Zone B multiplied by a factor of 1.5, which is believed to be a conservative multiplier (MScience, 2019). Within both Zones A and B, spongers and filter feeders will occur among the corals, and the mixed community is best evaluated using coral-focused thresholds.

The taxa-specific thresholds and appropriate time-averaging periods (related to exposure times from experimental data) used to define the extents of the ZoMI are detailed in Table 4.3. A background SSC value appropriate for each ecological zone and month of the year was added to the dredge-induced SSC predictions from the sediment fate model prior to evaluation of the thresholds.

Potential exceedances of the thresholds were evaluated over the duration of each dredge scenario by calculating rolling 3-day, 7-day, 10-day, 14-day and 28-day averages (as appropriate in each ecological zone) of SSC concentrations in each model grid cell and checking for breaches as this time-window progressed through the data set at hourly increments (the temporal resolution of the data set). If any time-average SSC concentration exceeds the corresponding threshold value at any time, even if only on one occasion, the model grid cell is included in the appropriate ZoMI area.

**Table 4.3 Threshold SSC values used as the criteria to define the ZoMI outer boundary within each ecological zone.**

| Ecological Zone | Time-Averaged Period (days) | Threshold SSC (mg/L) |
|---|---|---|
| A | 3 | 29.1 |
| | 7 | 22.5 |
| | 10 | 19.6 |
| | 14 | 17.6 |
| B | 3 | 19.4 |
| | 7 | 14.7 |
| | 10 | 13.1 |
| | 14 | 11.7 |
| Offshore | 28 | 22.5 |

# 4.5 Zone of High Impact (ZoHI)

Thresholds chosen to indicate a transition between the ZoMI and ZoHI areas are largely based on the ‘probable mortality’ thresholds of Fisher *et al.* (2019).

Within the offshore zone, a threshold relating to an $LC_{50}$ (50% Lethal Concentration) effect on filter feeder-sponge habitats over a 28-day exposure period was selected (Pineda *et al.*, 2017).

For Zone B, the high-impact thresholds of Fisher *et al.* (2019) for coral/mixed benthos communities were deemed to be appropriate (MScience, 2019).

For Zone A, the high-impact thresholds were defined as those of Zone B multiplied by a factor of 1.5, which is believed to be a conservative multiplier (MScience, 2019).

The taxa-specific thresholds and appropriate time-averaging periods (related to exposure times from experimental data) used to define the extents of the ZoHI are detailed in Table 4.4. A background SSC value appropriate for each ecological zone and month of the year was added to the dredge-induced SSC predictions from the sediment fate model prior to evaluation of the thresholds.

Potential exceedances of the thresholds were evaluated over the duration of each dredge scenario by calculating rolling 3-day, 7-day, 10-day, 14-day and 28-day averages (as appropriate in each ecological zone) of SSC concentrations in each model grid cell and checking for breaches as this time-window progressed through the data set at hourly increments (the temporal resolution of the data set). If any time-average SSC concentration exceeds the corresponding threshold value at any time, even if only on one occasion, the model grid cell is included in the appropriate ZoHI area.

**Table 4.4 Threshold SSC values used as the criteria to define the ZoHI outer boundary within each ecological zone.**

| Ecological Zone | Time-Averaged Period (days) | Threshold SSC (mg/L) |
|---|---|---|
| A | 3 | 53.6 |
| | 7 | 36.8 |
| | 10 | 31.4 |
| | 14 | 27.0 |
| B | 3 | 35.7 |
| | 7 | 24.5 |
| | 10 | 20.9 |
| | 14 | 18.0 |
| Offshore | 28 | 47.0 |

# 5 RESULTS OF SEDIMENT FATE MODELLING

## 5.1 Spatial Distributions of SSC

### 5.1.1 Summary

Simulations indicated that there may be significant spatial patchiness in the distribution of SSC at any point in time during the dredging, disposal and backfill operations because of variability in the number of sediment suspension sources, variability in the flux from each of these sources, and the varying dynamics of the transport, settlement and resuspension processes affecting the sediments.

The most pronounced differences in the predicted concentrations at any point in time are found in the vertical distributions, with a distinct increase in concentration towards the seabed. Most material will initially be suspended low in the water column, and material suspended higher in the water column will sink as it moves away from the source. Frequent resuspension of material will also mostly affect the lower reaches. Thus, the spatial area affected above a given concentration is typically greater in the near-seabed layer than in the near-surface layer. It should be noted, however, that there are instances throughout the simulations where elevated concentrations will occur in the near-surface layers – during TSHD overflow or split hopper barge dewatering operations, or during strong resuspension events affecting sediments that have migrated to shallow areas – but these will typically not be sustained for extended periods of time.

Although many of the activities related to dredging and backfilling of the pipeline will take place within Mermaid Sound, which is dominated by tidal currents year-round and is relatively sheltered from the variations in large-scale circulation observed beyond approximately KP30, reasonably distinct seasonal trends are evident in the modelling outcomes of each scenario.

The results observed on any given day will not always be representative of the given season's prevailing transport patterns, and plume concentrations and distributions are forecast to vary markedly. To explore this variability, statistical distributions for each scenario are examined. Percentile distributions will summarise the outcomes over the entire scenario and do not represent an instantaneous plume footprint at any point in time.

In the scenarios where the inshore borrow ground is utilised, forecasts of median depth-averaged SSC concentrations (values exceeded 50% of the time) for project works commencing in summer (Scenario 2B) were in the range 0.1-1 mg/L over an area stretching from the south-western end of Angel Island to the waters between Enderby Island and West Intercourse Island. For project works commencing in winter (Scenario 1B), the equivalent area is restricted to the waters between the inshore borrow ground and spoil ground AB. At the 95$^{th}$ percentile (values exceeded only 5% of the time), forecasts of depth-averaged SSC concentrations 5 mg/L or greater in both seasons are found between Intercourse Island and the waters between the Malus Islands and Gidley Island (Scenario 1B, Figure 5.4; Scenario 2B, Figure 5.8).

In the scenarios where the offshore borrow ground is utilised, forecasts of 50$^{th}$ percentile (median) depth-averaged SSC concentrations do not exceed 0.1 mg/L for works commencing in either season. At the 95$^{th}$ percentile, forecasts of depth-averaged SSC concentrations 5 mg/L or greater are found in nearshore areas between Intercourse Island and King Bay for project works commencing in summer (Scenario 2A, Figure 5.6), and also near Angel Island and Conzinc Island for project works commencing in winter (Scenario 1A, Figure 5.2).

When examined over the course of an entire scenario, the sediment distributions reveal areas that broadly straddle the dredging and disposal zones where recurrent elevations of near-seabed SSC are expected as a consequence of dredging operations. The forecast in each scenario is that the greatest concentrations will typically be found in the inshore waters of Mermaid Sound along the pipeline between the KP5 and KP25 points. This zone contains a significant volume of the overall in situ volume to be dredged, and there are many shallow locales where strong tidal flows both inhibit settlement of fine suspended sediments and stimulate significant levels of resuspension of sediments deposited after initial release in the water column. For Scenarios 1A and 2A, where the offshore borrow ground is dredged for backfill material, an additional plume signature results from recurrent elevations of near-seabed SSC north of Legendre Island and subsequent resuspension of this material as it is transported towards Nickol Bay.

Concentrations of suspended sediment in the key activity areas will represent the combined influence of new discharges and resuspension of fine sediments from earlier discharges. Temporal variations in intensity of the dredging operations, including overlap of multiple operations in time or downtime periods, will also influence turbidity peaks and troughs. At progressively more distant areas, the importance of resuspension as a contributor to the distribution of SSC concentrations in general, and near-seabed concentrations in particular, becomes a greater factor. The areas forecast to receive elevated concentrations are substantially larger than would be affected by plumes only from the initial sources. The plume extents tend to expand over periods of several weeks in the direction of net drift, indicating the progressive transport of fine sediments through continuous patterns of settlement and resuspension.

With the duration of each scenario (ten months) spanning almost the entire range of seasonal conditions, the direction of net drift will shift from summertime trends (generally longshore in a north-easterly direction) to wintertime trends (generally longshore in a south-westerly direction), or vice versa, depending on commencement times (winter for Scenarios 1A/1B and summer for Scenarios 2A/2B). A progressive shift in the available source of resuspendable fine sediments is also indicated. Periodic high wave-energy events will be a major contributor to estimates of high SSC in the near-seabed layer, particularly in shallow exposed areas. While these processes are forecast to extend the influence of dredging activities over a wider area, the longshore dispersal of finer sediments is indicated to be an important mechanism for limiting the trapping and build-up of fine sediments in the local region around the key activity areas. The build-up of resuspendable fine sediments in areas remote from dredging activities indicates that the supply of fines to these areas will be greater than their removal due to ongoing resuspension and longshore transport, for as long as sediment input from dredging activities continues.

### 5.1.2 Pipeline Dredging Activities

For pipeline dredging activities during winter conditions (Scenarios 1A and 1B), sediment plumes at low concentrations are forecast to drift generally towards the south-west. The plumes tend to follow the bathymetric contours between East Intercourse Island and East Lewis Island, and also between West Lewis Island and Rosemary Island.

In contrast, the net drift direction forecast for sediment plumes from pipeline dredging activities during summer conditions (Scenarios 2A and 2B) is towards the north-east, with the plumes following the bathymetric contours as they turn around Legendre Island towards Delambre Island. This drift is imposed by the prevailing south-westerly winds over the summer season. In general, the majority of the dispersing suspended material is forecast to migrate offshore rather than through Flying Foam Passage and Searipple Passage, which is attributable to the local bathymetric features. Much of the dredging occurs in water depths greater than that found within each passage, but strong tidal currents will drive significant sediment concentrations in and out of the passages on a regular basis.

### 5.1.3 Pipeline Backfill Activities

For the scenarios in which backfilling of the pipeline is facilitated by dredging of the inshore borrow ground (Scenarios 1B and 2B), the net drift direction of sediment plumes tends to be in opposition to that observed for the plumes attributable to pipeline dredging activities. This is because a gap of several months has been assumed between pipeline dredging and backfilling operations (see Section 3.5.5), meaning that the seasonal trend has reversed over time. Because similar loss rates are applied during both the pipeline dredging and backfilling phases, the contribution of sediment suspended by dredging at the inshore borrow ground to the overall plume footprint will be significant; the volume of backfill material to be dredged (~1.6 $Mm^3$) is comparable to that required to be dredged over the entire pipeline length (~1.9 $Mm^3$), but is confined to a relatively small area. Suspended sediments resulting from placement of the backfill material along the pipeline will be concentrated near the seabed and will quickly settle due to the relative coarseness of the material.

For the scenarios in which backfilling of the pipeline is facilitated by dredging of the offshore borrow ground (Scenarios 1A and 2A), the bulk of the sediment suspended by dredging is forecast to be dispersed in the offshore area between the borrow ground and Legendre Island in both seasons. Strong tidal flows between Hauy Island and Delambre Island will aid movement of sediment towards the shallow waters of Nickol Bay, with this effect being greater during summer (Scenario 1A, following pipeline dredging activities in winter) due to predominant net drift towards the east imposed by prevailing south-westerly winds. In contrast, the net drift direction forecast during winter conditions (Scenario 2A) is towards the south-west, mostly following the bathymetric contours to the north of Rosemary Island. The sediment plume from operations in this area is forecast to migrate to the offshore pipeline and spoil ground areas, most noticeably in Scenario 2A when borrow ground dredging occurs in winter (following pipeline dredging activities in summer) but at lower concentrations than will have already occurred during pipeline dredging activities.

### 5.1.4 Spatial Outcomes

#### 5.1.4.1 Scenario 1A: Dredging Operations Commencing during Winter, with Backfill Material Sourced from Borrow Ground A (Offshore)

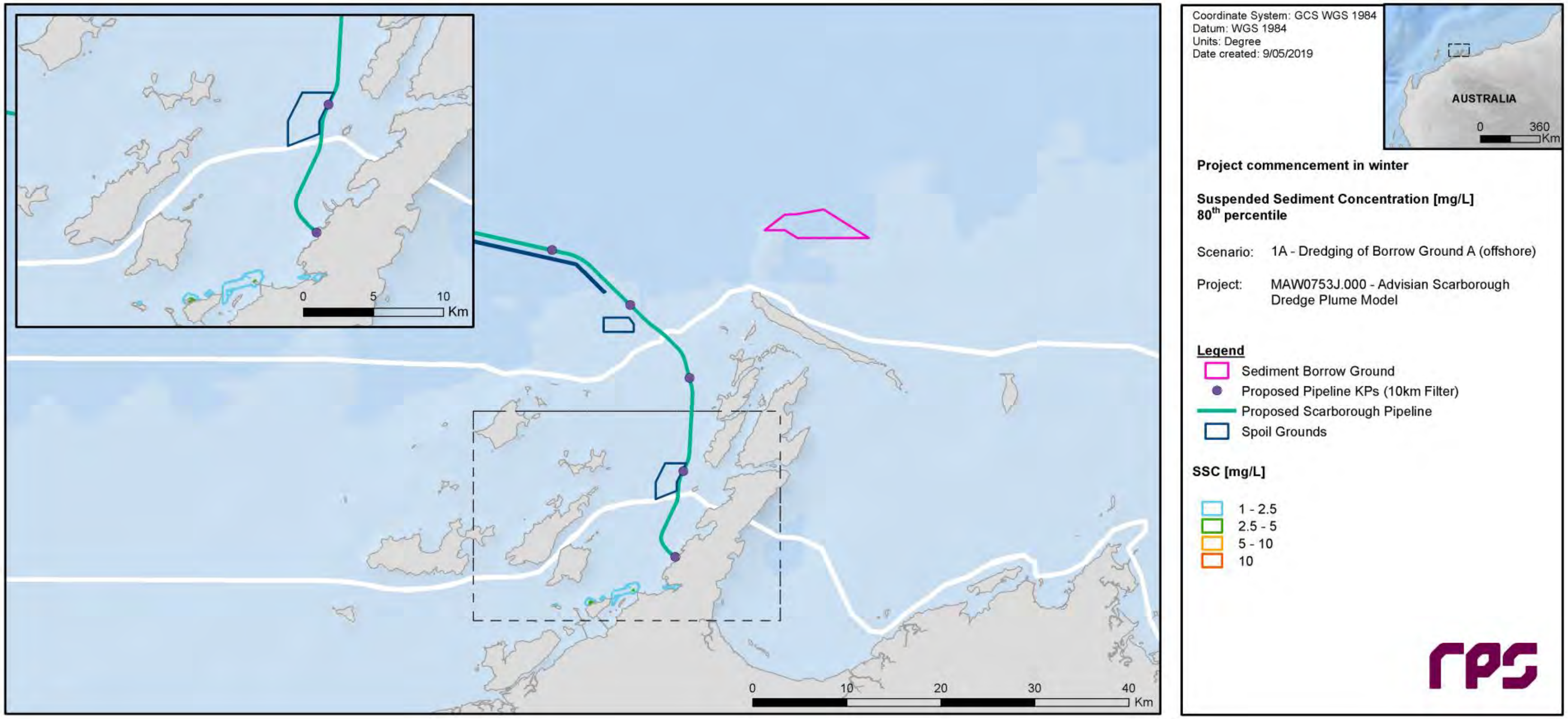


**Figure 5.1 Predicted 80th percentile dredge-excess SSC throughout the entire scenario duration (1st July 2016 to 30th April 2017).**

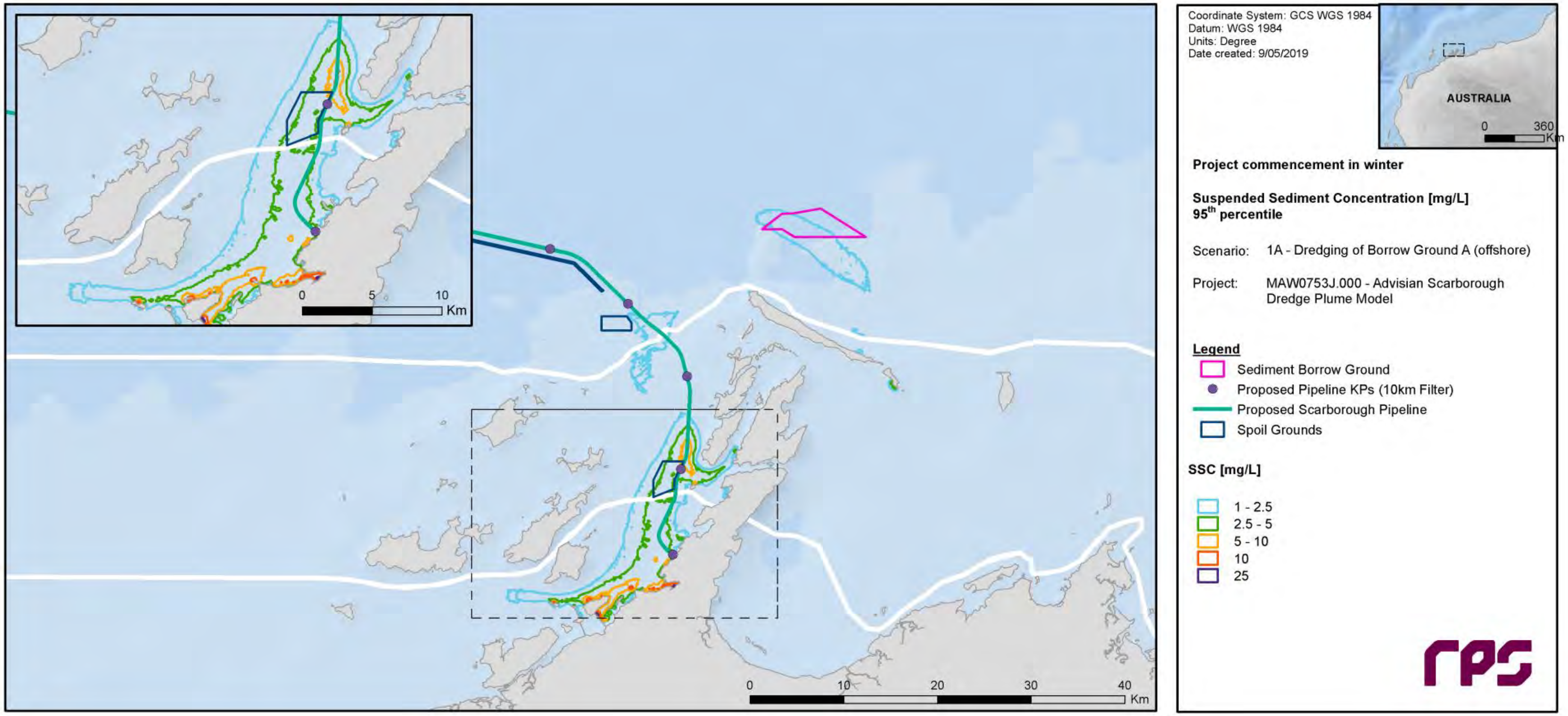


**Figure 5.2 Predicted 95th percentile dredge-excess SSC throughout the entire scenario duration (1st July 2016 to 30th April 2017).**

#### 5.1.4.2 Scenario 1B: Dredging Operations Commencing during Winter, with Backfill Material Sourced from Borrow Ground B (Inshore)

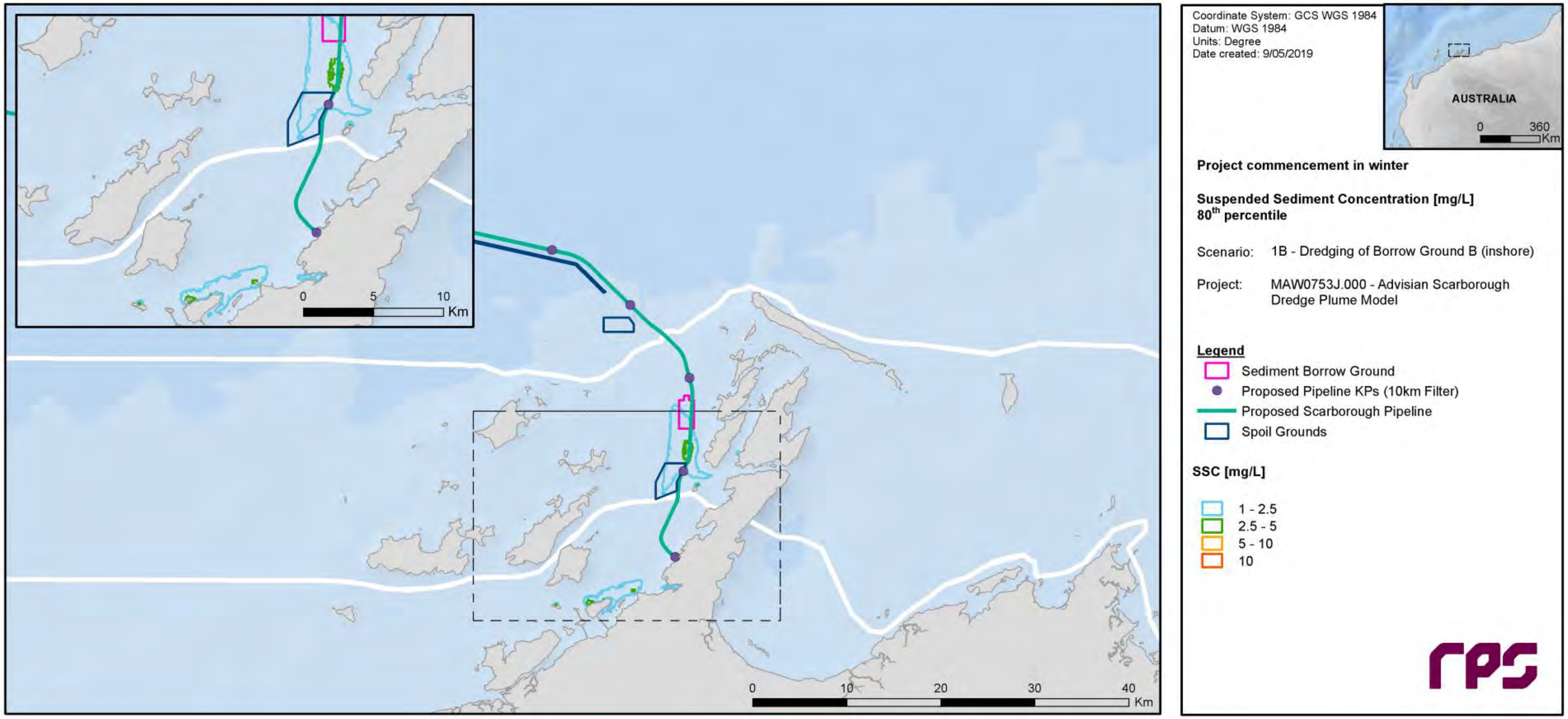


**Figure 5.3 Predicted 80th percentile dredge-excess SSC throughout the entire scenario duration (1st July 2016 to 30th April 2017).**

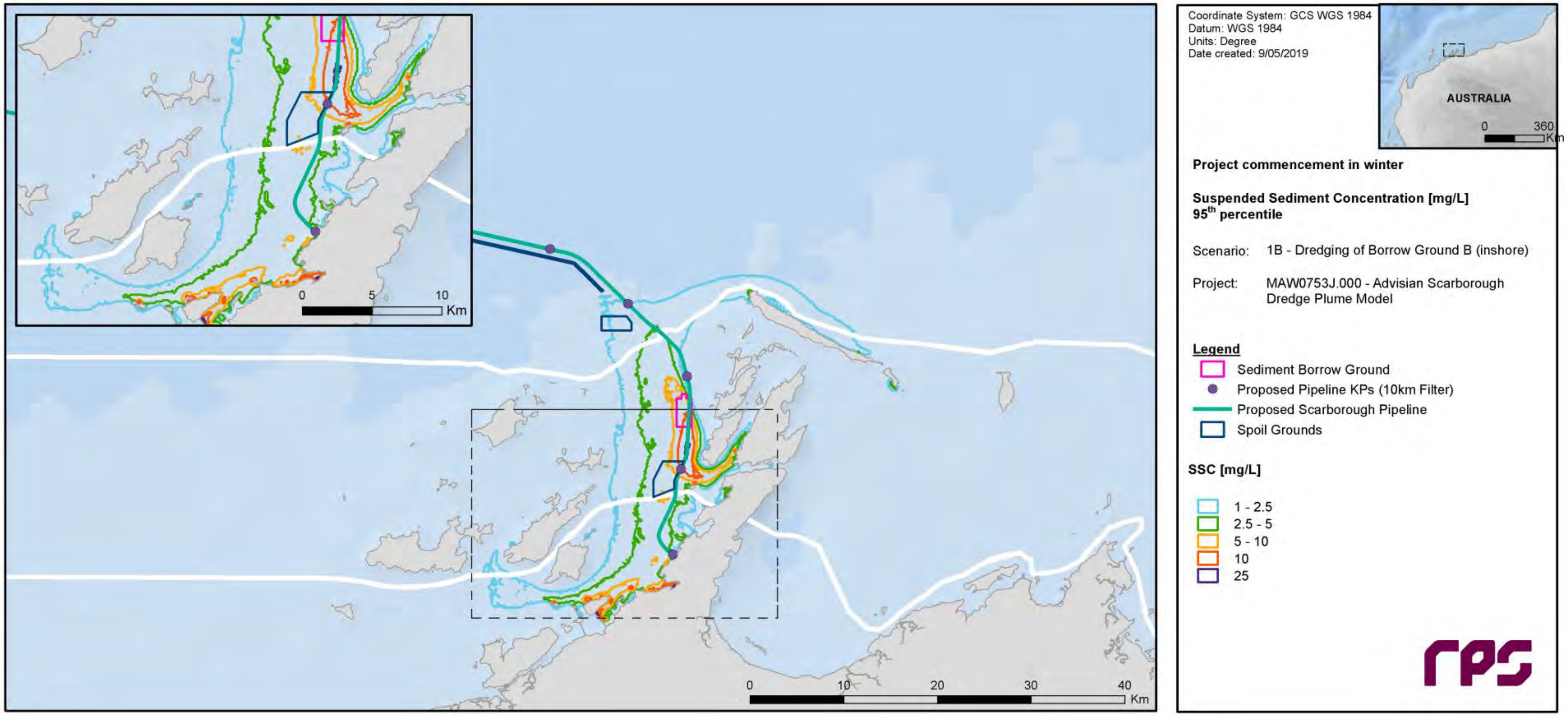


**Figure 5.4** Predicted 95th percentile dredge-excess SSC throughout the entire scenario duration (1st July 2016 to 30th April 2017).

#### 5.1.4.3 Scenario 2A: Dredging Operations Commencing during Summer, with Backfill Material Sourced from Borrow Ground A (Offshore)

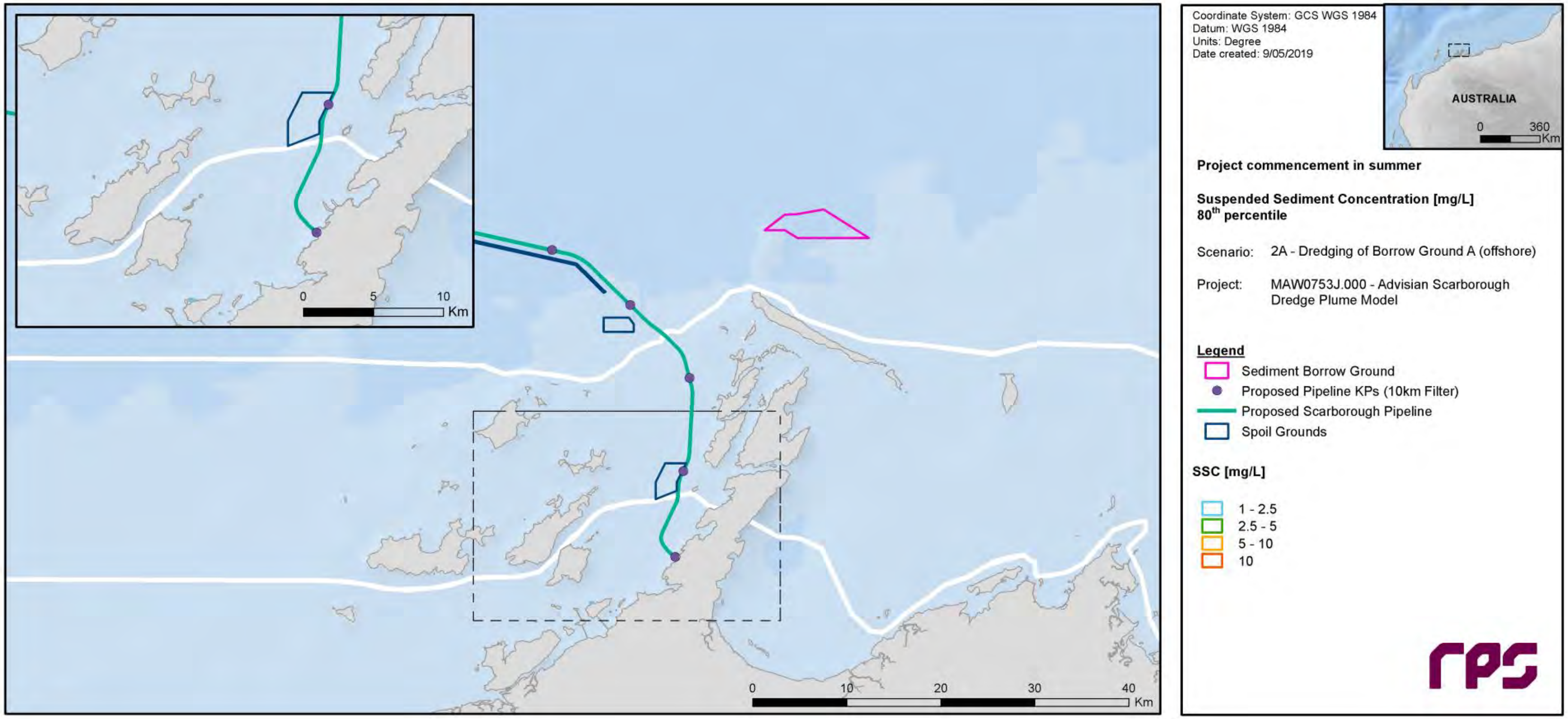


**Figure 5.5 Predicted 80th percentile dredge-excess SSC throughout the entire scenario duration (1st January 2017 to 31st October 2017).**

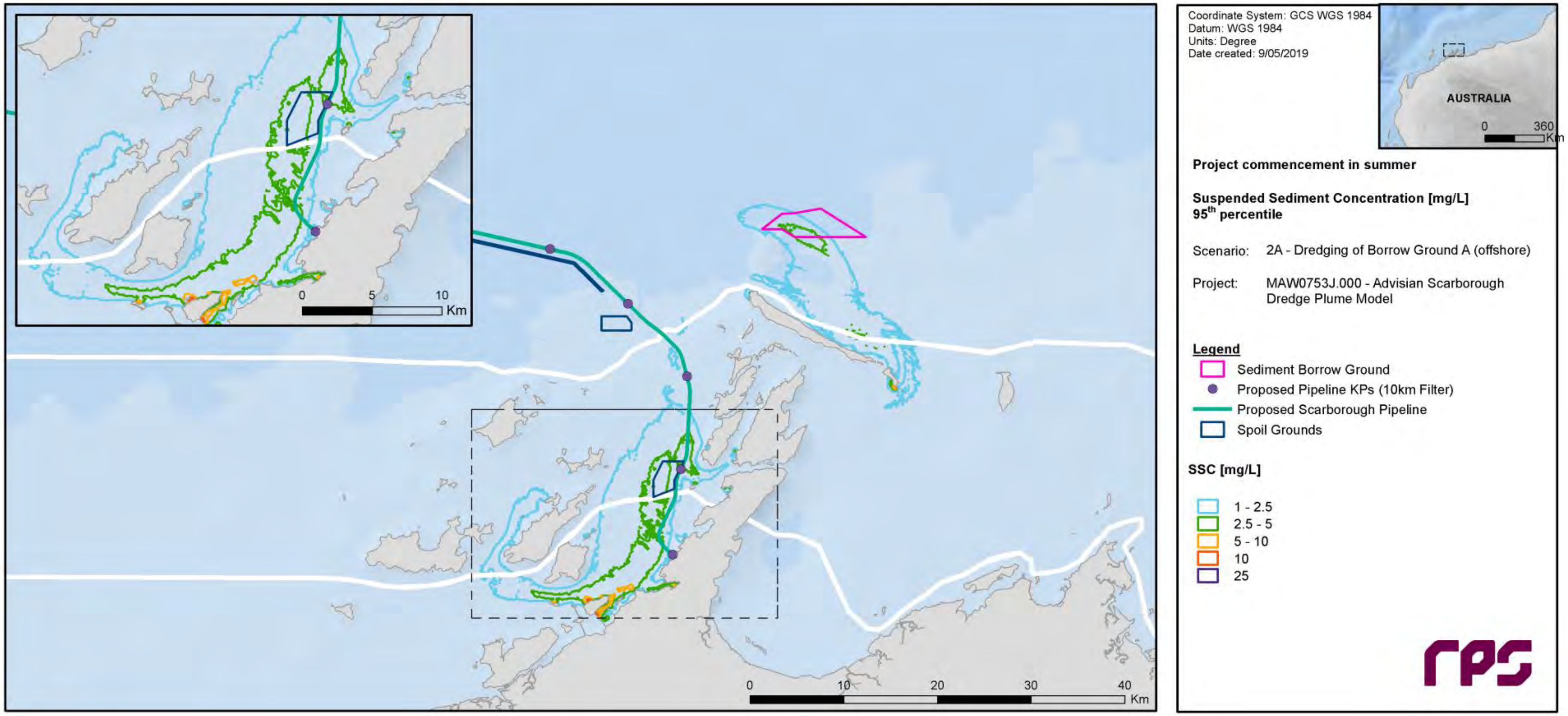


**Figure 5.6** **Predicted 95th percentile dredge-excess SSC throughout the entire scenario duration (1st January 2017 to 31st October 2017).**

#### 5.1.4.4 Scenario 2B: Dredging Operations Commencing during Summer, with Backfill Material Sourced from Borrow Ground B (Inshore)

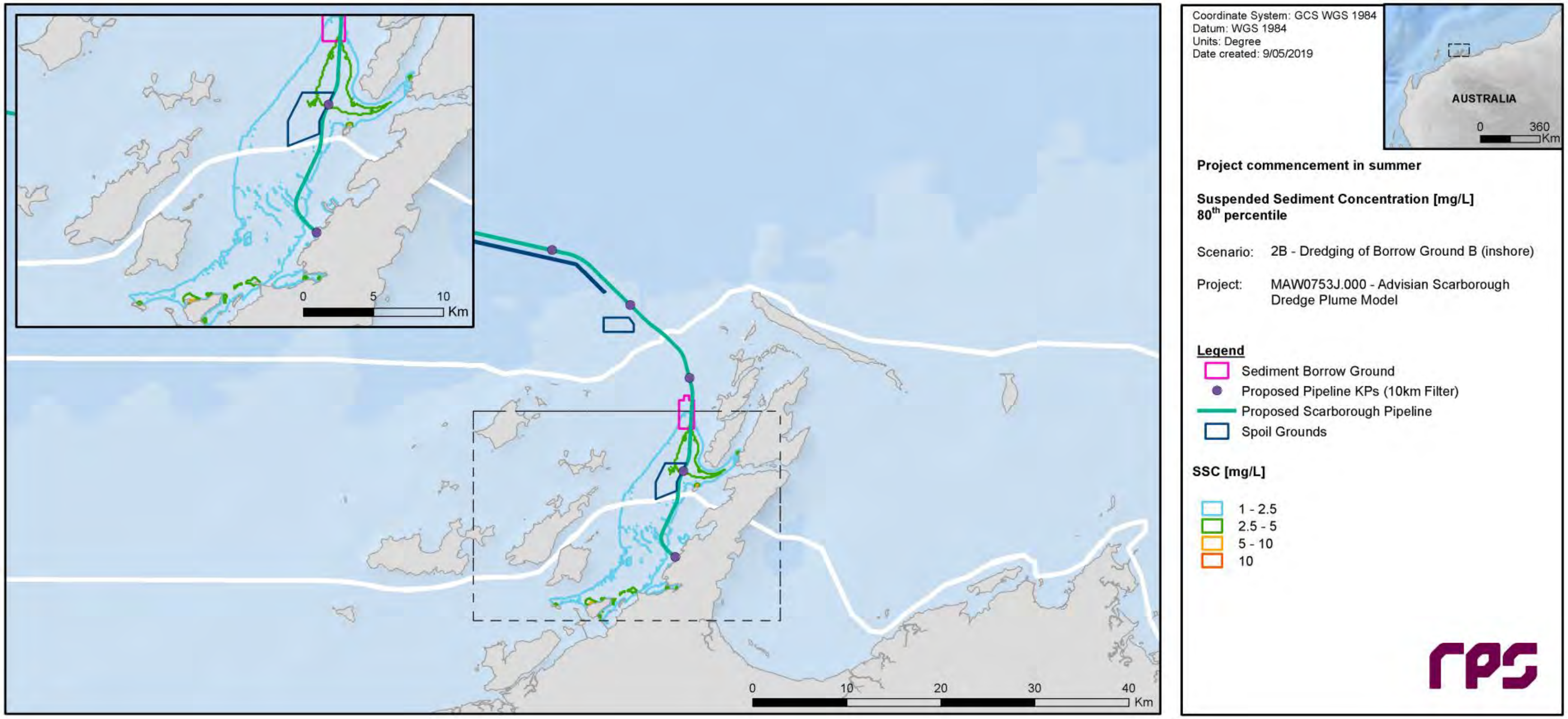


**Figure 5.7** Predicted 80th percentile dredge-excess SSC throughout the entire scenario duration (1st January 2017 to 31st October 2017).

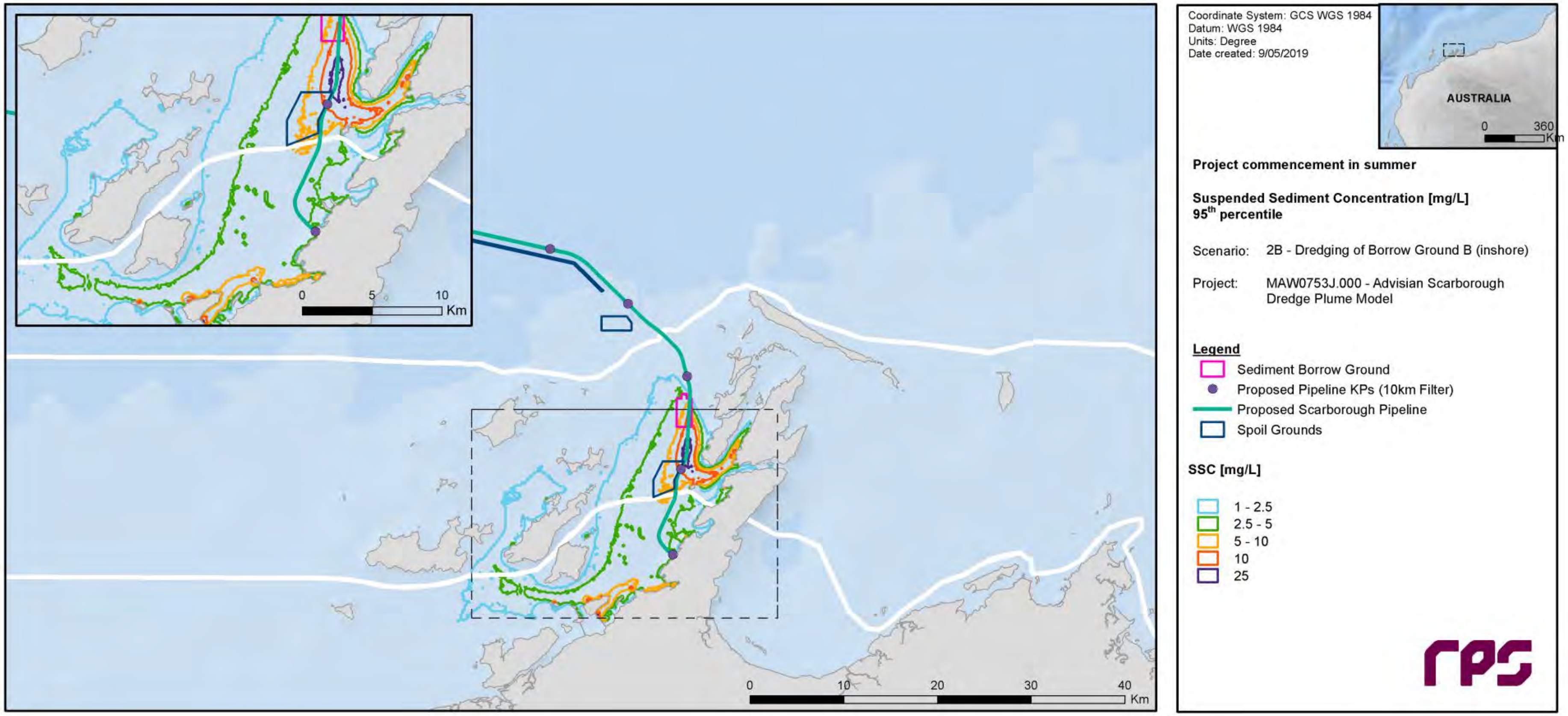


**Figure 5.8 Predicted 95th percentile dredge-excess SSC throughout the entire scenario duration (1st January 2017 to 31st October 2017).**

## 5.2 Predictions of Management Zone Extents

### 5.2.1 Summary

Figures showing the calculated extents of the defined management zones – ZoI, ZoMI and ZoHI – over the entire program of dredging, disposal and backfill operations are listed in Table 5.1 for each scenario.

Presentation of the ZoI areas is done on the basis of 95$^{th}$ percentile threshold exceedances for the 24-hour rolling average data.

It should be noted that the indicated management zone extents in each case represent a cumulative measure of exceedances of the relevant thresholds over a ten-month period, following the threshold criteria described in Section 4. They do not represent an instantaneous plume footprint at any point in time.

The indicated areas of threshold exceedances are largely a reflection of the areas of sediment confluence due to the proximity to key activity areas, where there is a sustained input of suspended sediments over periods of several months, and the influence of local metocean conditions acting to inhibit rates of settling and increase rates of resuspension.

The ZoI extents in ecological Zones A and B are broadly similar in all scenarios. In the Offshore ecological zone, a significantly larger ZoI is forecast along the pipeline in the vicinity of spoil grounds 2B and 5A for Scenarios 1A and 1B (where pipeline dredging operations will occur during winter) than for Scenarios 2A and 2B (where these operations will occur during summer). This is largely a consequence of the lower thresholds applicable during the winter period, and consequently the lower levels of dredge-excess SSC required to cause exceedances. In a similar manner, the larger ZoI predicted at the offshore borrow ground for Scenario 2A (where, following project commencement in summer, pipeline backfill operations will occur during winter) than for Scenario 1A (where these operations will occur during summer) is attributable to the lower winter thresholds.

The ZoMI/ZoHI threshold exceedances in isolated pockets of King Bay and around the Intercourse Islands may be attributable to the combined effects of model bathymetry and hydrodynamics, representing sediments that are transported into the shallowest-possible grid cells and then “trapped” upon reversal of the tide. While it is clear that there is a potential for dredged sediments to be found in the indicated areas, the persistently high concentrations at the water-land boundaries may be overstated – particularly in light of the long durations required to trigger the ZoMI/ZoHI thresholds.

**Table 5.1 Index of the ZoI, ZoMI and ZoHI figures for each scenario.**

| Management Zone | Scenario 1A | Scenario 1B | Scenario 2A | Scenario 2B |
|---|---|---|---|---|
| Zone of Influence (95$^{th}$ percentile): 24-hour rolling average of total SSC | Figure 5.9 | Figure 5.18 | Figure 5.27 | Figure 5.36 |
| Zone of Moderate Impact: 3-day (Zones A and B) and 28-day (Offshore) rolling average of total SSC | Figure 5.10 | Figure 5.19 | Figure 5.28 | Figure 5.37 |
| Zone of Moderate Impact: 7-day (Zones A and B) and 28-day (Offshore) rolling average of total SSC | Figure 5.11 | Figure 5.20 | Figure 5.29 | Figure 5.38 |
| Zone of Moderate Impact: 10-day (Zones A and B) and 28-day (Offshore) rolling average of total SSC | Figure 5.12 | Figure 5.21 | Figure 5.30 | Figure 5.39 |
| Zone of Moderate Impact: 14-day (Zones A and B) and 28-day (Offshore) rolling average of total SSC | Figure 5.13 | Figure 5.22 | Figure 5.31 | Figure 5.40 |
| Zone of High Impact: 3-day (Zones A and B) and 28-day (Offshore) rolling average of total SSC | Figure 5.14 | Figure 5.23 | Figure 5.32 | Figure 5.41 |
| Zone of High Impact: 7-day (Zones A and B) and 28-day (Offshore) rolling average of total SSC | Figure 5.15 | Figure 5.24 | Figure 5.33 | Figure 5.42 |
| Zone of High Impact: 10-day (Zones A and B) and 28-day (Offshore) rolling average of total SSC | Figure 5.16 | Figure 5.25 | Figure 5.34 | Figure 5.43 |
| Zone of High Impact: 14-day (Zones A and B) and 28-day (Offshore) rolling average of total SSC | Figure 5.17 | Figure 5.26 | Figure 5.35 | Figure 5.44 |

## 5.2.2 Spatial Outcomes

### 5.2.2.1 Scenario 1A: Dredging Operations Commencing during Winter, with Backfill Material Sourced from Borrow Ground A (Offshore)

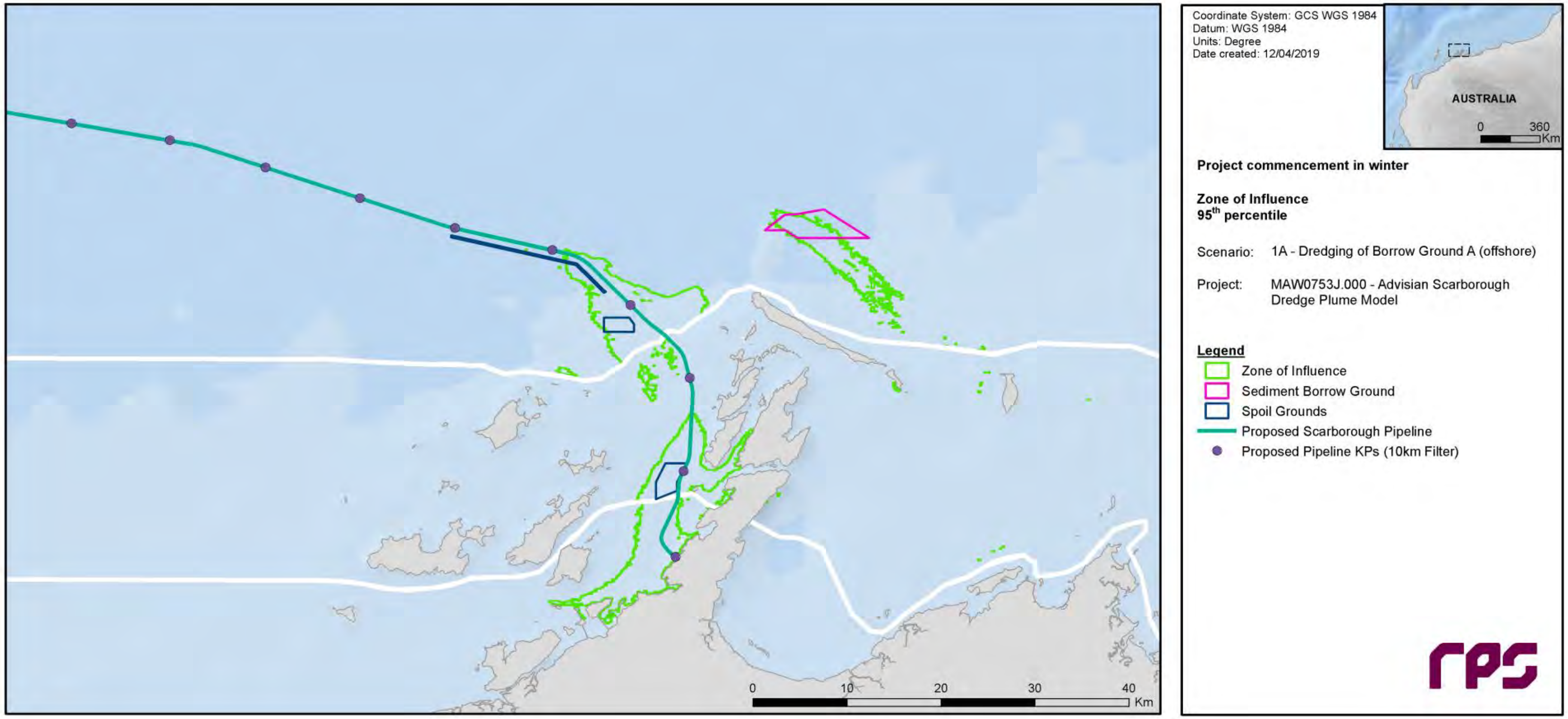


**Figure 5.9 Predicted 95th percentile Zone of Influence following application of the appropriate spatial thresholds in Table 4.2 to a 24-hour rolling average of total (dredge and background) SSC throughout the entire scenario duration (1st July 2016 to 30th April 2017).**

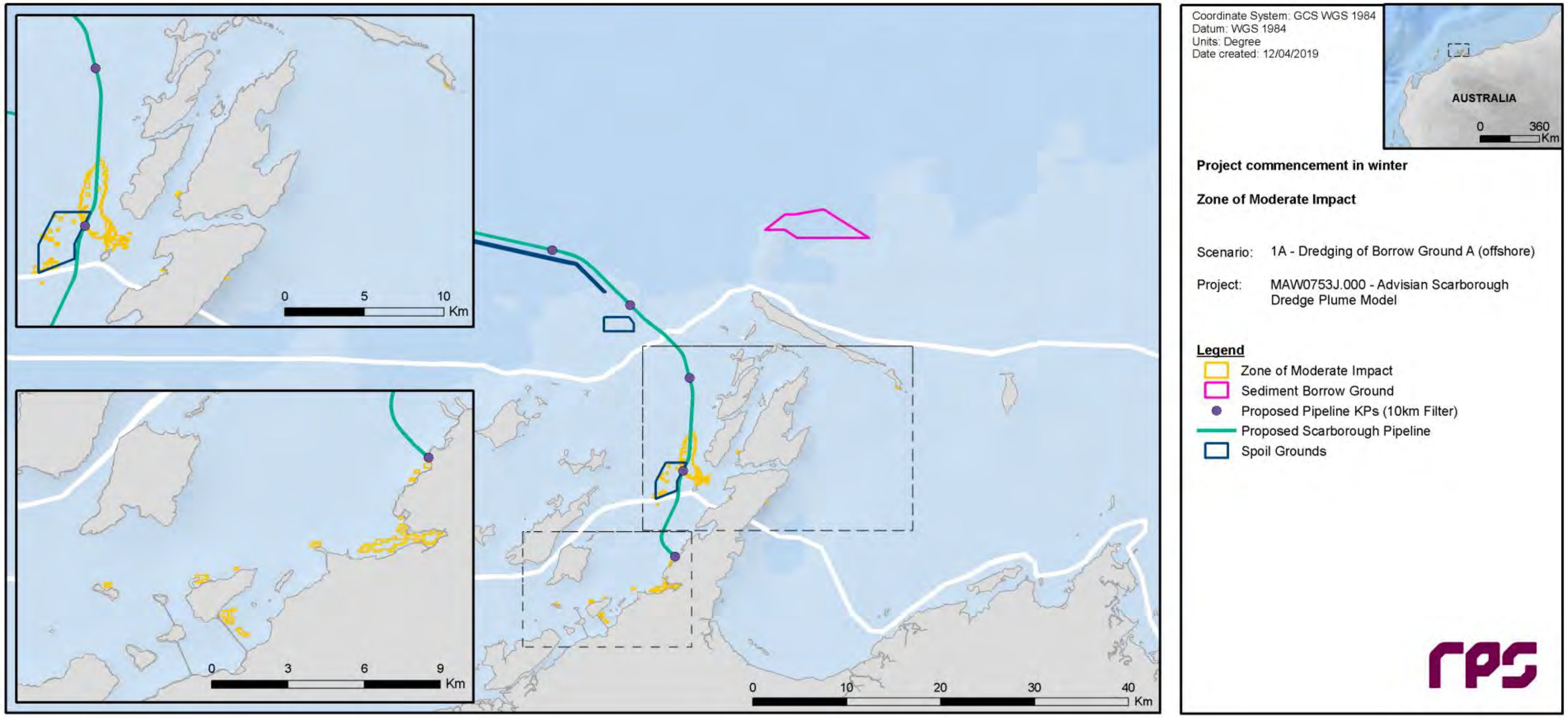


**Figure 5.10 Predicted Zone of Moderate Impact following application of the appropriate spatial thresholds in Table 4.3 to 3-day (Zones A and B) and 28-day (Offshore) rolling averages of total (dredge and background) SSC throughout the entire scenario duration (1st July 2016 to 30th April 2017).**

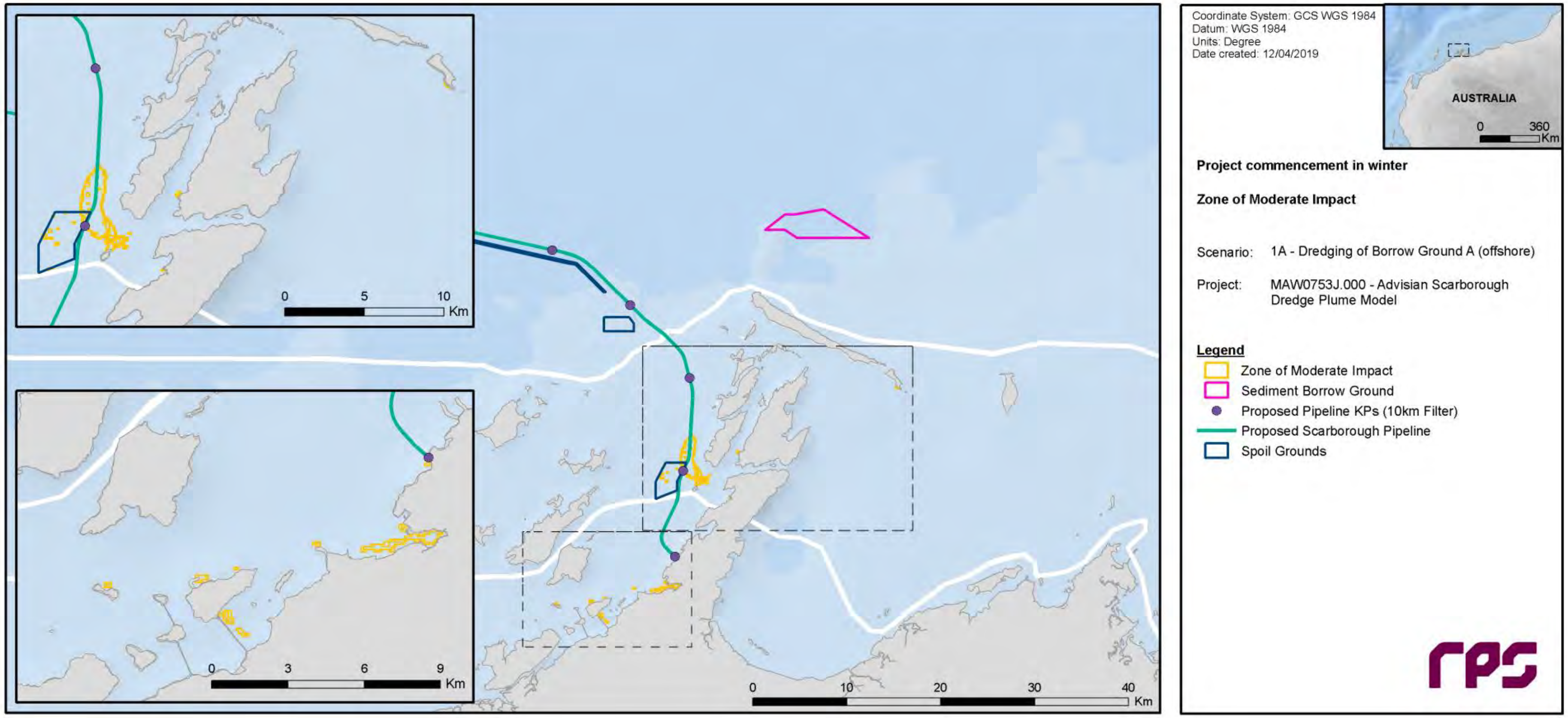


**Figure 5.11 Predicted Zone of Moderate Impact following application of the appropriate spatial thresholds in Table 4.3 to 7-day (Zones A and B) and 28-day (Offshore) rolling averages of total (dredge and background) SSC throughout the entire scenario duration (1st July 2016 to 30th April 2017).**

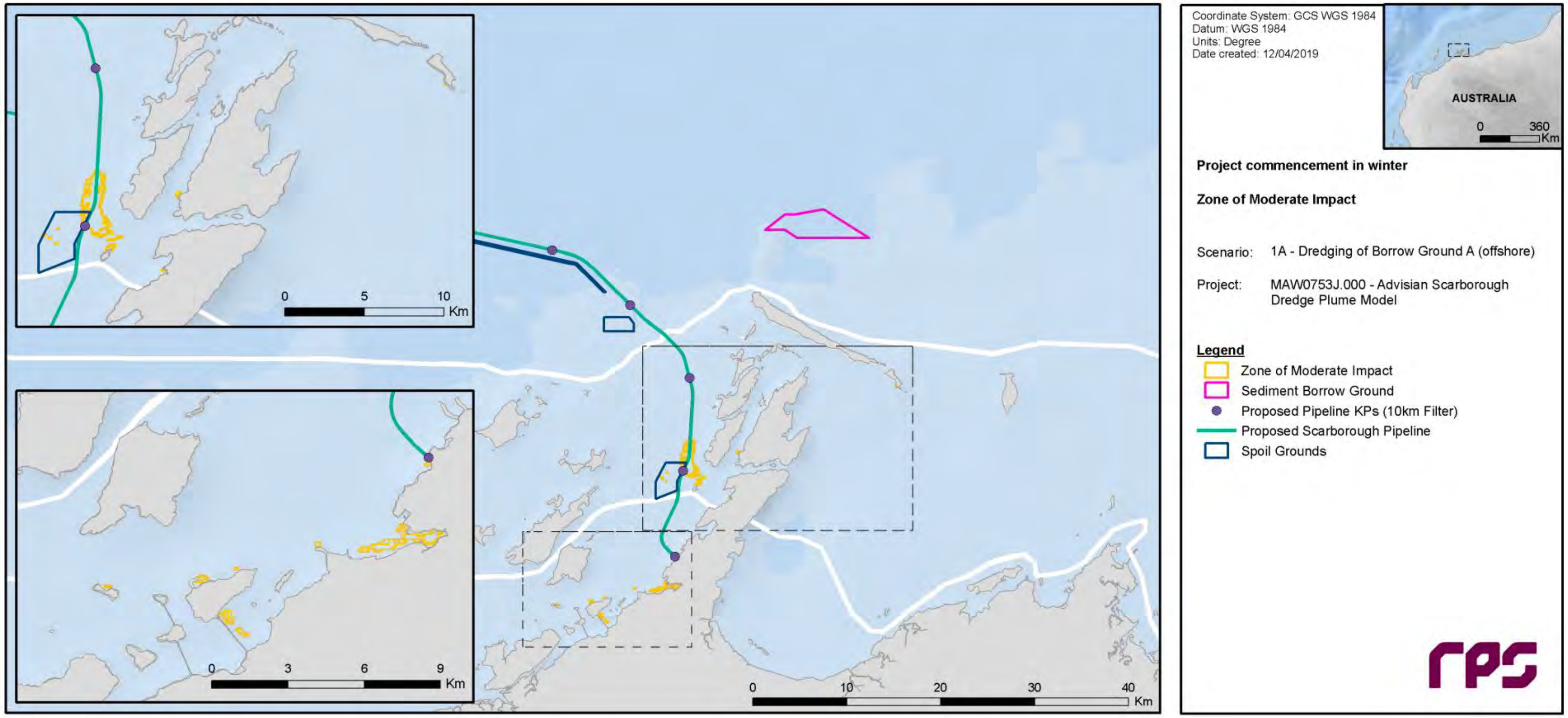


**Figure 5.12 Predicted Zone of Moderate Impact following application of the appropriate spatial thresholds in Table 4.3 to 10-day (Zones A and B) and 28-day (Offshore) rolling averages of total (dredge and background) SSC throughout the entire scenario duration (1st July 2016 to 30th April 2017).**

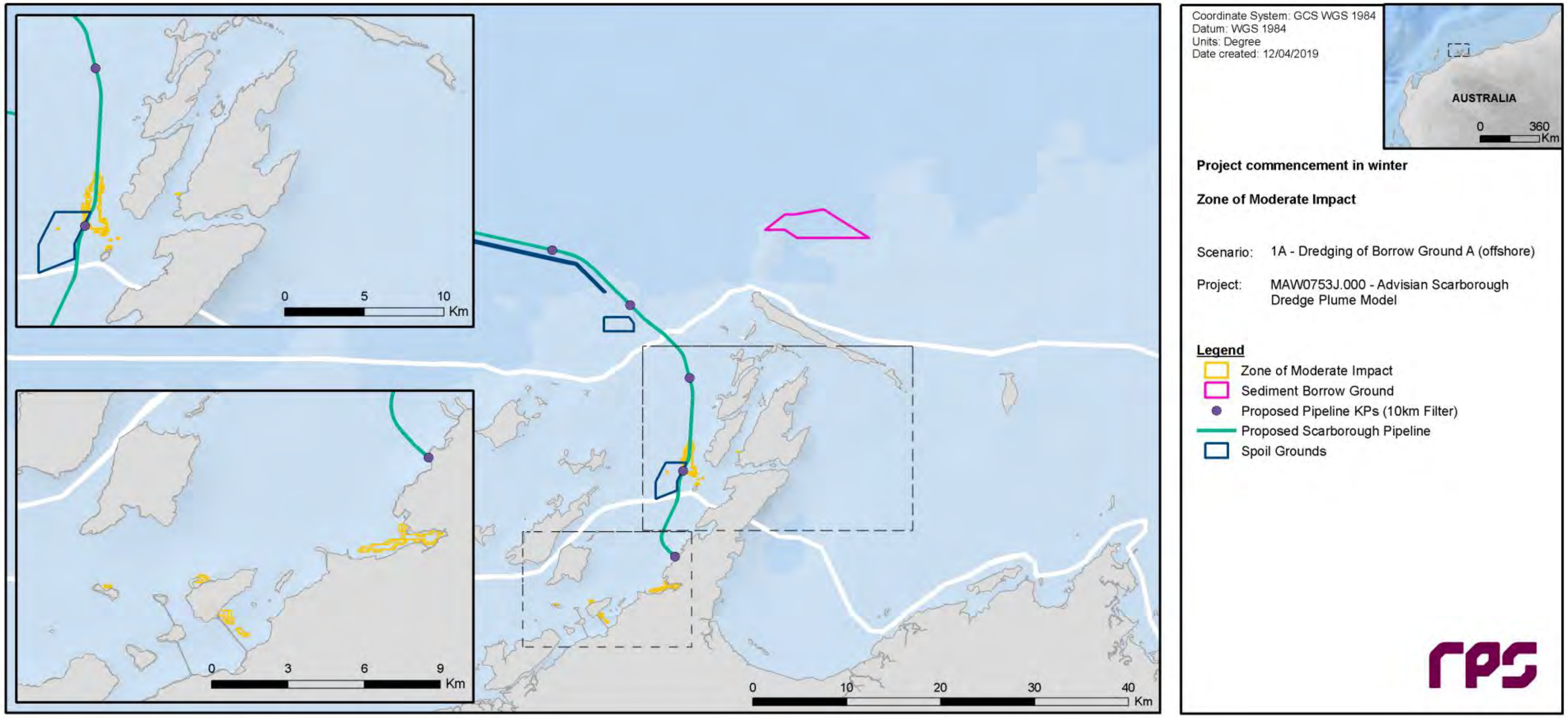


**Figure 5.13 Predicted Zone of Moderate Impact following application of the appropriate spatial thresholds in Table 4.3 to 14-day (Zones A and B) and 28-day (Offshore) rolling averages of total (dredge and background) SSC throughout the entire scenario duration (1st July 2016 to 30th April 2017).**

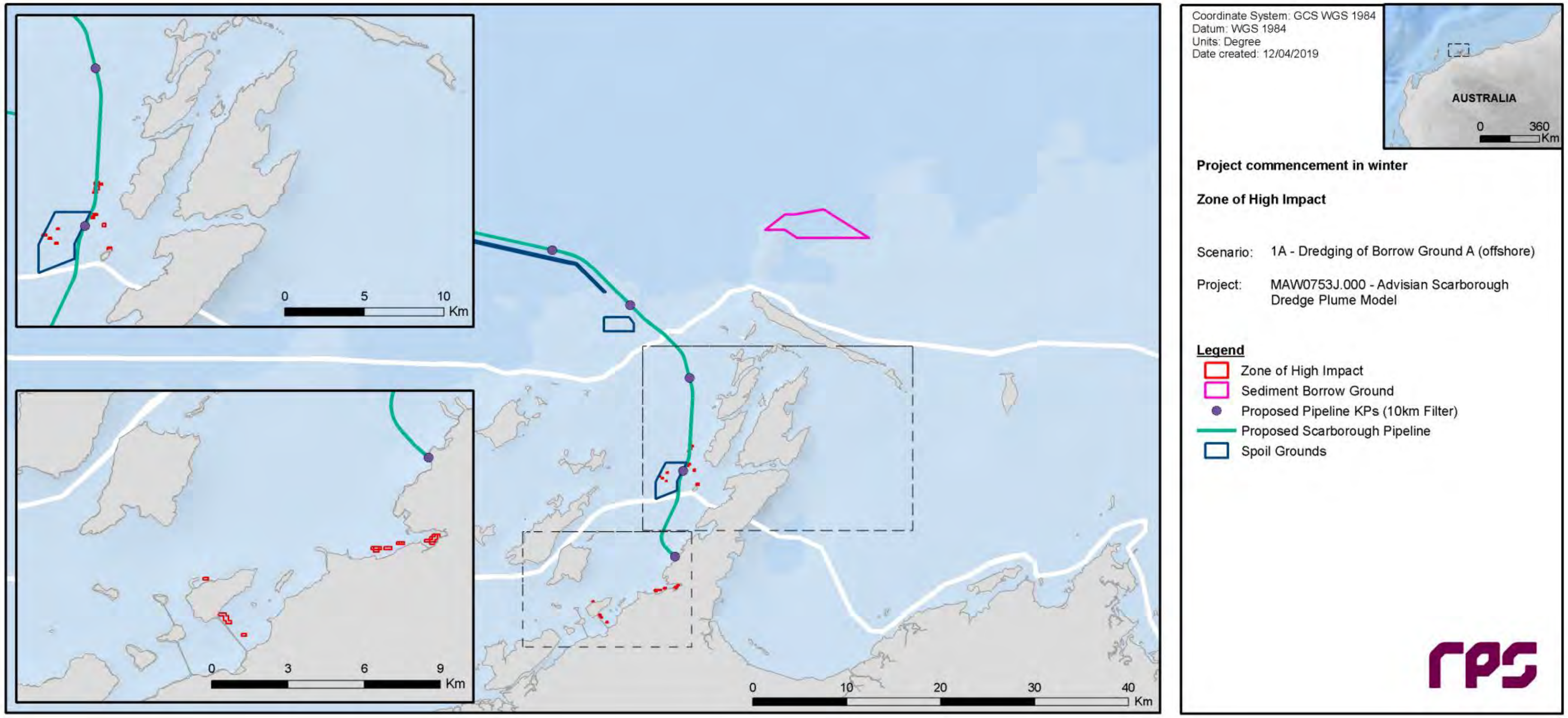


**Figure 5.14 Predicted Zone of High Impact following application of the appropriate spatial thresholds in Table 4.4 to 3-day (Zones A and B) and 28-day (Offshore) rolling averages of total (dredge and background) SSC throughout the entire scenario duration (1st July 2016 to 30th April 2017).**

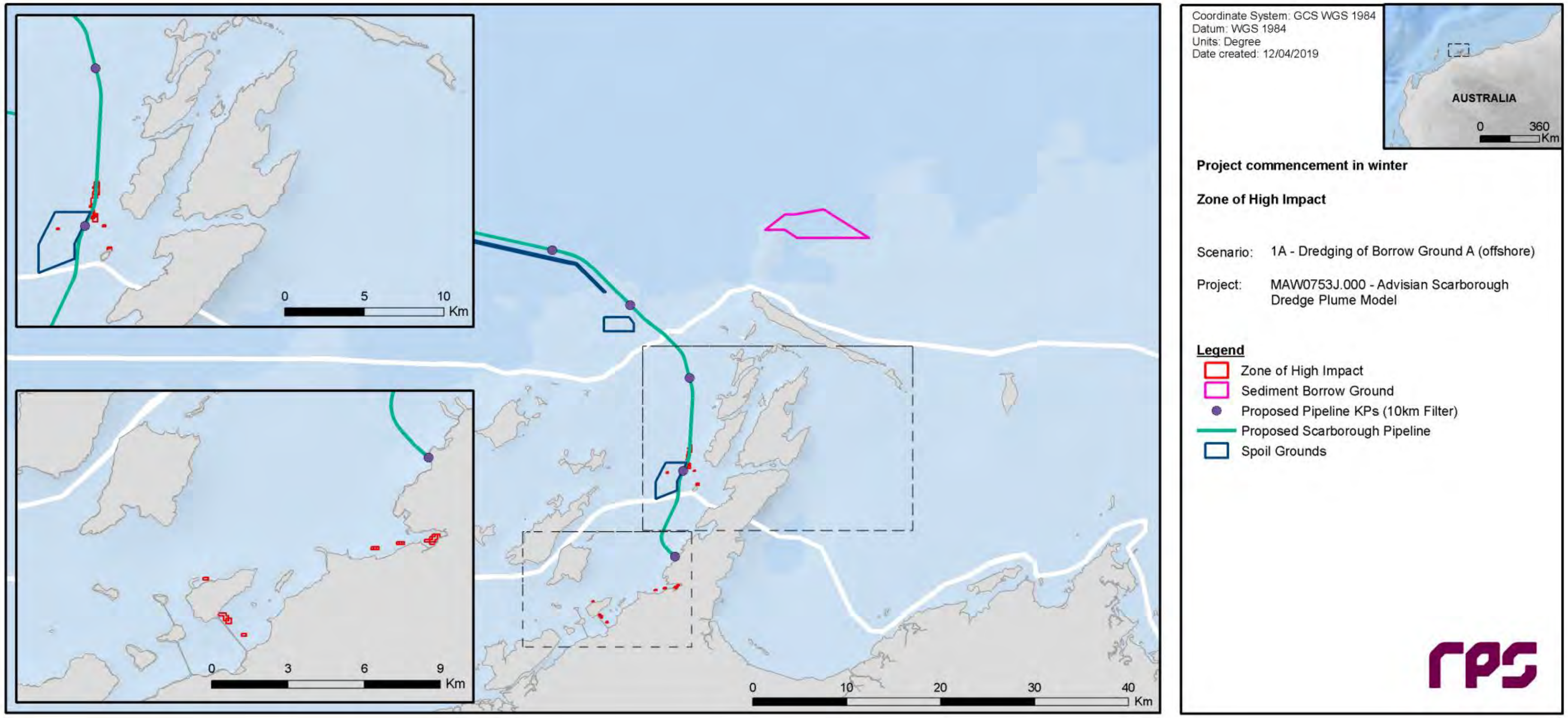


**Figure 5.15 Predicted Zone of High Impact following application of the appropriate spatial thresholds in Table 4.4 to 7-day (Zones A and B) and 28-day (Offshore) rolling averages of total (dredge and background) SSC throughout the entire scenario duration (1st July 2016 to 30th April 2017).**

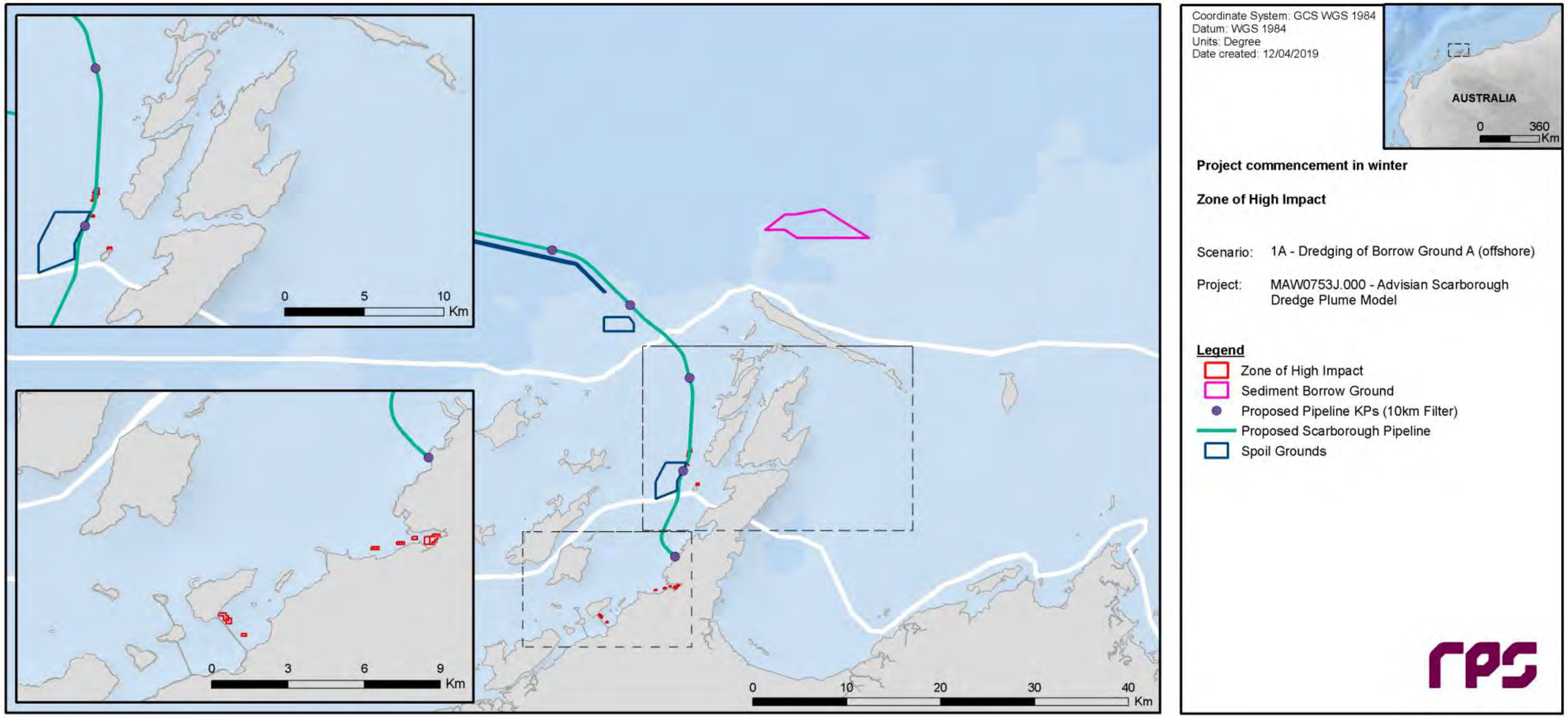


**Figure 5.16 Predicted Zone of High Impact following application of the appropriate spatial thresholds in Table 4.4 to 10-day (Zones A and B) and 28-day (Offshore) rolling averages of total (dredge and background) SSC throughout the entire scenario duration (1st July 2016 to 30th April 2017).**

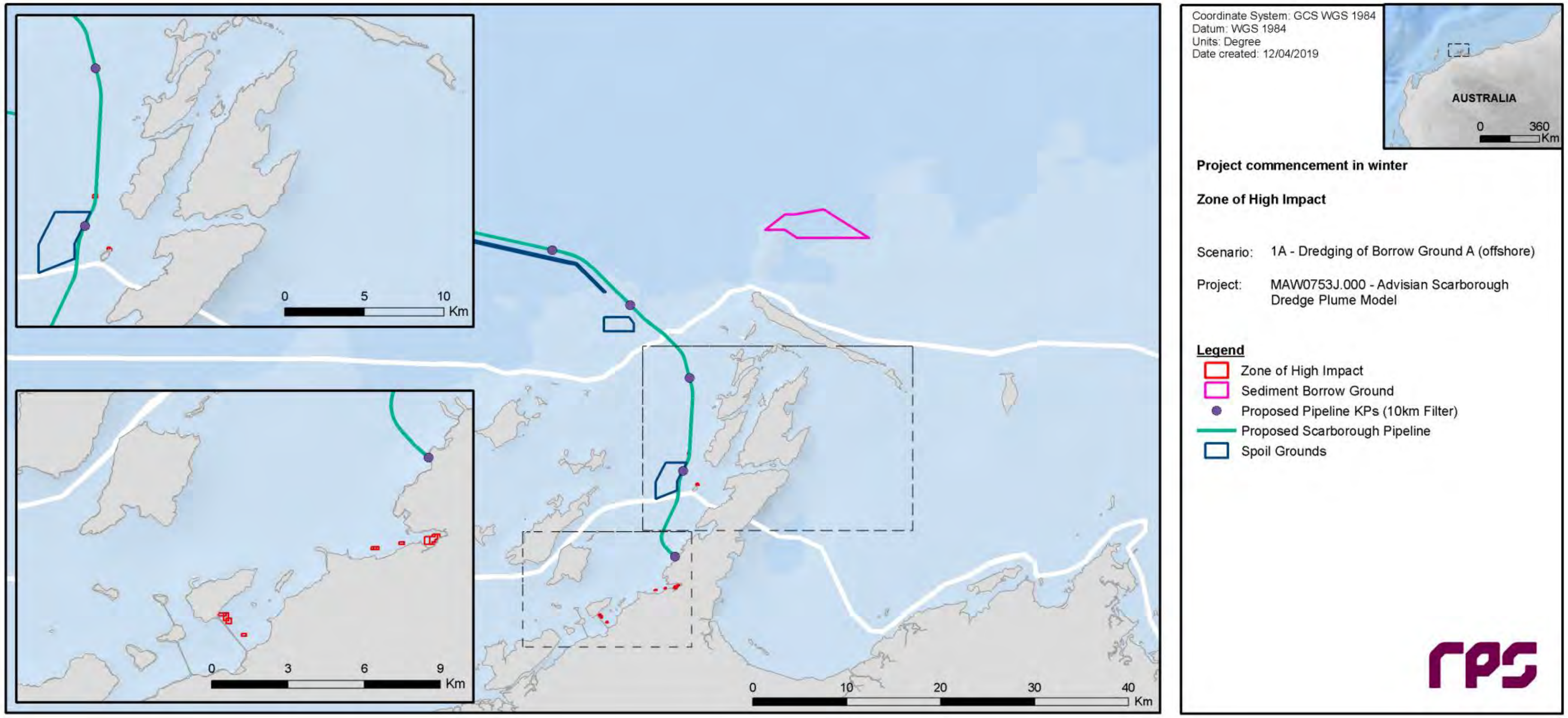


**Figure 5.17 Predicted Zone of High Impact following application of the appropriate spatial thresholds in Table 4.4 to 14-day (Zones A and B) and 28-day (Offshore) rolling averages of total (dredge and background) SSC throughout the entire scenario duration (1st July 2016 to 30th April 2017).**

### 5.2.2.2 Scenario 1B: Dredging Operations Commencing during Winter, with Backfill Material Sourced from Borrow Ground B (Inshore)

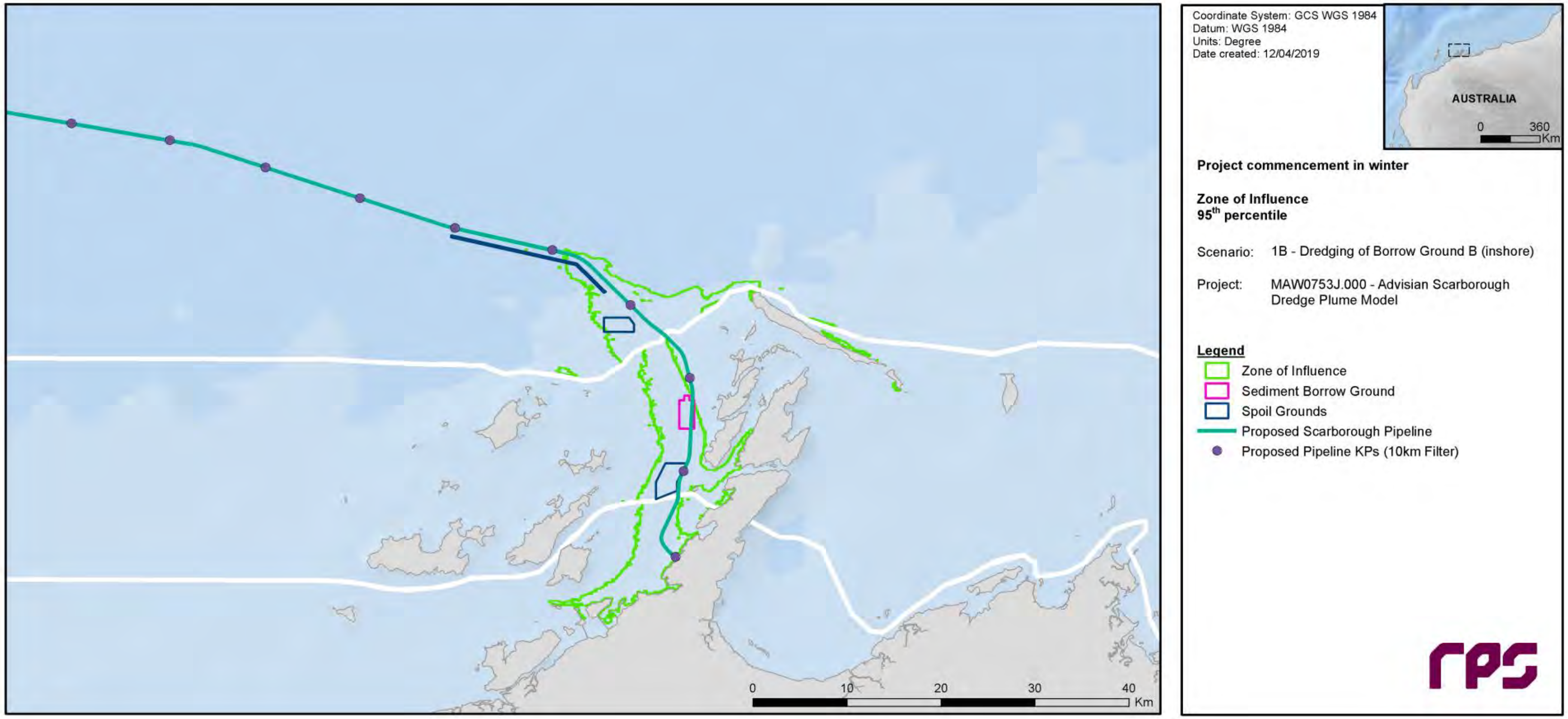


**Figure 5.18 Predicted 95th percentile Zone of Influence following application of the appropriate spatial thresholds in Table 4.2 to a 24-hour rolling average of total (dredge and background) SSC throughout the entire scenario duration (1st July 2016 to 30th April 2017).**

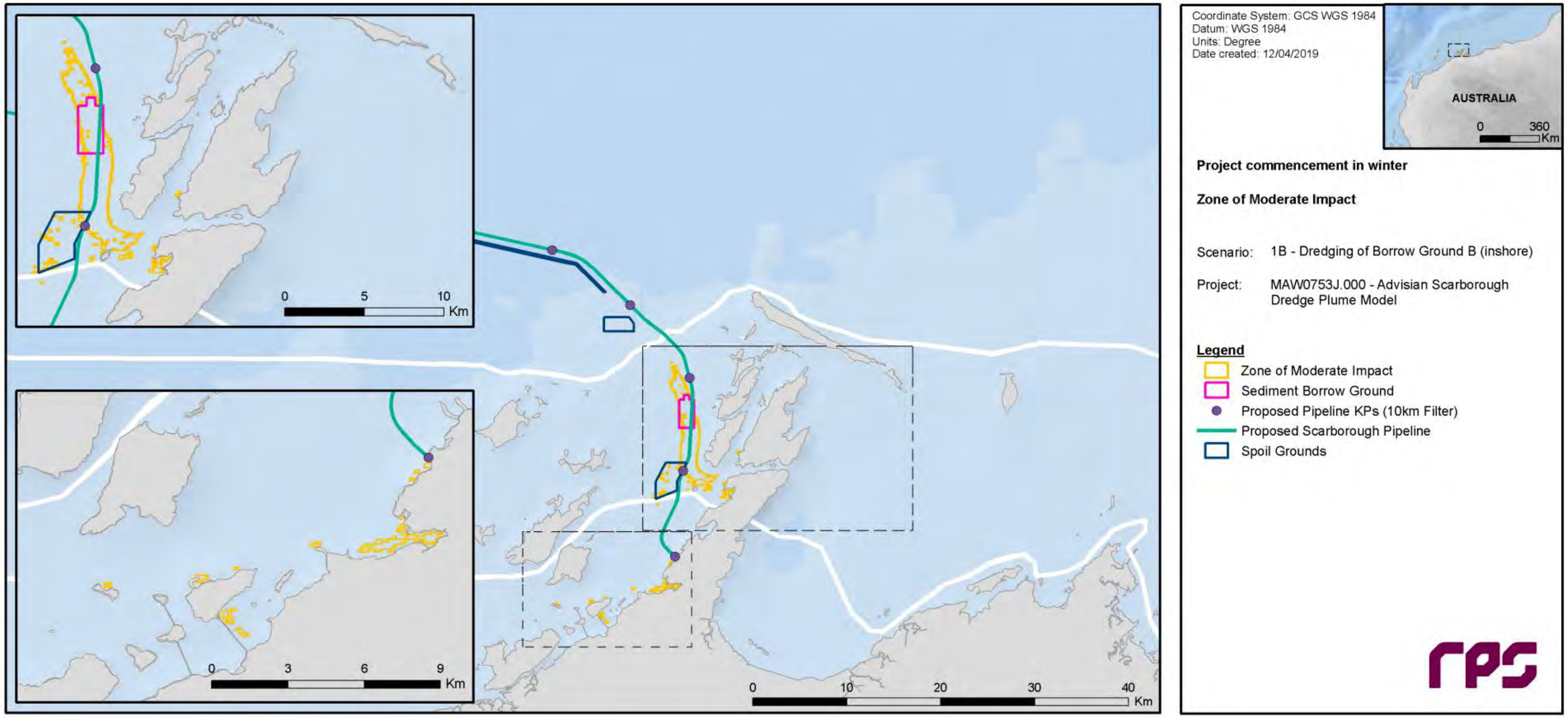


**Figure 5.19 Predicted Zone of Moderate Impact following application of the appropriate spatial thresholds in Table 4.3 to 3-day (Zones A and B) and 28-day (Offshore) rolling averages of total (dredge and background) SSC throughout the entire scenario duration (1st July 2016 to 30th April 2017).**

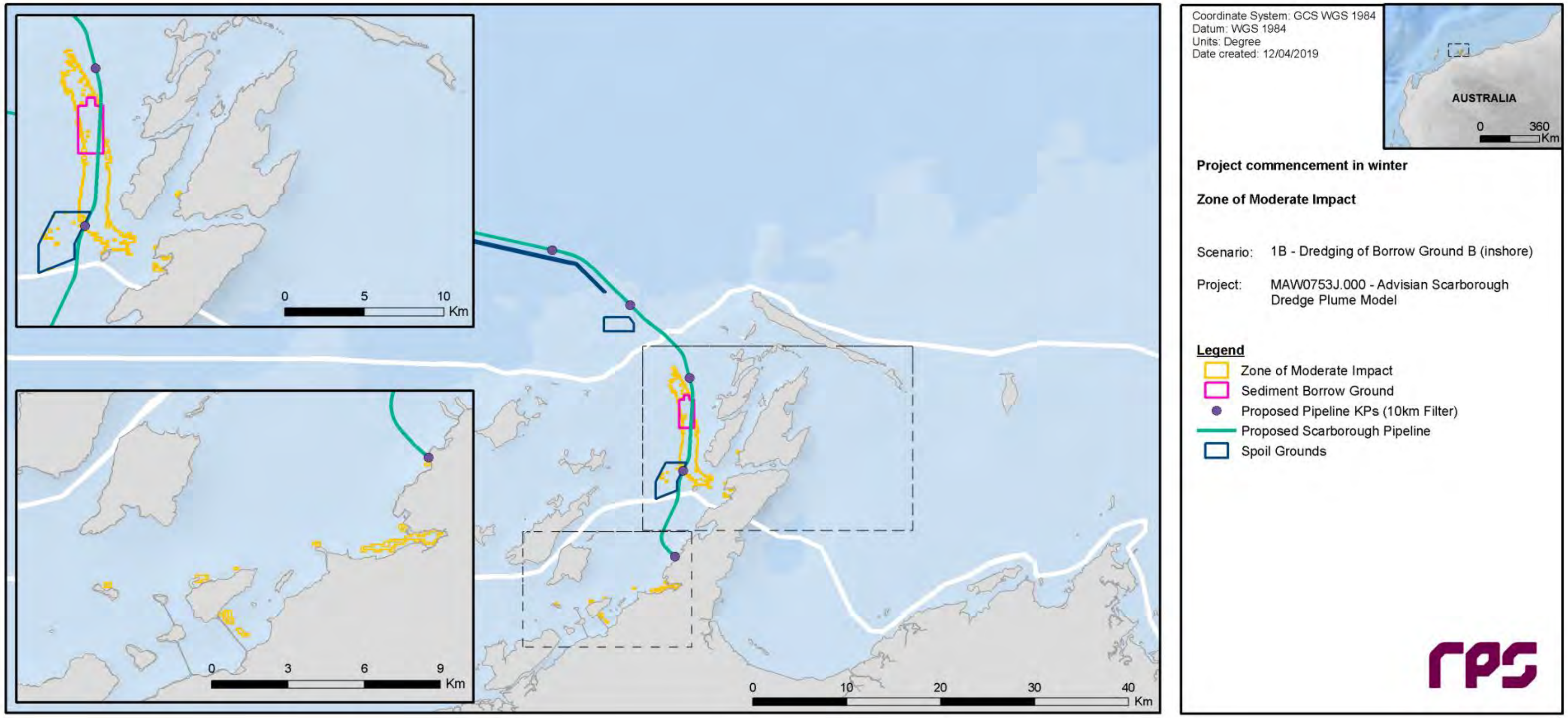


**Figure 5.20 Predicted Zone of Moderate Impact following application of the appropriate spatial thresholds in Table 4.3 to 7-day (Zones A and B) and 28-day (Offshore) rolling averages of total (dredge and background) SSC throughout the entire scenario duration (1st July 2016 to 30th April 2017).**

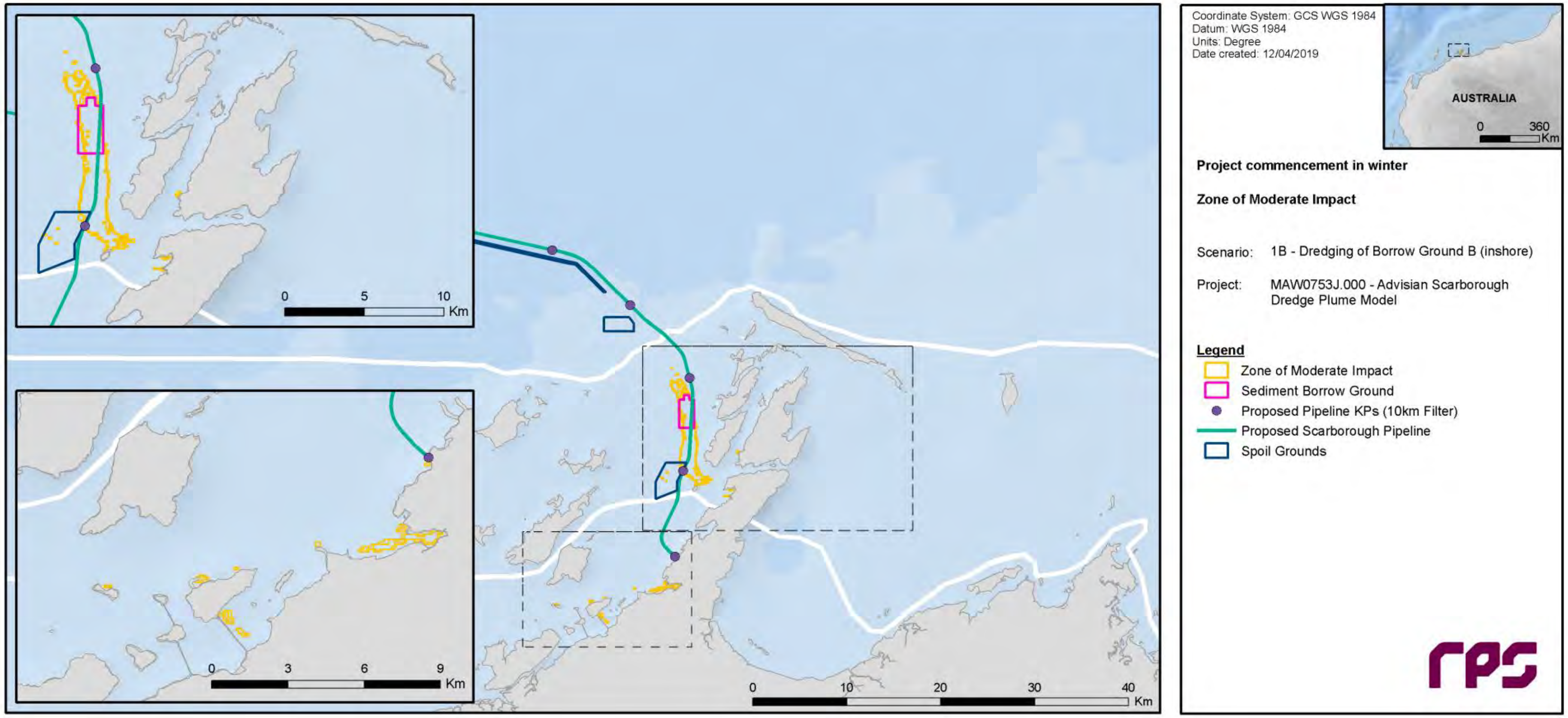


**Figure 5.21 Predicted Zone of Moderate Impact following application of the appropriate spatial thresholds in Table 4.3 to 10-day (Zones A and B) and 28-day (Offshore) rolling averages of total (dredge and background) SSC throughout the entire scenario duration (1st July 2016 to 30th April 2017).**

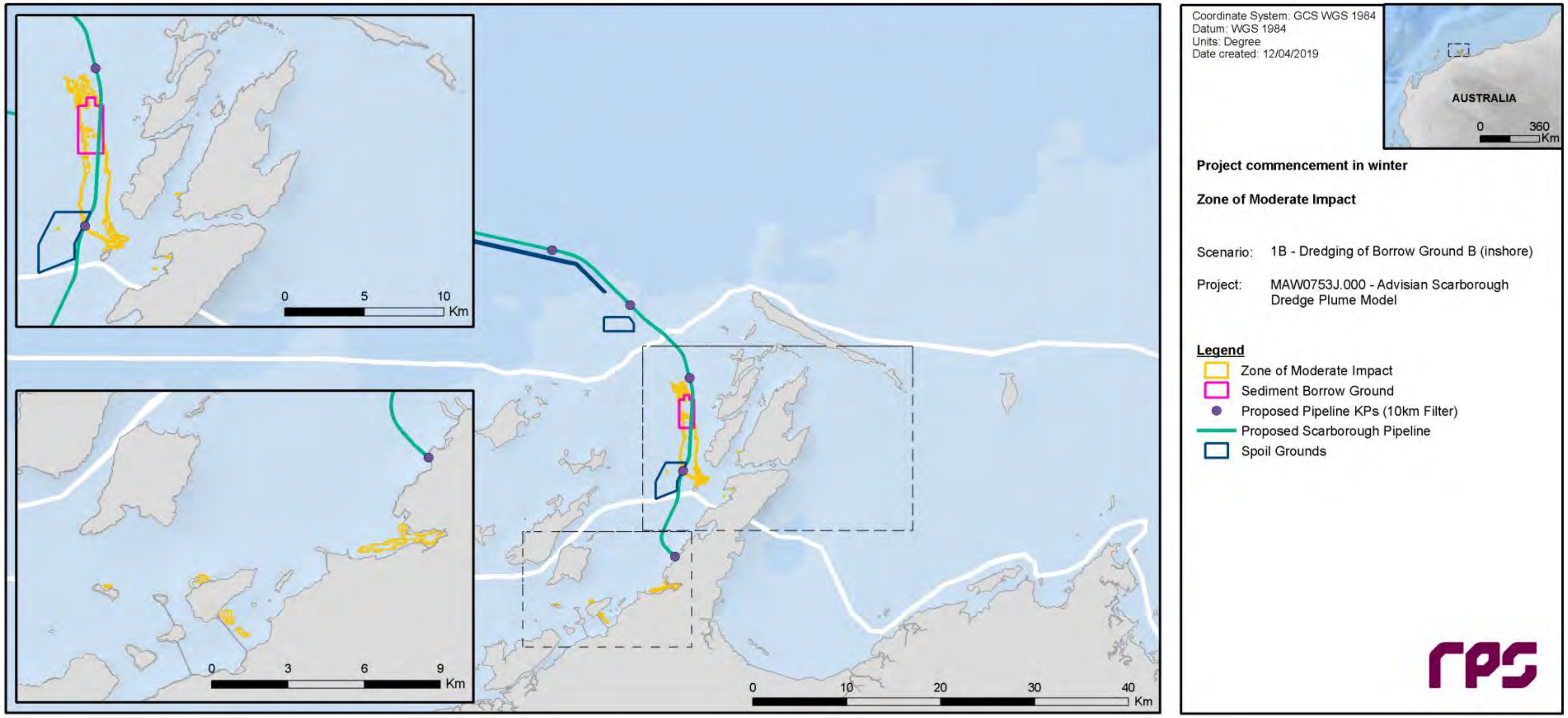


**Figure 5.22 Predicted Zone of Moderate Impact following application of the appropriate spatial thresholds in Table 4.3 to 14-day (Zones A and B) and 28-day (Offshore) rolling averages of total (dredge and background) SSC throughout the entire scenario duration (1st July 2016 to 30th April 2017).**

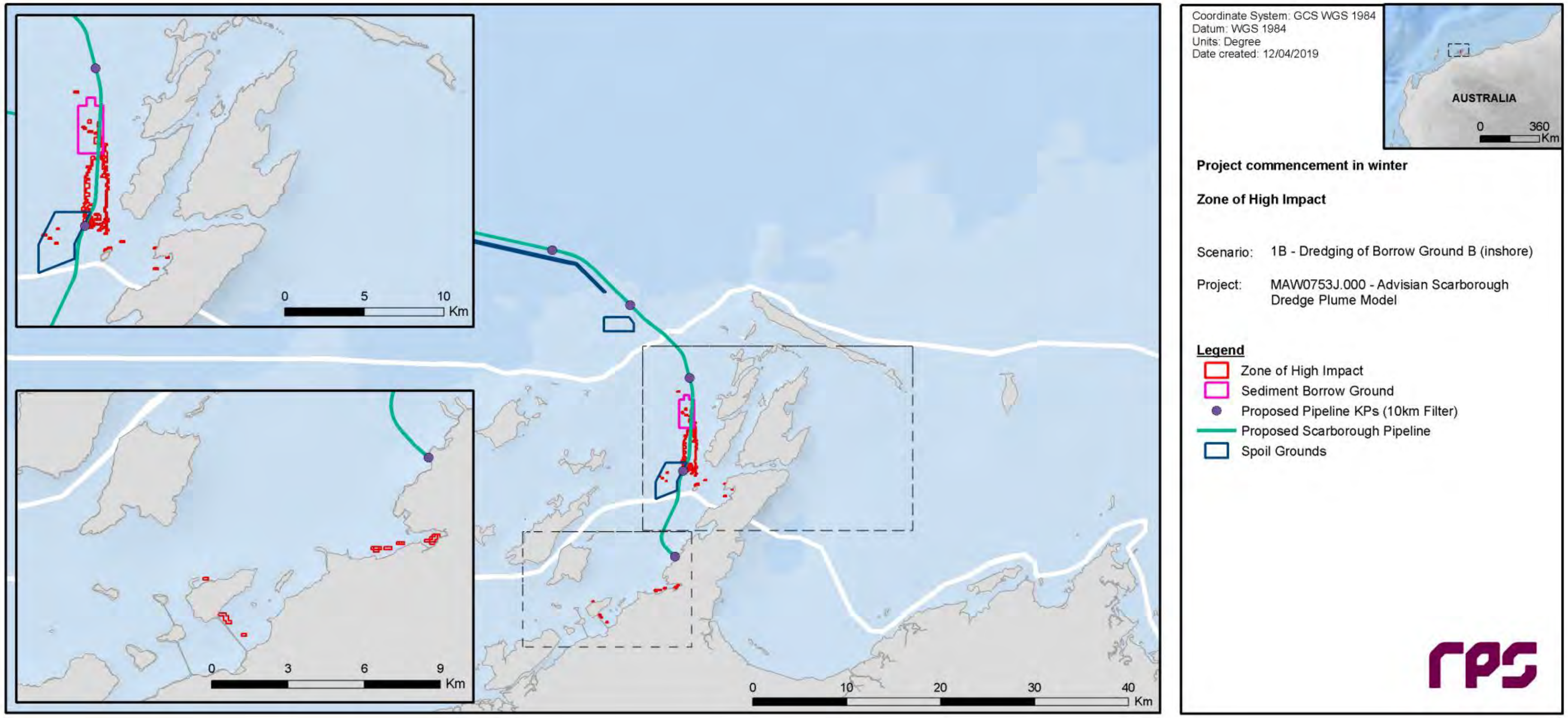


**Figure 5.23 Predicted Zone of High Impact following application of the appropriate spatial thresholds in Table 4.4 to 3-day (Zones A and B) and 28-day (Offshore) rolling averages of total (dredge and background) SSC throughout the entire scenario duration (1st July 2016 to 30th April 2017).**

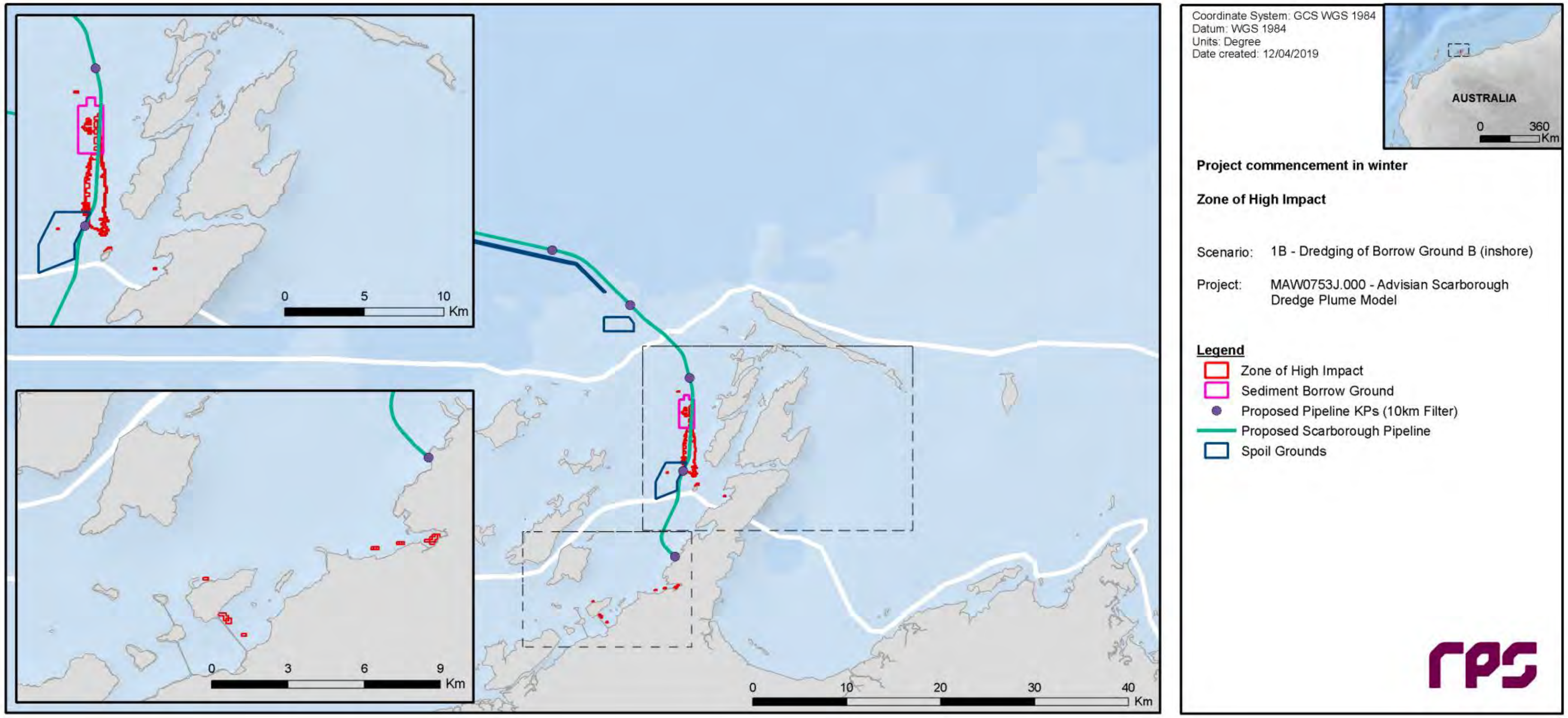


**Figure 5.24 Predicted Zone of High Impact following application of the appropriate spatial thresholds in Table 4.4 to 7-day (Zones A and B) and 28-day (Offshore) rolling averages of total (dredge and background) SSC throughout the entire scenario duration (1st July 2016 to 30th April 2017).**

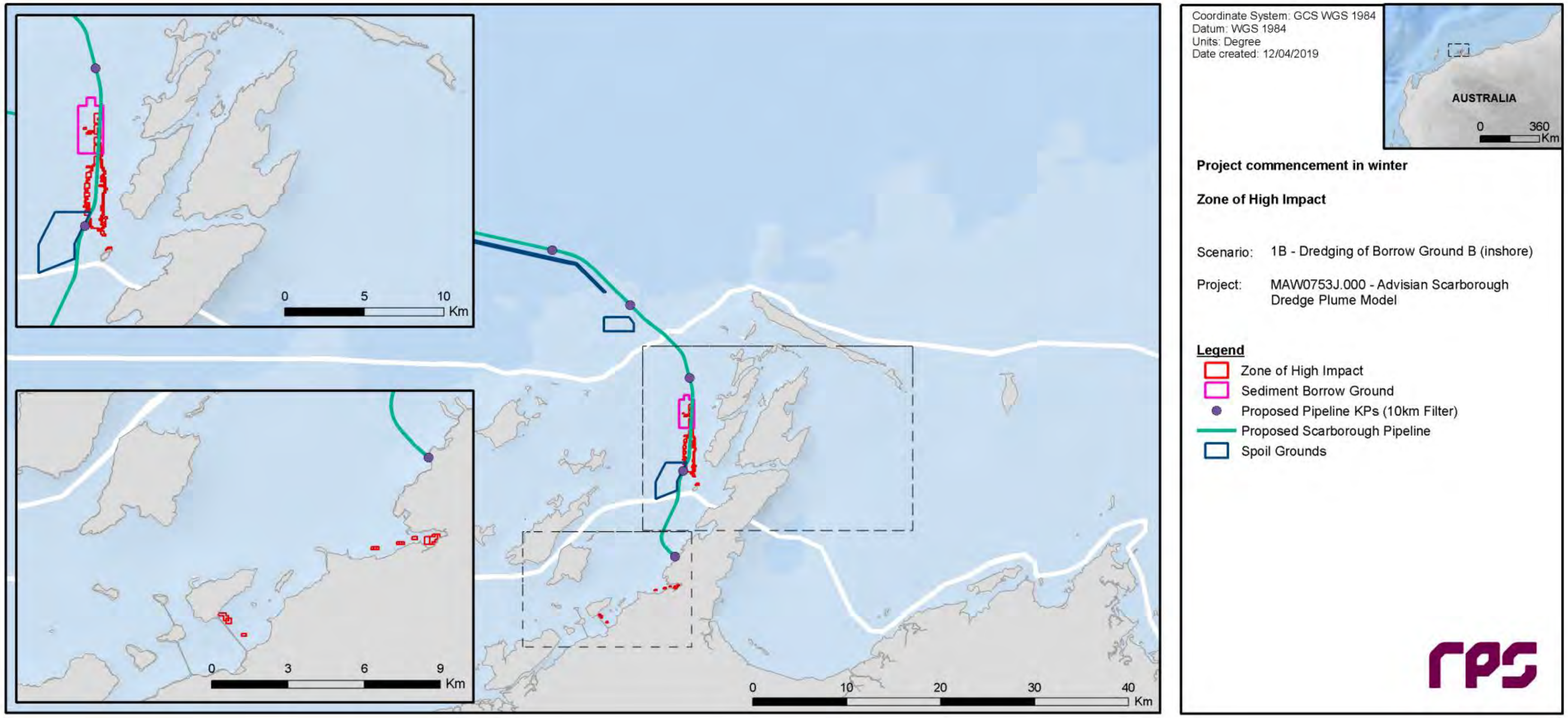


**Figure 5.25 Predicted Zone of High Impact following application of the appropriate spatial thresholds in Table 4.4 to 10-day (Zones A and B) and 28-day (Offshore) rolling averages of total (dredge and background) SSC throughout the entire scenario duration (1st July 2016 to 30th April 2017).**

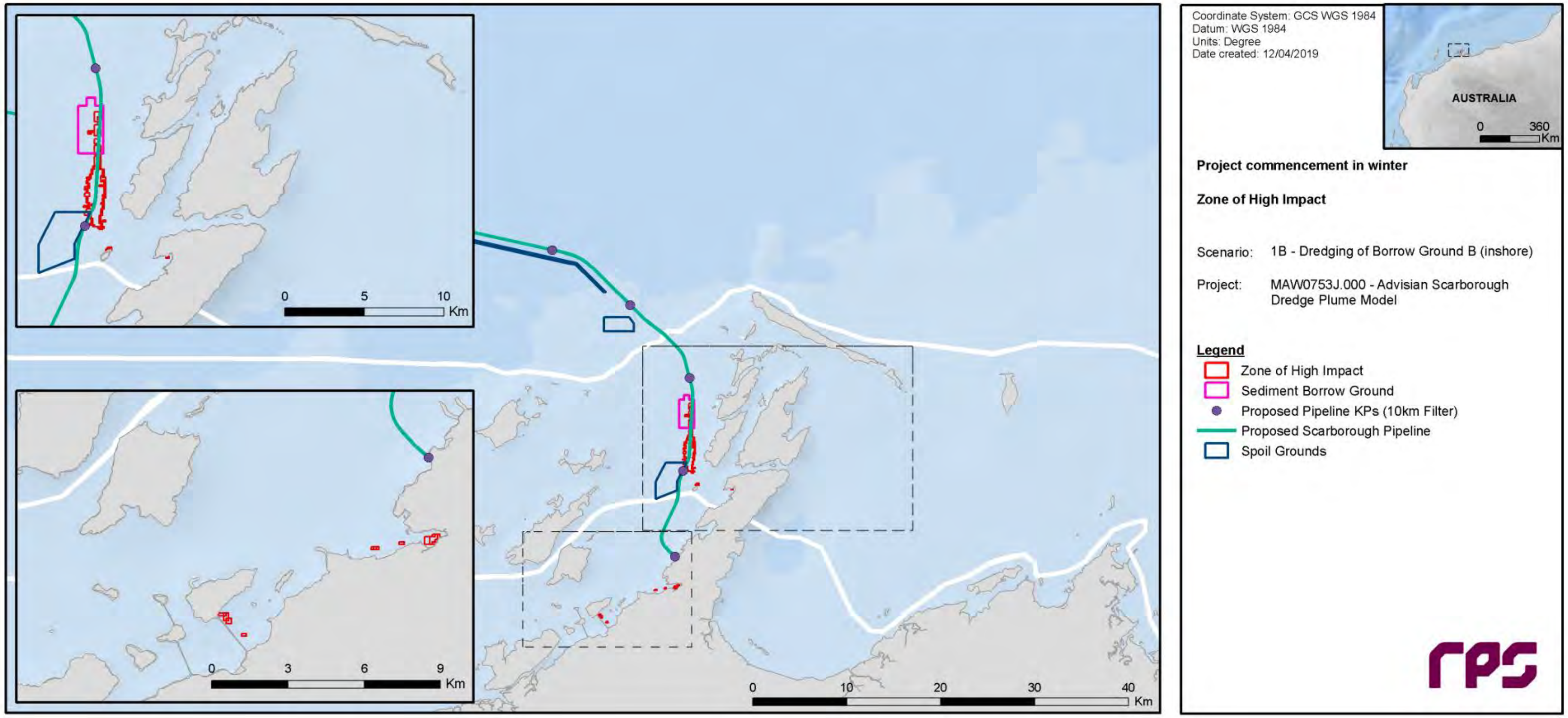


**Figure 5.26 Predicted Zone of High Impact following application of the appropriate spatial thresholds in Table 4.4 to 14-day (Zones A and B) and 28-day (Offshore) rolling averages of total (dredge and background) SSC throughout the entire scenario duration (1st July 2016 to 30th April 2017).**

#### 5.2.2.3 Scenario 2A: Dredging Operations Commencing during Summer, with Backfill Material Sourced from Borrow Ground A (Offshore)

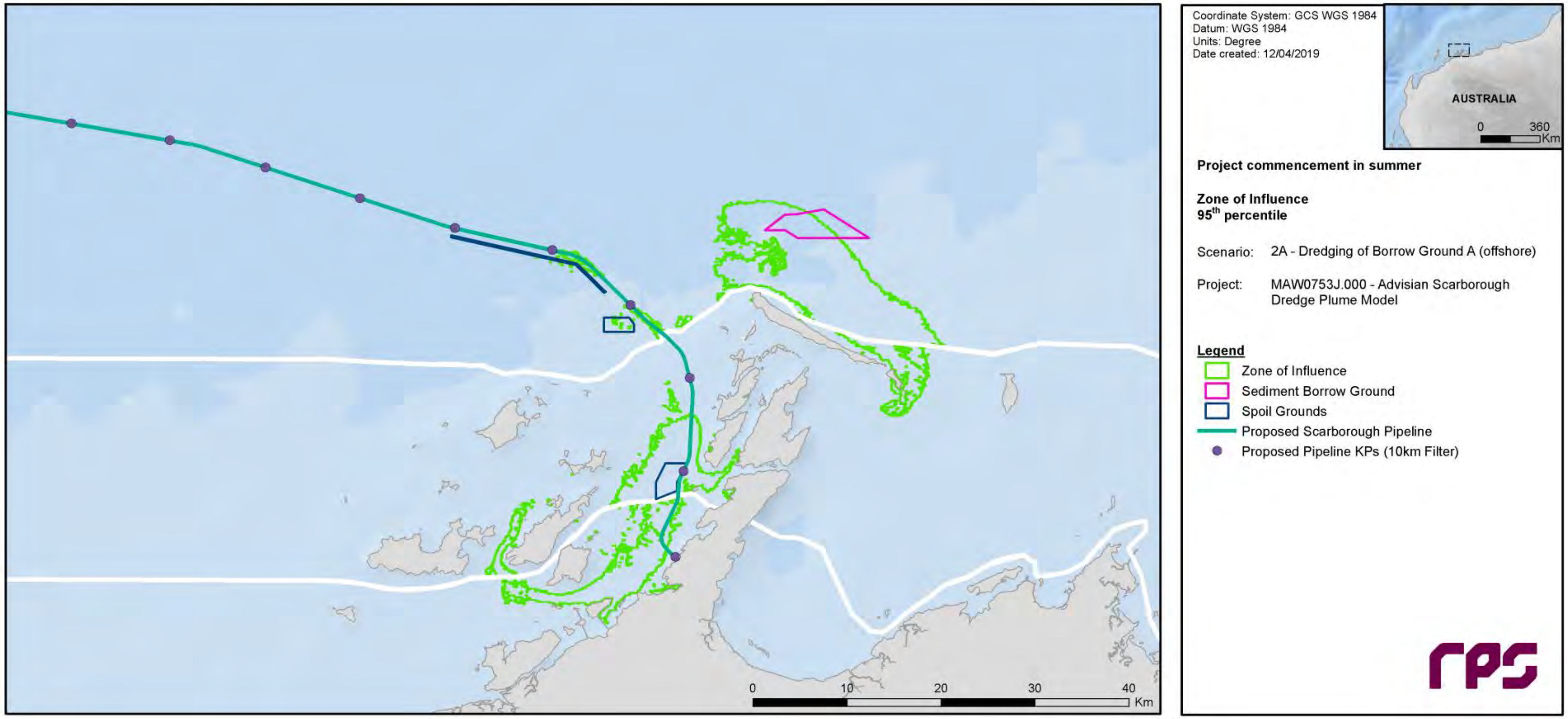


**Figure 5.27 Predicted 95th percentile Zone of Influence following application of the appropriate spatial thresholds in Table 4.2 to a 24-hour rolling average of total (dredge and background) SSC throughout the entire scenario duration (1st January 2017 to 31st October 2017).**

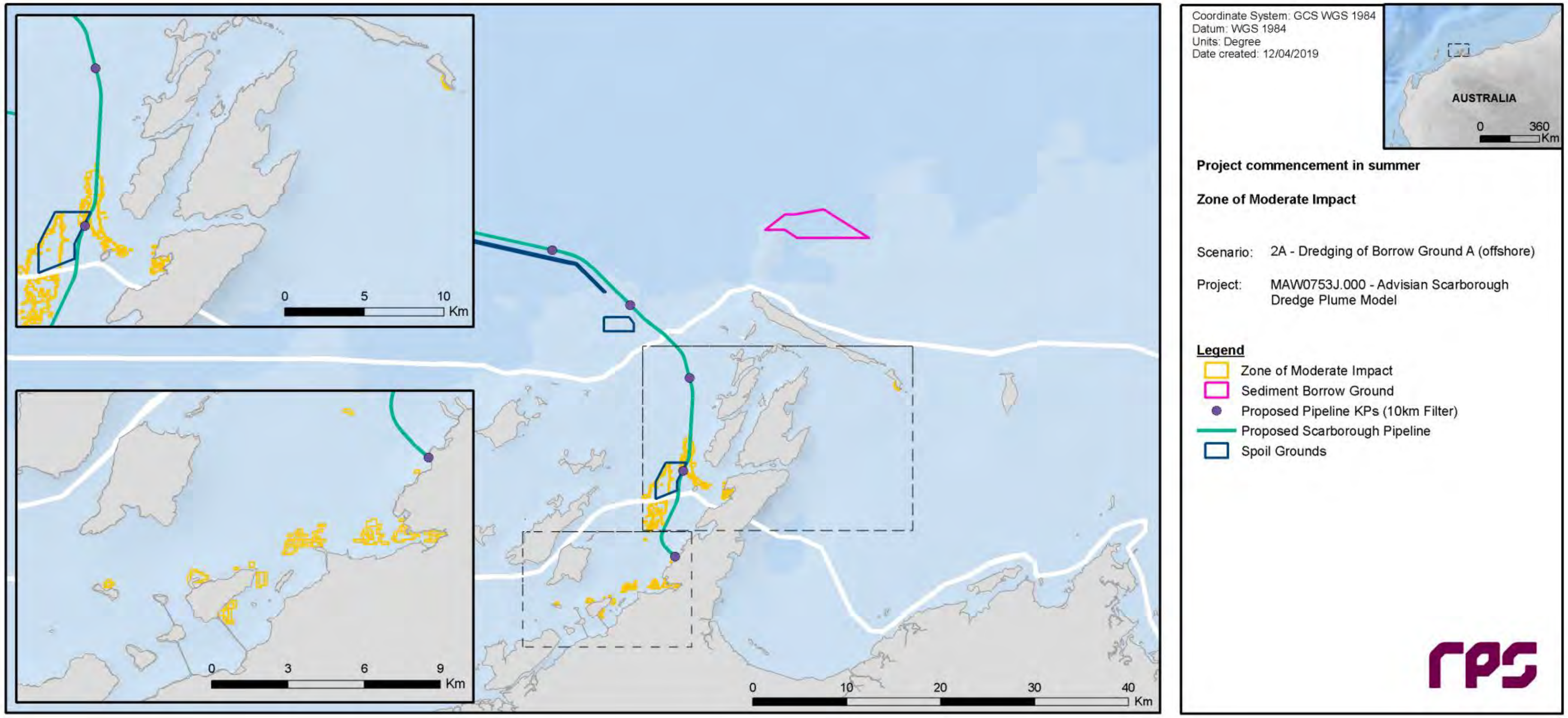


**Figure 5.28 Predicted Zone of Moderate Impact following application of the appropriate spatial thresholds in Table 4.3 to 3-day (Zones A and B) and 28-day (Offshore) rolling averages of total (dredge and background) SSC throughout the entire scenario duration (1st January 2017 to 31st October 2017).**

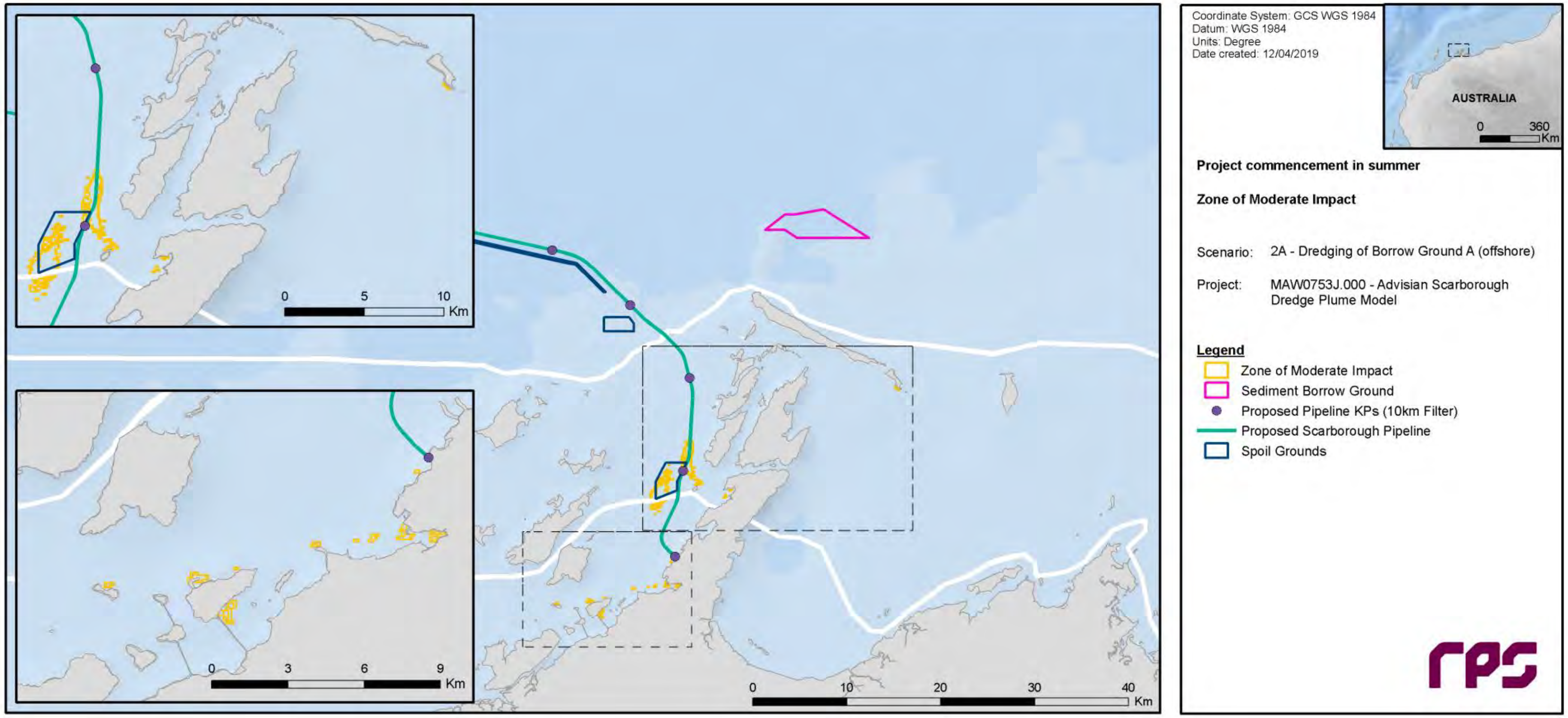


**Figure 5.29 Predicted Zone of Moderate Impact following application of the appropriate spatial thresholds in Table 4.3 to 7-day (Zones A and B) and 28-day (Offshore) rolling averages of total (dredge and background) SSC throughout the entire scenario duration (1st January 2017 to 31st October 2017).**

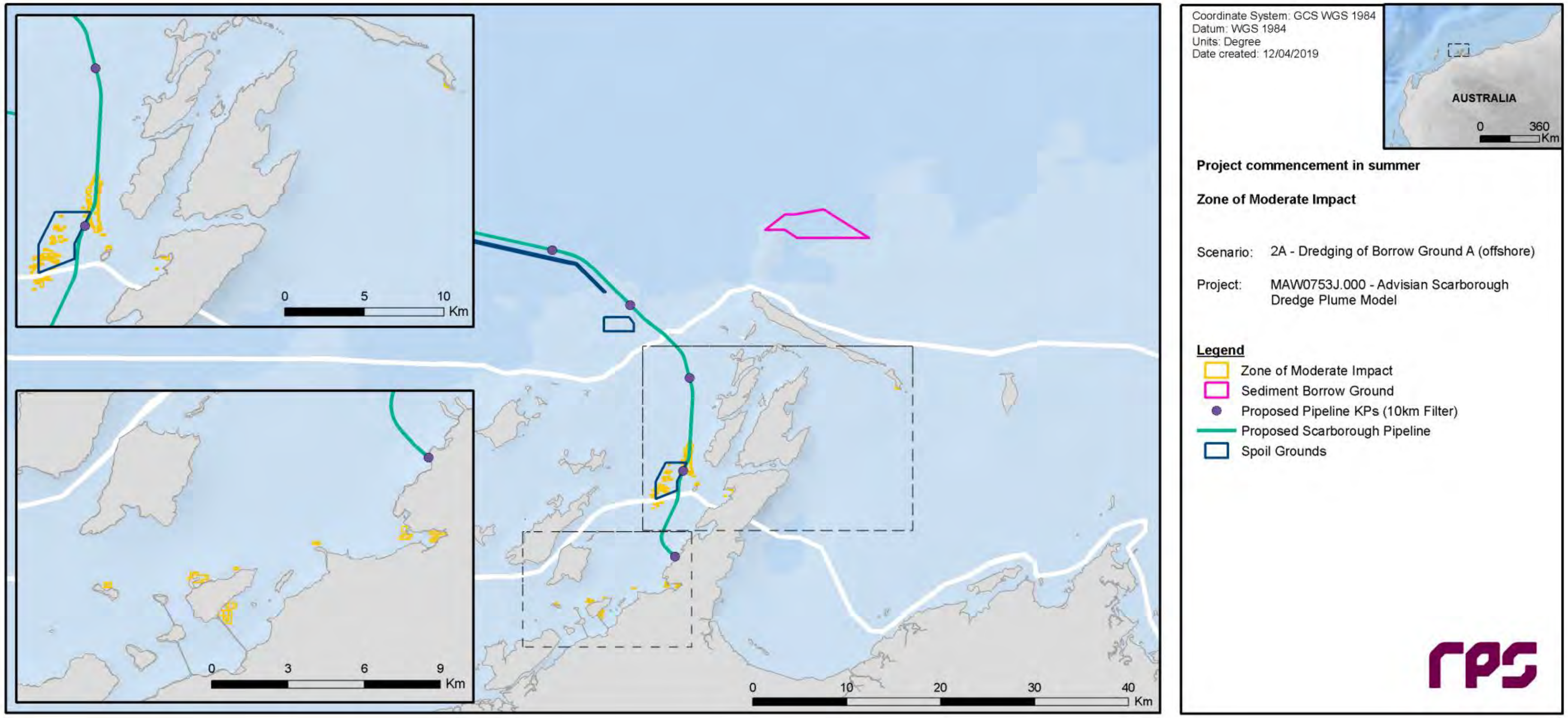


**Figure 5.30 Predicted Zone of Moderate Impact following application of the appropriate spatial thresholds in Table 4.3 to 10-day (Zones A and B) and 28-day (Offshore) rolling averages of total (dredge and background) SSC throughout the entire scenario duration (1st January 2017 to 31st October 2017).**

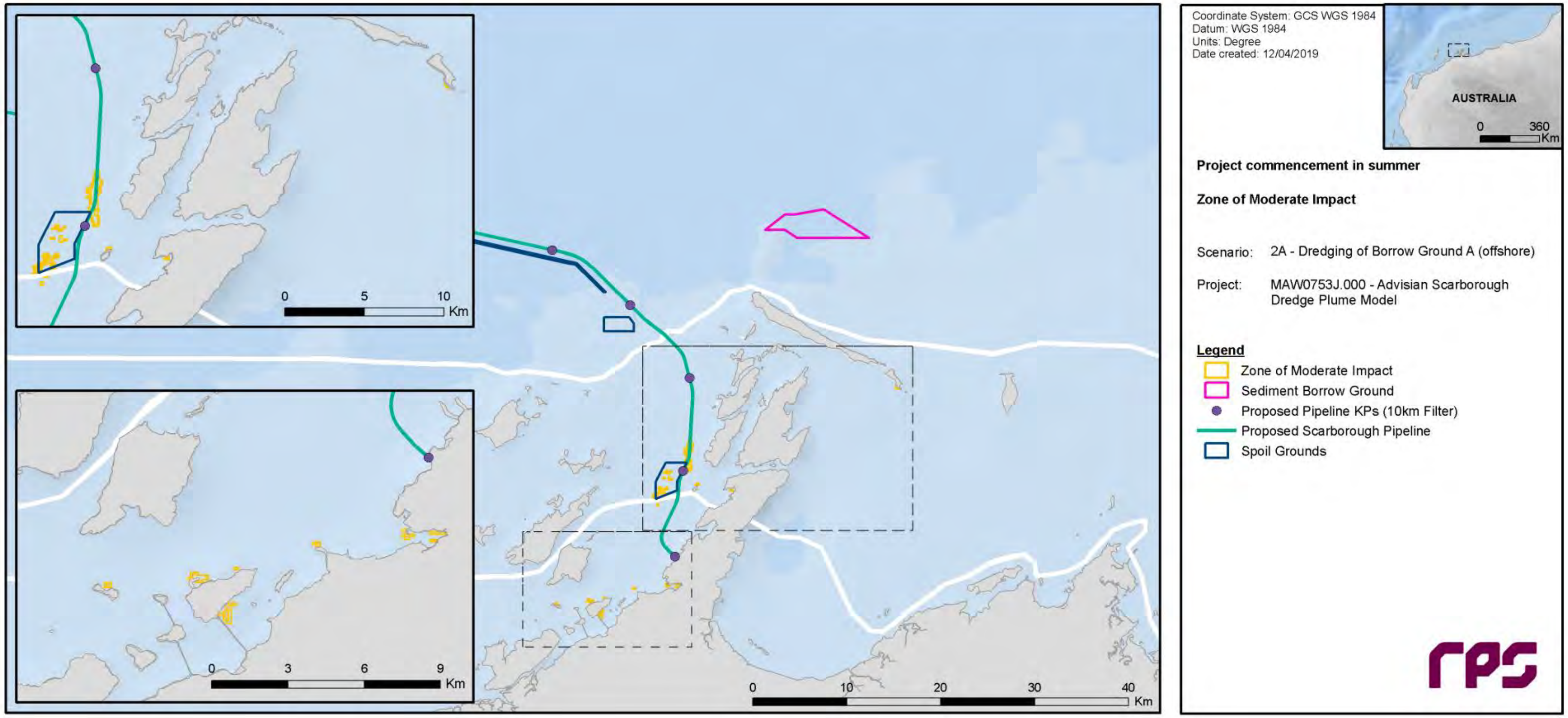


**Figure 5.31 Predicted Zone of Moderate Impact following application of the appropriate spatial thresholds in Table 4.3 to 14-day (Zones A and B) and 28-day (Offshore) rolling averages of total (dredge and background) SSC throughout the entire scenario duration (1st January 2017 to 31st October 2017).**

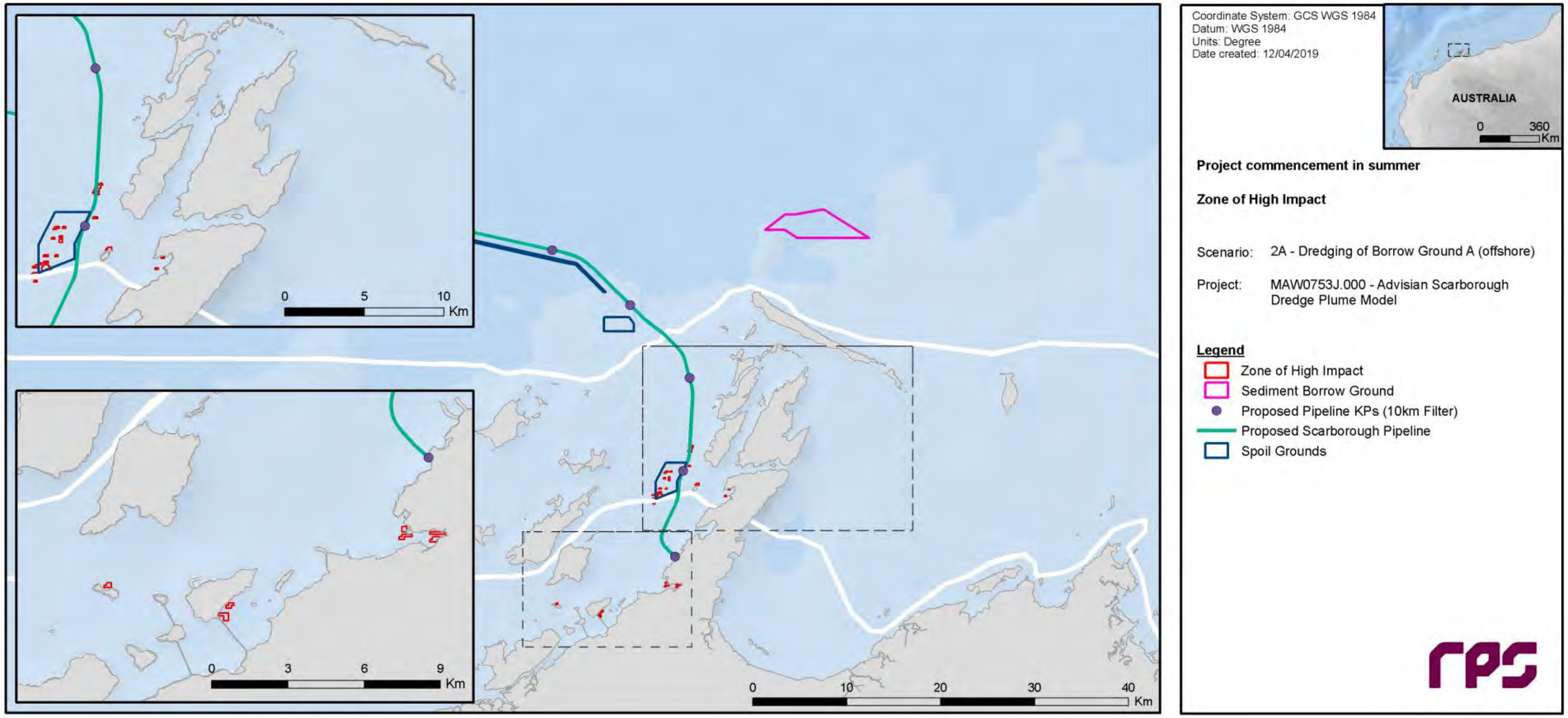


**Figure 5.32 Predicted Zone of High Impact following application of the appropriate spatial thresholds in Table 4.4 to 3-day (Zones A and B) and 28-day (Offshore) rolling averages of total (dredge and background) SSC throughout the entire scenario duration (1st January 2017 to 31st October 2017).**

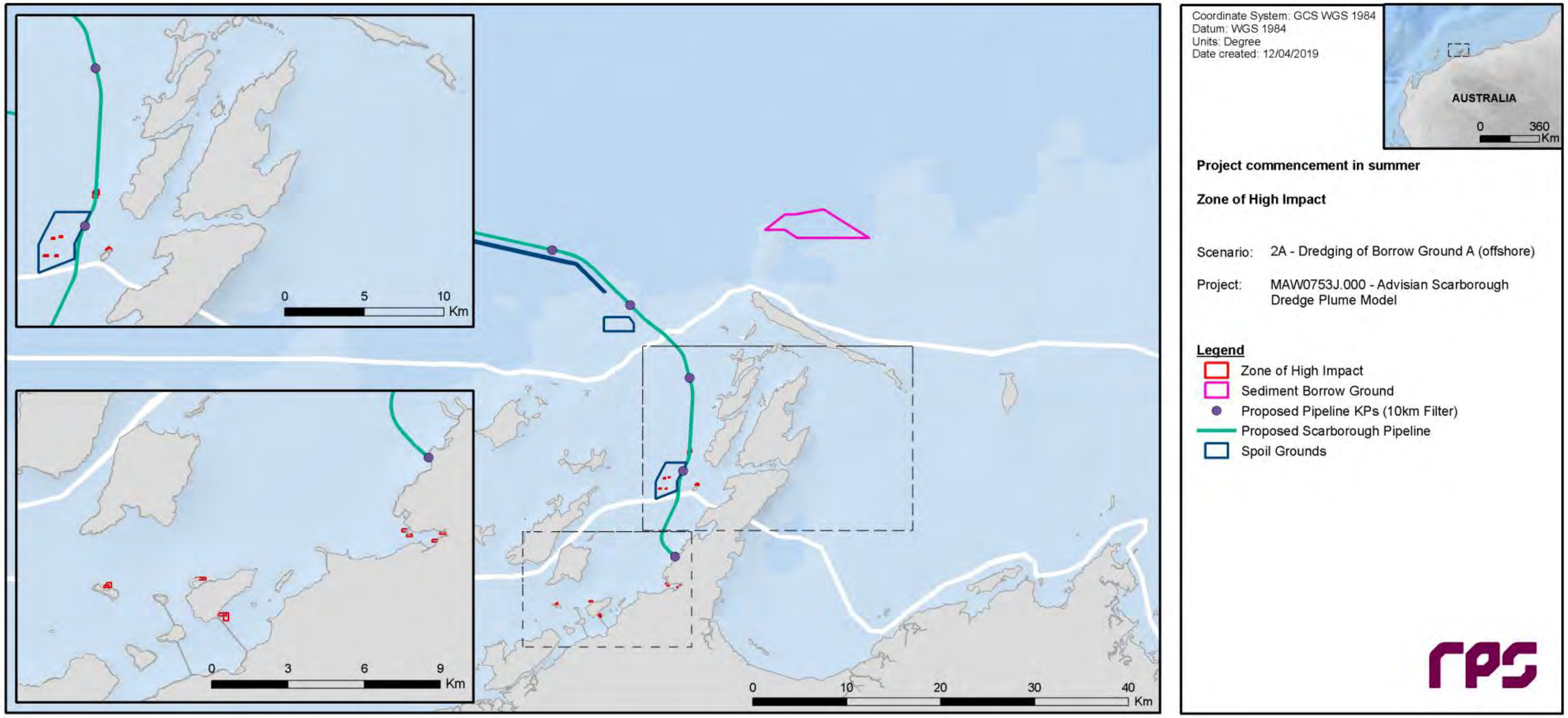


**Figure 5.33 Predicted Zone of High Impact following application of the appropriate spatial thresholds in Table 4.4 to 7-day (Zones A and B) and 28-day (Offshore) rolling averages of total (dredge and background) SSC throughout the entire scenario duration (1st January 2017 to 31st October 2017).**

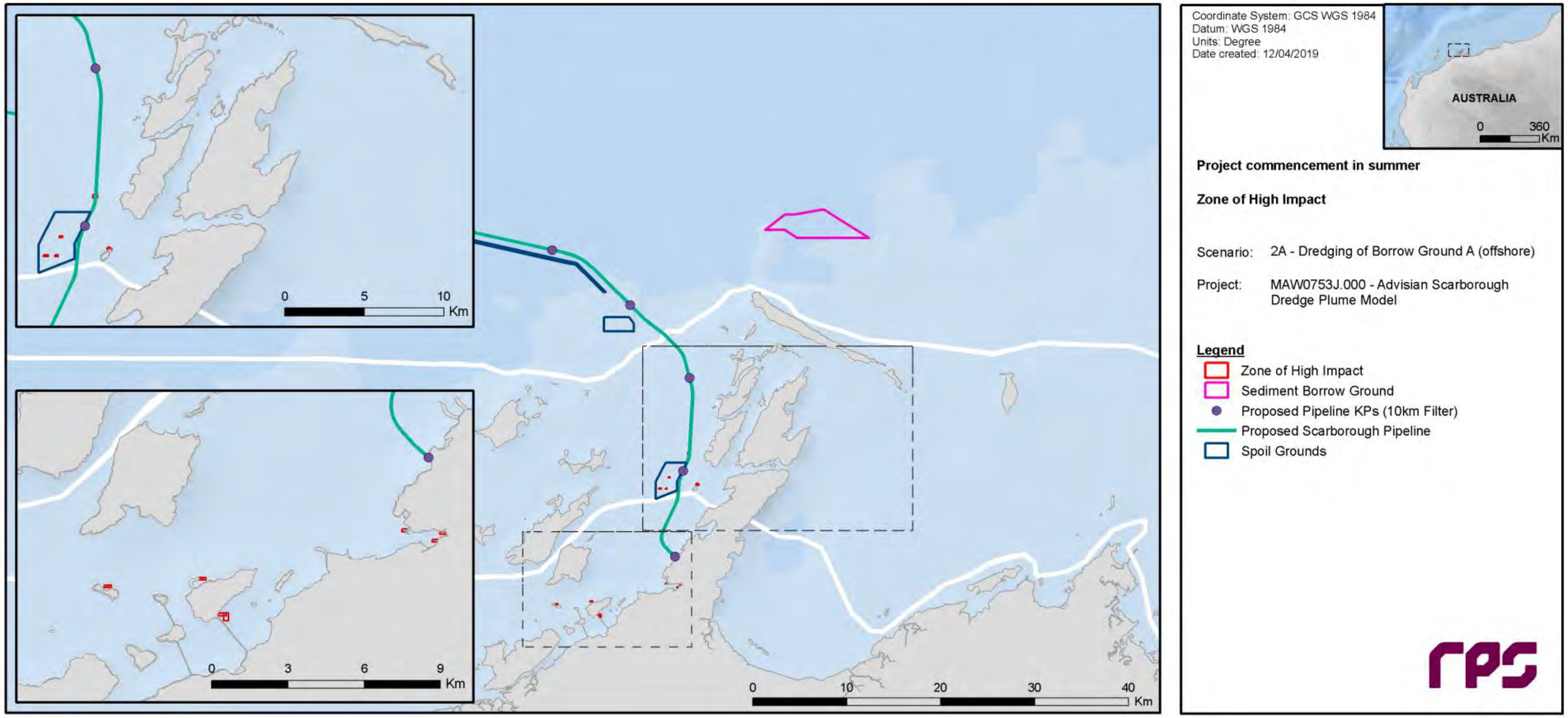


**Figure 5.34 Predicted Zone of High Impact following application of the appropriate spatial thresholds in Table 4.4 to 10-day (Zones A and B) and 28-day (Offshore) rolling averages of total (dredge and background) SSC throughout the entire scenario duration (1st January 2017 to 31st October 2017).**

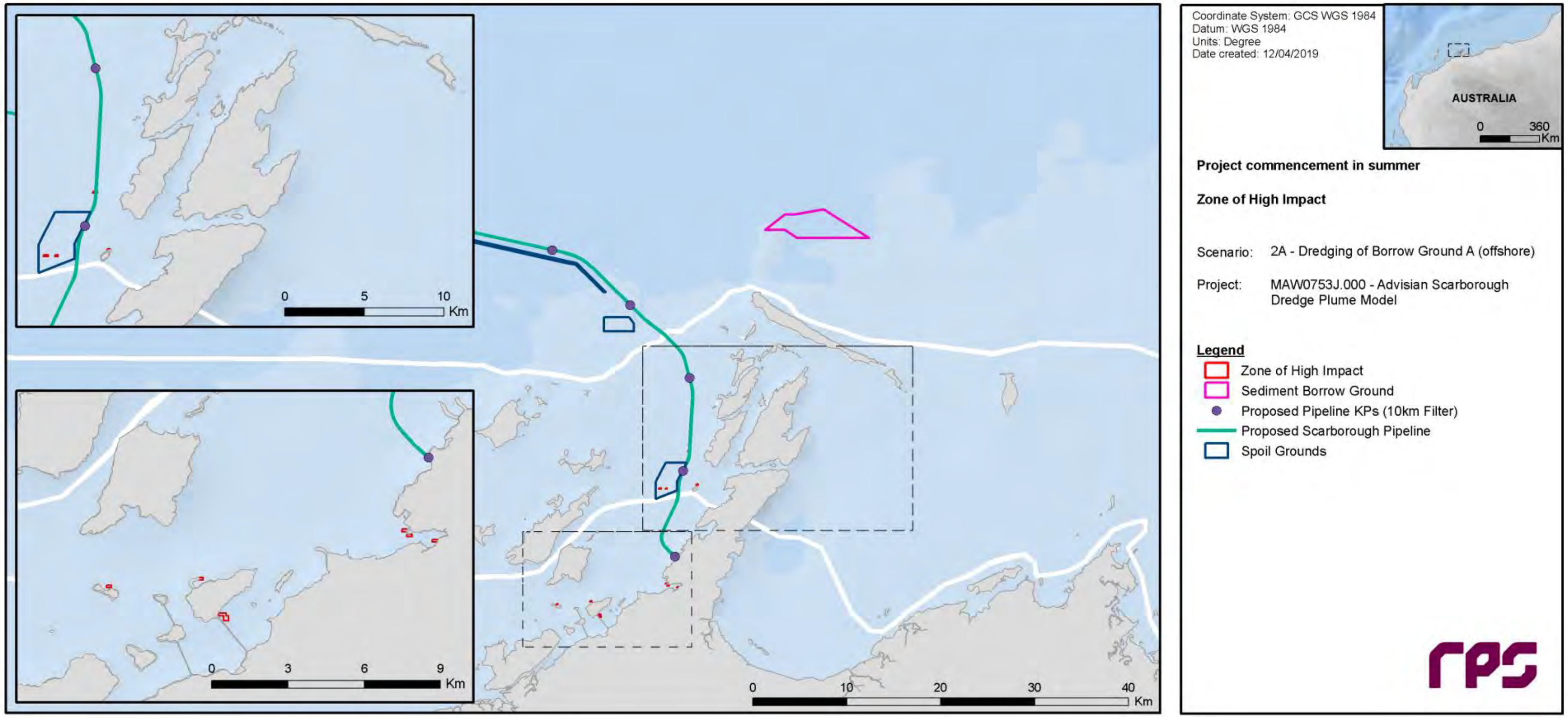


**Figure 5.35 Predicted Zone of High Impact following application of the appropriate spatial thresholds in Table 4.4 to 14-day (Zones A and B) and 28-day (Offshore) rolling averages of total (dredge and background) SSC throughout the entire scenario duration (1st January 2017 to 31st October 2017).**

#### 5.2.2.4 Scenario 2B: Dredging Operations Commencing during Summer, with Backfill Material Sourced from Borrow Ground B (Inshore)

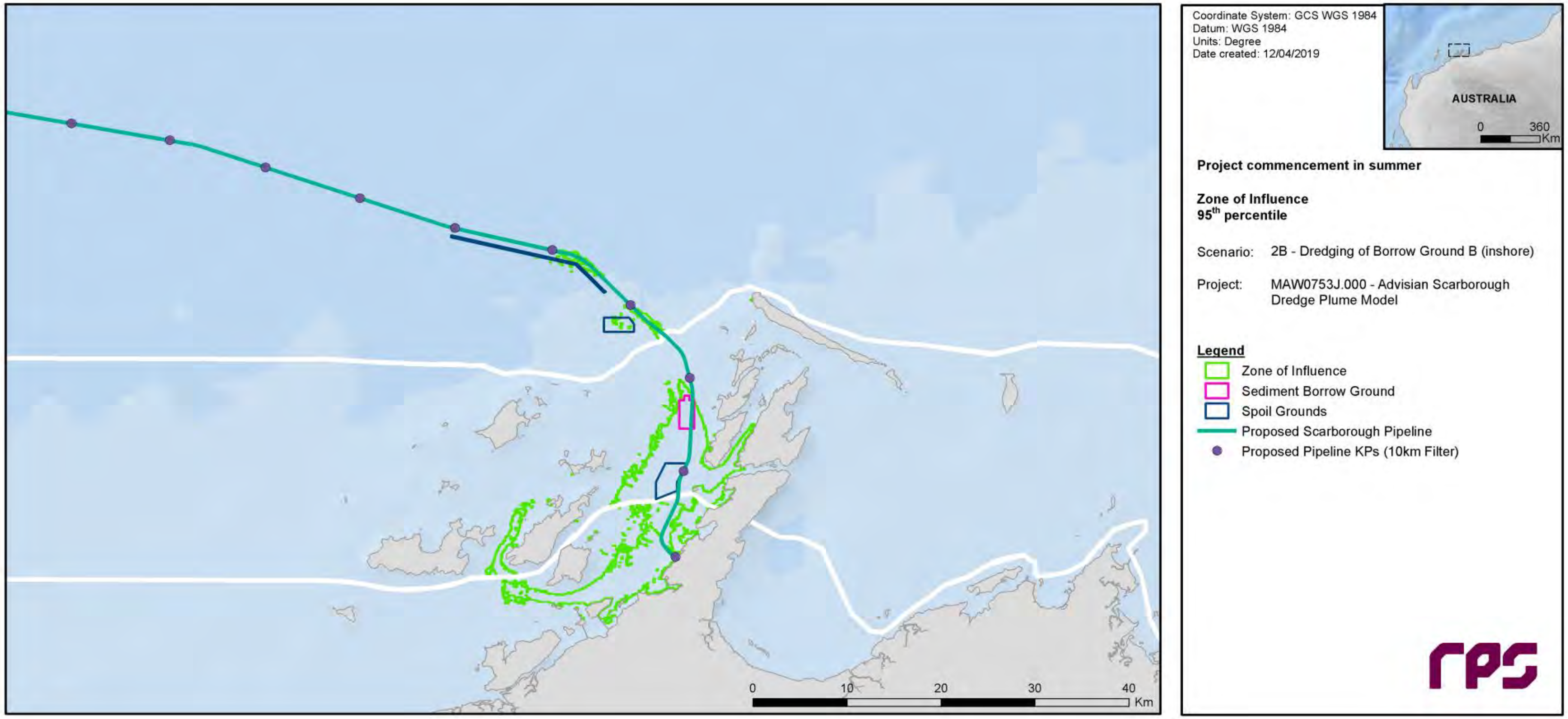


**Figure 5.36 Predicted 95th percentile Zone of Influence following application of the appropriate spatial thresholds in Table 4.2 to a 24-hour rolling average of total (dredge and background) SSC throughout the entire scenario duration (1st January 2017 to 31st October 2017).**

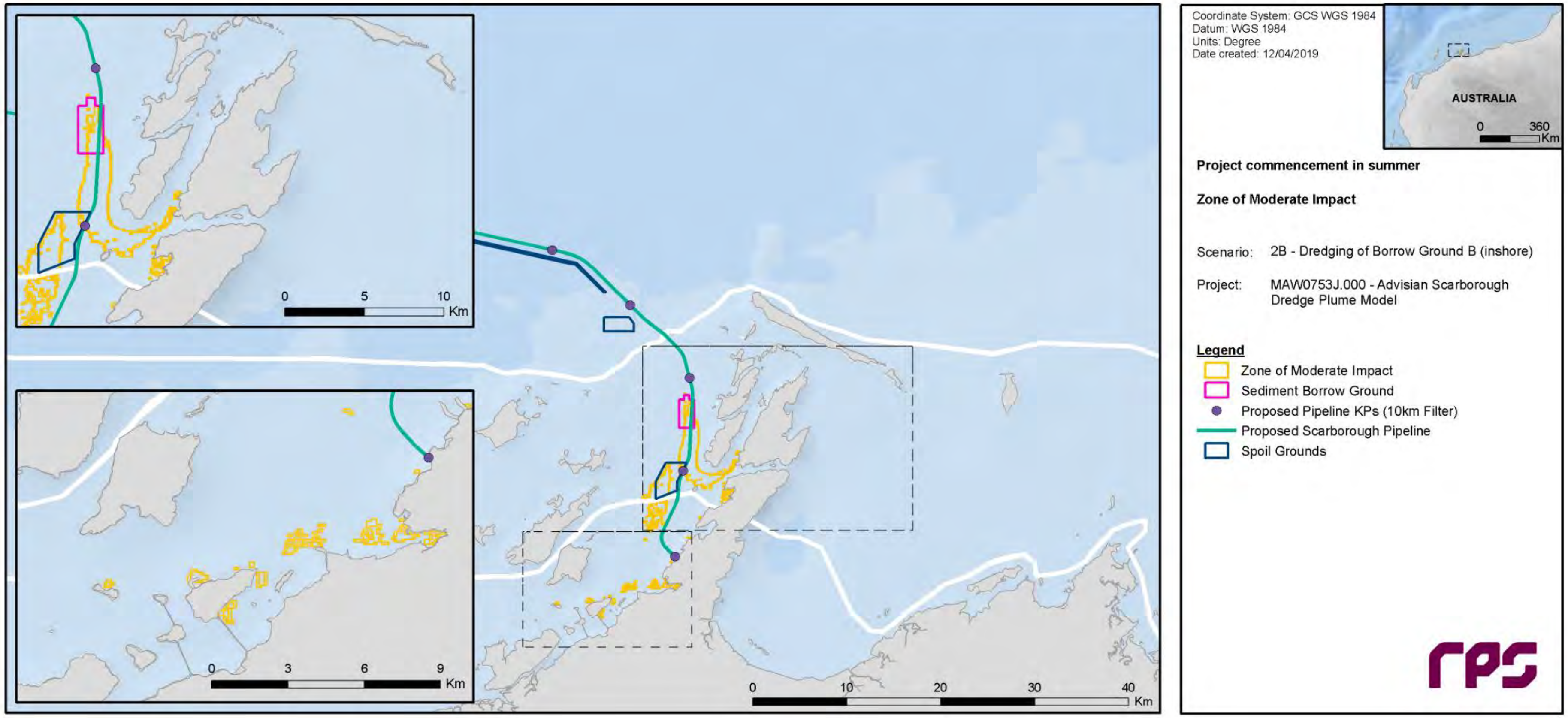


**Figure 5.37 Predicted Zone of Moderate Impact following application of the appropriate spatial thresholds in Table 4.3 to 3-day (Zones A and B) and 28-day (Offshore) rolling averages of total (dredge and background) SSC throughout the entire scenario duration (1st January 2017 to 31st October 2017).**

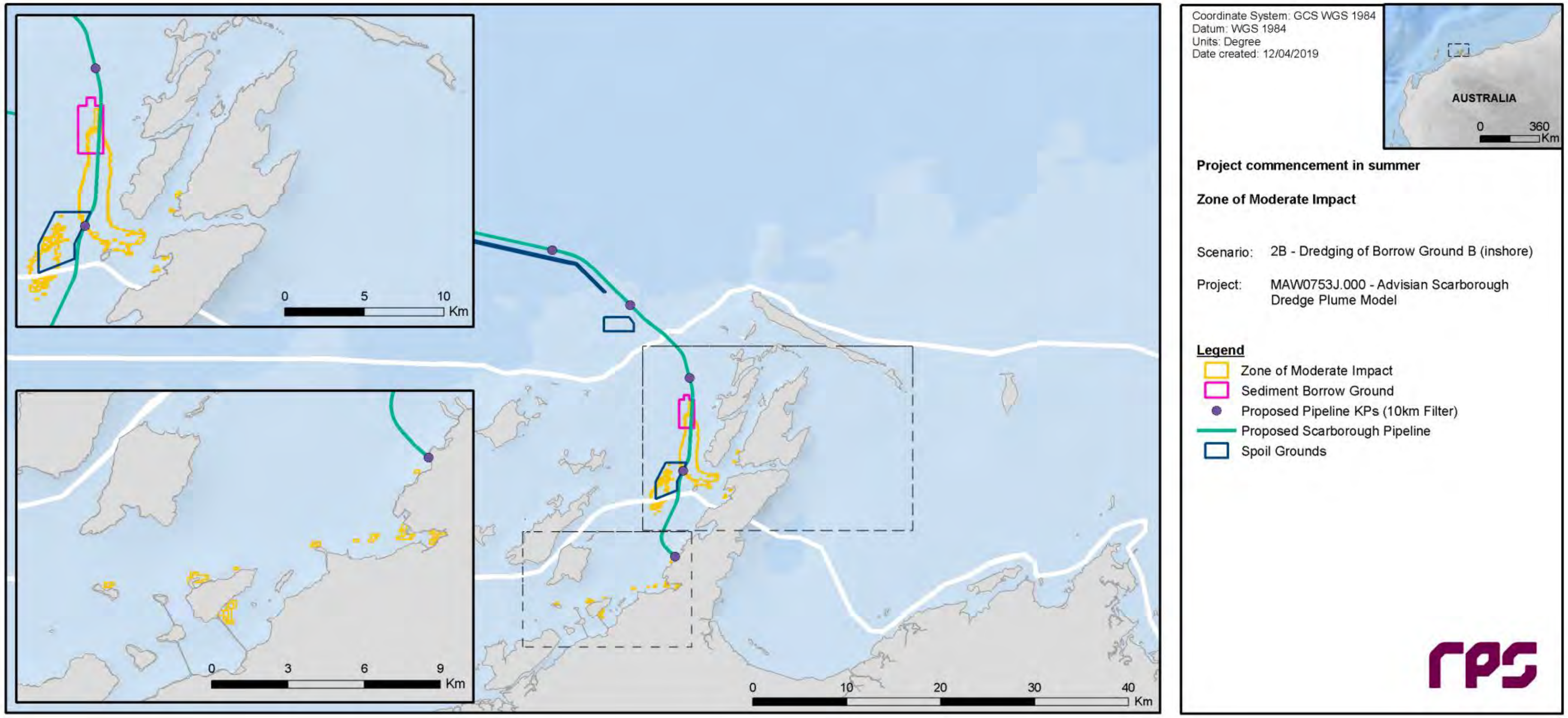


**Figure 5.38 Predicted Zone of Moderate Impact following application of the appropriate spatial thresholds in Table 4.3 to 7-day (Zones A and B) and 28-day (Offshore) rolling averages of total (dredge and background) SSC throughout the entire scenario duration (1st January 2017 to 31st October 2017).**

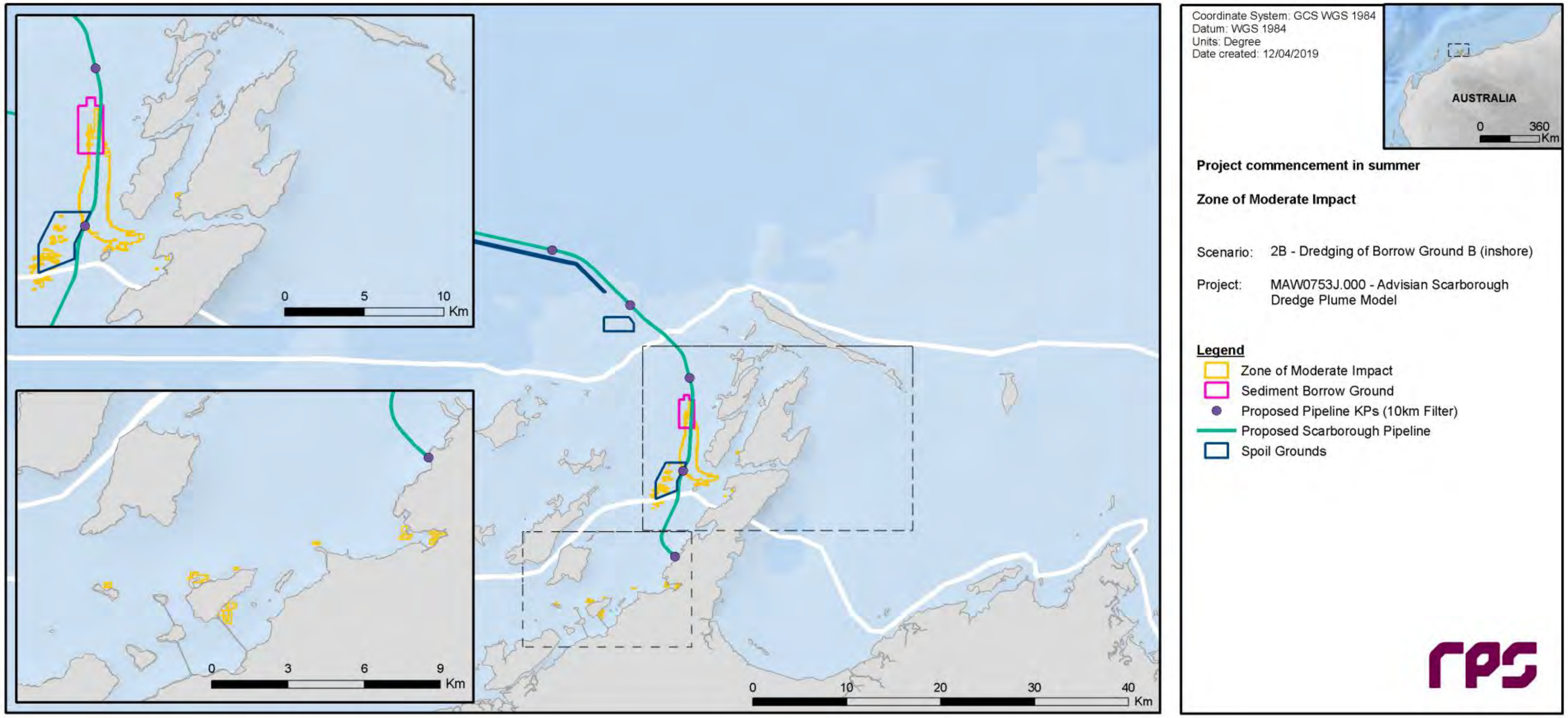


**Figure 5.39 Predicted Zone of Moderate Impact following application of the appropriate spatial thresholds in Table 4.3 to 10-day (Zones A and B) and 28-day (Offshore) rolling averages of total (dredge and background) SSC throughout the entire scenario duration (1st January 2017 to 31st October 2017).**

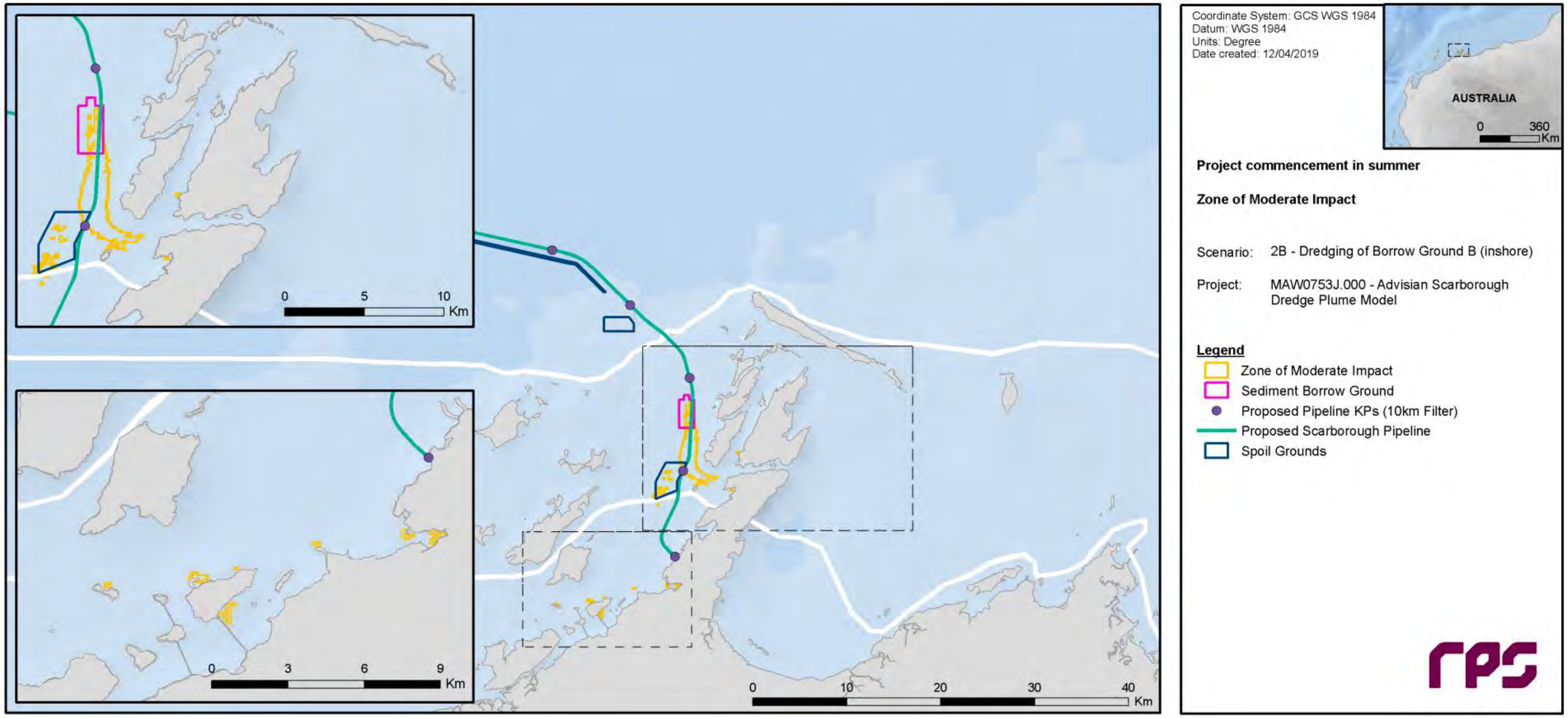


**Figure 5.40 Predicted Zone of Moderate Impact following application of the appropriate spatial thresholds in Table 4.3 to 14-day (Zones A and B) and 28-day (Offshore) rolling averages of total (dredge and background) SSC throughout the entire scenario duration (1st January 2017 to 31st October 2017).**

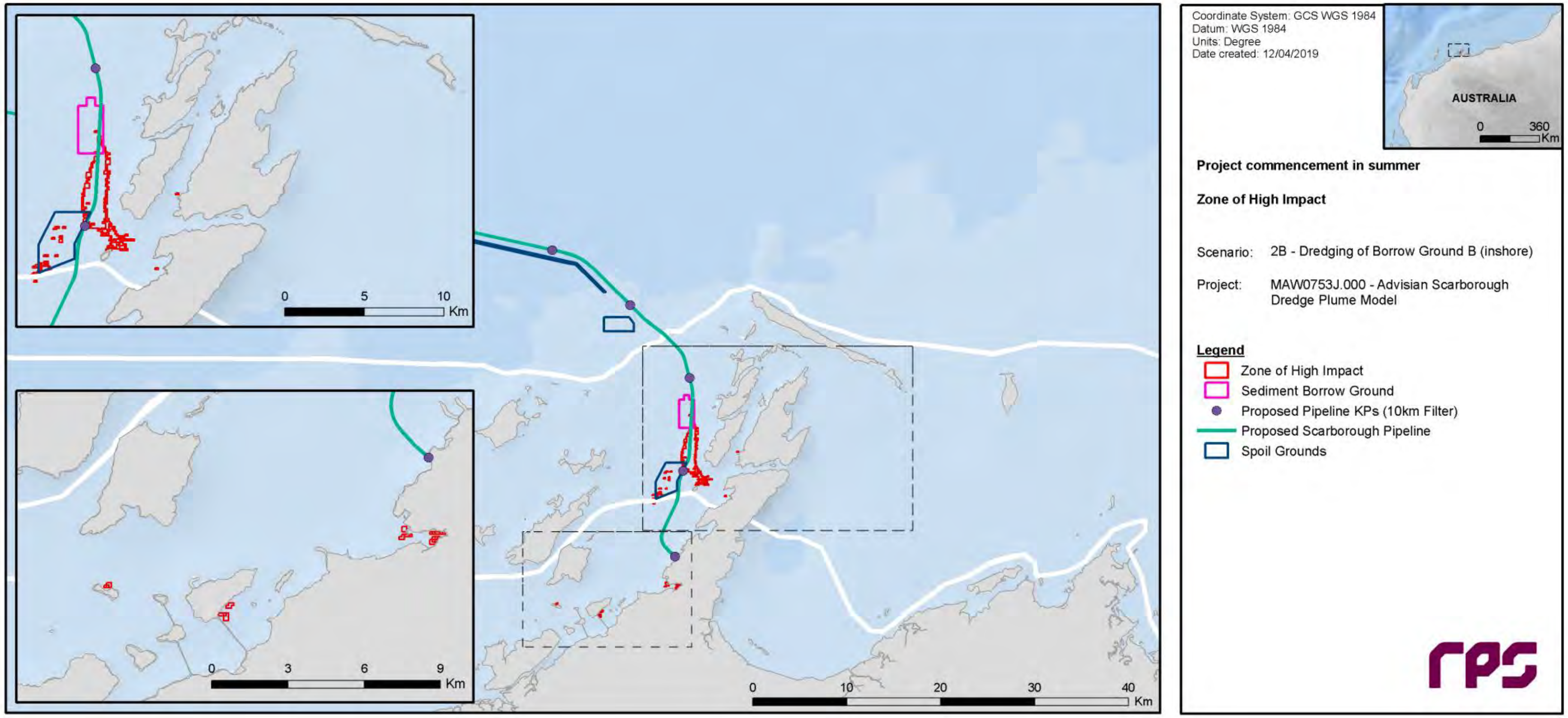


**Figure 5.41 Predicted Zone of High Impact following application of the appropriate spatial thresholds in Table 4.4 to 3-day (Zones A and B) and 28-day (Offshore) rolling averages of total (dredge and background) SSC throughout the entire scenario duration (1st January 2017 to 31st October 2017).**

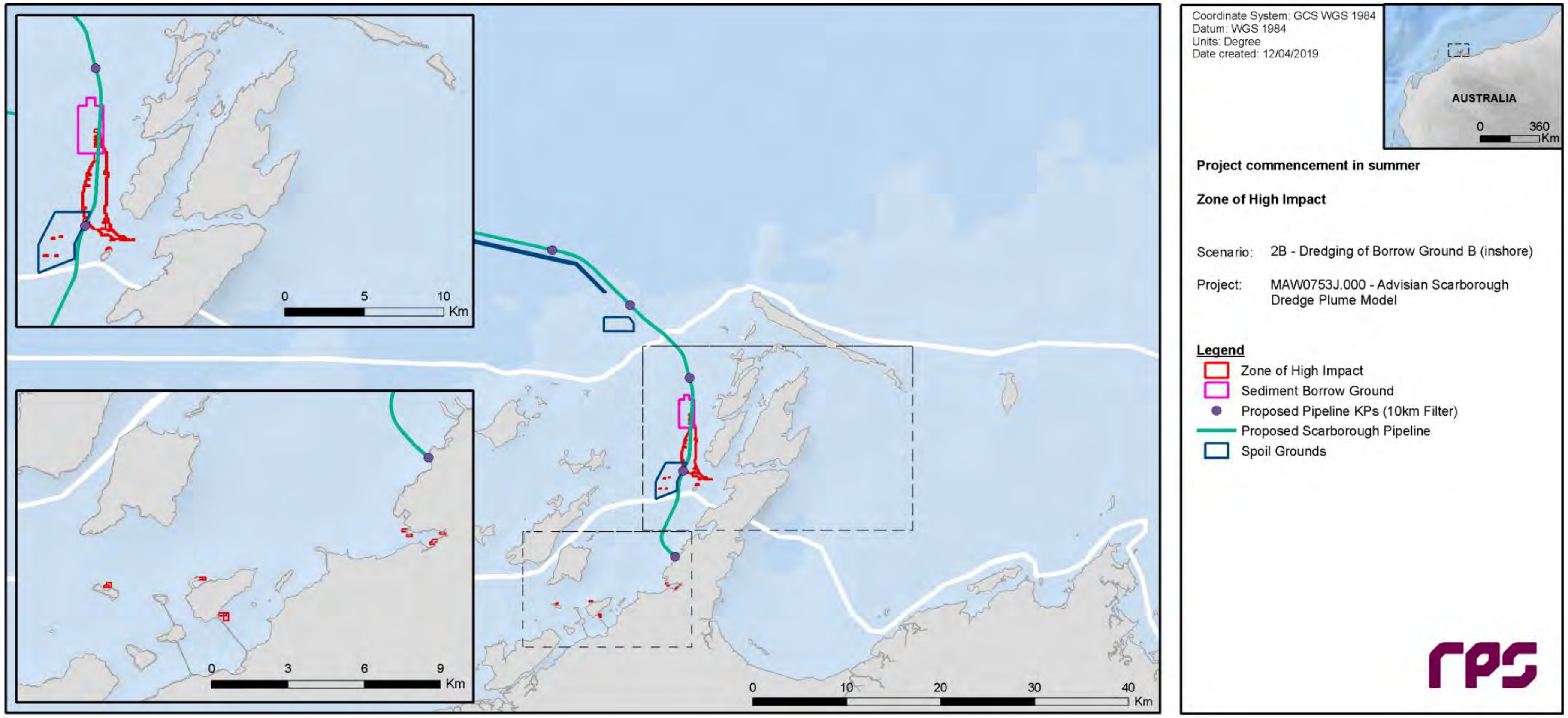


**Figure 5.42 Predicted Zone of High Impact following application of the appropriate spatial thresholds in Table 4.4 to 7-day (Zones A and B) and 28-day (Offshore) rolling averages of total (dredge and background) SSC throughout the entire scenario duration (1st January 2017 to 31st October 2017).**

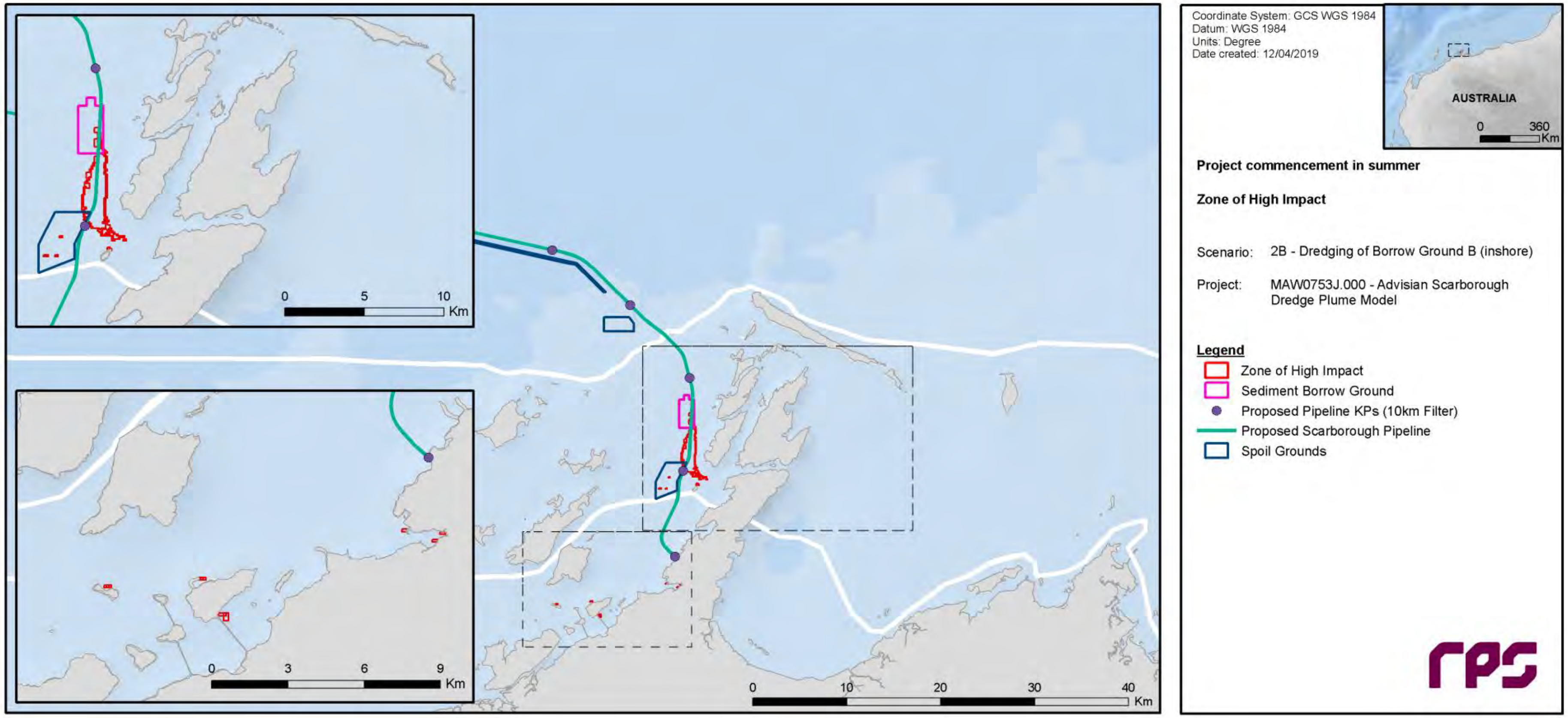


**Figure 5.43 Predicted Zone of High Impact following application of the appropriate spatial thresholds in Table 4.4 to 10-day (Zones A and B) and 28-day (Offshore) rolling averages of total (dredge and background) SSC throughout the entire scenario duration (1st January 2017 to 31st October 2017).**

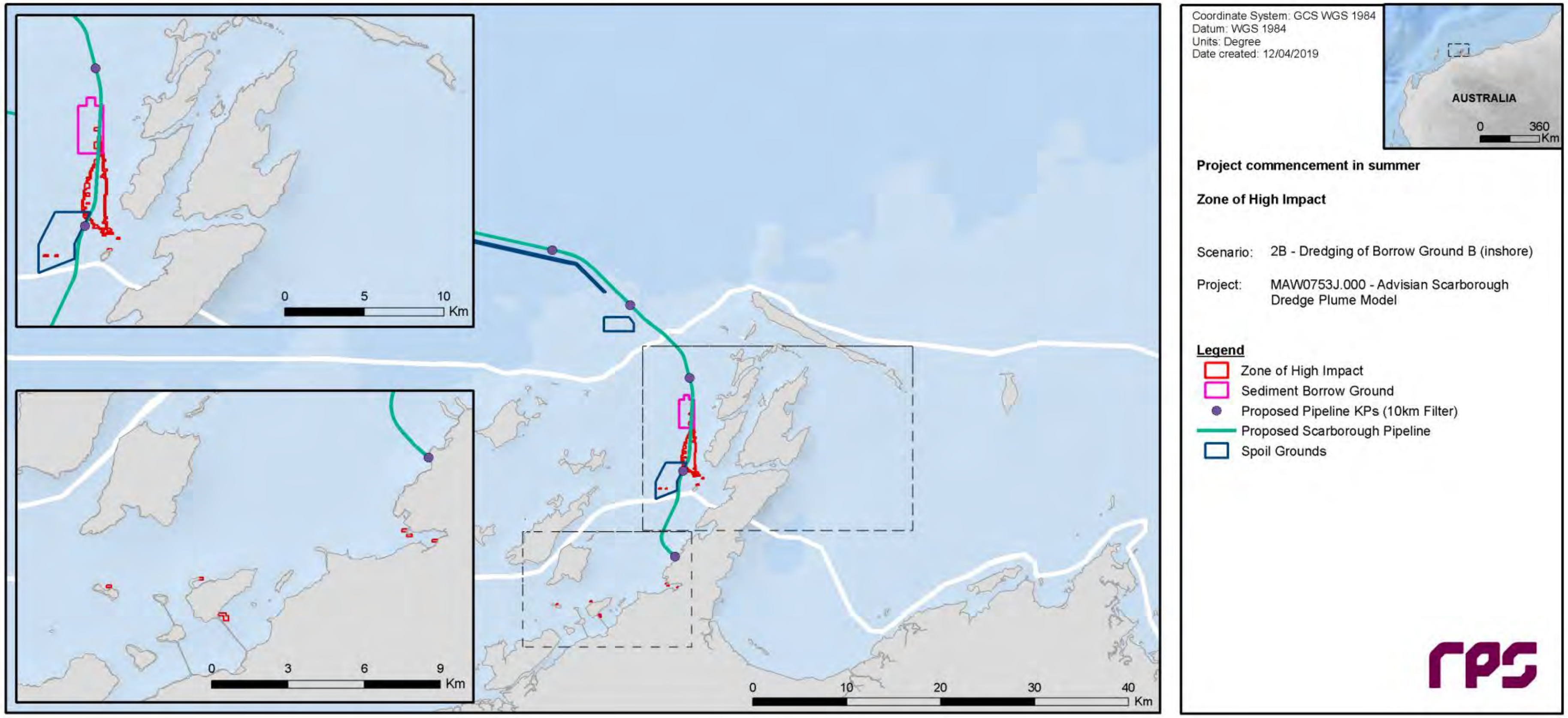


**Figure 5.44 Predicted Zone of High Impact following application of the appropriate spatial thresholds in Table 4.4 to 14-day (Zones A and B) and 28-day (Offshore) rolling averages of total (dredge and background) SSC throughout the entire scenario duration (1st January 2017 to 31st October 2017).**

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# Appendix K

## Scarborough Desktop Light Assessment

## ADVISAN

# SCARBOROUGH DESKTOP LIGHT ASSESSMENT

Prepared by

Pendoley Environmental Pty Ltd

For

Advisian

**21 February 2020**

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# Acronyms

| | |
|---|---|
| ALARP | As low as reasonably practicable |
| BIA | Biologically Important Areas |
| E | East |
| EPBC | Environment Protection and Biodiversity Conservation |
| F-Pil | Flatback turtle Pilbara breeding stock |
| G-NWS | Green turtle north west shelf breeding stock |
| H-WA | Hawksbill Western Australia breeding stock |
| KP | Kilometre point |
| $m/s^{-1}$ | Meters per second |
| MODU | Mobile Offshore Drilling Unity |
| N | North |
| NE | Northeast |
| NNW | North-northwest |
| NW | Northwest |
| NWS | North West Shelf |
| S | South |
| SW | Southwest |
| TSHD | Trailing suction hopper dredger |
| W | West |

# 1 INTRODUCTION

Woodside Energy Limited (Woodside), is proposing to develop the Scarborough gas resource through new offshore facilities. These facilities are proposed to be connected to the mainland through an approximately 430 km trunkline to an onshore facility.

Installation of the trunkline will involve pre-lay dredging and pipelay, followed by post-lay backfill within a Trunkline Project Area. Backfill material will be dredged from a separate area, the Borrow Grounds Project Area. Specialised vessels will be utilized for specific activities.

The Trunkline and Borrow Grounds Project Areas overlap, and are in proximity to, areas designated as Biologically Important Areas (BIAs) and habitat critical for the survival of a species ('habitat critical') for marine turtles. The Recovery Plan for Marine Turtles in Australia 2017-2027 (the 'Recovery Plan') (Commonwealth of Australia, 2017) identifies light pollution as high risk threat to marine turtles in the North West Shelf (NWS) region.

Advisian have engaged Pendoley Environmental on behalf of Woodside to conduct a desktop lighting impact assessment to support demonstration that the received levels of light within BIAs and habitat critical (including nesting beaches) associated with trunkline installation and borrow ground activities will be of an acceptable level and managed consistently with the Recovery Plan.

## 1.1 Exclusions

- This report assesses the potential impacts of activities undertaken in Commonwealth waters only.
- This report assesses the impacts of artificial light on marine turtles only, no other receptors are considered.

# 2 BACKGROUND

## 2.1 Project Description

Activities associated with the trunkline installation within 20 km of land are summarised in Table 2-1. The main activities of trunkline trenching, pipelay and backfill are required to be completed sequentially and will not occur concurrently. Of the vessels described in Table 2-1, the TSHD and pipelay vessels have the greatest potential for light emissions based on their size. Although an approximate schedule for activities is available, start dates are estimates only and are subject to change. Therefore, for the purpose of this report it is assumed that the activities below could occur at any time of year.

All activities will be undertaken in the Trunkline Project Area with the exception of dredging activities in the Borrow Grounds Project Area. The dredging will involve removal of sand from the borrow grounds to be transported to the trunkline for backfill.

**Table 2-1: Details of activities to be undertaken in the Trunkline and Borrow Grounds Project Areas within 20 km of land**

| Activity | Estimated duration | Location | Vessels |
|---|---|---|---|
| Hydrographic, geophysical and geotechnical surveys | 2 months<br><br>Vessel continuously present within project areas and constantly moving | Trunkline and Borrow Grounds Project Areas | Survey vessels |
| Pre-lay trenching and spoil disposal | 8 weeks<br><br>Vessel continuously present within project areas and constantly moving | Trunkline Project Area | Trailing suction hopper dredger (TSHD) |
| Pipelay | 3.5 weeks<br><br>Vessel continuously present within project areas and constantly moving | Trunkline Project Area | Pipelay vessel (largest vessel), plus:<br>• B-type bulk carrier<br>OR<br>• 1 - 2 primary support vessels<br>• General Supply Vessels |
| Pre- and post-lay span rectification | 2 weeks<br><br>Intermittent activity:<br>Activities at individual location ~48 hours | Trunkline Project Area | Construction Vessel |
| Post-lay dredging and backfill | 8 weeks<br><br>Intermittent cyclical activity:<br>2 hours dredging ion borrow grounds, material transported to trunkline for backfill. Material from borrow grounds placed in trench (5 hours), return to borrow grounds | Trunkline and Borrow Grounds Project Area s | TSHD |

## 2.2 Light Sources and Area of Impact

Light may appear as a direct light source from an unshielded lamp with direct line of sight to the observer or through sky glow. Where direct light falls upon a surface, be it land or ocean, this area of light is referred to as light spill. Sky glow is the diffuse glow caused by light that is screened from view but through reflection and refraction creates a glow in the atmosphere. Scattering of light by dust, salt and other atmospheric aerosols increases the visibility of light as sky glow, while the presence of clouds reflecting light back to earth can substantially illuminate the landscape (Kyba *et al.,* 2011). White/blue light scatters more easily and further in the atmosphere compared to yellow-orange light (Kyba *et al.,* 2011). Therefore, the distance at which direct light and sky glow may be visible from the source is dependent on the number, intensity and types of lights, and how such lights are orientated or shielded, in addition to environmental conditions.

Existing light sources at the eastern end of the Trunkline Project Area (within 20 km of land) include heavy vessel traffic within the Pilbara Port Authority Management area and 26 designated anchorages for bulk carriers, petroleum and gas tankers, drilling rigs, offshore platforms, and pipelay vessels located offshore of Rosemary Island. These anchorages are located between Rosemary Island and the Trunkline Project Area (Figure 2-1). Although light monitoring within the Dampier Archipelago has not been undertaken, existing light pollution in this area is expected.

As described in Section 2.1, the TSHD and pipelay vessels have the greatest potential for light emissions based on size. In absence of representative light monitoring or modelling, or the required level of detail to allow meaningful comparison to existing information, it is assumed for this assessment that received light intensity within 20 km of the Project Areas may result in impacts to marine turtle behaviour. A 20 km buffer was selected based on recommendations proposed in the National Light Pollution Guidelines for Wildlife (Commonwealth of Australia, 2020; and references therein).

## 2.3 Relevant Marine Turtle Species

Five species of marine turtle may occur in the Trunkline and Borrow Grounds Project Areas: flatback (*Natator depressus*), green (*Chelonia mydas*), hawksbill (*Eretmochelys imbricata*), loggerhead (*Caretta caretta*) and leatherback (*Dermochelys coriacea*) turtles.

Although CALM (1990) reports loggerhead turtle nesting activity on Cohen Island, Pendoley *et al*. (2016) did not find any evidence of loggerhead nesting activity in over 20 years of track data. The northernmost key loggerhead nesting areas include the North West Cape and Muiron Islands and any nesting activity by loggerhead turtles in the Dampier Archipelago will not represent significant rookeries for this species. No major leatherback turtle rookeries are known to occur in Australia, with scattered nesting reported in Queensland (Limpus & MacLachlan, 1979, 1994; Limpus *et al.,* 1984) and the Northern Territory (Hamann *et al.,* 2006; Limpus & MacLachlan, 1994) only. As such, loggerhead and leatherback turtles are not considered further.

Marine turtles in Australia belong to discrete genetic stocks, within each species, that are defined by the presence of regional breeding aggregations. Marine turtles breeding in the vicinity of the activities belong to the Green North West Shelf (G-NWS), Flatback – Pilbara (F-Pil) and Hawksbill – Western

Australia (H-WA) genetic stocks. The Recovery Plan provides information for each stock which is summarised below:

- Green turtles: The trend for the G-NWS stock is reported as stable. Important nesting areas include the Montebello Islands (major), and Rosemary Island, Legendre Island and Delambre Island (minor).

- Flatback turtles: The trend of the F-Pil genetic stock is currently unknown. Important nesting areas include Delambre Island (major), and the Montebello Islands and Dampier Archipelago (minor).

- Hawksbill turtles: The trend for the H-WA stock is also unknown. Rosemary Island, Delambre Island and the Dampier Archipelago are all listed as major important nesting areas for this hawksbill stock.

- Light pollution was assessed as a high-risk threat to all three genetic stocks (green, G-NWS; flatback, F-Pil; hawksbill, H-WA).

### 2.3.1 Life Cycle

In general, marine turtle species share a very similar life cycle pattern. During non-breeding, adults of both sexes, and sexually immature juveniles, inhabit open ocean foraging habitat. Breeding adults then undergo a breeding migration from foraging areas to mating areas, which may or may not be close to the nesting beach (Miller, 1996). After mating, the males return to the foraging areas while the females will spend several months in internesting habitat in proximity to nesting beaches. Females typically demonstrate strong site fidelity, laying each of their clutches on the same group of beaches or island. As capital breeders, marine turtles are understood to show inactive behaviour during the internesting period (the period between a successful clutch and the next nesting attempt) (Hays *et al.,* 1999, Fossette *et al.,* 2012), presumably to conserve energy for successive reproductive events (see Hays *et al.,* 1999). Once the last clutch of eggs is laid, females will return to the foraging areas, building up their fat reserves before the next breeding migration. Most females will not nest in consecutive years (Miller, 1996).

Hatchlings emerge from the nest and orient towards the sea using the low elevation light horizon (Witherington & Bjorndal, 1991). After entering the water, hatchlings use a combination of cues (wave direction and currents) to orient and travel into deeper offshore waters (Lohmann & Lohmann, 1992; Wilson *et al*., 2018; Wilson *et al.,* submitted). Crossing and swimming away from the beach is thought to imprint the hatchlings with the cues that allow individuals to return to their natal region to breed as adults (Lohmann *et al.,* 1997). Hatchlings do not feed for the first few days of life, relying on the remains of internalised yolk resources (Witherington, 1991). In general, hatchlings disperse into oceanic currents and gyres where they will stay in these pelagic environments (the pelagic juvenile stage) until large enough to settle in coastal feeding habitats (Boyle *et al.,* 2009; Car, 1987; Witherington, 1991). Flatback turtles have a slightly different life cycle to this generalised life cycle, as they do not have a pelagic phase. Juveniles grow to maturity in shallow coastal waters, thought to be close to their natal beaches (Musick & Limpus, 1996).

### 2.3.2 Habitat use

The Recovery Plan identifies BIAs and habitat critical for flatback, hawksbill and green turtles. Areas overlapping the Trunkline and Borrow Grounds Project Areas include:

- Flatback turtle internesting BIA (80 km) around the Montebello Islands and Dampier Archipelago.
- Green turtle internesting BIA (20 km) around the Dampier Archipelago.
- Hawksbill turtle internesting BIA (20 km) around the Dampier Archipelago.
- Flatback turtle internesting habitat critical (60 km) around the Montebello Islands and Dampier Archipelago.

Nesting areas identified as habitat critical for flatback, green and hawksbill turtles in the vicinity of the Project Areas include:

- Green turtle: Montebello Islands (all with sandy beaches) and Dampier Archipelago.
- Flatback turtle: Montebello Islands, Dampier Archipelago (including Delambre Island and Huay Island [adjacent to Legendre Island]).
- Hawksbill turtle: Dampier Archipelago (including Rosemary Island and Delambre Island) and Montebello Islands (including Ah Chong Island, South East Island and Trimouille Island).

Turtle nesting activity has been observed on a number of islands of the Dampier Archipelago, as summarised in Table 2-2 and shown in Figure 2-1 (CALM, 1990; Pendoley *et al.,* 2016). Islands that could occur within 20 km of the Project Areas are indicated in Table 2-2. The Montebello Islands also have important nesting beaches for flatback, green and hawksbill turtles (Pendoley *et al.,* 2016).

Within the Dampier Archipelago, Rosemary Island has the most significant nesting beaches, determined as mean number of hawksbill, green and flatback turtle tracks per day (Pendoley *et al*., 2016) and is recognised as an internationally significant rookery for hawksbill turtles (Limpus, 2009). On Rosemary Island, the majority of hawksbill nesting occurs on the north-western (NW) beaches (K. Pendoley, pers. comm.) with lower density flatback and green nesting occurring at beaches on the east of the island. An analysis of turtle track data from these beaches on Rosemary Island between 1990 and 2017 has been undertaken (Whiting, 2018), whichconcluded that nest counts were dominated by hawksbill turtles (9860 nesting events, or 92.1%), with lower flatback and green nests counts at 366 (3.4%) and 478 (4.5%), respectively. These results corroborate other conclusions that the nesting population of hawksbill turtles at Rosemary Island is one of the largest populations in Australia and globally (Limpus, 2009).

Other islands also with moderate nesting activity (11 – 100 tracks per day) for all three species, include Delambre Island, Enderby Island and Eaglehawk Island (Pendoley *et al*., 2016). Although track data confirmed presence of flatback turtles only at Legendre Island (Pendoley *et al.,* 2016), a tagging program conducted in 2008 demonstrated that flatbacks, hawksbill and green turtles nested in notable numbers at this island (Biota, 2009). Delambre Island has been recognised as the largest flatback turtle rookery in Australia with an estimated 3500 nesting females per year (Chaloupka, 2018). Track counts at Angel Island also demonstrate low nesting activity of hawksbill turtles and records of flatback turtle nesting. No additional published information regarding turtle nesting on Angel Island is available.

Seasonality of nesting differs between flatback, green and hawksbill turtles; Table 2-3 outlines the generalised seasonality across the NWS region. Whiting (2018) provides defined seasonality specific nesting data for Rosemary Island (indicated in Table 2-3 by *) and found that hawksbill turtles have a much earlier peak (October/November) compared to flatback turtles (December/January peak). Seasonality for green turtles was not well defined from the available data (Whiting, 2018). Given the discrete duration of surveys at Legendre Island (Biota, 2009), insufficient data is available to refine seasonality for this location.

**Table 2-2: Records of nesting behaviour of green, flatback and hawksbill marine turtles on islands of the Dampier Archipelago (CALM, 1990; Pendoley *et al.*, 2016; Biota, 2009)**

| | Angel | Burrup Peninsula | Conzinc | Delambre | Dolphin | Eaglehawk | East Goodwyn | East Intercourse | Elphick Nob | Enderby | Hauy | Intercourse | Keast | Lady Nora | Legendre | Rosemary | West Intercourse | West Mid Intercourse |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Trunkline Project Area distance (km) | 17 | 22 | 22 | 38 | 17 | 41 | 25 | 32 | 14 | 27 | 27 | 34 | 13 | 12 | 12 | 14 | 36 | 35 |
| Borrow ground Project Area distance (km) | 21 | 26 | 28 | 20 | 16 | 57 | 41 | 42 | 32 | 43 | 14 | 45 | 10 | 28 | 6.6 | 40 | 48 | 46 |
| Flatback | X | X | X | M | X | L | X | X | X | M | X | X | X | X | L | M | X | X |
| Green | - | X | - | L | X | L | - | X | - | L | X | - | - | - | X | M | X | - |
| Hawksbill | L | - | - | L | - | L | X | - | X | M | - | - | - | - | X | H | - | - |

| **Key** | |
|---|---|
| (dark blue) | Island is within 20 km of the Project Areas plus nesting at 'Low' or above |
| (mid blue) | Island is within 20 km of the Project Areas, but nesting is less than 'Low' |
| (light blue) | Island is more than 20 km from Project Areas |
| - | Absent |
| X | Present |
| L | Low: 1 – 10 tracks per day |
| M | Moderate: 11 – 100 tracks per day |
| H | High: 101 – 500 tracks per day |

**Table 2-3: Peak activity of nesting females and emerging hatchlings of green, flatback and hawksbill turtles in the North West Shelf region.**

| Species | Activity | Jul | | Aug | | Sep | | Oct | | Nov | | Dec | | Jan | | Feb | | Mar | | Apr | | May | | Jun | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Green | Nesting | | | | | | | | | | | | | | | | | | | | | | | | |
| | Emergence | | | | | | | | | | | | | | | | | | | | | | | | |
| Hawksbill | Nesting | | | | | | | * | * | * | * | | | | | | | | | | | | | | |
| | Emergence | | | | | | | | | | | * | * | * | * | | | | | | | | | | |
| Flatback | Nesting | | | | | | | | | | | * | * | * | * | | | | | | | | | | |
| | Emergence | | | | | | | | | | | | | | | * | * | * | * | | | | | | |

*Peak nesting reported for Rosemary Island (Whiting, 2018), peak hatchling emergence based on ~two month incubation (Commonwealth of Australia, 2017)

Although the body of literature describing marine turtle movement patterns during the breeding season is increasing, information specific to the Dampier Archipelago is more limited. Pendoley (2005) provides details of tracking data for green and hawksbill turtles nesting on Rosemary Island. Results suggested that nesting female hawksbill turtles remained within 1 km of nesting beaches on Rosemary Island (Pendoley, 2005). Female green turtles travelled greater distances, up to 5 km, but typically remained within shallow, nearshore waters between 0 and 10 m deep (Pendoley, 2005). Studies on the movements of internesting flatback turtles nesting within the Dampier Archipelago are lacking. However, an exhaustive analysis of a large dataset of satellite tracking data showed that flatback females remained in water depths of <44 m and favoured a mean depth of <10 m (Whittock *et al.,* 2016a). Flatback turtles generally demonstrate internesting displacement distances of 3.4 – 62 km from the nesting beach, typically confined to longshore movements in nearshore coastal waters or travelling between island rookeries and the adjacent mainland (Whittock *et al.,* 2014). There is no evidence to date to indicate that flatback turtles swim out into deep offshore waters during the internesting period. Incorporating tracking data, along with environmental variables, into a habitat suitability model, Whittock *et al.,* (2016) defined suitable internesting habitat as water 0 – 16 m deep and within 5 – 10 km of the coastline, while unsuitable internesting habitat was defined as water >25 m deep and >27 km from the coastline (Whittock *et al.,* 2016a).

Based on this understanding, it is considered unlikely that internesting turtles will occur in the Trunkline Project Area around the Montebello Islands where water depths range from 46 m to 214 m. At the shallowest point, which is in water adjacent to the Dampier Archipelago, water depths in the Trunkline Project Area are approximately 30 m. Water depths of the Borrow Grounds Project Area range between approximately '30 to 40 m. Internesting green and hawksbill turtles are unlikely to utilise habitat at these water depths. Flatback turtles nesting on beaches of the Dampier Archipelago may internest in the shallower waters of the Trunkline Project Area and Borrow Grounds Project Area, however, large numbers are not expected.

Following incubation, hatchlings emerge from the sand, crawl to the ocean and swim offshore, in a behaviour termed the "swim frenzy", under the influence of tides and currents before reaching deeper, less predator rich, waters. This offshore migration occurs in the top 30 cm of the ocean and this swimming behaviour is regularly interrupted by rest periods when hatchlings float on or near seaweed at the sea surface (Duran & Dunbar, 2015, Bell *et al.,* 2016). Current data for the Project Area at the closest point to the Montebello Islands and islands of the Dampier Archipelago are presented in RPS (2019). Estimates of the net currents were derived by combining predictions of the drift currents, available from mesoscale ocean models, with estimates of the tidal currents (RPS, 2019).

During peak hatchling season (November to April, inclusive of all species) currents at the Montebello Islands location flow in a westerly direction. Current speed ranged between <0.1 to 0.5 $m/s^{-1}$ with the greatest proportion of records within the 0.1 – 0.2 $m/s^{-1}$ range. At the Dampier Archipelago location, currents were predominantly in a northeast (NE) direction over the same time period. Current speed ranged from <0.04 to 0.16 $m/s^{-1}$ (RPS, 2019). When modelled to include tidal influences incorporated, current speed at the Dampier Archipelago location increased to range between <0.1 – 0.5 $m/s^{-1}$ and were predominantly in a west (W) or east (E) direction. Tidal influences had less of an effect on current speed at the Montebello Islands location, although the proportion of current speeds recorded in the 0.4 – 0.5 $m/s^{-1}$ range increased. Currents in an easterly direction were also as dominant as those in a westerly direction (RPS, 2019).

Non-breeding habitat use may include migratory pathways (adults) or foraging areas (adults and pelagic juveniles) for loggerhead, green, hawksbill, leatherback and flatback turtles. During non-breeding, green turtles typically occupy nearshore, coastal bays, feeding on seagrasses and macroalgae (Bjorndal, 1997; Bolten, 2003). They are herbivorous for the majority of their life history; however, post-hatching green turtles are omnivorous in their pelagic stage, and recent findings point to an oceanic diet including sea jellies for some populations (Arthur *et al.,* 2008; Bolten, 2003). Flipper tagging data suggest WA waters are probable foraging grounds for green turtles that nest not only in WA, but also the Northern Territory and Indonesia (Prince, 1997). Flatback turtle foraging areas have been found to occur in waters shallower than 130 m and within 315 km of the shore, with many areas located in 50 m water depth and 66 km from shore (Whittock *et al.,* 2016b). Their main diet comprises algae, squid, invertebrates, and molluscs. Loggerheads feed on benthic invertebrates including molluscs and crustaceans (Shigenaka, 2003). Loggerhead turtles are a nearshore species who prefer warm, shallow continental shelves and coastal bays and estuaries (Shigenaka, 2003). Hawksbill turtles are the most tropical of all sea turtle species and are found within rock and reef habitats, coastal areas and lagoons. They are known to forage amongst vertical underwater cliffs, on coral reefs and on gorgonian (soft coral) flats, as well as seagrass or algae meadows (Bjorndal, 1996). Hawksbills feed primarily on sponges, but will also consume shrimp, squid, anemones, algae, seagrass, sea cucumber and soft corals (Bjorndal, 1996).

Benthic surveys of the trunkline route between the State waters boundary and approximately kilometre point (KP) 50, to determine the presence and extent of any sessile benthic assemblages adjacent to the proposed trunkline route, found that the seabed was characterised as fine to coarse sand with low species abundance and diversity with sparse sponges and soft corals typical of habitat on the NWS (Woodside, 2009). Benthic habitat surveys within the Borrow Grounds Project Area suggested that the benthic habitat is dominated by sandy bottom and with little to no biota (Advisian, 2019). Based on the key food sources of marine turtle species, and the relative abundance of epifauna and infauna found in the Trunkline and Borrow Grounds Project Areas, the trunkline and borrow grounds are unlikely to support foraging aggregations of marine turtles.

Tracking data has highlighted the importance of the Dampier Archipelago for both green and hawksbill turtles on migration, though tracks indicated individuals stayed outside the furthermost islands of the Archipelago, and the eastern side of the Burrup Peninsula (Pendoley, 2005). The tracking data from Pendoley (2005) did not identify any foraging grounds for greens and hawksbills within the Dampier Archipelago. However, foraging aggregations of unidentified marine turtles during a mid-winter aerial marine fauna survey of the NWS region were concentrated in warm shallow waters off the offshore islands (Prince, 2001).

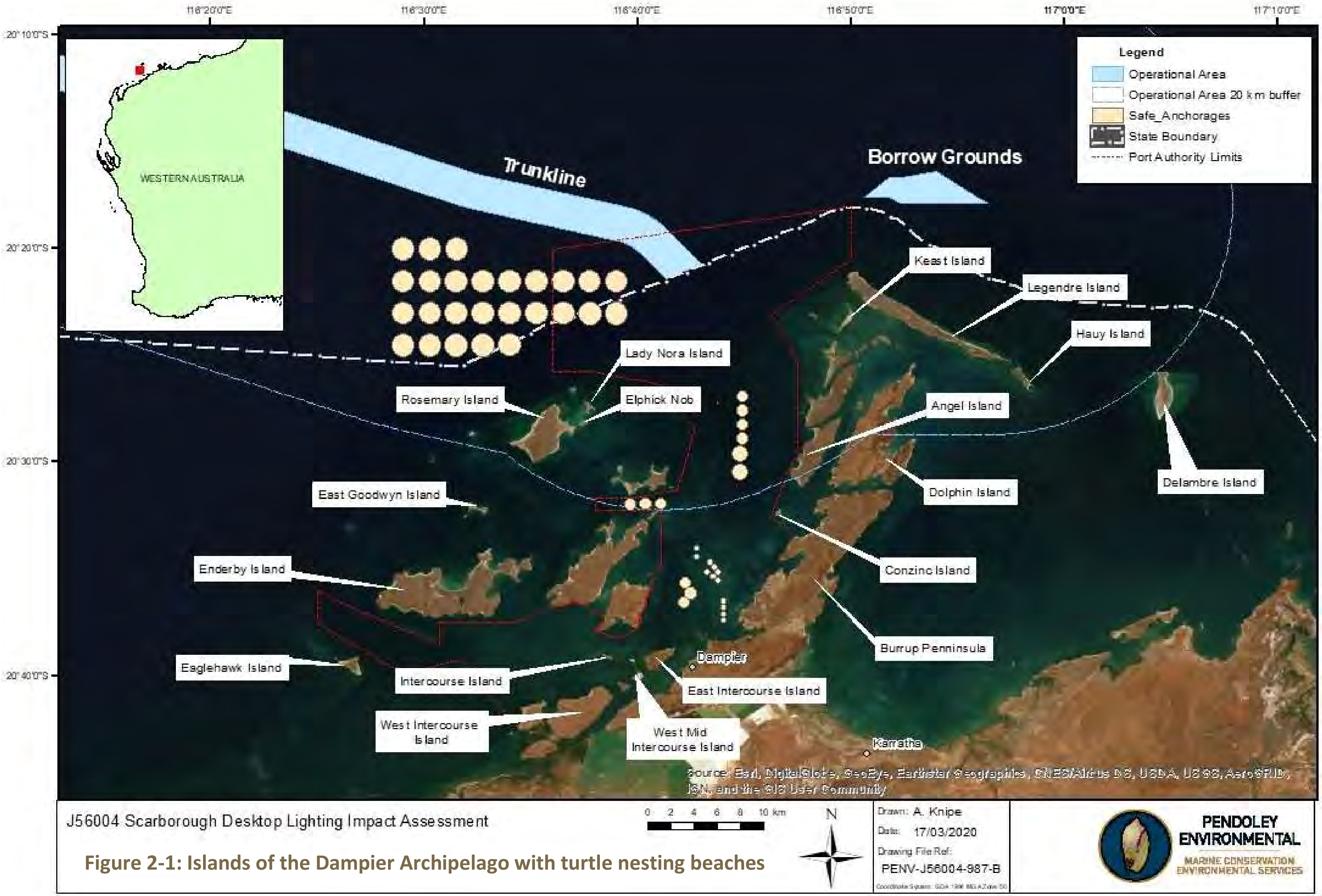



**Figure 2-1: Islands of the Dampier Archipelago with turtle nesting beaches**

# 3 IMPACT ASSESSMENT

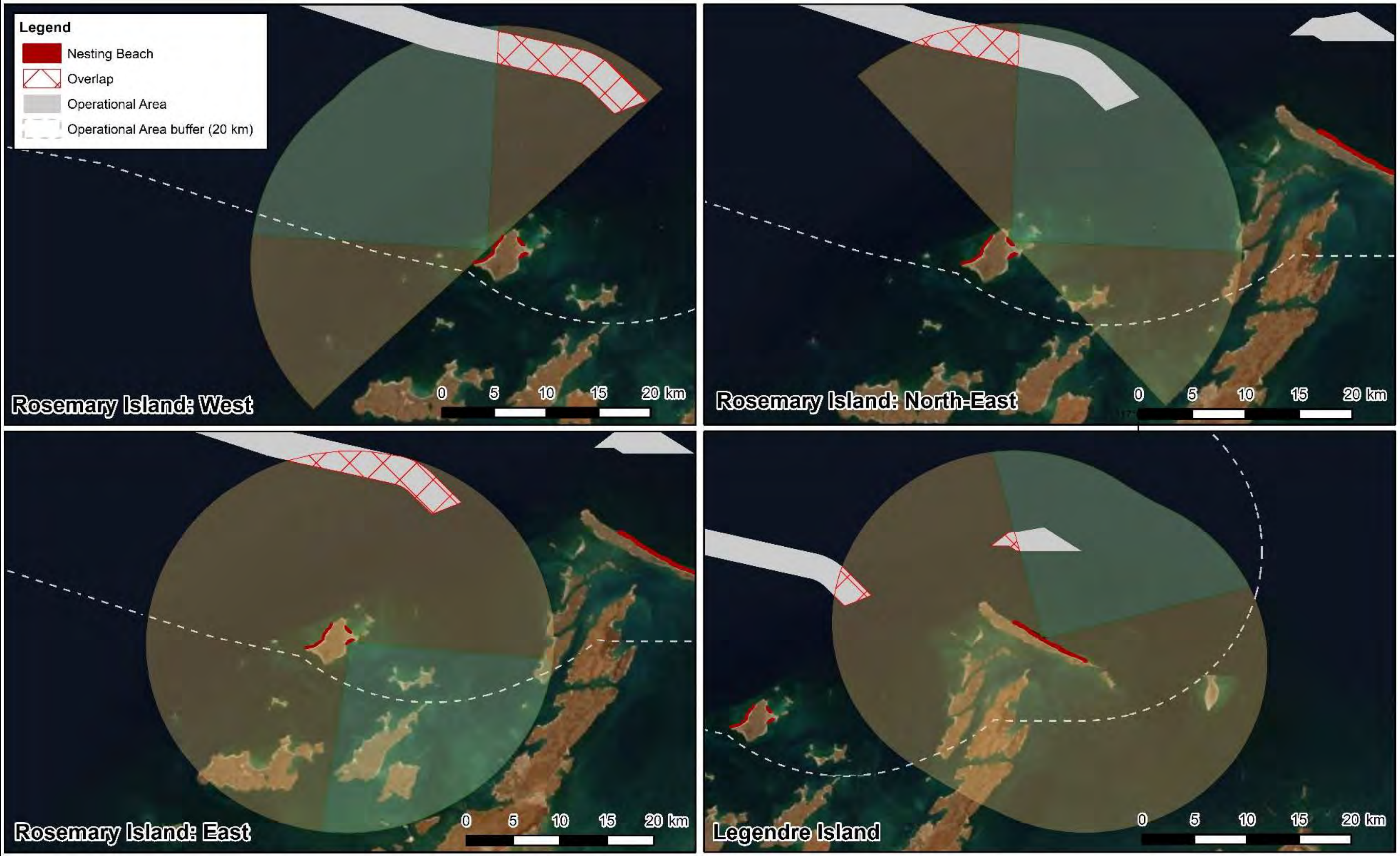
## 3.1 Rationale

As described in Section 2.2, this impact assessment assumes that received light intensity at nesting beaches within 20 km of the Project Area may result in impacts to marine turtle behaviour at these nesting beaches (Figure 2-1). The assessment is focused upon islands which have recorded at least 1 – 10 tracks per day (i.e low or above low activity) for either flatback, hawksbill or green turtles, as summarised in Table 2-2. These islands include Rosemary Island (14 km south (S) of the Trunkline Project Area), Legendre Island (12 km E of the Trunkline Project Area and 6.5 km S of the Borrow Grounds Project Area), and Angel Island (17 km southeast (SE) of the Trunkline Project Area). Although Delambre Island is located 20 km SE of the Borrow Grounds Project Area, the area within 20 km comprises rocky coastline unsuitable for turtle nesting. The sandy beaches where turtle nesting will occur at higher density are located more than 20 km from the Project Area. Therefore, potential impacts to nesting habitat of Delambre Island are not considered further.

Although the Project Areas are located in a general offshore direction from the islands listed above, variations in the coastline exist such that, at an individual beach level, the orientation of the vessels from individual nesting turtles may not always be in an offshore direction. Furthermore, as the vessels traverse through the Project Areas, the relative orientation to nesting beaches will change. Figure 3-1 presents the relative orientation of the Project Area from three nesting beaches on Rosemary Island, and one from Legendre Island. A generalised representation of unfavourable orientation of the Project Areas to these beaches was based on angles either less than 45°, or more than 135°, assuming that 90° was the most direct line to the ocean. The portions of the Project Areas that are considered to be at an unfavourable orientation to the nesting beaches are shown in red hatching. These hatched areas represent an area of increased vulnerability to behavioural impacts due to artificial light as a visualisation tool only; they do not constitute a definitive threshold at which an impact will or will not occur. Factors such as the aspect, including the location of individual nests/clutches on the beach, and surrounding topography, will all influence the vulnerability of individual turtles to behavioural impacts.

The majority of hawksbill nesting on Rosemary Island occurs on the west coast, while lower density nesting occurs on NE and E facing beaches (Whiting, 2018; K. Pendoley, pers. comm.). The portion of the Project Area that occurs within 20 km of Rosemary Island includes an area which ranges in orientation from north-northwest (NNW) to northeast (NE), resulting in potentially unfavourable orientations presented in Figure 3-1. Legendre Island runs on a northwest (NW) to SE axis; turtle nesting beaches are predominantly found on the NE and southwest (SW) coasts of the eastern half of the island (Biota, 2009; K. Pendoley, pers. comm.). The orientation of the Trunkline Project Area to Legendre Island ranges from E to NE and the orientation of the borrow grounds Project Area to Legendre Island range from NNW to north (N). Given the combination of distance and orientation, relatively small proportions of either the borrow grounds or Trunkline Project Areas overlap with areas of potentially unfavourable orientation (Figure 3-1). Nesting beaches on Angel Island face in a NW direction, with orientation of the Trunkline Project Area in a NNW direction.

Although the TSHD or pipelay vessels may be consistently present in the Trunkline Project Area for up to eight weeks, depending on the activity being undertaken, the continual movement of the vessel will prevent any one specific receptor (e.g. a particular nesting beach or an individual turtle) being exposed for the duration of each activity and is most likely limited to less than eight weeks, depending on the nesting beach. Dredging activities in the Borrow Grounds, and backfill activities in the Trunkline Project Areas, will be undertaken intermittently; cycling between two hours in the borrow grounds followed by five hours in the Trunkline Project Area.




J56004 Scarborough Desktop Light Assessment

**Figure 3-1: Orientation of the Project Areas to individual nesting beaches**

Drawn: P. Whittock
Date: 13/02/2020
Drawing File Ref:
PENV-J56004-987-A
Coordinate System: GDA 1994 MGA Zone 50

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## 3.1 Nesting

Adult female marine turtles return to land, predominantly at night, to nest on sandy beaches, relying on visual cues to select, and orient on, nesting beaches. That artificial lighting on or near beaches has been shown to disrupt nesting behaviour is relatively well documented (see Witherington & Martin, 2003 for review). Beaches with light spill, such as those located adjacent to urban developments, roadways and piers, often have lower densities of nesting females compared to beaches with less development (Salmon, 2003; Hu *et al.,* 2018). Further, on completion of laying, nesting females are thought to use light cues in order to return to open ocean, orientating towards the brightest light (Witherington & Martin, 2003). However, observations of nesting females and emerging hatchlings at the same beach showed that females were disorientated much less frequently than hatchlings (Witherington, 1992) indicating that nesting females are less vulnerable to impacts of artificial light on sea-finding.

Although it is assumed that artificial light emitted from project vessels may be visible at nesting beaches, given the distance between the light sources and the beaches (minimum of 6.5 km from Borrow ground and 12 km from Trunkline Project Area), direct light spill onto the beach is not considered credible. As such, the vessel light sources are not expected to discourage females from nesting, or effect nest site selection, and hence will not displace females from nesting habitat. There is a possibility that the orientation of light sources relative to individual nesting females returning to sea, may be in a longshore direction that could cause disruption to sea-finding behaviour. Although the maximum duration of a pipelay or TSHD vessel activity is eight weeks (Table 2-1), these vessels are either continually moving (within the Trunkline Project Area) or have intermittent presence (in the Borrow Ground Project Area), and, therefore, the relative orientation between the vessel and an individual beach will not occur for the duration of the activity. Intermittent activities are limited to a maximum of five hours in the Trunkline Project Area or two hours in the Borrow Grounds Project Area. The continuous movement, or intermittent presence, will unlikely result in the TSHD and pipelay vessel being located at an unfavourable orientation for the duration of the activity, limiting the number of females at risk to an insignificant proportion of the nesting population. Since females are not considered highly vulnerable to disorientation due to artificial light, the risk of artificial light preventing nesting behaviour at nesting beaches is considered low.

## 3.2 Mating, Internesting, Foraging and Migration

The Project Areas overlap habitat critical (internesting buffers) and BIAs for the flatback turtle around the Dampier Archipelago and Montebello Islands, and internesting BIAs for green and hawksbill turtles around the Dampier Archipelago (see Section 2.3). However, as described in Section 2.3.2, green and hawksbill internesting turtles showed preference for water depths less than 10 m and suitable flatback turtle internesting habitat is considered to be less than 25 m deep.

Minimum water depths within the Project Areas are 32 m suggesting that the majority of flatback, green and hawksbill turtles are not expected to use waters within the Project Areas for internesting, although some individual turtles may be encountered. Individuals may migrate through the Project Areas, and although foraging aggregations have not been identified, individuals may forage in low densities. No mating aggregations have been identified in the Project Areas.

Although individuals undertaking internesting, migration, mating (adults) or foraging (adults and pelagic juveniles) may occur within the Project Areas, marine turtles do not use light cues to guide these behaviours. Further, there is no evidence, published or anecdotal, to suggest that internesting, mating, foraging or migrating turtles are impacted by light from offshore vessels. As such, light emissions from the vessels are unlikely to result in displacement of, or behavioural changes to, individuals in these life stages.

## 3.3 Emerging hatchlings

Hatchling turtles emerge from the nest, typically at night (Mrosovsky & Shettleworth, 1968), and must rapidly reach the ocean to avoid predation (Salmon, 2003). Hatchlings locate the ocean using a combination of topographic and brightness cues, orienting towards the lower, brighter oceanic horizon, and away from elevated darkened silhouettes of dunes and/or vegetation behind the beach (Pendoley & Kamrowski, 2015; Lohmann *et al.,* 1997; Limpus & Kamrowski, 2013).

Artificial lights interfere with natural light levels and silhouettes, which disrupts hatchling sea-finding behaviour (Withington & Martin, 2003; Pendoley & Kamrowski, 2015; Kamrowski, *et al.,* 2014). Hatchlings may become disorientated - where hatchlings crawl on circuitous paths; or become misorientated - where they move in the wrong direction, possibly attracted to artificial lights (Withington & Martin, 2003; Lohmann *et al.,* 1997; Salmon, 2003). Hatchling orientation has been shown to be disrupted by light produced at distances of up to 18 km from the nesting beach (Hodge *et al.,* 2007, Kamrowski *et al.,* 2014), although the degree of impact will be influenced by a number of factors including light intensity, visibility (a function of lamp orientation and shielding), spectral power distribution (wavelength and colour), atmospheric scattering, cloud reflectance, spatial extent of sky glow, duration of exposure, horizon elevation and lunar phase. Hatchlings disoriented or misoriented by artificial lighting may take longer, or fail, to reach the sea. This may result in increased mortality through dehydration, predation or exhaustion (Salmon & Witherington, 1995).

Studies of hatchling sea-finding behaviour found that, on Curtis Island in Queensland, 20% of hatchling fans within proximity to artificial light associated with an onshore LNG plant had an offset bearing of >90°, indicating severe sea-finding disruption (Kamrowski *et al.,* 2014). However, the number of individual hatchlings that traversed the beach at bearings that indicated misorientation or disorientation are not reported. Although direct comparisons between light emissions of the proposed vessels and the LNG plant in this study are not possible (given the size of the LNG plant), it is considered credible that light emissions from the LNG plant will exceed those from the project vessels.

Disruption to orientation of emerging hatchlings has been found to occur most often during the new moon phase and least frequent during full moon phases (Salmon & Witherington, 1995). Experiments showed that background illumination from the moon (while in phases closer to full moon), restored normal seafinding behaviour in hatchlings but did not result in attraction in the direction of the moon. It was concluded that background illumination from the moon reduced light intensity gradients of artificial light, reducing, but not eliminating, its effect on hatchling orientation (Salmon & Witherington, 1995).

Although the Project Areas are located offshore, the orientation of vessels in relation to individual clutches at the local beach scale may occur in a longshore direction (as described above and presented in Figure 3-1) providing the potential for emerging hatchlings to become mis- or disorientated. However, the proportion of hatchlings that may become mis or disorientated is unlikely to comprise a significant proportion of the total number of hatchlings emerging from nesting beaches for the following reasons:

- Since the TSHD and pipelay vessels will be continually moving within the Trunkline Project Area, and the TSHD will only be intermittently present in the Borrow Grounds Project Area, vessels will only be temporarily (i.e. days to weeks) located at an orientation that could result in hatchling mis- or disorientation.
- The potential impact of artificial light may be reduced during the full moon period (Salmon & Witherington, 1995), further reducing the overall timeframe within which an impact could occur.
- It is not credible that all nests on a given beach will hatch during the activity duration (less than eight weeks) given the length of the peak hatchling emergence season (Table 2-3), and considering the effects of moon phase (above), meaning that the number at risk of behavioural impact will be less than the total number of hatchlings hatching on any given beach.
- Even if it is assumed that sea-finding is disrupted for all hatchlings in a given clutch, which is highly unlikely (K. Pendoley, pers. comm.), the proportion of clutches that could demonstrate sea-finding disruption is expected to be less than 20% (assuming a lower probability of impact compared to that reported in Kamrowski *et al.,* (2014)).

Therefore, should light emissions from the project vessels result in sea-finding disruption, it would likely be limited to a small proportion of individual hatchlings, which is not expected to result in significant impacts to flatback, green or hawksbill turtles within important nesting areas in the Dampier Archipelago and Montebello Islands (as defined in the Recovery Plan) or at the level of the genetic stock. While disruption to the behaviour of a small number of hatchlings may occur, the temporary presence of the light sources allows hatchling sea-finding behaviour to continue, once the vessel has moved away. Since the vessel activities are not planned to occur in multiple breeding seasons, such behavioural response are highly unlikely to result in impacts at a population level or result in decreasing trends in nesting abundance.

## 3.4 Dispersing hatchlings

Once in nearshore waters, artificial lights on land can also interfere with the dispersal of hatchlings. Presence of artificial light can slow down their in-water dispersal (Witherington & Bjorndal, 1991; Wilson *et al.,* 2018) or increase their dispersion path, potentially depleting yolk reserves, or even attract hatchings back to shore (Truscott *et al.,* 2017). In addition to interfering with swimming, artificial light can influence predation rates, with increased predation of hatchlings in areas with significant sky glow (Gyuris, 1994; Pilcher *et al.,* 2000). Since the nearshore area tends to be predator-rich, hatchling survival may depend on them exiting this area rapidly (Gyuris, 1994). Should this be the case, aggregation of predatory fish occurring in artificially lit areas (e.g. Wilson *et al.,* 2019) may further increase predation of hatchlings.

An internal compass set while crawling down the beach, together with wave cues, are used to reliably guide hatchlings offshore (Lohmann & Lohmann, 1992, Stapput & Wiltschko, 2005; Wilson *et al.,* submitted). In the absence of wave cues, however, swimming hatchlings have been shown to orient towards light cues (Lorne & Salmon, 2007, Harewood & Horrocks, 2008) and in some cases, wave cues were overridden by light cues (Thums *et al.,* 2013, 2016; Wilson *et al.,* 2018).

The speed and direction of at-sea dispersal is substantially influenced by currents; the offshore trajectory of flatback hatchlings at Thevenard Island was displaced by tidal currents that ran parallel to the beach, an effect that increased as the hatchlings moved further offshore (Wilson *et al.,* 2018, 2019). However, when light was present this effect was diminished, showing that hatchlings actively swam against currents and towards the light source, which slowed their offshore dispersal from 0.5 m/s$^{-1}$ when no light was present, to 0.35 - 0.44 m/s$^{-1}$, depending on the type of light (Wilson *et al.,* 2018). Wilson *et al.* (2018) demonstrated that when flatback hatchlings were within 150 m of the beach, they were able to swim against currents up to 0.3 m/s$^{-1}$.

These results suggest that hatchlings can move in any direction when their swimming speed is greater than the speed of the nearshore current, although the speed at which currents can no longer be overcome by hatchlings will be species specific and related to swimming speeds. The mean swimming of flatback hatchlings under natural light conditions (0.5 m/s$^{-1}$) were similar to speeds of green turtle hatchlings (0.49 m/s$^{-1}$) (Thums *et al.,* 2016), both of which are greater that hawksbill turtle hatchlings (0.21 m/s$^{-1}$) (Chung *et al.,* 2009). Given the similarities in swim speeds between flatback and green turtles, it is possible that green turtles will have the ability to swim against similar strength currents as reported for flatback turtles (0.3 m/s$^{-1}$). However, the slower swimming speeds recorded for hawksbill turtles suggest that current speeds at which hawksbill hatchlings could swim against would be weaker than 0.3 m/s$^{-1}$, though to what extent is currently unknown.

When tidal influences were considered, modelled currents around the Dampier Archipelago and Montebello Islands ranged from <0.1 to 0.5 m/s.$^{-1}$, with the greatest proportion of records within the 0.1 – 0.2 m/s$^{-1}$ range (RPS, 2019). These modelling results suggest that flatback and green turtle hatchlings may be able to swim against currents, for at least a proportion of the activity, should they be attracted to artificial light. Hawksbill turtles may be able to swim against currents at the lowest end of the predicted range, which is less likely to comprise a significant proportion of the activity duration. In the event that hatchlings are able to swim against current speeds, there is a risk that they could become entrapped in areas of light spill. Wilson *et al.,* (2018) observed flatback hatchlings becoming entrapped in the light spill from a small survey vessel for up to one hour. Other reports of the duration of time in which hatchlings may be entrapped in direct light spill varies widely; while Thums *et al.* (2016) found that light trapping was very temporary (minutes), anecdotal observations of hatchlings entrapped by light spill from a pipelay vessel off Barrow Island found hatchlings remained within the light spill in the lee of the barge all night until dawn (K. Pendoley, pers. obs. 2003). It is possible that larger vessels, such as the pipelay vessel, provide shelter on the leeward side from tidal currents allowing hatchlings to remain trapped in the light spill longer (K. Pendoley, pers. obs. 2003).

Hatchlings emerging from nesting beaches of the Montebello Islands are expected to be carried E or W by the predominant current direction, and not in the direction of the Trunkline Project Area. Since the light sources are located more than 20 km from the nesting beaches, the risk of dispersing hatchlings becoming attracted to light sources in the Project Area is not considered credible.

The majority of hatchlings emerging from nesting beaches of Rosemary Island are hawksbill turtles, which, given their swimming speeds, are considered less likely to swim against the predominant currents for a significant proportion of the activity duration. Further, the predominant current direction (E or W) are unlikely to carry hatchlings (of any species) from Rosemary Island towards an artificial light source in the Trunkline Project Area. At Legendre Island, the predominant current direction (E or W) is unlikely to carry hatchlings in the direction of the Borrow Grounds Project Area. Should light emissions be at a level that results in attraction, green and flatback hatchlings may be able to swim against currents towards the TSHD light sources. However, given that the TSHD will only be present for two hours at a time within the Borrow Grounds Project Area, any attraction will be temporary, and once the TSHD has left the Project Area, dispersing behaviour under can continue under natural conditions. Since the Trunkline Project Area is W of Legendre Island, it is possible that hatchlings could be carried towards vessels within this area. However, while not tested empirically due to the logistical constraints of tracking large numbers of hatchlings concurrently, the density of hatchlings will decrease with distance from the nesting beach as individuals disperse in open ocean (see ambient treatment results in Thums *et al.,*2016, Wilson *et al.,* 2016, Wilson *et al.,*2019). Since the distance between Legendre Island and the Trunkline Project Area is 14 km, the number of hatchlings emerging from Legendre Island occurring within the Trunkline Project Area is likely be a small proportion of the total number emerging from the closest nesting beaches.

In the unlikely event that dispersing hatchlings from Rosemary Island or Legendre Island are carried by currents into the vicinity of the TSHD or pipelay vessel and become attracted to sources of artificial light, the impact will be temporary in that attraction will only occur during hours of darkness; following sunrise, the attraction will cease hatchling dispersal will return. Although attraction to light sources may have consequences at the individual level (e.g. energy depletion and increased predation risk), the numbers that could be impacted is unlikely to comprise a significant proportion of the annual number of hatchlings emerging from the nesting beaches.

# 4 SUMMARY

This impact assessment was conservatively based on the assumption that light emissions (in the form of either direct light or sky glow) from project vessels within the Trunkline and Borrow Ground Project Areas may be received at intensities that could result in behavioural disturbance at nesting beaches with 20 km of the light sources.

While conservative, the impact assessment concluded that the light emissions from vessel activities in the Trunkline and Borrow Grounds Project Areas would not have a significant impact on marine turtle species across the whole life cycle, when assessed against the EPBC Act Matters of National Environmental Significance Significant Impact Guidelines 1.1 (Commonwealth of Australia, 2013), as described in Table 4-1. Although behavioural impacts to marine turtles may occur, it is not expected that these impacts will be contrary to the priority actions or the measure of success criteria outlined in the Recovery Plan (Commonwealth of Australia, 2017) for the relevant marine turtle genetic stocks, or management of artificial light (Table 4-1).

**Table 4-1: Alignment with the Recovery Plan and Significant Impact Criteria based on a conservative impact assessment**

| Consideration | Conclusion |
|---|---|
| *Recovery Plan* | |
| Marine turtles are not displaced from identified habitat critical to the survival | Vessel light sources are not expected to discourage females from nesting, or effect nest site selection, and hence will not displace females from nesting habitat.<br><br>There is no evidence to suggest that internesting females are impacted by artificial light and, therefore, internesting females will not be displaced from internesting habitat. |
| That biologically important behaviour can continue in biologically important areas | Vessel light sources are not expected to discourage females from nesting, or affect nest site selection, meaning that impacts to nesting behaviour is not expected to occur. While there is a small potential for impact on post-nesting sea-finding behaviour of nesting females to occur, nesting females are not considered highly vulnerable to disorientation due to artificial light. Further, since vessels are either continually moving or intermittently present within the Project Areas, the number of adult females potentially impacted is further reduced.<br><br>There is no evidence, published or anecdotal, to suggest that internesting turtles are impacted by light from offshore vessels and, therefore, changes to internesting behaviour are not expected to occur.<br><br>While disruption to the behaviour of an insignificant proportion of the total annual number of emerging hatchlings may occur, the pipelay and TSHD vessels are continually moving within the Trunkline Project Area (at least 12 km away) meaning that specific beaches are not exposed to unfavourable orientation of light sources that could result in disruption of sea-finding behaviour for the duration of activities in this area. Once the vessels have moved out of an unfavourable orientation from individual beaches (which is likely to occur within days to weeks), hatchling sea-finding behaviour can continue. The Borrow Grounds Project Area is located 6.6 km from Legendre Island, the closest point to shore. However, activities within the borrow grounds are intermittent (approximately two-hour presence in the area and |

| Consideration | Conclusion |
|---|---|
| | absent for at least five hours) further reducing the timeframe in which behavioural impacts to emerging hatchlings could occur.<br><br>While disruption to hatchling dispersal behaviour (e.g. attraction to or trapping by light at a vessel) of an insignificant proportion of the annual number of hatchlings emerging from a given beach is credible, following sunrise, any effect of the light sources on hatchlings will be eliminated allowing dispersal behaviour to resume. Further, the potential for hatchling dispersal behaviour to be affected decreases with distance to shore. The closest point between the Project Areas and turtle nesting beaches, where the potential of impacts to hatchling dispersal are more likely, is 6.6 km between the Borrow Ground Project Area and Legendre Island. However, TSHD activities within the borrow grounds are intermittent, as described above, further reducing the timeframe in which behavioural impacts could occur in the borrow grounds.<br><br>While the above behavioural impacts are credible, under a conservative assessment, it is not expected these impacts will impede recovery of the relevant green (G-NWS), flatback (F-Pil) or hawksbill (H-WA) genetic stocks, or result in a decreasing trend in numbers/abundance and, therefore, the project will not impact the measure of success criteria of the Recovery Plan (Commonwealth of Australia, 2017). |
| Develop and implement best practice light management guidelines for existing and future developments adjacent to turtle nesting beaches | Additional controls outlined in Section 5 will ensure that the activity is conducted in a manner consistent with the National Light Pollution Guidelines for Wildlife (Commonwealth of Australia, 2020). |
| Identify the cumulative impact on turtles from multiple sources of onshore and offshore light pollution | The TSHD and pipelay vessels will not operate concurrently since activities are required to be undertaken sequentially. Although these vessels may be in the Project Areas for up to eight weeks, depending on the activity being undertaken, the continual movement of the vessels will prevent any one specific receptor (e.g. a particular nesting beach or an individual turtle) being exposed for the duration of each activity. Dredging activities in the borrow grounds Project Area, and backfill activities in the Trunkline Project Area, will also be undertaken intermittently, with periods of time in which the vessel will be absent. |

| **Consideration** | **Conclusion** |
|---|---|
| | Additional support vessels may be present during some activities (e.g. pipelay activities), however, given the size of the support vessels in comparison to the pipelay vessel, light emissions from the support vessels are unlikely to contribute significantly to overall light emissions.<br><br>When considered in the context of existing industrial light sources in the region, light emissions from the activities are unlikely to significantly increase light pollution of the Dampier Archipelago. Specifically, at Rosemary Island, visibility of light emissions from the TSHD and pipelay vessels may be limited by existing light emissions from vessels at the designated anchorages. |
| *Significant impact criteria* | |
| Lead to a long-term decrease in the size of a population or important population | Behavioural impacts are limited to an insignificant proportion of the overall annual number of hatchlings emerging from nesting beaches when considered at the 'important nesting area'* level. |
| Reduce the area of occupancy of important population | The activity will not permanently displace marine turtles from habitats occupied during different life stages. |
| Fragment an existing important population into two or more populations | Given the temporary nature of the activity (as described in Section 3.1), fragmentation of important population is not credible. |
| Adversely affect habitat critical to the survival of a species | The activity is not expected to adversely affect nesting or internesting habitat due to the temporary nature of the activity (as described in Section 3.1), and that impacts at the individual level are unlikely. |
| Disrupt the breeding cycle of an important population | Behavioural impacts are limited to an insignificant proportion of the overall annual number of hatchlings emerging from nesting beaches when considered at the 'important nesting area' scale ('important nesting areas' as defined in the Recovery Plan). Disruption to mating, migration, internesting or nesting is not expected. |

| Consideration | Conclusion |
|---|---|
| Modify, destroy, remove, isolate or decrease the availability or quality of habitat to the extent that the species is likely to decline | Given the temporary nature of the activity (as described in Section 3.1), the availability or quality of the habitat will not be affected so that marine turtle species may decline. |
| Result in invasive species that are harmful to an endangered or vulnerable species becoming established in the species' habitat | Not applicable to light emissions. |
| Introduce disease that may cause the species to decline | Not applicable to light emissions. |
| Substantially interfere with the recovery of the species | Behavioural impacts are limited to an insignificant proportion of the overall annual number of hatchlings emerging from nesting beaches when considered at the 'important nesting area'* level. Such impacts will be temporary in nature (as described in Section 3.1) and will not interfere with the recovery at neither the species nor genetic stock level. |

* Important nesting areas as defined in the Recovery Plan.

# 5 RECOMMENDATIONS

It is recommended that Woodside consider the application of a hierarchy or controls in accordance with the National Light Pollution Guidelines for Wildlife (Commonwealth of Australia, 2020) to reduce potential impacts to as low as reasonably practicable (ALARP) and acceptable levels. Controls for consideration are described below.

## 5.1 Control measures

These control measures are consistent with the National Light Pollution Guidelines for Wildlife (Commonwealth of Australia, 2020).

### 5.1.1 Avoid night work in sensitive windows

- Trunkline Project Area: peak hatchling emergence periods at Rosemary Island, Legendre Island.
- Activities in borrow grounds Project Area: peak hatchling emergence periods at Legendre Island.
- If night work cannot be avoided, limit non-routine activities at night. For example, heavy lift activities or crew transfers which may require additional or higher intensity of lighting, or orientation of lighting towards nesting beaches.

### 5.1.2 Activity-specific Lighting Management Plan

The Lighting Management Plan for specific activities should include details on:

**Light modelling**

Modelling can estimate light emissions from the worst-case scenario and identify:

- Specific nesting beaches that may receive light levels at an intensity that could result in behavioural impact.
- The distance from the vessel at which light radiance is considered ambient.
- Identify lights which contribute most to overall light emissions.

The modelling could therefore inform:

- The credibility of impacts at nesting beaches occurring (nesting females and emerging hatchlings).
- The distance at which hatchlings would need to swim offshore before encountering light sources that could result in disturbance to dispersal behaviour.
- The size of spatial buffers around important habitats within which additional or adaptive management may be required.

Light model accuracy can be increased by incorporating measurements of existing lighting levels within the region. This model could show that light from the pipelay vessel will not add significantly to light intensity and sky glow at regional scale, when accounting for existing light sources (i.e. moorings and anchorages between Rosemary Island and the Trunkline Project Area).

**Light type and positioning**

If light modelling indicates impacts at beaches is credible, the following controls should be considered:

- Adjusting orientation of lights to minimise horizontal light spill (all lights)
- Apply additional shielding to a) all lights, or, if not practicable, b) the highest intensity lights, where practicable
- Change a) all lights, or, if not practicable, b) the highest intensity lights, to amber wavelength were safety standards allow.

Where orientation and additional shielding can be applied, the model can be rerun to indicate efficacy of these control measures.

**Housekeeping**

In all cases, additional housekeeping controls would reduce overall light emissions, including:

- Closing blinds during hours of darkness
- Switching off non-operational lights when not required
- Consider motion activated lights were safety standards allow

**Vessel inspection**

Prior to the vessel entering within 20 km of nesting beaches, or a spatial buffer informed by modelling, a vessel inspection would occur to:

- Ensure orientation of lights is such that only the intended object is illuminated
- Identify areas of direct light spill on the water and apply additional shielding
- Ensure compliance with housekeeping control measures

### 5.1.3 Adaptive management

If the activity is undertaken during peak hatchling season, and modelling predicts impacts are credible, adaptive management could be applied, such as:

- Dedicated observers will monitor the area of light spill for entrapped hatchlings. If a number of hatchlings, to be determined, are observed in an area of light spill, the lights will be switched off for half an hour (to allow dispersal behaviour to continue).
- If impacts at the nesting beach are credible, and activity is undertaken in hatchling season, hatchling orientation data will be collected when the vessel is operating within distances at which impacts may occur. If either the spread or offset angle is considered to deviate

significantly (to be determined) from a known baseline, restrictions in night operations will be considered.

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# Appendix L

## Scarborough Light Modelling

Advisian

# SCARBOROUGH LIGHT MODELLING


Prepared by

Pendoley Environmental Pty Ltd

For

Advisian

**21 February 2020**

PENDOLEY ENVIRONMENTAL
MARINE CONSERVATION ENVIRONMENTAL SERVICES

# DOCUMENT CONTROL INFORMATION

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# ACCRONYMS

| | |
|---|---|
| ALAN | Artificial Light At Night |
| km | Kilometer |
| m | Meters |
| NWS | North West Shelf |
| SME | Subject Matter Expert |
| sr | steradian |
| TSHD | Trailing suction hopper dredger |
| W | Watts |

# 1 INTRODUCTION

Woodside Energy Limited (Woodside), is proposing to develop the Scarborough gas resource, located on the North West Shelf (NWS), through new offshore facilities. These facilities are proposed to be connected to the mainland through an approximately 430 km trunkline to an onshore facility.

Installation of the trunkline will involve pre-lay dredging and pipelay, followed by post-lay backfill within a Trunkline Project Area. Backfill material will be dredged from a separate area, the Borrow Grounds Project Area. Specialised vessels will be utilized for specific activities. As described in the National Light Pollution Guidelines for Wildlife Including Marine Turtles, Seabirds and Migratory Shorebirds (Commonwealth of Australia, 2020), light emissions from project vessels have the potential to impact marine turtles at nesting beaches and in open ocean.

A conservative desktop assessment of potential impacts of ALAN on marine turtles was undertaken in absence of light modelling by assuming that potential impacts were credible within 20 km of the light sources (Pendoley Environmental, 2020). While this impact assessment is considered conservative, due to the uncertainties associated with predicting light emissions of the vessels without relevant information, Advisian engaged Pendoley Environmental on behalf of Woodside to undertake light modelling to aid assessment of light emissions from the proposed pipelay vessel and trailing suction hopper dredger (TSHD) vessel.

# 2 METHODOLOGY

Light modelling was undertaken for the proposed pipelay and TSHD vessels to predict the extent of biologically relevant light spill. Specifics of the respective vessel's lighting design and luminaire specifications were applied to the ILLUMINA Artificial Light At Night (ALAN) model (Aube *et al*. 2005). The ILLUMINA model is a three-dimensional model that accounts for both line of sight and atmospheric scattering, allowing the attenuation of light over distance and extent of light glow to be modelled. The reader is directed to Aube *et al*. (2005) for details of equations and model parameterisation.

Unlike a simple line of sight model based on the inverse square law formula, this is a more sophisticated model which allows individual light sources (i.e. individual luminaires) to be placed within the area of interest (as opposed to assuming a single large light point source for the entire vessel). The model input parameters also include project specific details about light type, spectral distribution, height and orientation of individual luminaires, including any shielding, which substantially increases the model precision and accuracy.

## 2.1 Model Inputs

Information regarding the light inventory was extracted from lighting layout drawings and light manufacturer data sheets provided to Pendoley Environmental by Woodside for both the *Casterone* pipelay vessel and *Gateway* TSHD, and included:

- number of each type of light
- spectral output of light type
- angular distribution of light (shielding)
- lumen output of each type of light
- height of each light

Details of individual lights are summarised in (Annex 1).

Because the atmospheric conditions over the NWS are typically clear, the model simulations presented here assumed no contribution of light from cloud reflectance.

Surface reflectance and elevation values are incorporated into the model from aerial imagery supplied by NASA (National Aeronautics and Space Administration) Earthdata and the NOAA (National Oceanic and Atmospheric Administration) (NASA, 2020; NOAA, 2020) as per the methodology outlined in Aube *et al*. (2005).

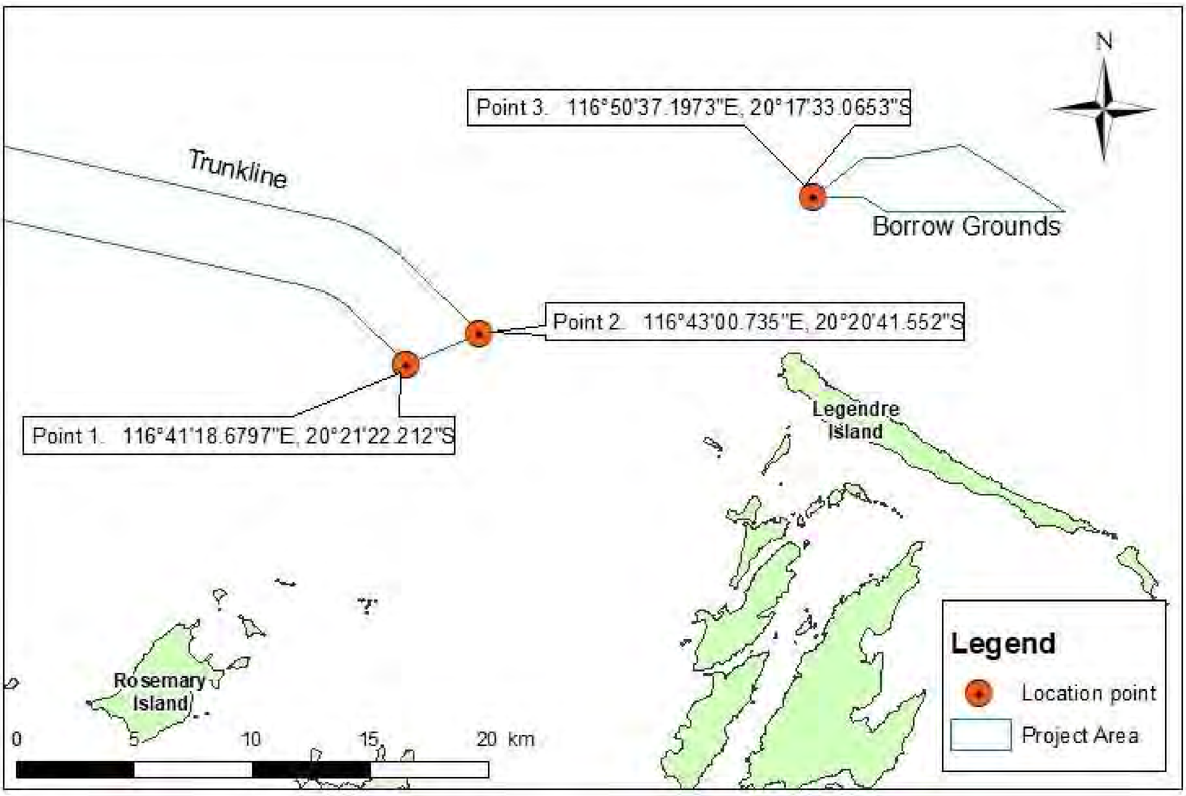
Model outputs are provided in radiance (W/m$^2$/sr, where W = watts, m$^2$ =meters squared and sr = steradian).

## 2.2 Scenarios

Four scenarios were modelled:

1. Pipelay vessel *Casterone* at the closest point of the Trunkline Project Area to Rosemary Island (point 1, 14.15 km)
2. Pipelay vessel *Casterone* at the closest point of the Trunkline Project Area to Legendre island (point 2, 12 km)
3. TSHD *Gateway* at the closest point of the Trunkline Project Area to Rosemary Island (point 1, 14.15 km)
4. TSHD *Gateway* at the closest point of the Borrow Grounds Project Area to Legendre island (point 3, 6.6 km)

Location and coordinates of these location points are provided in Figure 2-1.




J56004 Scarborough Desktop Light Assessment

**Figure 2-1: Location and coordinates of light modelling source points**

Drawn: A. Knipe
Date: 20/02/2020
Drawing File Ref:
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## 2.3 Interpretation and Limitations

In the absence of any published or generally accepted units of measurement, or scale, for measuring the impact of ALAN on marine turtles, moonlight was selected as a proxy and the light model output (radiance, units of Watts/$m^2$/sr) was converted to units of full moon equivalents in an attempt to give the radiance output some biological relevance and to aid interpretation in an environmental impact assessment context. The reasoning used was:

- the range of moon brightness across a whole lunar cycle is a realistic scale representative of the ambient light levels that turtle eyes are adapted to, at the lower end of the scale the radiant output is equivalent to no light in the sky while the upper limit is greater than the radiance from a single full moon and was selected to try to account for the increase in radiance levels that would occur if the light was reflected from clouds (recognizing that cloudy conditions are not the norm for this site). Extending the scale beyond this limit was deemed unnecessary.

- the scale for the units "the proportion of radiance of one full moon" was derived from the logarithmic nature of light decay with distance (a function of the inverse square law), e.g. the scale of <0.01, 0.01 – 0.1, 0.1 – 1, 1 – 10 represents a range of radiant brightness from a minimum of <0.01 full moon (so essentially a new moon) to a maximum radiant brightness of the equivalent to 10 full moons.

- While the behavioural response of marine turtles to light is relatively well understood (see Witherington and Martin (2003) for review), there is currently no agreed upon intensity limits for determining what the impact of a given light might be. A large range of factors influence the visibility and impact of light on hatchlings including light intensity, visibility (a function of lamp orientation and shielding), spectral power distribution (wavelength and colour), atmospheric scattering, cloud reflectance, spatial extent of sky glow, duration of exposure, horizon elevation, lunar phase, hatchling swimming speeds, tide and current speeds and flow direction etc. Using the scale of light radiance derived from the calculated decrease in light intensity with distance (proportion radiance of a full moon) and together with our extensive SME experience observing marine turtles and their response to both onshore and offshore construction light in field settings, we have proposed conservative, potential impact criteria for marine turtles based on radiance thresholds relative to moon radiance, as shown in Table 2-1.

**Table 2-1: Artificial light impact potential criteria (marine turtles)**

| Proportion of radiance of a full moon* | Impact potential to marine turtles |
|---|---|
| 1 - 10 | Light or light glow visible and impact likely, represents a very bright light equivalence to up to 10 times the radiance of one moon. This light radiance will override the moderating influence of the ambient full moon at the time of exposure. |
| 0.1 - 1 | Light or light glow visible and behavioural impact possible, depending on ambient moon phase at the time of exposure, which will influence the visibility of the artificial light sources, equivalent to the light output. Artificial lights will be more visible to marine turtles under a first quarter moon than under a full moon. |
| 0.01 - 0.1 | Light or light glow visible but behavioural impact unlikely (i.e. not biologically relevant). Equivalent to the light output from the first quarter moon to new moon. |
| <0.01 | Light or light glow is considered ambient and no impact expected, equivalent to a new moon |

*Where 10 equals the radiance of ten full moons and 0.01 equals 100th the radiance of one full moon

# 3 RESULTS

## 3.1 Pipelay vessel

Results from the ILLUMINA model undertaken for the pipelay vessel at point 1 (closest point to Rosemary Island, 14.15) and point 2 (closest point to Legendre Island, 12 km) are summarised in Table 3-1 and presented in Figure 3-1 and Figure 3-3. At a given radiance (reported as proportion of radiance of a full moon) there is a small difference in distances reported for the same vessel at the two different points, with greater distances from source when modelled at point 2 compared to point 1 (Table 3-1). For example, radiance is equivalent to 0.01 of a full moon at 1,783.80 m when modelled at point 1, but 1,783.97 m when modelled at point 2 (Table 3-1). However, this difference is not detectable when the distance to source is reported in km to one decimal place. Since all other model inputs are identical (e.g. light inventory and cloud reflectance), site-specific differences in surface reflectance, as determined from the satellite imagery model inputs at each location, is the likely cause. Reflectance of the water surface can be influenced by oceanographic variables such as water turbidity, wave height and water depth.

When applying the potential impact criteria in Table 2-1 the results show that, at ~5.7 km from the source, radiance has reduced to ambient. At distances between ~ 1.8 km and ~5.7 km from the source, radiance is equivalent to between 0.1 and 0.01 radiance of a full moon and, therefore, light may be visible but unlikely to result in a behavioural impact (i.e. biologically relevant). Impacts may occur within ~1.8 km of the pipelay vessel, depending on moon phase, and are more likely within ~0.6 km of the vessel, when radiance is equivalent to that of one full moon.

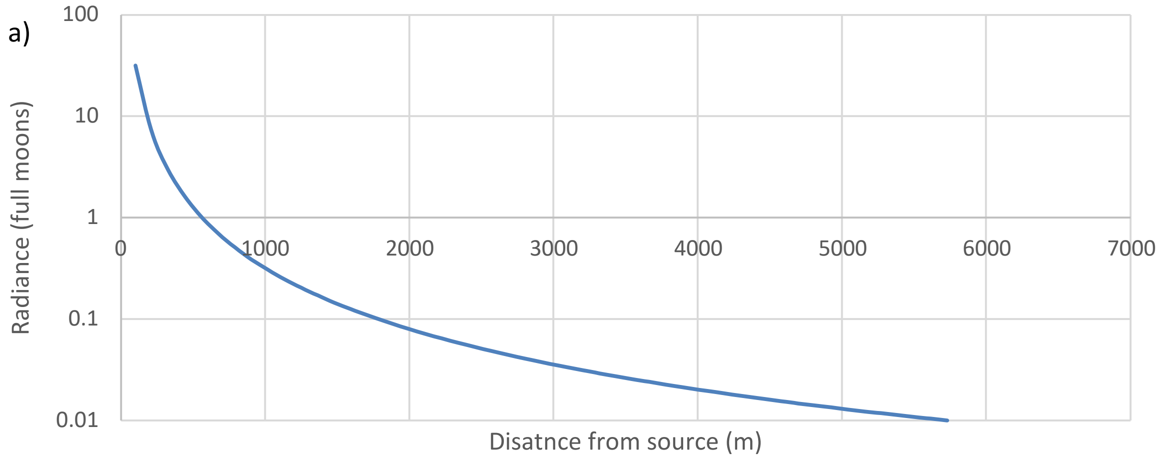
At the closest point to Rosemary Island (14 km), radiance is equal to 0.002 (0.2%) that of a full moon. At the closest point to Legendre Island (12 km), radiance is equal to 0.003 (0.3%) that of a full moon.

**Table 3-1: Distance of equivalent moon radiances for the pipelay vessel**

| **Proportion of radiance of a full moon*** | **Distance from pipelay vessel at which equivalent moon radiance is reached (m)** | |
|---|---|---|
| | Point 1 *(closest point from Trunkline Project Area to Rosemary Island)* | Point 2 *(closest point from Trunkline Project Area to Legendre Island)* |
| 10 | 178.01 | 178.08 |
| 1 | 563.22 | 563.22 |
| 0.1 | 1783.80 | 1783.97 |
| 0.01 | 5730.33 | 5735.81 |

*Where 10 equals the radiance of ten full moons and 0.01 equals 100th the radiance of one full moon

a)




b)

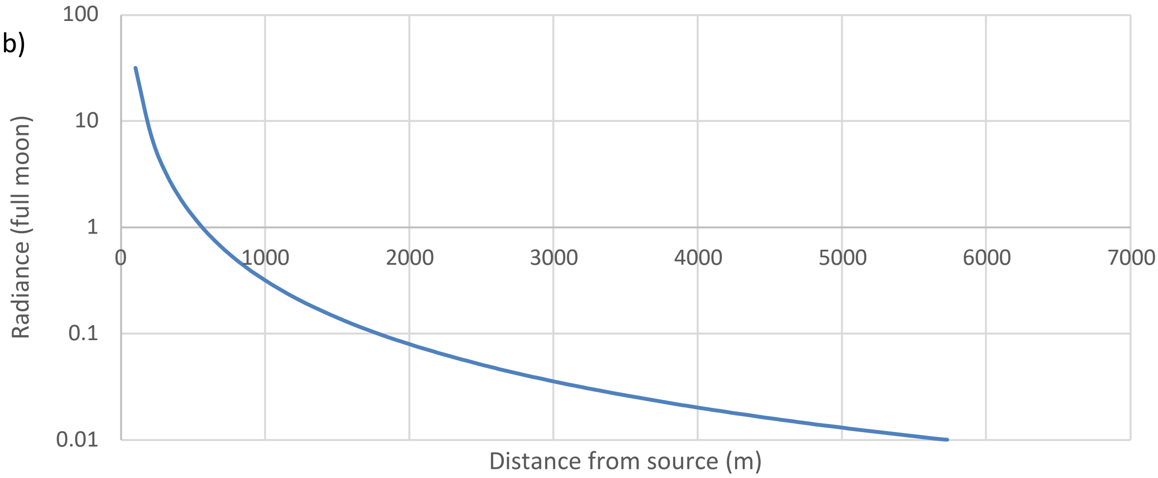



**Figure 3-1: Radiance of light sources with distance from the pipelay vessel at a) point 1 (closest point to Rosemary Island) and b) point 2 (closest point to Legendre Island).** Radiance (full moons) of 10 equals the radiance of ten full moons and 0.01 equals 100th the radiance of one full moon

## 3.2 TSHD

Results from the ILLUMINA model undertaken for the TSHD at point 1 (closest point to Rosemary Island, 14.15 km) and point 3 (closest point to Legendre Island, 6.6 km) are summarised in Table 3-2 and presented in Figure 3-2 and Figure 3-3. As with the pipelay vessel, there is a small difference in distances reported at the two different locations, with greater distances from source when modelled at point 3 compared to point 1 (Table 3-2). For example, radiance is equivalent to 0.01 of a full moon at 1,477.98 m when modelled at point 1, but 1,479.49 m when modelled at point 3 (Table 3-2). However, this difference is not detectable when the distance to source is reported in km to one decimal place. As described in Section 3.1 above, this difference is due to variation in surface reflectance at each location which is influenced by oceanographic variables.

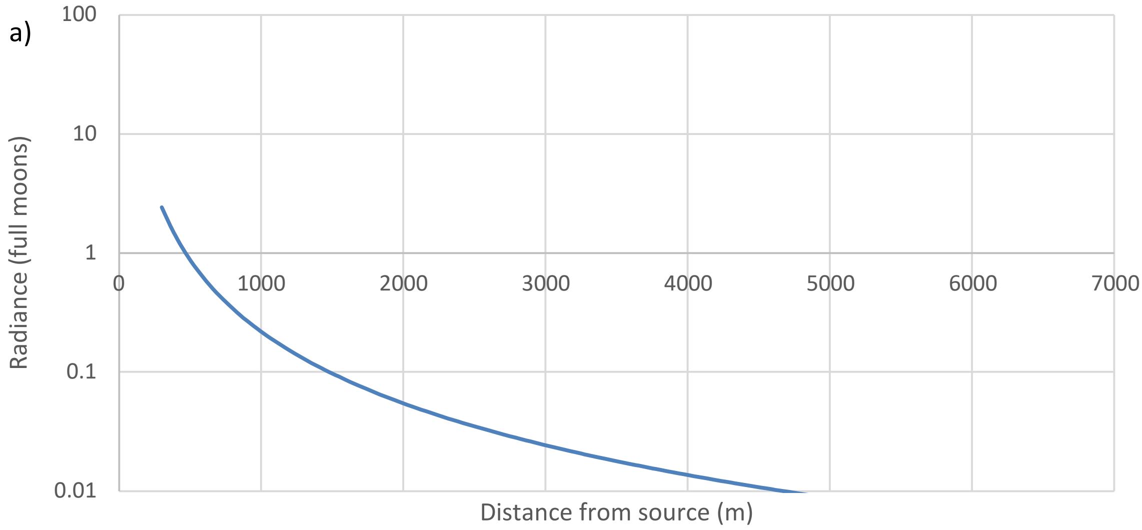
Applying the potential impact criteria in Table 2-1, the results show that at ~4.7 km from the source light levels have reduced to ambient. At distances between ~ 1.5 km and 4.7 km from the source, radiance is equivalent to between 0.1 and 0.01 radiance of a full moon and, therefore, light may be visible but unlikely to result in a behavioural impact. Impacts may occur within ~1.5 km of the TSHD, depending on moon phase, and are more likely within ~0.5 km of the TSHD, when radiance is equivalent to that of one full moon.

At the closest point to Rosemary Island (14 km), radiance is equal to 0.001 (0.1%) that of a full moon. At the closest point to Legendre Island (6.6 km), radiance is equal to 0.005 (0.5%) that of a full moon.

**Table 3-2: Distance of equivalent moon radiances for the TSHD.**

| **Proportion of radiance of a full moon*** | **Distance from TSHD at which equivalent moon radiance is reached (m)** | |
|---|---|---|
| | Point 1 *(closest point from Trunkline Project Area to Rosemary Island)* | Point 3 *(closest point from Borrow Grounds Project Area to Legendre Island)* |
| 10 | 147.80 | 147.80 |
| 1 | 467.38 | 467.43 |
| 0.1 | 1477.98 | 1479.49 |
| 0.01 | 4673.84 | 4722.37 |

*Where 10 equals the radiance of ten full moons and 0.01 equals 100th the radiance of one full moon



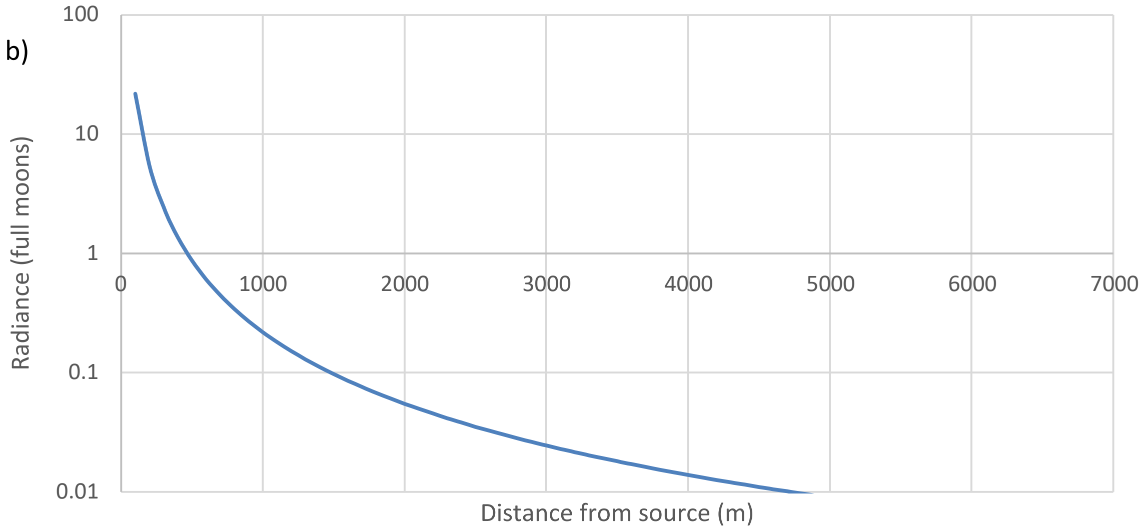




**Figure 3-2: Radiance of light sources with distance from the TSHD at a) point 1 (closest point to Rosemary Island) and b) point 3 (closest point to Legendre Island)..** Radiance (full moons) of 10 equals the radiance of ten full moons and 0.01 equals 100th the radiance of one full moon.

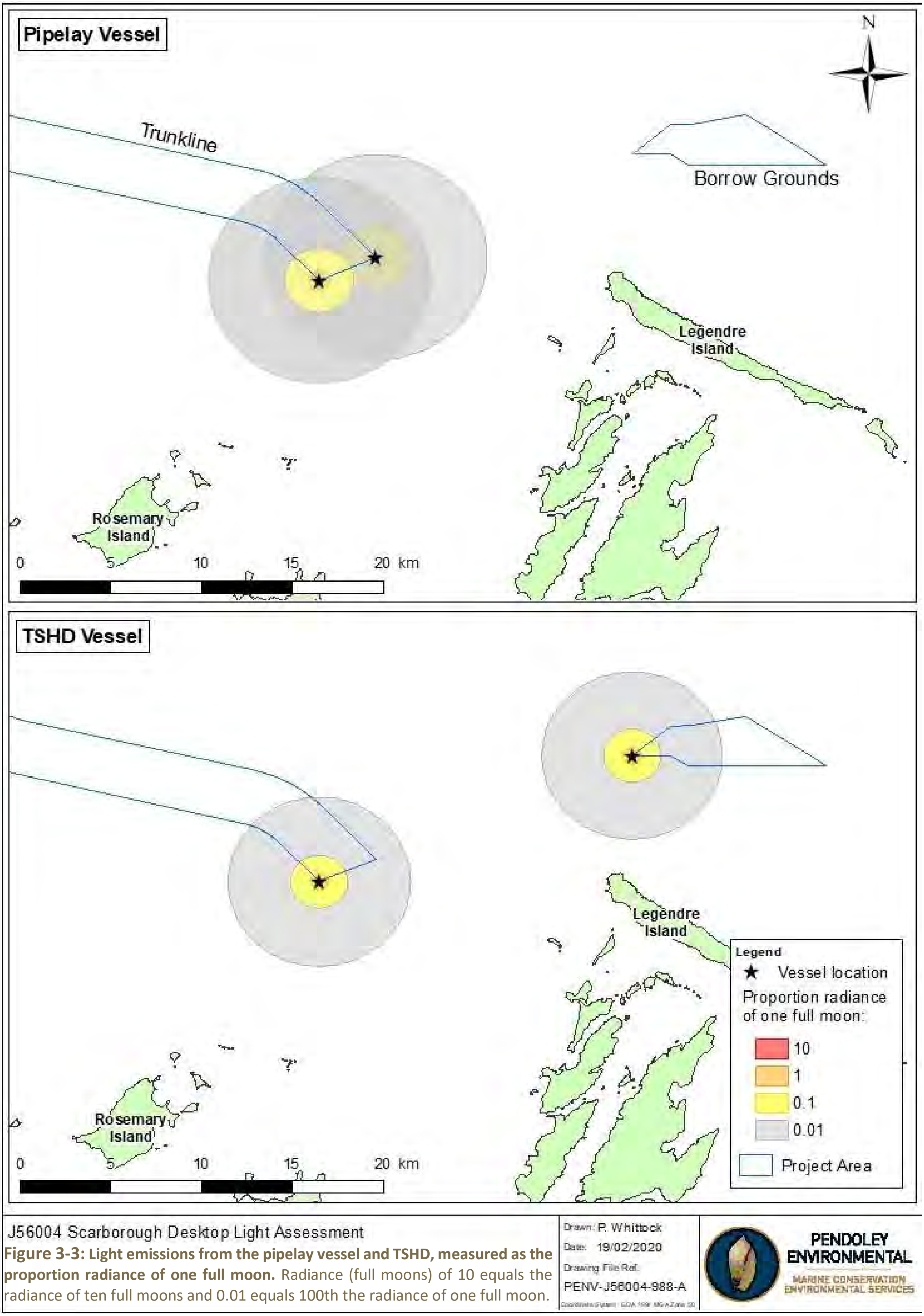



**Figure 3-3: Light emissions from the pipelay vessel and TSHD, measured as the proportion radiance of one full moon.** Radiance (full moons) of 10 equals the radiance of ten full moons and 0.01 equals 100th the radiance of one full moon.

# 4 CONCLUSION

## 4.1 Model Results

ILLUMINA light modelling was undertaken using methodology presented in Aube *et al*., (2005) for four scenarios associated with the Scarborough trunkline installation activities:

1. Pipelay vessel *Casterone* at the closest point of the Trunkline Project Area to Rosemary Island (point 1, 14.15 km)
2. Pipelay vessel *Casterone* at the closest point of the Trunkline Project Area to Legendre island (point 2, 12 km)
3. TSHD *Gateway* at the closest point of the Trunkline Project Area to Rosemary Island (point 1, 14.15 km)
4. TSHD *Gateway* at the closest point of the Borrow Grounds Project Area to Legendre island (point 3, 6.6 km)

Model outputs are in radiance ($W/m^2/sr$) and presented as a proportion of the radiance of a full moon as a realistic scale representative of the natural conditions experienced by a marine turtle in the field and to provide biological context.

The distance from source at which a given level of radiance was reached (reported as proportion of radiance of a full moon) was greater for the pipelay vessel compared to the TSHD, indicating that light emissions from the pipelay vessel are greater than the TSHD. Modelled light emissions of the same vessel differed between locations due to differences in the ocean reflectance values at each location. However, this difference is not detectable when the distance to source is reported in km to one decimal place.

Light emissions were predicted to reduce to ambient levels (0.01, or 1%, radiance of a full moon) at 5.7 km and 4.7 km from the pipelay vessel and TSHD, respectively. There is potential for behavioural impacts (more than 0.01, or 1%, radiance of a full moon) to occur within 1.8 km and 1.5 km from the pipelay vessel and TSHD, respectively. Behavioural impacts are more likely (≥ radiance of one full moon) within 0.6 km and 0.5 km of the pipelay vessel and TSHD, respectively.

At the closest point to Rosemary Island (14 km), radiance from the pipelay vessel is equal to 0.002 (0.2%), and from the TSHD 0.003 (0.3%), that of a full moon.

At the closest point to Legendre Island (12 km), radiance from the pipelay vessel is equal to 0.003 (0.3%) that of a full moon. From the TSHD (6.6 km), radiance is equal to 0.005 (0.5%) that of a full moon.

## 4.2 Impact Assessment

A conservative assessment of potential impacts of ALAN on marine turtles was undertaken in absence of light modelling by assuming that potential impacts were credible within 20 km of the light sources (Pendoley Environmental, 2020). The impact assessment concluded that the light emissions from vessel activities in the Trunkline and Borrow Grounds Project Areas would not have a significant impact on marine turtle species across the whole life cycle, when assessed against the EPBC Act Matters of National Environmental Significance Significant Impact Guidelines 1.1 (Commonwealth of Australia, 2013). Although behavioural impacts to marine turtles were assessed as credible, it was concluded that these impacts would not be contrary to the priority actions or the measure of success criteria outlined in the Recovery Plan (Commonwealth of Australia, 2017) for the relevant marine turtle genetic stocks, or management of artificial light (Pendoley Environmental, 2020).

While this impact assessment is considered conservative, due to the uncertainties associated with predicting light emissions of the vessels without relevant information, light modelling was conducted, as detailed in this report.

Results of the light modelling suggest that, given the distance to Rosemary and Legendre Islands at the closest point (14 km and 6.6 km, respectively), light emissions from neither vessels are expected to be visible at nesting beaches of these islands and, therefore, impacts to nesting females and emerging hatchlings are not considered credible.

Dispersing hatchlings may be attracted to artificial light within 1.8 km and 1.5 km of the pipelay vessel and TSHD, respectively, but this potential for attraction is expected to be overridden by the radiance of the moon during full moon periods. Attraction of hatchlings to vessel lighting is more likely within 0.6 km and 0.5 km of the pipelay vessel and TSHD, respectively. Even assuming the greater distances of 1.8 km and 1.5 km, considering the predominant currents and distances to the nearest important nesting beaches, the proportion of hatchlings vulnerable to attraction is expected to be notably less than that assumed in the conservative impact assessment (Pendoley Environmental, 2020).

With consideration to the modelling results outlined in Section 3, the assessment of potential impacts against the Significance Significant Impact Guidelines 1.1 (Commonwealth of Australia, 2013), priority actions and measure of success criteria outlined in the Recovery Plan (Commonwealth of Australia, 2017) was reassessed, as summarised in Table 4-1.

It is recommended that Woodside consider the proposed control measures described in Section 5 of Pendoley Environmental (2020) in the context of these modelling results.

**Table 4-1: Alignment with the Recovery Plan and Significant Impact Criteria based on a conservative impact assessment**

| Consideration | Conclusion |
|---|---|
| | *Recovery Plan* |
| Marine turtles are not displaced from identified habitat critical to the survival | Vessel light sources are not expected to be visible from nesting beaches and, therefore, displacement of females from nesting habitat will not occur.<br><br>There is no evidence to suggest that internesting females are impacted by artificial light and, therefore, internesting females will not be displaced from internesting habitat (see Pendoley Environmental (2020) for further discussion). |
| That biologically important behaviour can continue in biologically important areas | Vessel light sources are not expected to be visible from nesting beaches and, therefore, disruption to female nesting behaviour, or hatchling emergence behaviour, is not expected to occur.<br><br>There is no evidence, published or anecdotal, to suggest that internesting turtles are impacted by light from offshore vessels and, therefore, changes to internesting behaviour are not expected to occur (see Pendoley Environmental (2020) for further discussion).<br><br>While disruption to hatchling dispersal behaviour (e.g. attraction to or trapping by light at a vessel) is credible, the number of hatchlings potentially impacted is expected to be an insignificant proportion of the annual number of hatchlings emerging from a given beach since the predominant currents are unlikely to transport hatchlings towards the Project Areas and that the distance from important nesting beaches to the point at which light emissions could elicit a behavioural response are:<br><br>• 5.1 km from Legendre Island (when determined as the closest point to the Borrow Grounds Project Area (6.6 km) subtracted by the distance from the source at which impacts could occur – i.e. 1.5. km for the TSHD); or |

| Consideration | Conclusion |
|---|---|
| | • 12.2 km from Rosemary Island (when determined as the closest point to the Trunkline Project Area (14 km) subtracted by the distance from the source at which impacts could occur – i.e. 1.8. km for the pipelay vessel).<br><br>In the unlikely event that hatchlings are attracted to vessel lighting, and become entrapped in light spill, following sunrise, any effect of the light sources on hatchlings will be eliminated allowing dispersal behaviour to resume.<br><br>While behavioural impacts to dispersing turtle hatchlings are credible, it is not expected these impacts will impede recovery of the relevant green (G-NWS), flatback (F-Pil) or hawksbill (H-WA) genetic stocks, or result in a decreasing trend in numbers/abundance and, therefore, the project will not impact the measure of success criteria of the Recovery Plan (Commonwealth of Australia, 2017). |
| Develop and implement best practice light management guidelines for existing and future developments adjacent to turtle nesting beaches | Additional controls are outlined in Section 5 of Pendoley Environmental (2020) will ensure that the activity is conducted in a manner consistent with the National Light Pollution Guidelines for Wildlife (Commonwealth of Australia, 2020). |
| Identify the cumulative impact on turtles from multiple sources of onshore and offshore light pollution | The TSHD and pipelay vessels will not operate concurrently since activities are required to be undertaken sequentially. Although these vessels may be in the Project Areas for up to eight weeks, depending on the activity being undertaken, the continual movement of the vessels will prevent any one specific receptor (e.g. an individual turtle at sea) being exposed for the duration of each activity. Dredging activities in the Borrow Grounds Project Area, and backfill activities in the Trunkline Project Area, will also be undertaken intermittently, with periods of time in which the vessel will be absent (see Pendoley Environmental (2020) for further details on the activity).<br><br>Additional support vessels may be present during some activities (e.g. pipelay activities), however, given the size of the support vessels in comparison to the pipelay vessel, light emissions from the support vessels are unlikely to contribute significantly to overall light emissions. |

| **Consideration** | **Conclusion** |
|---|---|
| | When considered in the context of existing industrial light sources in the region, light emissions from the activities are unlikely to significantly increase light pollution of the Dampier Archipelago. Specifically, at Rosemary Island, visibility of light emissions from the TSHD and pipelay vessels may be limited by existing light emissions from vessels at the designated anchorages (see Pendoley Environmental (2020) for further details on existing light sources). |
| *Significant impact criteria* | |
| Lead to a long-term decrease in the size of a population or important population | Behavioural impacts are limited to an insignificant proportion of the overall annual number of hatchlings dispersing from nesting beaches and is not considered likely to result in a long-term decrease in the size of a population or important population. |
| Reduce the area of occupancy of important population | The activity will not permanently displace marine turtles from habitats occupied during different life stages. |
| Fragment an existing important population into two or more populations | Given the temporary nature of the activity (in comparison to a permanent facility, for example), fragmentation of important population is not credible. |
| Adversely affect habitat critical to the survival of a species | The activity is not expected to adversely affect nesting or internesting habitat due to the limited spatial extent of potential impact, temporary nature of the activity, and that impacts at the individual level are unlikely. |
| Disrupt the breeding cycle of an important population | Behavioural impacts are limited to an insignificant proportion of the overall annual number of hatchlings dispersing from nesting beaches. Disruption to mating, migration, internesting or nesting is not expected. |
| Modify, destroy, remove, isolate or decrease the availability or quality of habitat to the extent that the species is likely to decline | Given the temporary nature of the activity, the availability or quality of the habitat will not be affected so that marine turtle species may decline. |

| **Consideration** | **Conclusion** |
|---|---|
| Result in invasive species that are harmful to an endangered or vulnerable species becoming established in the species' habitat | Not applicable to light emissions. |
| Introduce disease that may cause the species to decline | Not applicable to light emissions. |
| Substantially interfere with the recovery of the species | Behavioural impacts are limited to an insignificant proportion of the overall annual number of hatchlings dispersing from nesting beaches. Such impacts will be temporary in nature and will not interfere with the recovery at neither the species nor genetic stock level. |

# 5 REFERENCES

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## Annex 1: Vessel light inventory details: *Casterone* pipelay vessel

**Summary of Vessel light inventory details: Casterone pipelay vessel**

A summary of the Casterone pipelay vessel light inventory used as a basis for the light modelling is shown in the below table. A series of vessel lighting plans were also provided along with light elevations.

| Light Type/Brand | Luminare Type | Wattage | Number of lights |
|---|---|---|---|
| Floodlight (Arran) | LED | 122 W | 12 |
| Floodlight (Aquasignal) | High Pressure Sodium/Metal halide | 400 W | 34 |
| Light tubing | Fluorescent (Cool white Phillips) | 2 x 36 W<br>2 x 18 W | 180 |
| Floodlight (Aquasignal) | LED | 1000W | 42 |

# Annex 2: Vessel light inventory details: *Gateway* TSHD

**Summary of Vessel light inventory details: Gateway TSHD**

A summary of the Gateway TSHD vessel light inventory used as a basis for the light modelling is shown in the below table. A vessel lighting plan was also provided.

| Light Type/Brand | Luminare Type | Wattage | Number of lights |
|---|---|---|---|
| Light tubing | Phillips (yellow) | 36 W | 67 |
| Light tubing | Phillips (yellow) | 18 W | 16 |
| Floodlight (Aquasignal) | R7s Halogen | 200 W | 6 |
| Floodlight (Aquasignal) | SON-t | 250 W | 20 |
| Floodlight | LED | 100 W x 2 | 3 |
| Searchlight (Norselight) | Xenon | 1000 W | 2 |
| Floodlight (Aquasignal) | LED | 100W | 6 |

# Appendix M

## Scarborough OPP Formal Consultation Report

| | Name | Organisation | Email address | Key comment(s) on proposal (summarised where lengthy comment has been made) - including any objections or claims | Woodside assessment of merit of comment(s) and response to comment(s) | Changes made to the OPP in response to comment(s) |
|---|---|---|---|---|---|---|
| 1 | | Murujuga Aboriginal Corporation (MAC) | | *"The Murujuga Aboriginal Corporation (MAC) as the approved body corporate for the Burrup and Maitland Industrial Estates Agreement (BMIEA), respectfully requests a two-week extension to allow us time to prepare and finalise a submission on the Scarborough Offshore Project Proposal.*<br>*MAC is typically reliant on pro bono support to review documents such as this proposal, so we are not able to always respond as quickly as we would like. I should add that we are broadly supportive of the proposed Burrup Hub project and do not seek to unnecessarily delay the process.*<br>*If our request for an extension until the 13th of September 2019 can be granted, it would be most appreciated by MAC's members who are the cultural custodians of the land and waters which could potentially be impacted by this proposal."* | On the afternoon that the OPP public comment period closed on 30 August 2019, the Murujuga Aboriginal Corporation (MAC) lodged a request for a two-week extension to comment on the OPP. In response to this request, Woodside's Indigenous Affairs Manager met with MAC's CEO on 2 September 2019. Woodside explained the proposed Scarborough development area and asked whether there was a specific issue MAC had wished to raise. While MAC advised of its intention to make comment on the Dredging and Spoil Disposal Management Plan required by the Western Australian Environmental Protection Authority as part of its assessment of the proposed development, MAC responded that it did not have any particular concerns about the OPP. MAC further advised, the intention for requesting an extension was to reserve its right to comment, if necessary. Consequently, MAC was advised it would be unlikely Woodside would support an extension and MAC confirmed it would accept a decision not to extend the comment period. No further action was recorded.<br>Woodside notes MAC's purpose is to administer the Burrup and Maitland Industrial Estate Agreement (BMIEA) on behalf of Traditional Owner "contracting parties". We further note that the organisation is the representative for joint management of the Murujuga National Park.<br>MAC receives annual funding from Woodside under the BMIEA Agreement to carry out its specific cultural obligations and responsibilities including input on regulatory approvals. Annual payments in direct benefits are made under the BMIEA (annual lease payment) in addition to Conservation Agreement funds for MAC Rangers other direct financial support provided for related programs and activities.<br>Woodside will continue to work with MAC and Traditional Owner representatives as the proposed Scarborough development is progressed. | Record of this engagement has been added to Table 10.5 ('Phase 2 stakeholder consultation activities'). |
| 2 | | Environmental Defenders Office (on behalf of CCWA) | | Comments have been compiled by the EDO on behalf of CCWA. The key issues are summarised below according to the EDO submission section. | Subsections of the submission are addressed below. | Subsections of the submission are addressed below. |
| 2.1 | | Environmental Defenders Office (on behalf of CCWA) | | **Background**<br>Contains statements about the proposal from the OPP. | The statements about the project reflect information in the OPP and do not require a response. | The statements about the project reflect information in the OPP and do not require amendment of the document. |
| 2.2 | | Environmental Defenders Office (on behalf of CCWA) | | **Impact of GHG Emissions (summary section)**<br>(EDO submission sections 6-14) *<br>It is submitted that:<br>• the OPP fails to manage the impacts/risks of the Proposal's GHGe to a level that is acceptable in accordance with the established science of climate change, the EPBC Act or Australia's international obligations under the Paris Agreement<br>• the OPP and the above controls are insufficient to manage the impacts and risks of the Proposal's GHGe to an acceptable level or as low as reasonably practicable (ALARP)<br>• changes to the OPP are required to sufficiently manage impacts and risks of Greenhouse Gas emissions (GHGe); and | The themes raised in this summary section of the submission are covered in more detail in subsections of the submission. Responses to each subsection are provided below. | The themes raised in this summary section of the submission are covered in more detail in subsections of the submission. Changes to the OPP relevant to each subsection are described below. |

| | Name | Organisation | Email address | Key comment(s) on proposal (summarised where lengthy comment has been made) - including any objections or claims | Woodside assessment of merit of comment(s) and response to comment(s) | Changes made to the OPP in response to comment(s) |
|---|---|---|---|---|---|---|
| | | | | • discussion of risk to Murujuga rock art and controls are included and changes to the OPP are required to sufficiently manage risk. | | |
| 2.3 | | Environmental Defenders Office (on behalf of CCWA) | | **Insufficient Management and Regulation of Impacts of GHGE to Acceptable Level**<br>(EDO submission sections 15-23) *<br>It is submitted that:<br>• national GHG regulation, Woodside's Climate Change Policy and WA EPA Public Environment Review (PER) documentation do not adequately regulate or manage GHG to acceptable levels.<br>• The Pluto PER documentation is outdated and does not consider processing of Scarborough Gas at Pluto Train 2, and it is therefore inappropriate to rely on this to evaluate and manage scope 2 and 3 emissions.<br>• a fresh Commonwealth assessment of risks and impacts associated with processing Scarborough gas through Pluto be undertaken; and<br>• the OPP be amended to include details of additional GHG emitted from processing through the Pluto LNG and introduction of specific control measures that achieve net zero emissions. | The Paris Agreement represents global consensus on controls to limit anthropogenic climate change to an acceptable level. The Australian Government has ratified the Paris Agreement and implemented policy mechanisms as described in Section 3.4.1 (which has been added to provide further detail).<br>Compliance with Australian legislation, as described in Sections 3.4.1 and 6.5 ensures that GHGe from the Project will be acceptable by keeping GHGe at or below the emissions baselines set by the Clean Energy Regulator or dealing with any excess emissions accordingly.<br>As described in the OPP, raw product from the Scarborough Project will be processed at the onshore Pluto LNG facility. Existing environmental approvals for the Pluto LNG facility already include processing emissions for a second train and scope 3 emissions associated with sold product. Figure 7.6 has been added to section 7.1.3 of the OPP to better illustrate how related onshore processing emissions are considered in the existing approved Pluto PER.<br>Pluto is required to have in place management plans including a Greenhouse Gas Abatement Program developed to address the requirements of Ministerial Statement 757, which ensures ongoing regulatory oversight. The Pluto approvals process is out of scope for the OPP. | Section 3.4.1 ('Greenhouse Gas Legislation') has been added, which describes Australian GHG legislation.<br>A statement in the second paragraph of section 6.2.3 ('Risk Assessment – Environmental Legisation and other requirements') has been added about Australia's ratification of the Paris Agreement as a relevant international standard.<br>Paragraph six has been added to Section 6.5 ('Environmental Perfomance Outcomes and Acceptable Levels') to link Australia's implementation of the Paris Agreement via legislation to the acceptability of the project.<br>The part of section 7.1.3 (Planned Aspects – Routine Greenhouse Gas Emissions) describing related onshore processing emissions has been expanded, including incorporation of updated assumptions relating to scope 3 emissions.<br>Discussion of risks and impacts associated with climate change, including change in habitats, fauna behaviour, injury/mortality to fauna, and social changes has been added in section 7.1.3.8 |
| 2.4 | | Environmental Defenders Office (on behalf of CCWA) | | **Total Lifecycle GHGe Should be Considered and Managed**<br>(EDO submission sections 24-30) *<br>It is submitted that:<br>• the Pluto PER process did not assess and approve Scope 3 emissions and proposes amendment of the OPP to include details and management of total lifecycle GHG, including risk and impact to the environment and rock art using the best available climate science. | As described in the OPP, raw product from the Scarborough project will be processed at the onshore Pluto LNG facility. Existing environmental approvals for the Pluto LNG facility already include processing emissions for a second train and scope 3 emissions associated with sold product. Figure 7.6 has been added to section 7.1.3 of the OPP to better illustrate how related onshore processing emissions are considered in the existing approved Pluto PER. | The part of section 7.1.3 (Routine Greenhouse Gas Emissions) describing indirect GHG emissions has been updated to include a reference to where in the Pluto PER lifecycle emissions are included and recalculation of scope 3 emissions attributed to Scarborough with updated assumptions.<br>The new sections 7.1.3.3 (Lifecycle and Intensity) and 7.1.3.4 (Natural Gas in the Context of Global Emissions) have been added to more comprehensively explain how |

| | Name | Organisation | Email address | Key comment(s) on proposal (summarised where lengthy comment has been made) - including any objections or claims | Woodside assessment of merit of comment(s) and response to comment(s) | Changes made to the OPP in response to comment(s) |
|---|---|---|---|---|---|---|
| | | | | | | Scarborough fits into a decarbonising global economy.<br>Discussion of risks and impacts associated with climate change, including change in habitats, fauna behaviour, injury/mortality to fauna, and social changes has been added in section 7.1.3.8 |
| 2.5 | | Environmental Defenders Office (on behalf of CCWA) | | **Cumulative Impacts Should be Considered and Managed**<br>(EDO submission sections 31-44) *<br>It is submitted that:<br>• the OPP does not adequately consider the impacts of the broader Burrup Hub, including cumulative impacts.<br>• given the decision to assess the Burrup Hub projects individually, the cumulative emissions from the proposal should be considered in context of the other projects and global GHG.<br>• There are multiple cases which identify that small incremental increases to emissions as contribute to a broader global impact. | Burrup Hub is Woodside's vision to develop an integrated regional LNG production centre on the Burrup Peninsula. The Burrup Hub is not a proposal for a single activity for impact assessment; it describes Woodside's vision of several separate but related activities that, subject to respective joint venture approvals and relevant regulatory approvals, may be undertaken. The current allocation of approvals between jurisdictions has been established with all relevant regulatory bodies.<br>As described in the OPP, the contribution of the Scarborough floating petroleum unit (FPU) to Australian and global GHGE is very low. Attempting to model the impact on global climate change is not feasible, and similarly it is not practical to describe associated risk to global receptors. | Woodside has determined that the approvals approach in place for the individual Burrup Hub activities are adequate and no changes were made to the document. |
| 2.6 | | Environmental Defenders Office (on behalf of CCWA) | | **Net Zero Emissions Outcome Should be Applied as Environmental Performance Outcome**<br>(EDO submission sections 45-54) *<br>It is submitted that:<br>• the environmental performance outcomes described in the OPP are insufficient to achieve acceptability for GHG emissions, and that a "net zero" performance outcome should be adopted, stating that this should be the fundamental test for environmental acceptability.<br>• by reference to the DOE Report for the Prelude FLNG Facility (2010), the project should result in no net increase in Australia's GHG emissions, and<br>• the IPCC Special Report on Global Warming statement has established that global GHG must achieve net zero by 2050 to avoid global warming above 1.5°C is relevant.<br>• a carbon budget approach is appropriate and proposes that internationally agreed science has established that the amount of emissions allowable to maintain a safe climate has already been exceeded and therefore all future developments should achieve net zero GHG emissions.<br>• the project requires implementation of technologies such as renewables, all-electric design or carbon capture and storage, or offsets. | Achieving "net zero" GHGe abatement goes beyond the Climate Change Authority's recommendation to achieve that outcome by 2050. The Australian Government has established a 26-28% emissions reduction target by 2030 and the Paris Agreement encourages Australia to submit a new target by 2025. The State of Western Australian Government has also set an aspiration to achieve net zero emissions by 2050. Woodside's climate policy encourages government to set targets based on climate science.<br>Acceptability for Scarborough project GHGe is achieved by actions taken to achieve compliance with Australian legislation which implements the Paris Agreement by keeping GHGe at or below the emissions baselines set by the Clean Energy Regulator or dealing with any excess emissions accordingly. Further details are provided within the response to 15-23 (Item 2.3). | Section 3.4.1 ('Greenhouse Gas Legislation') has been added, which describes Australian GHG legislation.<br>A statement in the second paragraph of Section 6.2.3 ('Risk Assessment – Environmental Legisation and other requirements') has been added about Australia's ratification of the Paris Agreement as a relevant international standard. A new section 7.1.3.5 (Customer Commitments under the Paris Agreement) has been included to provide examples of how Scope 3 emissions from Scarborough will fit within the international agreement,<br>Paragraph six has been added to section 6.5 ('Environmental Perfomance Outcomes and Acceptable Levels') to link Australia's implementation of the Paris Agreement via legislation to the acceptability of the project.<br>The new sections 7.1.3.3 (Lifecycle and Intensity) and 7.1.3.4 (Natural Gas in the Context of Global Emissions) have been added to more |

| | Name | Organisation | Email address | Key comment(s) on proposal (summarised where lengthy comment has been made) - including any objections or claims | Woodside assessment of merit of comment(s) and response to comment(s) | Changes made to the OPP in response to comment(s) |
|---|---|---|---|---|---|---|
| | | | | | | comprehensively explain how Scarborough fits into a decarbonising global economy. |
| 2.7 | | Environmental Defenders Office (on behalf of CCWA) | | **Energy Efficiency Measures Insufficient to Manage Impacts of GHGe to Acceptable Level**<br>(EDO submission sections 55-58) *<br>It is submitted that:<br>• the energy efficiency measures listed in the OPP (allowance for battery energy storage system, waste heat recovery unit, gas-gas exchanger, flow coated trunkline, turbine and equipment selection) are not sufficient to achieve the current environmental performance outcome of reducing GHGe to ALARP and Acceptable Levels because there is no inclusion of control measures to avoid, reduce or offset the Proposal's GHG emissions. | The energy efficiency measures presented in section 4.5.4.1 reflect the design decisions taken to date based on ALARP principles. Demonstrations that greenhouse gas emissions have been reduced to ALARP levels in future design decisions will be submitted to NOPSEMA for approval as part of the regular Environment Plan process which will follow approval of this OPP. | A new section in the Assessment of Alternatives section (4.5.4.1 – Energy Efficiencies) has been added to describe measures implemented to date in design phase. A new section 7.1.3.6 (Greenhouse Gas Management and Mitigation) has been added to describe relevant controls in a hierarchy, including these design features but also how GHG emissions will be managed during operations. |
| 2.8 | | Environmental Defenders Office (on behalf of CCWA) | | **Specific Control Measures Required to Manage Impacts of GHGe to Acceptable Level**<br>(EDO submission sections 59-64) *<br>It is submitted that:<br>• the OPP does not refer to any specific control measures to manage impacts or avoid, reduce or offset. DOE report on Prelude is cited in reference to required measures and offsets that result in no net increase to Australia's $CO_2$ emissions.<br>• the OPP should consider LNG projects (Kitimat, Gorgon) that are employing renewable energy and carbon capture storage for management of GHG to an acceptable level. | The environmental performance outcomes in the OPP are designed to ensure that the risks and impacts associated with the project are acceptable. Compliance with the safeguarding mechanism will ensure that emission reductions implemented through the Emissions Reduction Fund (ERF) are not offset or exceeded by significant GHG emissions (above 'business-as-usual levels') emanating from other industrial or economic sectors. The safeguarding mechanism includes a framework to offset emissions if necessary for compliance. | Section 3.4.1 ('Greenhouse Gas Legislation') has been added, which describes Australian GHG legislation.<br>A statement in the second paragraph of section 6.2.3 ('Risk Assessment – Environmental Legislation and other requirements') has been added about Australia's ratification of the Paris Agreement as a relevant international standard. |
| 2.9 | | Environmental Defenders Office (on behalf of CCWA) | | **Reporting Under NGER Act Insufficient to Manage Impacts of GHGe to Acceptable Level**<br>(EDO submission sections 65-69) *<br>Submits that voluntary public reporting should be implemented that includes facility level GHG data, including Scope 3, performance on managing GHG to acceptable and ALARP, publish through a government hosted portal and include data on offsets. | The NGER Act requires the Clean Energy Regulator to publish facility level emissions on an annual basis for facilities subject to the Safeguard Mechanism, including the use of Australian Carbon Credit Units.<br>Additionally, Woodside also currently voluntarily participates in the Carbon Disclosure Project which includes publishing scope 3 emissions data at an equity, portfolio level. | Woodside considers that GHG emissions reporting is adequately described in the document and no changes were made.<br>The new sections 7.1.3.3 (Lifecycle and Intensity) and 7.1.3.4 (Natural Gas in the Context of Global Emissions) have been added to more comprehensively explain how Scarborough fits into a decarbonising global economy.<br>A new section in the Assessment of Alternatives section (4.5.4.1 – Energy Efficiencies) has been added to describe measures implemented to date in design phase. A new section 7.1.3.6 (Greenhouse Gas Management and Mitigation) has been added to describe relevant controls in a hierarchy, including these design features but also how GHG emissions will be |

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| | | | | | | managed during operations and reporting. |
| 2.10 | | Environmental Defenders Office (on behalf of CCWA) | | **Argument that LNG Displaces Emission Intensive Fuels Not Substantiated**<br>(EDO submission sections 70-79) *<br>It is submitted that:<br>• the statement that LNG is able to displace higher carbon intensity fossil fuels and complements renewables is not valid because it is not aligned with market mechanics and fails to consider policy trends and global market transition away from fossil fuels; and<br>• the Proponent must produce proof that the claim is substantiated and backed with credible evidence, data from customer countries and robust reporting of Scope 3 GHG emissions. | Woodside acknowledges that the effect of LNG exports on global GHGe is complex and subject to market mechanisms. However, it does have the potential to play a role in displacing higher carbon intensity fossil fuels and complementing renewables. In 2019, the International Energy Agency concluded that gas use has resulted in over 500 MtCO2e emissions savings since 2010, where it had displaced coal power. Providing clean burning LNG as a power source can displace higher emissions energy sources in transport and power generation and provide firming capacity for renewable energy sources in a growing global economy. | The new sections 7.1.3.3 (Lifecycle and Intensity) and 7.1.3.4 (Natural Gas in the Context of Global Emissions) have been added to more comprehensively explain how Scarborough fits into a decarbonising global economy. |
| 2.11 | | Environmental Defenders Office (on behalf of CCWA) | | **Impact on Rock Art**<br>(EDO submission sections 80-86) *<br>It is submitted that:<br>• the OPP does not contain details of risk and impact of the project and related Burrup Hub on Murujuga rock art, or any control measures.<br>• includes reference to NOx and $CO_2$ from the proposal over estimated 2070 life of field and refers to controls for French cave paintings which include mitigation of $CO_2$ from tourists' breath. | The effective management of Aboriginal cultural heritage is critical to Woodside's continued operations and growth success.<br>Woodside's preferred development concept is to transport gas from the Scarborough fields through a pipeline for processing at the Woodside operated onshore Pluto LNG Facility. Emissions from the Pluto LNG Facility will remain within the impact envelope of the existing approval for that facility. Woodside has contributed to air monitoring studies of the Burrup Peninsula since 2008 and our approach to emissions management practices has been informed by third-party studies including the work undertaken by the Burrup Rock Art Monitoring Management Committee. Woodside's approach to protection of rock art on the Burrup Peninsula is further informed by our relationship with the Murujuga Aboriginal Corporation and Traditional Owners and takes into account their vision for the protection and management of cultural heritage. Woodside is also playing an active and productive role in the Department of Water and Environmental Regulation's Burrup Rock Art Stakeholder Reference Group, established in 2018.<br>Woodside will continue to focus on emissions reductions from all its operations and support appropriate scientific air emissions monitoring. | Woodside considers potential measures described in this comment to be outside the scope of the OPP. As indicated in the response to this comment, Woodside will continue to work with stakeholders on this issue through the appropriate mechanisms. |
| 2.12 | | Environmental Defenders Office (on behalf of CCWA) | | **Control Measures to Manage Impacts on Rock Art Required**<br>(EDO submission sections 87-91) *<br>It is submitted that:<br>• the OPP must include control measures for managing the impacts/risks on rock art and proposes a precautionary approach in context of UNESCO World Heritage nomination for the Burrup Peninsula. | Woodside supports the decision of Traditional Owners and the State to pursue World Heritage listing for the Burrup Peninsula. This support reflects our commitment to the successful co-existence of heritage and industry. In this context, Woodside also supports the reinstatement of ambient air quality monitoring on the Burrup Peninsula and is working with stakeholders including Traditional Owners and the State on the preferred monitoring options and approach. | Woodside considers potential measures described in this comment to be outside the scope of the OPP. As indicated in response to a related comment above, Woodside will continue to work with stakeholders on this issue through the appropriate mechanisms. |
| 3 | | Western Gas | | It is suggested that in relation to Woodside's statement in the OPP that it is engaging other resource owners on future development opportunities (section 4.1) these opportunities should be included as alternate development options in the OPP. | The OPP currently identifies the Equus development as a future proposal in section 5.7.6. This section has been further updated to show the location of the Equus fields in Figure 5-57 and notes the proposed project in Table 5-11.<br>As per Table 10.5 Woodside has held a series of consultations with Western Gas with regards to alternate development concepts. The merits of these concepts were subject to internal assessment processes and were considered unsuitable for the current development timeline. Details of this assessment process were communicated to | Updates have been made to section 5.7.6 ('Description of the Environment – Industry') and consultation has been added to the table in section 10.4.2 ('Formal OPP Consultation'). |

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| | | | | | Western Gas along with a commitment to consider future opportunities for cooperation including tie-backs.<br>This consultation has been added to the table in section 10.4.2. | |
| 4 | Anonymous | | | *"It is clear reviewing all combined impacts from the Scarborough project that offsetting residual impacts (e.g. on protected matters impacted including but not limited to pygmy blue whales, other whales/cetaceans, seabirds, whale sharks, turtles, commonwealth marine area) should occur because the project is not delivering net biodiversity benefit.*<br>*In addition, cumulative impacts of the O&G industry operating on the NW shelf should be taken into account here i.e. considering what's there already and what is planned to come and what may reasonably be expected to come in future, the cumulative impacts on the MNES of the marine environment are nothing short of significant.*<br>*EPBC policy and international impact assessment process (hierarchy of control) requires offsets to be considered in such circumstances which result in a net biodiversity benefit from the project.*<br>*Note, I don't think like for like offsets are appropriate or required in the case of Scarborough, however there should be a strong case of indirect offsets which add value to the broader region from a biodiversity perspective.*<br>*Implementing this will ensure the impact assessment follows EPBC policy (http://www.environment.gov.au/epbc/publications/epbc-act-environmental-offsets-policy) and is consistent with international practice for impact assessment (see bottom of page 16 https://www.unepfi.org/fileadmin/documents/biodiversity_offsets.pdf and principle 7 of https://www.iaia.org/uploads/pdf/SP3%20Biodiversity%20Ecosystem%20Services%2018%20Jan.pdf).*<br>*These standards, and many more like them apply to setting the acceptable levels of impact of the project as a whole - no net loss of biodiversity."* | The Australian Government's *Environmental Protection and Biodiversity Conservation Act 1999 Environmental Offsets Policy, October 2012*, refers to 'environmental offsets' as measures that compensate for all residual adverse impacts of an action on the environment. The policy states that for assessments under the EPBC Act, offsets are only required if residual impacts are significant, with significance to be as defined in the *Matters of National Environmental Significance (MNES) – Significant impact guidelines 1.1.*<br>The residual impacts of Scarborough to all MNES has been assessed to not be significant under the significant impact guidelines.<br>In terms of cumulative impacts, in section 8.2.2 ('Receptor-based Culmulative Impacts'), the cumulative impacts from Pluto, Equus, Fisheries and Shipping were assessed, and it was identified that the aspects that were common to those activities related to vessel movements (i.e. physical presence – displacement, light emissions and vessel discharges). Cumulative assessment has been undertaken which indicates that residual impacts to species (including MNES) are low. | A seventh paragraph was added to section 6.2.3 ('Risk Assessment – Environmental Legisation and other requirements') which describes obligations under the *Environmental Protection and Biodiversity Conservation act 1999 Environmental Offsets Policy.* |
| 5 | | Possible Spam | eupoqala@eerr.namnerbca.com | Spurious web link provided. | Comment appears to be spam. This comment is not relevant and has not been addressed further. | No changes made to the document. |
| 6 | | Possible Spam | eupoqala@eerr.namnerbca.com | Spurious web link provided. | Comment appears to be spam. This comment is not relevant and has not been addressed further. | No changes made to the document. |
| 7 | [redacted] | Private | | *"Great to see another project in the planning. W/A and communities like Exmouth need these projects to go ahead to create secure long-term jobs."* | Woodside is pleased to note that independent economic modelling indicates its Burrup Hub proposals, of which Scarborough is a key component, will support the creation of an average 4,000 full-time equivalent jobs per annum nationally over a 40-year time-frame. Almost half of these will be located in northern Western Australia. | Woodside considers that no modification to the document is necessary. |
| 8 | Anonymous | | | *"It's great to see these projects going ahead and delivering much needed employment opportunities and opportunities for local businesses under the company's local content policy. In particular the Exmouth community has suffered from all this activity happening offshore for many years now yet very little economic benefit to the town or meaningful contracts for the town and its community. "* | Woodside welcomes community support for the proposed development of the Scarborough gas field and will work with communities to identify opportunities for local content and employment. | Woodside considers that no modification to the document is necessary. |

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| | | | | *"Get it going as soon as possible and push as much work through Exmouth as practicable. Don't let the loud voices of the minorities drown out the support of the silent majority. The Exmouth community wants it and it is in line with the shire council's strategic plans."* | | |
| 9 | [redacted] | Private | [redacted] | *"The Scarborough development proposal is an excellent opportunity for further expansion of Australia's gas resource potential.*<br>*This development should be fully endorsed by all Australians for the benefit of all Australians."* | Woodside is pleased to note that independent economic modelling indicates its Burrup Hub proposals, of which Scarborough is a key component, will boost Australia's Gross Domestic Product by $414 billion between now and 2063 while tax and royalties payments are estimated to total $82 billion. | Woodside considers that no modification to the document is necessary. |
| 10 | [redacted] | Private | [redacted] | *"What capping plan is in place to meet highest risk i.e. a spill results from a leaking well?*<br>*We know from Macondo failings majority of loss / risk resulted from spill.*<br>*Why has little been done by operators / regulators to assure that a faster safer capping system is not in place for offshore projects, i.e. a system designed around a Xmas tree that can be kept on site in the field to be able to respond to cap and kill a well in hrs vs days or weeks of spillage that could result to meet worst case needs?*<br>*There are systems available; e.g. Abel Engineering well control specialists etc. Why is such a safer better cheaper faster response system not to be used?"* | The OPP process, is in place to allow the regulator to make an assessment of the environmental acceptability of proposed offshore projects.<br>Following OPP acceptance, activity specific Environment Plans (EPs) (and other permissioning documents such as Well Operations Management Plans (WOMPs) will be required to be prepared and accepted.<br>Broadly, the purpose of EPs will be for the titleholder to confirm that the impacts and risks are within the scope of that accepted under the OPP, and to identify the control measures that will manage the impacts and risks ALARP. The EP will describe the level of performance for these control measures during activities and including emergency situations.<br>An emergency response plan which identifies source control options including capping systems, will be developed and submitted as a part of the activity's EPs. At this stage of the approval process, there will be consideration of source control methods and technology in order to demonstrate that the impacts and risks will be managed to ALARP levels.<br>Hydrocarbons of the Scarborough, Jupiter and Thebe reservoirs contain no measurable liquid condensate fraction. It is therefore expected that there would be no, or negligible, liquid component in a loss of containment scenario. In the event of a loss of well control, the response strategy detailed in the EP will be based on the risk, and the properties of the released hydrocarbons. | On review of the merit of this comment, Woodside considers that the concern raised is adequately addressed and no modification to the document is required. |
| 11 | [redacted] | Private | [redacted] | *"I think that this project should go ahead with the caveat that cheaper gas is made available for Western Australia.*<br>*What would be even better is that the AU government develops the fields, undertake all production and distribution / sales of LNG. That way Australia would have a sustainable income for years to come. Not only that all future exploration and development of fields should be under the control of the Australian government not a foreign government or company.*<br>*With this then could be the Australian engineering rig/ship building capability to ensure jobs and growth for Australia."* | Woodside is proposing to expand the Pluto LNG facility to process Scarborough gas and work is underway on the design of a domestic gas plant at Pluto to facilitate supply to Western Australia.<br>As an Australian company, Woodside has a proud history of developing resources and delivering long term benefits to the country. Independent economic modelling indicates tax and royalties payments from the proposed Burrup Hub projects will add up to $82 billion.<br>Woodside has also developed an Australian Industry Participation Plan for the proposed Scarborough development. This plan has been approved by the Australian Government and is designed to maximise opportunities for Australian businesses. | Woodside considers that no modification to the document is necessary. |

*EDO's comments have been summarised and grouped in accordance with section headers provided in EDO's submission.

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