Appendix J: Dredge Plume Modelling Report

Independent Peer Review

Client	Mineral Resources Limited
Author	O2 Metocean
Title	Ashburton Infrastructure Project Dredge Plume Modelling
Version	Rev E
Report Date	01/10/21
Reviewer	Dr Bruce Hegge, Teal Solutions Pty Ltd
Review Date	12/10/21

Section	Review Comment	O2 Metocean Response	MRL Close
Overall	Consider restructure to more clearly present the finding of this study, e.g.: Introduction, Environmental Setting, Previous Plume Modelling in Area, Model Setup and scenarios (including hydrodynamic and plume model), Model Results, References A stronger logic to the report structure will help to bring together the information. At present the document structure tends to split similar information across multiple sections (e.g the sediment characteristics of the plume)	This has been actioned.	Accepted.
(new section) Environmental Setting	More details regarding the sedimentology, metocean conditions (including identification of key weather events which may be experienced during the period of dredging operation) and benthic habitat would provide strong foundering for assessing and interpretation of the model results	This has been actioned.	Accepted.
2.4 Prior Dredge Plume Modelling Studies	Include selected figures of prior plume modelling to show (modelled) extent and behaviour of previous plumes	Previous studies have been referenced. This section has been written to pull the relevant information and similarities to previous studies rather than presenting the entire outcome of other studies. However as the comparison to the Wheatstone study is centred around the size of zones of impact, a description of the spatial extent of the zones has been provided.	Adequately addressed.
3 Dredge Plume Modelling	Include details (and reference(s)) of the modelling platform and reduce the modelling technical details (is necessary perhaps consider use of an appendix for details). I understand there may be a separate report which presents the details on the	This has been actioned. During the restructure, changes to numerical modelling section have been made and some technical information removed from the ducoment for clarity.	Adequately addressed.

Section	Review Comment	O2 Metocean Response	MRL Close
	hydrodynamic model. However, it would be valuable to summarise the key outcomes from the hydrodynamic modelling (e.g. vector plots for selected weather conditions) and provide information on validation as the hydrodynamic model is a key driver of plume behaviour. This information will provide reader better context in which to review the plume model results. Include example outputs of plume behaviour (e.g. timeseries plots, spatial plume dilution plots, plume dilution with distance down plume from discharge points [both dredge and disposal site]) under selected weather conditions. This should assist readers to understand and interpret the integrated assessment of impact thresholds exceedances (as presently included in the report)	This information may be provided if requested. Plume behaviour has been expanded with the inclusion of figures to support the discussion.	
5.2. Intersection of Zones of Impact and Mapped Benthic Habitat	The Zones of impact extend beyond the areas of benthic habitat mapping and the Loss Assessment Units. It will be important to provide some commentary on the likely benthic habitats across the full extent of the areas of potential plume impacts	New zones of impact inclusive of DLI do not expend beyond this and are relatively small. This has all been updated accordingly.	Adequately addressed.

Ashburton Infrastructure Project

Dredge Plume Modelling Assessment

CLIENT: Mineral Resources Limited

STATUS: Rev 1

REPORT NUMBER: R210111

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Version Register

Version	Status	Author	Reviewer	Change from Previous Version	Authorised for Release (signed and dated)
A-D	Draft	J Owen-Conway C Lane, G Motherwell	S Morillo		
E	Draft for client review	J Owen-Conway	A Zulberti	Structural Changes	S Morillo – pp A Zulberti
0	Issued for use	J Owen-Conway	A Zulberti	Review comments addressed	S Morillo – signed
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MARINE

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1. Executive summary

MRL engaged O2 Marine (O2M) to undertake the required marine studies to support environmental assessments for the Ashburton Infrastructure Project (AIP). This report presents the dredge plume modelling inputs, assumptions, and outputs to support the environmental assessments of the AIP dredging campaign.

The AIP includes capital dredging to modify the marine offloading facility's (MOF) existing access channel and to allow safe access and berthing of trans-shipment vessels (TSVs) at the proposed nearshore wharf. The total proposed dredge volume is approximately 135,000 m^3 with a dredge footprint area of approximately 30,000 m^2. The proposal is for a backhoe dredging program with oceanic disposal at Pilbara Port Authority's (PPA) existing Spoil Ground C by split-hopper barges. The programme is anticipated to run for 50 consecutive days with 24-hour operations during the 2022-2023 summer months.

The dredge and spoil disposal plumes were modelled using a 3D hydrodynamic and sediment transport model built upon O2M's existing model of the Pilbara region. The model results were interpreted against the Environmental Protection Authority's (EPA) technical Guidance for environmental impact assessment of marine dredging proposals (EPA, 2021). The resultant zones of impact (determined through application of EPA 2021) were compared against the Benthic Communities and Habitats (BCH) study described in O2 Marine (2021e), to identify the areas that each BCH class may be affected by the predicted dredge plume.

The regions of overlap between the BCH and the zones of impact for the proposed dredge and disposal program show no overlap of any zone of impact with coral, sand with sparse filter feeders, sand with sparse seagrass or sand veneered limestone pavement. The zones of impact only intersect bare substrate in the order of tens of hectares. The zones of impact are predominately located around the dredge location, the MOF, and nearshore areas within proximity to the MOF.

2. Introduction

Onslow Iron Pty Ltd (ACN 612 668 201, herein MRL), a wholly owned subsidiary of Mineral Resources Limited (ACN 118 549 910), is undertaking planning for AIP (the Proposed Action) to service iron ore mining and export developments in the West Pilbara region of Western Australia (WA).

The Proposed Action is being referred under Section 38, Part IV, of the WA Environmental Protection Act 1986 (EP Act). The referral will also be submitted for assessment under the Environmental Protection, Biodiversity and Conservation 1999 (EPBC Act).

2.1. Description of the proposed action

As part of an overarching business and operational strategy, MRL is undertaking planning to unlock stranded mineral assets in the West Pilbara region. The AIP will support MRL's approved mine, the Buckland Project (herein referred to as Bungaroo South), (Ministerial Statement [MS] 906 and MS1147), other future iron ore deposits at Kumina and facilitate export opportunities for third party stranded iron ore from the West Pilbara.

The AIP includes a fully sealed private haul road, commencing at the boundary of the approved Bungaroo South haul road and will continue approx. 150 km west to the Port of Ashburton (Port), where landside and marine facilities are proposed to be developed to export iron ore (Figure 1, Figure 2). The AIP comprises four separate Development Envelopes (DEs): the Haul Road DE and three port marine DEs (Landside DE, Nearshore DE and Offshore DE).

Export facilities within the Port include a dedicated nearshore berth facility along with offshore anchorages. The AIP will initially support the export of approximately 30million tonnes per annum of (Mtpa) of iron ore through the Port over a 10-year period as a Direct Shipping Ore (DSO). Future plans (pending approvals) are for the AIP to support export of up to 40 Mtpa over a 30-year period. These future plans are discussed in more detail within this section of this submission.

The Port was established by Chevron for the Wheatstone Liquified Natural Gas Project (Wheatstone) and is located within the Ashburton North Strategic Industrial Area (ANSIA) and is managed by the Pilbara Ports Authority (PPA).

In 2020, a change in the nominated proponent from Chevron to PPA was approved for the shipping channel, Materials Offloading Facility (MOF), and access road at the Port. Through consultation with PPA, MRL understands that a s.45C application under the Environmental Protection Act 1986 (EP Act) to amend MS1131 to allow for the development of the AIP. MRL are planning on entering a commercial arrangement with PPA (via the submission of Development and Construction Applications), whereby, MRL enter into a lease agreement with PPA, allowing the AIP to be developed and for MRL to carry out activities on PPA vested lands, seabed or water areas.

The AIP will utilise proposed and existing marine facilities to load ore onto Transhipping Vessels (TSVs) that will travel along PPA's dredged shipping channel, out to deep water (up to 40 m depth), to five dedicated anchorage points approx. 10 km from Thevenard Island. Iron ore will be loaded from TSVs onto Capesize, Ocean Going Vessels (OGVs) at a maximum of two of the five anchorage points at any one time. Five anchorage points have been included within the AIP to allow for operational flexibility to factor in for adverse weathers conditions, operational issues, maintenance requirements and ship scheduling.

In relation to the port, the location of the jetty and associated components within the Landside and Nearshore DEs are situated away from mangroves adjacent to existing port infrastructure. The design of the piled jetty structures also minimises impacts on longshore current patterns.

MRL are proposing to use PPA's existing Spoil Ground C adjacent to the Port for placement of dredge material. Utilising an existing offshore disposal location vs developing a new offshore dredge material area or an onshore disposal area, was considered to present a better overall outcome, due to the avoidance of new disturbance to the seabed or native vegetation. Detailed investigation into onshore disposal was not recommended nor undertaken due to the known nature of potential spoil material from the AIP being unsuitable composition for onshore disposal.

The final location of the five anchorage points within the Offshore DE were selected to avoid benthic habitat, which was mapped within the anchorage investigation area as being limited to the 30 m depth contour, with the seabed beyond this depth being predominantly bare sand.

The AIP Port Marine elements will be located within the existing Port and includes a 'Landside', 'Nearshore' and 'Offshore' DE (Figure 1; Figure 2; Table 1). Each DE represents the maximum area within which the proposal footprint will be located, whereas the footprint is the location where the physical proposal elements occur.

Table 1 Spatial Coverage of Marine Elements.

Location	Development Envelope (DE)	Infrastructure Footprint (IF)
Landside	118 ha	-
Nearshore	11 ha	5 ha
Anchorage	4,483 ha	-

Landside DE: located within the Eastern Planning Precinct (EPP), of the PPA's landside planning area. No new disturbance is proposed within this DE.

Landside facilities include a storage of bulk handling of iron ore, a seawater desalination plant, power station bulk storage of fuel, administration building, a sewerage treatment facility.

Nearshore DE: The Marine Nearshore infrastructure, includes a dedicated berthing pocket, a modular jetty wharf and ship loader and will be constructed in Port Waters managed by the PPA east of the existing MOF. The modular wharf has been designed to be a fixed-point loading wharf, with roadway access and lifting areas for up to 130 tonne cranes. The jetty and wharf structure includes provision for desalination plant seawater intake and outfall pipelines.

A temporary causeway (rock structure) is required for the construction of the approach jetty for approximately six months and will be removed once jetty construction has been completed. Construction from a temporary causeway versus overhand construction will reduce the number of piles required, also reducing the duration of proposed piling. This will reduce potential impacts to sensitive marine fauna. Piling for the temporary causeway will involve the installation of twenty 1,000 mm drive piles.

The new berth and jetty will require a dredging programme and offshore disposal of dredge material at PPA's existing Spoil Ground C (Figure 2). Capital dredging of approximately 135,000 m^3 to modify the existing access channel for the MOF to allow safe access and berthing of TSVs at the nearshore wharf facility is required. Capital dredging will be undertaken to achieve a depth of 8 m mean sea level (MSL), with the proposed dredge footprint extending approximately 30,000 m^2. The location of the jetty has been selected to enable transhipment barges to sail into port under ballast draft (3.5 m maximum draft) without any tidal constraints and moor at the berth. For loading the barges, a berth pocket and basin will be dredged to facilitate loading during all tides. Dredging operations will occur for 50 days to be scheduled within the 2022-2023 summer months. Dredging-related operations are planned to occur 24-hour/day, seven days a week.

Offshore DE: Includes the offshore anchorage points (located in State Waters) for transfer of ore from TSVs to Capesize Ocean Going Vessels (OGVs).

The TSV navigation route traverses between the Offshore and Nearshore DEs.

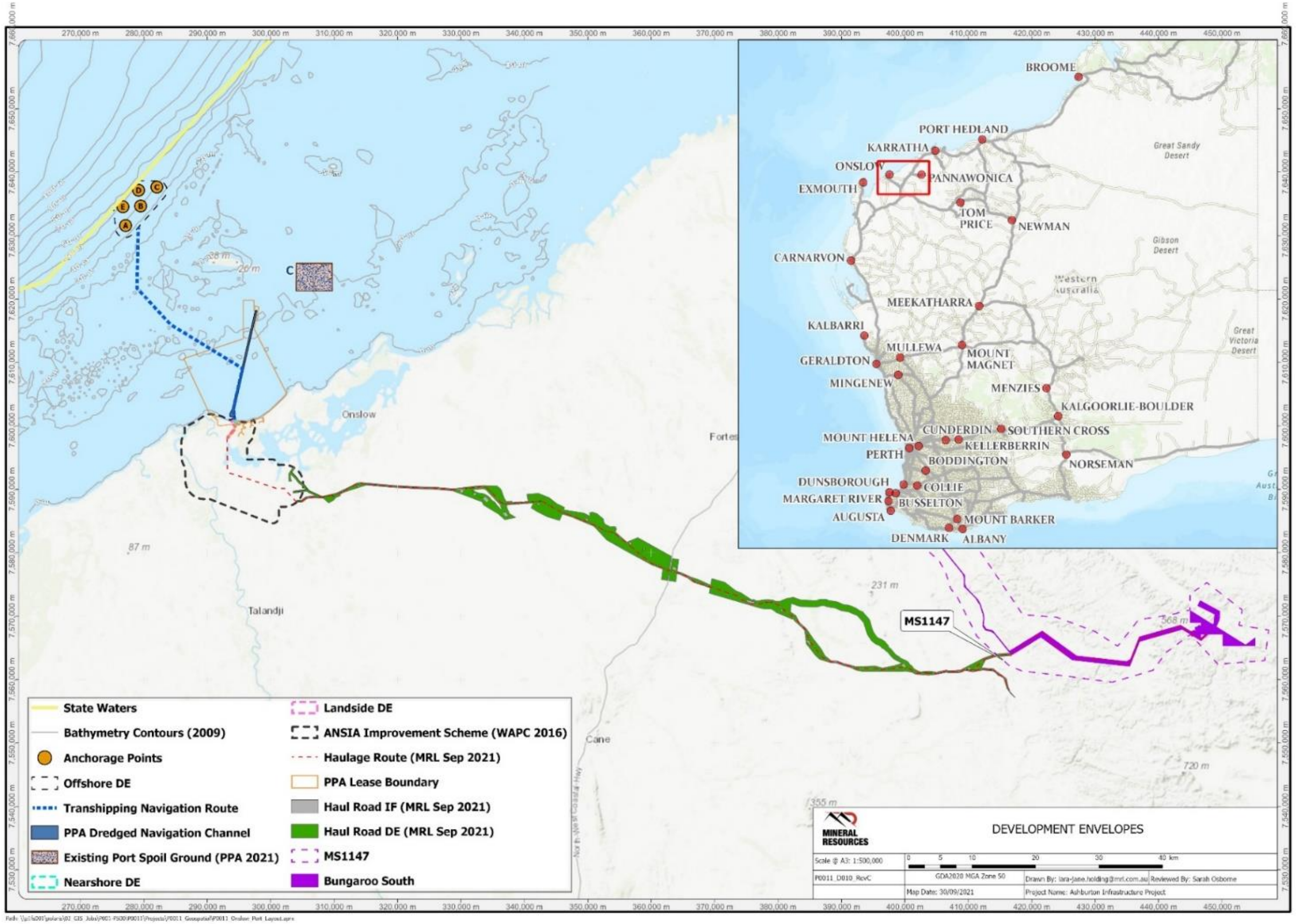


Figure 1: AIP Location

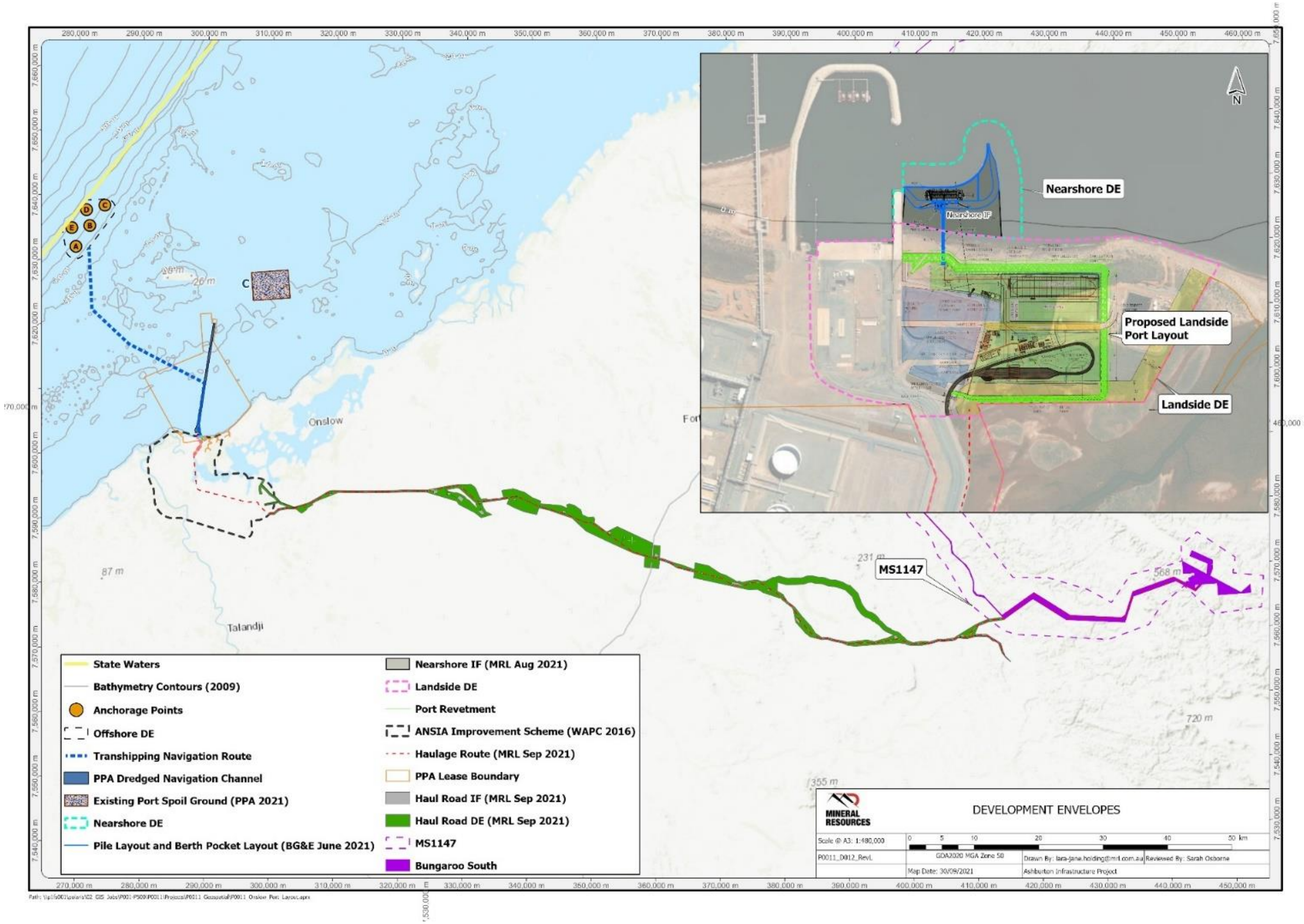


Figure 2 AIP Infrastructure and Development Envelopes.

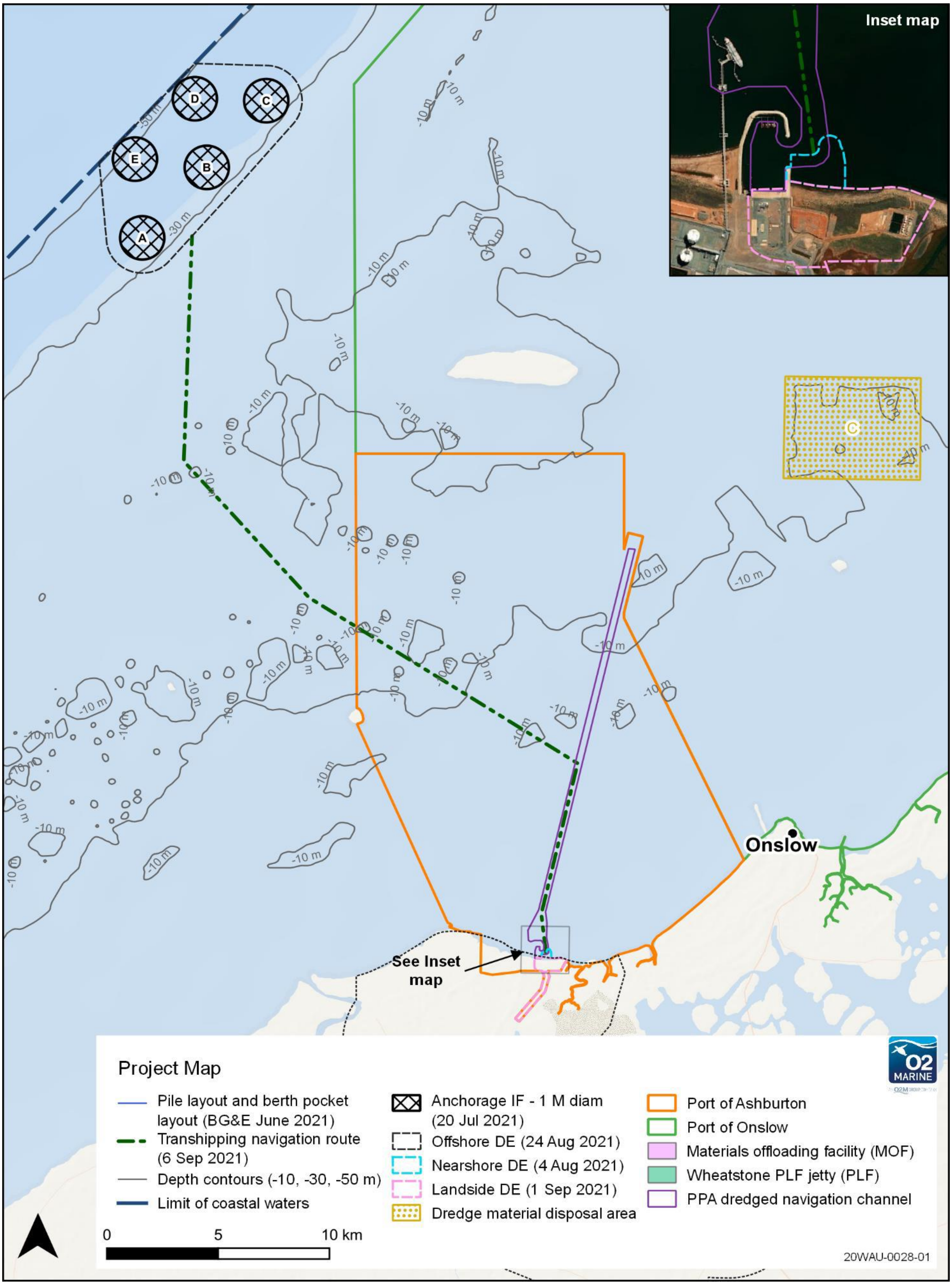


Figure 3 Proposed Action Marine Elements and Development Envelopes.

2.2. Changes from previous versions of this Report

This report is based on O2 Marine (2021z) dredge plume modelling report of MRL's AIP proposed dredging operations. O2 Marine (2021z) outlined the dredge plume that would arise from dredging approximately 150,000 m^3 with a backhoe dredger (BHD) over a 90-day period, accounting for 16-hour/day operations. A bulk material disposal of 180,000 m^3 was assumed, with dredge material disposal at Spoil Ground C occurring every 6-hours. Originally, MRL planned to undertake the dredging activities during the second quarter (Q2) of 2022.

In February 2022, MRL advised O2M that a new set of parameters had been defined for their proposed dredge program. These new parameters included a shortening of the dredge period from 90 to 50-days achieved through a 24-hour/day operations. MRL also revised their dredge and bulked disposal volumes to 135,000m^3 (in-situ dredging) and 165,000 m^3 (bulked disposed material), respectively. The longer daily operations meant larger barges would need to be considered which, in turn, lead to a reduction in barge disposal frequency. Importantly, MRL revised the start of the dredging campaign to December of 2022. Borehole data and a geotechnical investigation report from the dredging site also became available post submission of O2 Marine (2021z); this new information allowed for significant increase in confidence of the assumed particle size distribution (PSD) adopted in the dredge plume model, which was previously based only on surficial sediment samples.

The updates to the dredging program and revised dredging period, in addition to new information about the dredge material composition, warranted a revision to the dredge plume modelling study. Opportunistically, O2 Marine improved some of the modelling assumptions and methodologies adopted in simulating the previous dredge program (as described in this report).

This report presents the sediment plume results arising from the revised MRL AIP dredging program and its predicted zone of influence and zones of impact. This report supersedes all previously issued dredge plume modelling reports from O2M to MRL.

2.3. Objective

The primary objective was to conduct dredge plume modelling for the MRL AIP and provide zones of impact and a zone of influence to satisfy the requirements of environmental impact assessment, based on the updated dredging program.

This revision also strives to improve upon previous dredge plume modelling submissions through the availability of new geotechnical information and a review of previous assumptions and methodologies, thus increasing confidence in zones of impact for environmental impact assessment.

The secondary objective of this report was to update the previously simulated period (Q2 simulation) based upon the anticipated improvements noted above.

2.4. Scope of work

This report deals with the numerical assessment of the proposed capital dredge program and associated offshore disposal. The scope associated with the objective of this study was to:

- Conduct a desktop assessment of the revised proposed dredge methodology;

- Conduct a revised geotechnical review, incorporating the borehole data and geotechnical information to the surficial sediment samples adopted in prior versions of this report;
- Review and update (where necessary) model assumptions and methodologies;
- Set up and run O2M's hydrodynamic model and sediment transport model for the MRL AIP project for both the Q2 2022 representative dredging scenario (superseded dredging period) and the Q4 2022 to Q1 2023 representative dredging scenario (revised dredging period);
- Generate zones of impact and a zone of influence for the purpose of environmental impact assessment for both scenarios; and
- Assess the zones of impact against available benthic habitat surveys for both scenarios.

Excluded from the scope are:

- Review of background/environmental water quality.
- Assessment of benthic habitats and the most appropriate thresholds for the EIA; and

2.5. Proposed dredge programme

Dredging is to be completed through use of a BHD with at least two split hopper barges to carry the dredged material to an offshore ocean disposal site. Key parameters of the proposed dredging are given in Table 2.

Table 2 Dredge and disposal program for backhoe dredging

Parameter	Value	Notes
Dredge Volume	135,000 m^3	In-situ volume of material to be removed through BHD dredging.
Disposal Volume	165,000 m^3	Material within a barge is assumed to be bulked by (165,000/135,000). This increase in volume is to be accounted for in barge volume availability (bulking of volume only as mass is conserved).
Dredge equipment	Backhoe Dredger (BHD)	
Dredge rate	112.5 m^3/hour	Hourly dredge rate for the total material according to the dredge plan shown in this table, based upon provided times to achieve the dredge depth by MRL.
Dredge schedule	7 days a week; 24 hours a day	Continuous operation expected with the dredger operating 24 hours a day.
Duration of dredging	50 days	Anticipated duration of the dredge operation (for overburden material removal only). Anticipated for Q2 2022.
Disposal method	Sea dumping by ~1500 m^3 barges filled at site	In order to achieve the full time dredge operation, 2 x 1500 m^3 barges are required.
Disposal frequency	11 hours	Estimated based on dredge rate, bulking factor and typical loading, transit and disposal times for a 1500 m^3 barge.
Number of disposal events	110 Disposal events	Based on parameters listed above.
Dredge disposal location	Spoil ground C (offshore disposal)	Spoil ground C is located approximately 25 km from the dredging site at the following coordinates: • Latitude: 21° 28’ 51.34” S • Longitude: 115° 8’ 8.9” E

3. Background

Background information used in the derivation of the methodology adopted in this study (Section 4), necessary to interpret the results (Section 5) and follow the discussion (Section 6), is presented next.

3.1. Physical environment

Ashburton is in the western Portion of Western Australia's arid Pilbara region. The Pilbara experiences pronounced wet and dry season corresponding to the southern hemisphere summer and winter, respectively. The prevailing winds are Westerly to South-westerly in the wet season (summer) months, and easterly in the dry-season (winter) months influenced by the migrating trade winds and the Indonesian-Australian monsoon. The region is prone to tropical cyclones in the wet season and influenced by a year-round land-sea breeze system (O2 Marine 2021b).

Swell waves arrive predominantly from the southern Indian Ocean, losing considerable energy as they refract around Northwest Cape and propagate through the various islands of the Pilbara coast. Swell energy is thus generally low, though slightly larger in the dry season owing to more energetic Indian Ocean swells and arrives predominantly from the Northwest. Wind-waves respond to both the synoptic scale winds and the land-sea breeze, thus wave direction varies seasonally with the synoptic winds.

Currents are tidally dominated, with notable nonlinearities attributable to the shoals south of Barrow Island (O2 Marine 2021b). Inshore of the 30 m isobath there are weak drift currents driven by the reversing seasonal winds. The alongshore drift is thus eastward in the wet season, and westward in the dry season. Very near to the shore, alongshore currents are influenced by the combination of tides, seasonal wind drift, wave-driven alongshore drift, and other low-energy features such as seiches and shelf-waves.

Near-shore sediments are largely fine-grained terrigenous materials, likely sourced from flood discharge of the Ashburton River to the west. Larger quantities of marine sediments are found to the west of the Ashburton River. This suggests a net eastward transport sediments at the coast, as supported by satellite imagery of coastal morphology (Damara, 2010). Several physical mechanisms may contribute to this net drift, namely: (1) the wet season westerly winds are typically sustained for a longer period than the dry season easterlies, (2) the Ashburton River typically discharges sediment-laden floodwaters in the wet season which coincides with westerly winds, and hence eastward transport, and (3) the prevailing North to North-westerly swells driving an eastward alongshore transport.

3.2. Geotechnical Investigations

Geotechnical data relevant to this dredge plume modelling report has been collected through the following investigations:

- 2021 O2 Marine surficial sediment sampling; and
- 2022 CGC borehole data collection.

3.2.1. O2 Marine sediment sampling

Sediment sampling was conducted at nine randomly distributed sites within the dredge footprint by O2 Marine (2021k) using both push-corer and vibro-corer methods, sampling the top 1 m of the seabed (Figure 4). PSD of the samples are illustrated in Figure 5 from O2 Marine (2021k). PSD analysis indicate a sandy surface layer with varying levels of silt and clay in the dredge footprint. In some samples, the silt and clay can account for approximately half of the sample, however across most samples the sand fraction is predominant fraction. Note that fractions larger than sand (gravel, cobbles etc) were rarely found, only appearing to account for a small percentage of samples taken at locations 8 and 9.

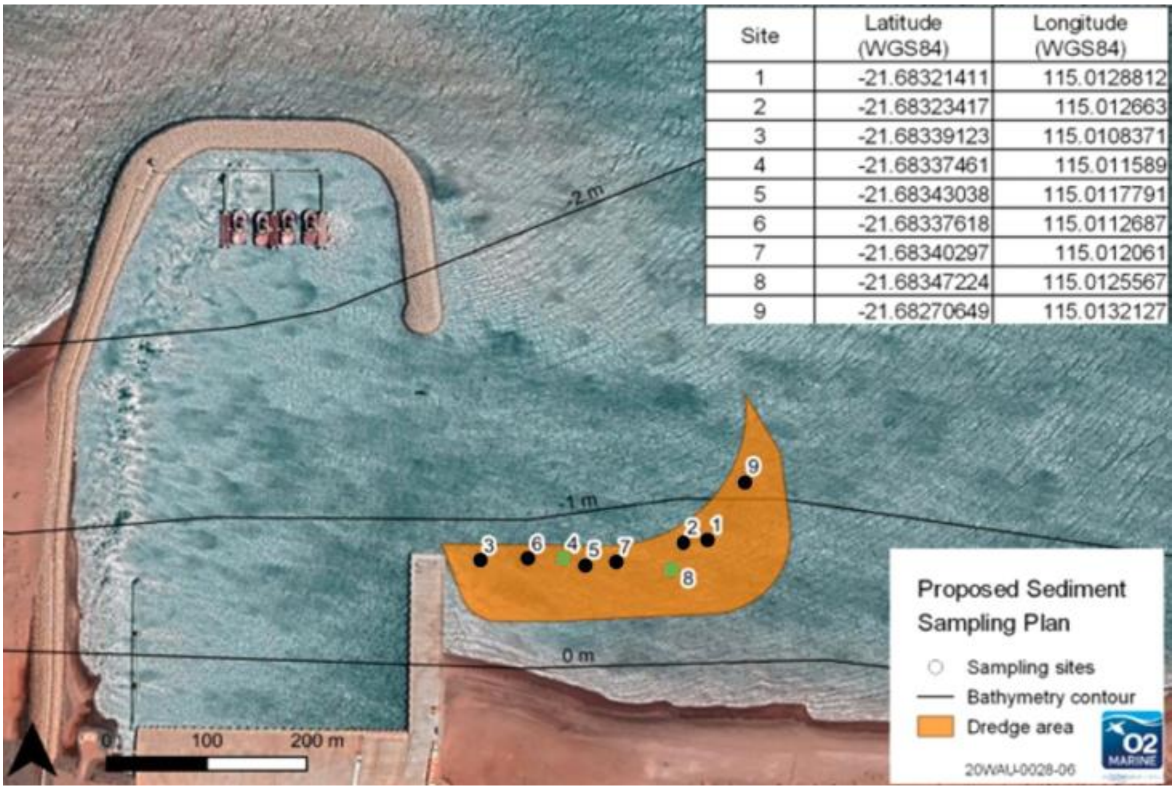


Figure 4 O2 Marine sediment sample sites (black = push-corer, green = vibro-corer) (O2 Marine, 2021k)

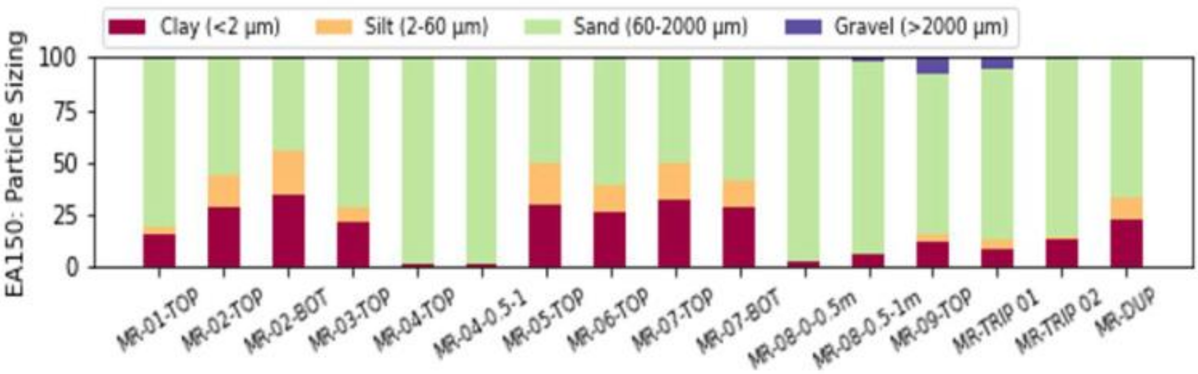


Figure 5 O2 Marine particle size distribution analysis (O2 Marine, 2021k)

3.2.2. CGC borehole data

A nearshore factual geotechnical report and a nearshore geotechnical interpretive report by CGC (2021a, 2021b) presented and interpreted borehole results that were conducted within and close to the AIP dredge footprint. In total, six boreholes were drilled, with borehole locations with respect to the dredge footprint illustrated in Figure 6. Of the six boreholes, only one (borehole 6) was drilled within the part of the dredge footprint that is to achieve the -8 m CD dredge level. Boreholes 2, 3, 4, and 5 all sit within the slope from the existing surface to the -8m Chart Datum (CD) dredge level and borehole 1 sits south of the dredge footprint. Samples at different depths from each borehole underwent PSD analysis as outlined in CGC (2021a and 2021b).

Figure 6 CGC Borehole locations

CGC's interpretive and factual report identifies four distinct layers within the borehole drilling depths across all borehole results. Only two of these four distinct layers are encountered between the surface levels and the desired dredge depth, and are defined by CGC as the following:

1. Recent marine sediments: calcareous clayey sand, calcareous sand, calcareous silty sand and silty sand ranging from being loose to very loose. The width of this layer varies from 0.8 m thick to 3.0 m thick across borehole results and is the upper surface layer.
2. Ashburton red beds (soils): Sand, silt, clay and occasional gravel. This layer is situated under the recent marine sediments and ranged in thickness from 8.5 m thick to 11.5 m thick. An occasional conglomeratic sandstone layer of 0.5 m thickness was also found in this layer at boreholes 3 and 6 at a depth of 4 m below the surface layer.

CGC interpolated the borehole results and layer thicknesses spatially and provided cross sections of the interpolated results in the form of both a south to north cross section and a west to east cross section. These interpolated cross sections are presented in Figure 7 and Figure 8 and have been cut off just below the desired dredge depth. The south to north interpolation shows a recent marine sediment layer that is decreasing in width from the shoreline through to borehole 6 where it is only 0.9 m thick. The west to east cross section shows a more consistent width in the marine sediment layer with an exception at borehole 3 where it reduces in width. The remaining depth to dredge within the footprint can entirely be classified as the Ashburton red bed (soil) layer.

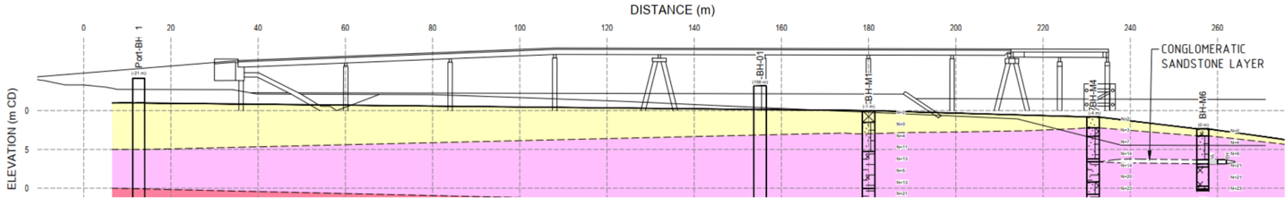


Figure 7 CGC (2021b) borehole layer interpolation: South to north cross section

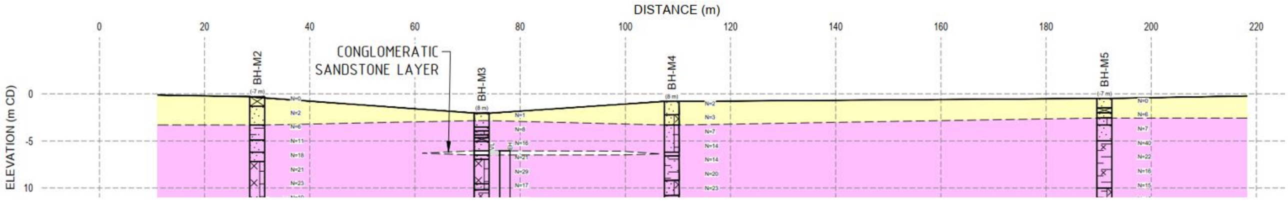


Figure 8 CGC (2021b) borehole layer interpolation: West to east cross section

3.3. Benthic habitat

Little light-sensitive benthic habitat is found in the immediate vicinity of the proposed dredging. The nearshore Local Assessment Units (LAUs 1D & 1C) adopted for the AIP are characterised by generally bare substrate with occasional areas of limestone pavement (O2 Marine 2021d). Two areas of low cover coral habitat were identified as most sensitive habitat type from previous mapping (URS 2010), one near Ward Reef and the other at a small, isolated reef West of Beadon Point (O2 Marine 2021d). No seagrass was identified in the nearshore LAUs either from literature review or field survey (O2 Marine 2021d).

Existing BCH mapping of Spoil Ground C (URS 2010) indicates that the spoil ground and the adjacent area is largely bare or sparsely covered substrate. However, during regulator consultation for the project it was noted that the URS (2010) mapping was more than 10 years old and further evidence was required to confirm that the previous mapping remains accurate. MRL engaged O2M to undertake a BCH survey of Spoil Ground C to validate and update the existing BCH mapping and consider any impacts to BCH arising from dredge spoil disposal at this location. Based on results from this new survey together with the URS (2010) study, BCH within and adjacent to Spoil Ground C is classified as sand substrate with a biota cover ranging from bare to sparse (<1% - 3%). These results align with Spoil Ground C being historically established as a designated disposal ground (O2 Marine 2022y).

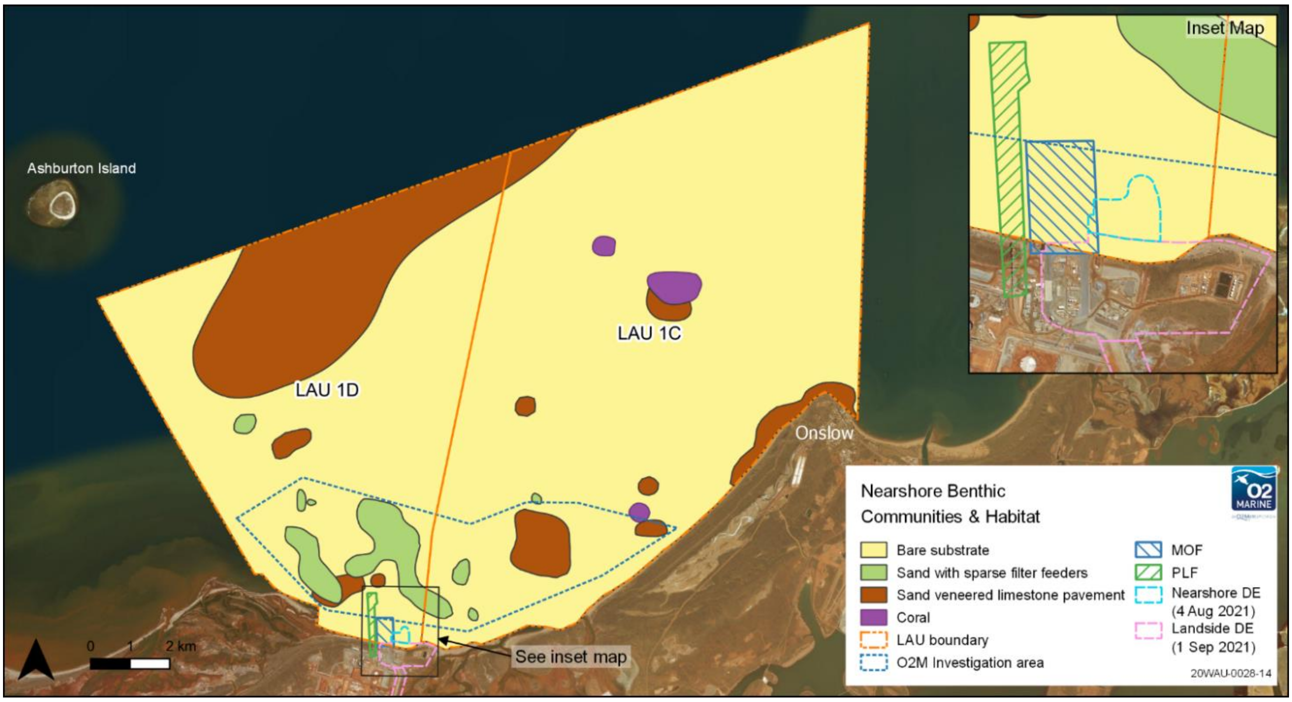


Figure 9 Inshore BCH map (O2 Marine 2021d)

3.4. Suspended solids concentration

There is a sustained suspended sediment load in the inshore waters for which the dredging is proposed. The recent monitoring for the near-by Wheatstone project provided a reasonable baseline for this project. A desktop review of background marine water quality in the Ashburton region provides recommendations for background total suspended sediment (TSS) concentrations when evaluating environmental impact of dredging in the Ashburton area (O2 Marine 2021m). Specifically, the report recommends a background TSS of 5.4 mg/L in nearshore (≤10 m) areas and 2.4 mg/L in offshore (>10 m) areas.

3.5. Underwater light climate

The light attenuation relationship containing a clear water attenuation variable and a variable that attenuates light as a function of SSC, has been defined in O2 Marine (2021m).

3.6. Regulatory framework for impact assessment

The EPBC Act and EP Act aim to support environmentally sustainable development while protecting environmental values, including biodiversity.

3.6.1. EPBC Act

The EPBC Act lists ‘nationally significant’ animals, plants, habitats and places as Matters of National Environmental Significance (MNES) and aims to ensure that potential negative impacts on them are carefully considered before changes in land use or new developments are approved. Increased turbidity through dredging has the potential to indirectly affect marine fauna species through reduced habitat quality and redistribution of prey species. Dredge plume modelling has been undertaken, in part, to inform this assessment.

3.6.2. EP Act Guidance

The *Environmental Protection Act 1986* (EP Act) is the primary legislation that governs environmental impact assessment (EIA) and environmental protection in Western Australia. EIA in Western Australia is conducted by the Environmental Protection Authority (EPA) which has prepared administrative procedures for the purposes of establishing the practices of EIA. Proposals likely to have a significant impact on the environment are required to be referred to the EPA under Section 38 of the EP Act.

The EPA expects proponents to present their assessment of dredging impacts in accordance with the EPA Technical Guidance for the Environmental Impact Assessment of Marine Dredging Proposals (Environmental Protection Authority, 2016). The guidance describes an impact zonation scheme (Table 3), and the appendices therein offer guideline trigger values for each of these zones of impact. While we do not reproduce the trigger values here, the approach for assessing impact to corals is laid out in (Table 4). Note that liaison with benthic habitat specialists confirmed that the most appropriate thresholds were the default values for corals in EPA (2021).

Table 3 EPA (2021) Impact zonation scheme

Zone	EPA (2021) Description
Zone of Influence (ZoI)	The area within which changes in environmental quality associated with dredge plumes are predicted and anticipated during the dredging operations, but where these changes would not result in a detectible impact on benthic biota. This area can be very large, but at any point in time the dredge plume is likely to be restricted to a relatively small portion of the ZoI.
Zone of Moderate Impact (ZoMI)	The area within which predicted impacts on benthic organisms are sub-lethal, and/or the impacts are recoverable within a period of five years.
Zone of High Impact (ZoHI)	The area where serious damage to benthic communities is predicted or where impacts are considered irreversible. Serious damage is defined as damage that is irreversible or damage that is unlikely to be recovered for at least five years following the completion of dredging activities.

Table 4 EPA (2021) Appendix A guidelines to predict the impacts of dredging on corals

BCH category	Zone	Subcategory	Guideline description
Corals	ZOMI	Light Reduction (all corals)	Based on moving average of DLI exceeding a threshold value. Three separate averaging windows given for each of possible and probable effects, and exceedance of any of these constitutes an exceedance.
		Light Reduction and SSC combined (massive and foliose corals)	Based on moving average of both DLI and SSC exceeding a threshold value. Three separate averaging windows given for each of possible and probable effects. For a given averaging window, both the DLI and SSC thresholds must be exceeded simultaneously to be considered an exceedance. The exceedance of any averaging window constitutes an exceedance.

			**While no specific guidance is given, we interpret SCC to mean near-bed SSC, as the threshold is based around depositional effects.*
	ZOHI	All corals	Based on moving average of DLI, SSC and Sediment Deposition exceeding a threshold value. Three separate averaging windows given for each of possible and probable effects. Unlike the guidance for the ZOMI, the guidance is not clear on whether these should be exceeded contemporaneously to be considered an exceedance, though for consistency with the ZOMI it is considered here that they are. The exceedance of any of the three averaging windows constitutes an exceedance. **While no specific guidance is given, we interpret SCC to mean near-bed SSC, as the threshold is based around depositional effects.*

3.7. Guidance on dredge plume modelling for environmental impact assessment and source term estimation

In June of 2016, the Western Australian Marine Science Institute (WAMSI) provided an overview of various dredge plume modelling studies that had been conducted throughout Australia and set recommendations for standard practice for modelling such as clarity of model input parameters to be selected (Sun et al 2016).

In November of 2020, WAMSI published a guideline for dredge plume modelling for the purpose of environmental impact assessment (Sun et al 2020). This guideline emphasised the need for a standardised approach to estimate source terms for dredge plume modelling (in the absence of field datasets). WAMSI has encouraged the use of an approach set out by Becker et al. (2015) in estimating source terms, which has been adopted in this present study.

3.8. Recent relevant dredge plume modelling studies

3.8.1. Mardie project: Dredge plume modelling

The Mardie dredge plume modelling study (Baird, 2020) simulated a dredge plume for the capital dredging of approximately 800,000 m^3 over two successive years, with a pause in operations during the wet season. The impact assessment simulated a backhoe dredge program with a hopper barge which was dredging at a rate between 100 m^3/hour and 125 m^3/hour.

The modelled sediment plume was composed of the following size fractions:

- Fine sand: non-cohesive sediment with a median diameter of 125 µm
- Coarse silt: cohesive sediment with a settling velocity of 0.0017 m/s
- Fine silt: cohesive sediment with a settling velocity of 0.00006 m/s
- Clay: cohesive sediment with a settling velocity of 0.000004 m/s

The following sources of sediment were used in the plume modelling:

- Backhoe dredger: 4% of the total fine sand, clay and silt fractions dredged contributed to the far-field plume. This sediment spill was distributed through the water column with 40% at the seabed, 30% at mid depth and 30% near the surface.
- Hopper barge: 10% loss of clay and silt fractions due to overflow at the top of the water column contributed to the far-field plume.

While the Mardie study was much larger in terms of total dredge volume than the proposed AIP dredging, it is relevant to the present study due to the similarity of proposed dredge methods and the similar environmental setting. The regulatory environment is also similar, though the EPA has updated its guidance for EIA of dredging since the Mardie study. At the time of publication of this report, the dredge operations at Mardie had not commenced thus Baird's (2020) assumptions have not yet been validated with field data. The Mardie project is therefore relevant for comparison of certain model inputs and zone of impact extents.

3.8.2. Wheatstone LNG project

A dredge plume modelling study was conducted for the Wheatstone LNG Project (Chevron, 2010) whereby various stages of capital dredging, all using cutter suction dredge, was simulated. These stages varied in duration and volume of dredged materials and are summarised below:

- Temporary Access Channel: Two phases of dredging totalling to 650,000 m^3.
- MOF and MOF Approach Channel: 1.4 Mm^3 of dredging with offshore disposal and/or onshore material placement.
- Product Loading Facility: 7.2 Mm^3 of dredging with offshore disposal and/or onshore material placement.
- Product Loading Facility Approach Channel: Three phases of dredging totalling to 20.7 Mm^3 of dredging with offshore disposal and/or onshore material placement.

The simulation accounted for 84 different scenarios (2 release rates x 6 metocean scenarios x 7 dredging scenarios) the highest level of impact across the scenarios were illustrated with zones of impact plots. A sediment plume modelling and impact assessment was again conducted later in 2016 (Chevron, 2016) for the Wheatstone LNG Project with a more refined and optimised dredge program since the 2010 study. The Wheatstone study (Chevron, 2010) described that most of the sensitive coral and seagrass receptors were not located near the dredging area and were located outside of the zones of impact, of which stretched a relatively large distance along the coastline both in a north-easterly direction (approximately reaching Onslow) and in a south-westerly direction (stretching past the Ashburton River). However, there was some overlap particularly around the area of Ward reef, which required optimising the dredge program to protect these areas of coral. Disposal and offshore dredging also saw similar spread and behaviour in the zones of impact when compared to the nearshore case.

The subsequent optimisation of the dredge program (Chevron, 2016) resulted in a shrinking of these zones of impact and whilst there was still a westerly to easterly variation in the zones of impact, this variation as more confined to the dredge channel itself and nearshore of Ashburton port. The modelling of the refined dredge program concluded that the plumes and impact zones predominantly extended towards the east during summer and towards the west during winter. Transitional seasonal weather led to more localised plumes with occasional further extension in either direction. The results note that the net drift is driven by wind fields which vary with seasonality.

The Wheatstone project is comparable to this study in terms of its location, being in the Port of Ashburton. However, the dredge simulation is otherwise significantly different as the project simulated approximately a much larger dredging. and disposal program using different dredging methodologies. The main purpose of comparison against the Wheatstone project is two-fold:

1. To provide a scale reference: As this project is a much smaller scale dredge operation in the same area, the zones of impact and conclusions made within the AIP project should not exceed those reported for the Wheatstone project.
2. To provide validity to the spatial behaviour of the plume observed in this study.

4. Methodology

This section outlines the model that has been adopted to simulate the dredge and disposal program presented in Section 2.5.

4.1. Numerical Model

The 3D far-field dredge plume model adopted solves the 3D incompressible Reynolds averaged Navier Stokes (RANS) equations, and transport equations for temperature and salinity. The RANS equations are closed using a 2-equation (k-epsilon) closure scheme for the vertical fluxes, and a variable Smagorinsky scheme in the horizontal. Transport equations are closed by a scaled eddy diffusivity. The equations are discretised in space using a cell-centred finite volume approximation, with an unstructured grid in the horizontal, and a structured sigma-z scheme in the vertical.

The discretisation of the RANS and transport equations was second-order accurate in space, and flux limiting schemes were used to reduce shocks. A second-order explicit time step was used for the horizontal terms and the vertical convective terms, and a second-order implicit time step for the vertical diffusive terms. Pressure was baroclinic and hydrostatic, with density calculated by a non-linear equation of state.

The 3D dredge plume model was nested within the hydrodynamic model described in the base hydrodynamic modelling report (refer to O2 Marine 2021b for model validation). The extent of this model is shown with respect to the larger hydrodynamic model (to O2 Marine 2021b) in Figure 10, and greater resolution of the dredge plume model is presented in Figure 11. The element size at the open boundaries was commensurate with the resolution of the larger hydrodynamic model in this region, minimising interpolation.

The vertical grid consisted of ten vertical layers, with five sigma cells to the base of the main dredge channel at approximately -8 m MSL. Five equal thickness z layers down to a depth of approximately - 28 m MSL and one thicker bottom z layer beneath this 28 m MSL.

The bathymetry of the base hydrodynamic model (O2 Marine 2021b) was adjusted in the dredge area to represent the final dredge depth. Updating the bathymetry as dredge operations progressed (to account for changes in bathymetry due to dredged areas) was not considered necessary, as this only affects the hydrodynamics of the immediate dredge vicinity and the dredge footprint is reasonably small (compared to local hydrodynamic length scales). This is anticipated to have no effect on the extent of the zones of impact, and as the major environmental receptors are located a considerable distance away (O2 Marine 2021d).

Flather and Chapman boundary conditions were used for the open boundaries of the RANS equations, with water levels and fluxes from the base hydrodynamic model, and measured winds from the Bureau of Meteorology's Thevenard Island wind were used for the free-surface stress.

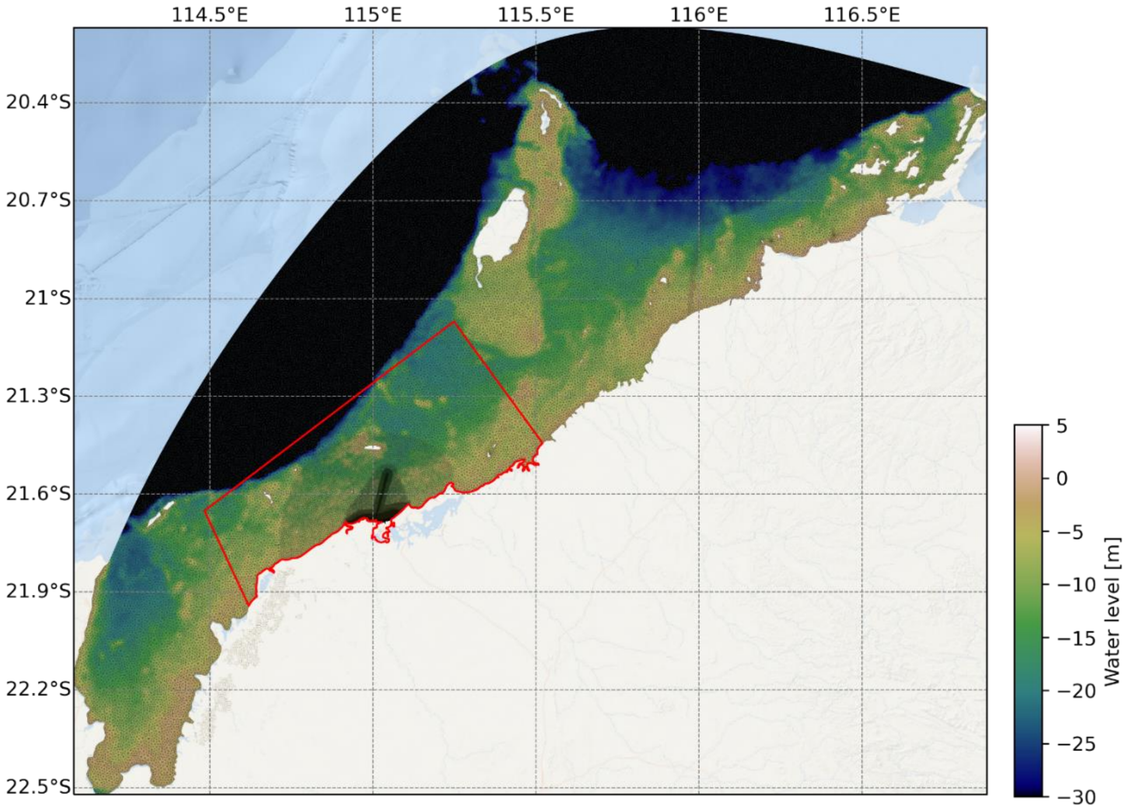


Figure 10 Hydrodynamic model domain with dredge plume model domain as a subset

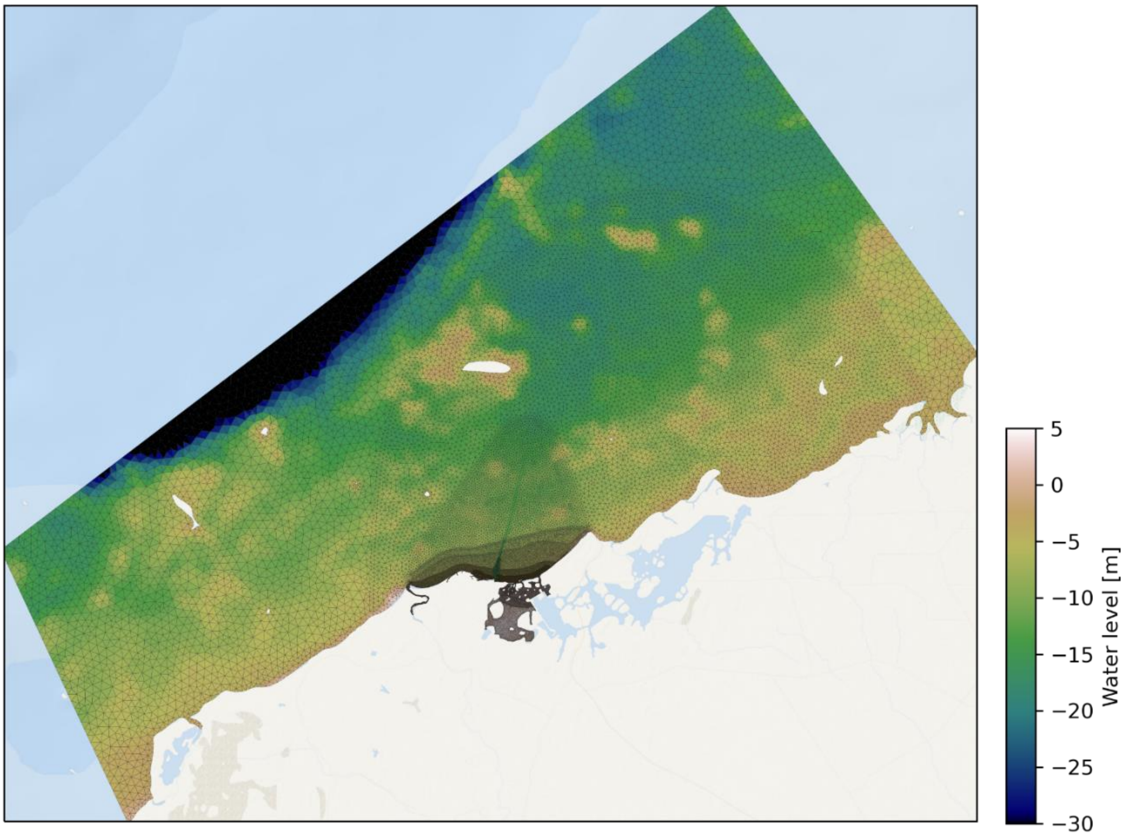


Figure 11 Numerical grid for the dredge plume model

4.2. Sediment transport model

The dredge and disposal program was generated using a sediment transport model, which simulated the far-field plume associated with the proposed dredging. Direct near-field impacts are not assessment in this model. Thus, only far-field source terms are used as input into the model. Therefore, clay, silt and fine sand fractions are modelled (fractions < 150 µm) and it is assumed that all fractions larger than this will settle rapidly within the near-field plume and therefore need not be included in a model for environmental impact assessment.

Two key simplifications were made to the representation of sediments in the model. First, simplistic 'bulk' representation of the dredge material was applied owing to the lack of distinct and geological strata in the dredge material, and the unknown order of dredging. The characteristics of the single representative material were estimated by a weighted average of all the sub geological strata in the geotechnical analysis. Second, erosion of the seabed was excluded from the model, owing to the lack of appropriate validation data for the spatially variable erosion/deposition terms. Instead, a single source at the disposal location has been assumed to represent erosion (value based upon review of other projects). Background SSC was thus not directly modelled. Rather the background values presented in Section 3.3 were added during post-processing and interpretation of potential environmental impact.

The numerical tool used was DHI's Mike 3 Mud Transport (MT) module (herein the sediment transport module). The sediment transport module handles multiple custom sediment fractions, specified in terms of a particle density, base (i.e. un-flocculated) settling velocity, cohesion characteristics, and critical stresses for erosion or resuspension. The erosion law used a discrete depth of erosion model, with distinct bed layers of varying density, erosion coefficient, critical shear-stress and roughness. Dredging and dumping of material allows for time varying release of mass for each sediment fraction, at time varying locations (both horizontal and vertical). The model also includes an online near-field model which simulates the rapid fall of dredge spoil released at the sea-surface and associated small-scale processes such as stripping (where shear-driven turbulence erodes the descending gravity current, releasing sediments into the water column).

4.2.1. Simulated Dredge Scenarios

Two different scenarios were modelled, representing the two different dredging periods (Q2 2022 representative of the formerly proposed dredging program, and Q4 2022 to Q1 2023 representative of the MRL's latest proposed programme). Parameters in Table 2 have been applied to both scenarios; hence there are no differences across scenarios other than the dredging period (thus underlying hydrodynamics). Representative periods have been selected based on available data to represent the two periods discussed with MRL, and are presented in Table 5 below.

Table 5 Dredge plume modelling scenarios and modelled dredging periods

Dredge plume model scenario	Modelled dredging period	Representative of
Scenario 1: Q2 scenario	15/03/2020 – 04/05/2020	Q2 2022
Scenario 2: Q4 to Q1 scenario	05/12/2020 – 24/01/2021	Q4 2022 to Q1 2023

4.2.2. Representation of dredge material

Given that two distinct layers have been identified within the dredge material by CGC (2021b), namely a) a 'recent marine sediment' layer, and b) the 'Ashburton red bed' -soil- layer, PSDs for two representative layers were determined before assigning a single material composition to the dredging program.

The PSD for the top 'recent marine sediment' layer was determined by combining O2 Marine (2021) surficial sediment sample and CGC's (2021a) PSD for that layer. The borehole PSD identified within the Ashburton red bed (soil) layer were averaged to produce a PSD representative of the Ashburton red bed (soil) layer. Representative PSD for these two layers are shown in Table 6. Consistent with the layer definitions in CGC (2022b), Ashburton red bed (soil) layer consists of a higher clay and silt content than the recent marine sediments, which is a sandier layer as evidenced by the higher percentage of fine sand.

Table 6 Representative PSD for recent marine sediments and Ashburton red bed (soil) layers – precursor of the modelled material (refer Table 7)

Geological layer	Clay (< 2 µm)	Silt (2 – 75 µm)	Fine Sand (75 µm to 150 µm)	Coarse Material (> 150 µm)
Recent marine sediments	17.2	10.1	28.6	44.1
Ashburton red bed (soil)	22.2	13.1	12.0	52.7

Some of the assumptions with regards to the PSD results are:

- Percentage of material within each fraction shown in Table 6 is based on raw PSD results
- Borehole samples did not distinguish fractions less than 75 µm. In the absence of fines distribution data for the borehole PSD, the ratio of silt to clay was assumed the same as the average ratio of silt to clay within the O2 Marine (2021) surficial samples.
- Whilst CGC reports a 0.5 m thick layer of sandstone between borehole 4 and 6 within dredge depths, no PSD data have been provided. It is noted, however, that this layer does not appear in any other borehole data within the dredge depth and may be deemed thin and isolated. It was therefore conservatively assumed that this layer does not extend into the dredge footprint and was instead omitted from analysis in defining the Ashburton red bed (soil) layer.

The final step consisted of assigning a single PSD to the dredge material. This was achieved by a weighted average approach based on the width of each layer at the closest borehole to the dredge pocket, borehole 6. As the recent marine sediment layer only accounts for 15.8% of the total dredge depth at borehole 6, the representative PSD skews towards the Ashburton red bed (soil) PSD (84.2 % of dredge depth). The PSD adopted for modelling is shown in Table 7.

Table 7 Representative PSD for in-situ modelled dredge material

Geological layer	Clay (< 2 µm)	Silt (2 – 75 µm)	Fine Sand (75 µm to 150 µm)	Coarse Material (> 150 µm)
Model dredge material	21.4	12.6	14.6	51.4

4.2.3. Settling Velocity

Coarse material does not contribute to the sediment plume as it drops near its release point. It is however considered in the volumetric calculations of dredged and disposed material.

Settling velocities of the three remaining sediment fractions contributing to the sediment plume have been estimated using Stoke's law (Sun et al 2015, DHI 2021) and are presented in Table 8. The settling velocity was then compared against settling velocities for previous dredge plume modelling projects discussed in Sun et al (2016 and 2020), providing confidence in the selected settling velocities.

Table 8 Settling velocities for modelled sediment fractions

Sediment fraction	Settling velocity (m/s)
Fine Sand (75 µm to 150 µm)	0.010935
Silt (2 – 75 µm)	0.001281
Clay (< 2 µm)	0.000004

4.2.4. Dry bulk density

The mass flux (in kg/h) of dredge material was estimated as the product of the volumetric dredge rate (in m^3/h) and the dry bulk density of the undisturbed seabed (kg/m^3). The dry bulk density (ρdry) of the in-situ representative model dredge material was therefore estimated by Van Rijn and Barth (2018). In the absence of organic material, ρdry is estimated by:

$$\rho_{dry} = \left[400\left(\frac{X_{clay}}{100}\right) + 800\left(\frac{X_{silt}}{100}\right) + 1600\left(\frac{X_{sand}}{100}\right)\right]$$

Here $Xclay$, $Xsilt$, $Xsand$ are the percentages of clay, silt, and sand based on the PSD presented previously in Table 7, resulting in a representative dry bulk density of 1242 kg/m^3 for the in-situ model dredge material. Note that in this definition, sand is defined as any material with a particle size greater than the upper limit of silt.

4.2.5. Spill sources

For the proposed dredge program there are four distinct spill sources. The key assumptions of each source term are noted below and follow the WAMSI guidelines for source term estimation (Sun et al, 2020, Becker et al, 2015 and Mills and Kemp, 2016).

1. Dredging spill:

- Far-field spill contribution of 4% of all fine sand, silt and clay.
- Half of this spill is assumed to be distributed evenly throughout the water column, representing the spilling/stripping of material as the bucket passes through the water column. The remaining half is assumed to distribute evenly in the top and bottom layers of the model, which represents the sediment stir up upon disturbing the surface and the water surface penetration/drip above the surface respectively.

2. Hopper barge overflow:

- Far-field spill contribution of 2% of all sediment less than 75 um (silt and clay) through overflow/dewatering of the barge. Due to being a mechanical process (BHD does not dilute dredged material with water such as a cutter suction dredger), the water content in the barge is very low. Overflow/dewatering will not often occur (if at all). It is still assumed that overflow may occur, with a an assumed 2% far-field contribution of silt and clay applied in the water (only these fractions are entrained in the overflown water).

- This overflown material is negatively buoyant (higher density than surrounding water due to entrained sediment) and travels down the water volume in the near-field phase. It is assumed to become passive in an even distribution through the water column. The following additional assumptions regarding this spill source apply:

3. Offshore disposal:

- Far-field spill contribution of 5% of all silt, clay and fine sand, with the assumed loss of all fractions reduced from the previous spill actions.
- The disposal plume is assumed to descend towards the seabed in the near-field plume disposal before becoming passive. Physical modelling by Gensheimer (2010) concluded that up to 30% of plume mass can be contained in the trailing stem of the descending plume, of which is susceptible to stripping. We have used this to inform our distribution of the disposal spill, distributing 30% of it (1.5% total mass) evenly within the water column due to loss of stripping. This distribution aligns with numerical modelling studies by Johnson and Fong (1995) concluded up to 2-3 % of mass can be lost due to stripping of a descending disposal plume. The remaining 70% (3.5% total mass) of the far-field contribution is assumed to occur in the collapse phase as the descending plume hits the seabed and is thus assumed to become passive in the bottom layer of the water column.
- Physical modelling from Gensheimer (2010) also concluded that the collapse phase of a descending disposal plume can spatially distribute the suspended sediment whereby approximately 68% of the suspended material remains within a radius equal to the depth of the water column. Given the depth at the disposal site (~15 m) and the model element size at this location, the far-field contribution is assumed to cover the spatial extent of one model element.
- Each disposal is assumed to occur over a 10-minute period, rather than a constant rate of release into the far-field as this process is fast and periodic. Disposal rates (in kg/hr) will be modified to ensure that 5% of the disposed clay, silt and fine sand is released during this 10-minute period.

4. Erosion of disposed material:

- Given the build-up loose material at the disposal site, it is expected that resuspension through erosion and thus passive transport of the disposed material occurs the duration of the model simulation.
- To represent this within the model, it is assumed that the 5% of the remaining clay, silt and fine sand post disposal is resuspended and available for far-field contribution.
- Resuspension of disposed clay, silt and fine sand through erosion is assumed to occur only in the bottom layer of the model.
- Unlike disposal, the erosion rate will be applied constantly over the entire period as the resuspension from erosion is assumed to occur uniformly (much lower rate of release than disposal which is fast and periodic).

4.2.6. Sediment Budget

As per Becker et al (2015), a sediment mass budget is required for each sediment fraction at each process stage (i.e., digging, lifting, barge filling, barge overflow, barge transit, barge dumping). The mass of each fraction is conserved. Figure 12 details this modelled sediment budget, including the proportion of total spill that is assumed to contribute to the far-field (as only the far-field contribution is modelled in this study). Note that volumes are expressed in terms of in-situ (unbulked) form across all phases for ease of following the budget, however this bulked volume has been accounted for in barge scheduling.

MARINE

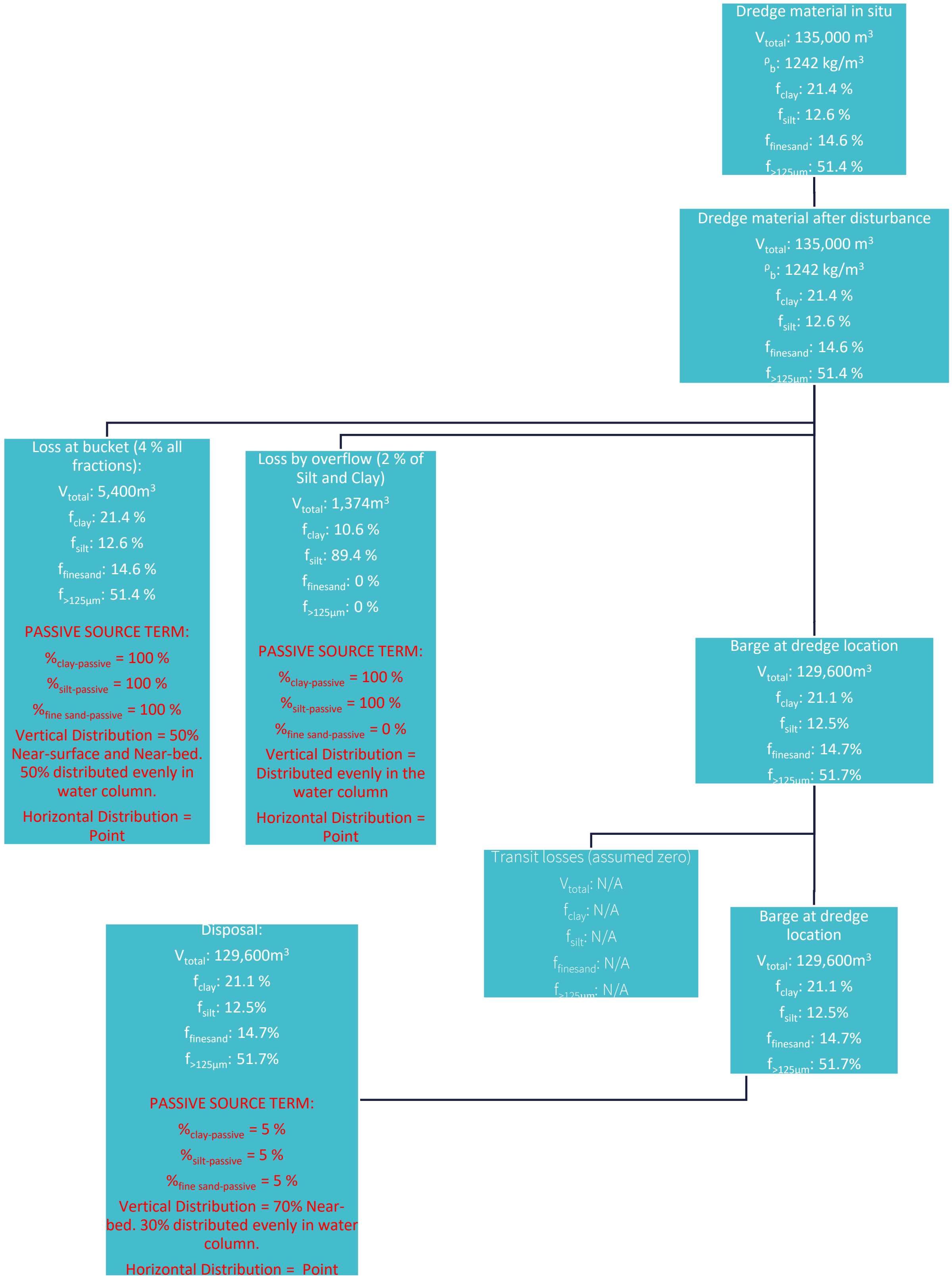


Figure 12 Sediment mass budget for the the proposed dredge and disposal program. Reading down the right hand side is the total material within the barge at various stages. The left hand branches are the spills that happen in between those stages. The passive source terms (red text) are the inputs into the far-field model.

4.3. Impact Assessment

As described in Section 3.6 , environmental impact was inferred using the EPA (2021) framework. O2M calculated the extent of the zone of influence (ZoI) by including any region where SSC (at any height in the water column) exceeded background by 5mg/L at any time. This is a highly conservative threshold in which the plume would not likely be visually discernible, where detectible impacts to stable benthic habitat would be highly improbable, and where change with respect to background could be observed in the field with appropriately selected control sites.

We also note that there is separate guidance for ZoMI estimation depending on the coral morphology and its inherent ability to clear low amounts of deposited sediment (Table 4). Here we calculated and present spatial zones according to both methods separately. Bottom layer SSC has been used for the SSC thresholds (in the combined SSC and DLI thresholds), however DLI has been calculated with light being attenuated through each layer with those layers appropriate SSC.

Note that in calculating the ZoHI using combined DLI and SSC thresholds, the deposition constraint to the thresholds was removed. This conservatively assumes that the deposition threshold is breached for all timesteps, and that only DLI and SSC in combination is further required to trigger or ZoHI.

4.3.1. Application of DLI relationship

DLI was calculated across the model domain and simulation with consideration of:

- Spatially and temporally variable solar elevation;
- Reflection of light at the sea surface;
- Refraction of light at the sea surface;
- Spatially and temporally variable total water depth and mean path length of solar radiation, and;
- Vertically variable SSC and light attenuation coefficient (see Section 3.5).

The light attenuation calculation accounted for three-dimensional variation in SSC for each of the model layers. To account for the effects of clouds and surface waves, the subsurface PAR was reduced by 15%. It is very difficult to determine this factor robustly, and this is an element of uncertainty in the model. However, a constant and uniform reduction of 15% over the entire simulation is deemed a conservative assumption.

Locations in the domain with a total water depth less than 0.5 m for any given timestep were assumed to have the same amount of light as calculated in the immediate subsurface (no SSC influence in water depths under 0.5 m). This depth cut-off was imposed to restrict very high SSC concentrations due to flooding and drying in the model domain.

The light attenuation calculation accounted for three-dimensional variation in SSC. he calculation of the zones of moderate impact using the DLI alone thresholds was restricted to depths within approximately 20 m. This was imposed to discount deeper water areas along the offshore boundary that do not receive enough light at the seabed based on clear water and background SSC attenuation to meet the DLI alone guidelines.

5. Results

This section presents the results of suspended sediment fate in each dredge and disposal scenario. The interpretation of the model results for the purposes of environmental impact assessment is left for the discussion (Section 6).

5.1. Qualitative description of dredge plume trajectory

The daily variation in the dredge and disposal plumes is controlled by tidal currents, with the dredge and disposal plumes oscillating in a north-easterly to westerly pattern along the coastline. Over a longer-term period rather than daily variation, the spatial extent of the plume is primarily dictated by low frequency seasonally variable wind currents.

Scenario 1 (Q2 simulation) experiences transitional wind conditions, as the months of March and April observe a net plume drift in the north-easterly direction before changes in wind conditions from May create a net drift along the westerly coastline. As the simulation completes around early May, only the very tail end of the simulation is consistent with a westerly drift, however this net westerly drift can still be observed. Examples of this net north-east drift early in the simulation changing to a net west drift in May is shown in Figure 13.

For scenario 2 (Q4 to Q1 simulation), a more consistent north-east net drift is observed, consistent with south-westerly wind conditions throughout December and January. There are still occasional shorter-term movements west of the MOF, however this south-west movement is often held for a short period of time and is insufficient to counter the net north-easterly drift. Examples of the long-term north-west drift and shorter-term plume movement west is shown in Figure 14.

Above background SSC percentile plots of Scenarios 1 and 2 are presented in Figure 15 and Figure 16 respectively, which show very similar spatial areas of coverage across the two simulations. In line with the description above, Scenario 1 extends slightly more toward the west than Scenario 2. Notably, higher concentrations of suspended sediments across the entire plume are seen in Scenario 2, which can be attributed to a stronger and persistent south-westerly winds in the December and January. During calmer months, sediment is partly retained within the dredge pocket but it is spilled out of it under stronger winds.

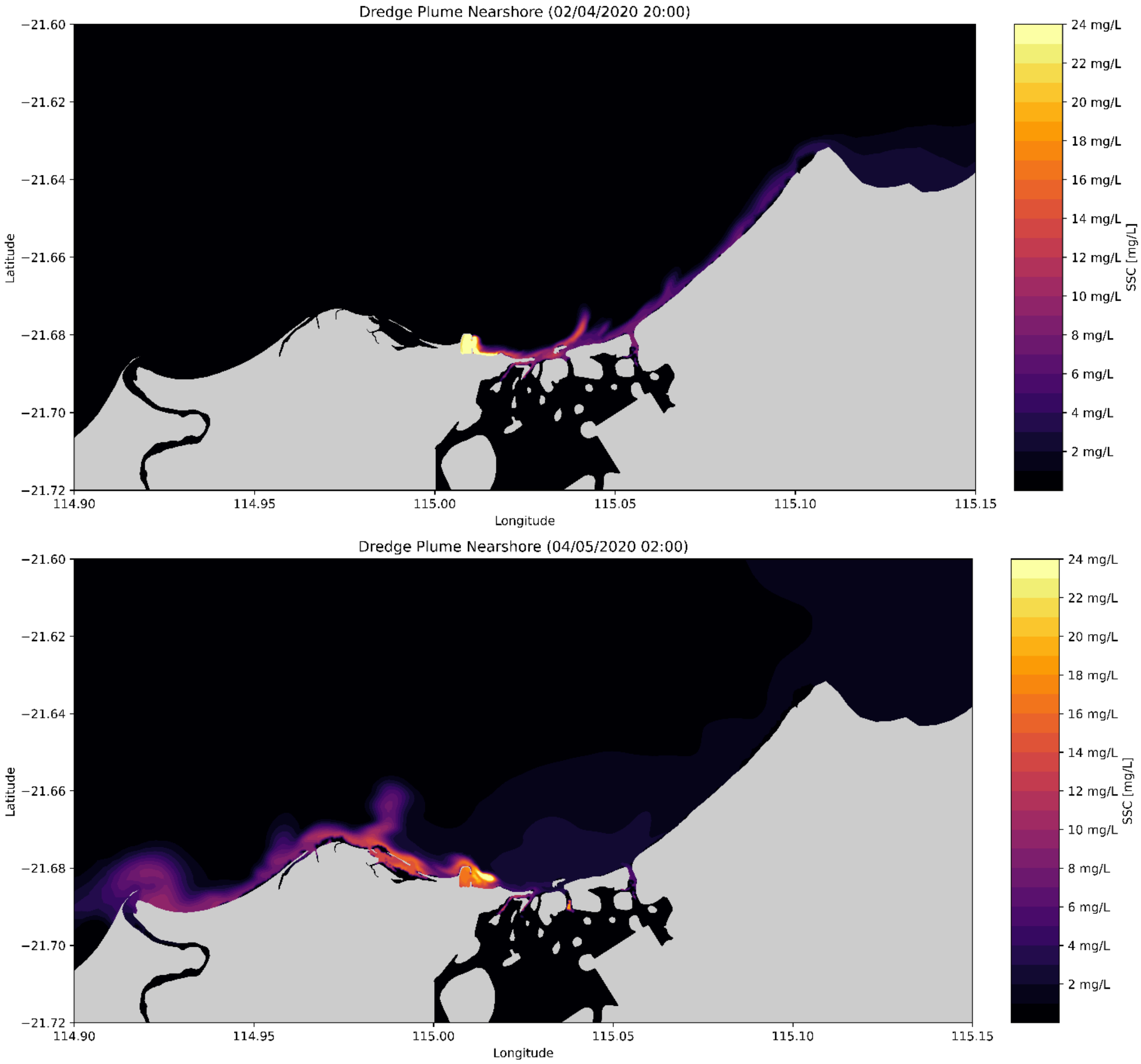
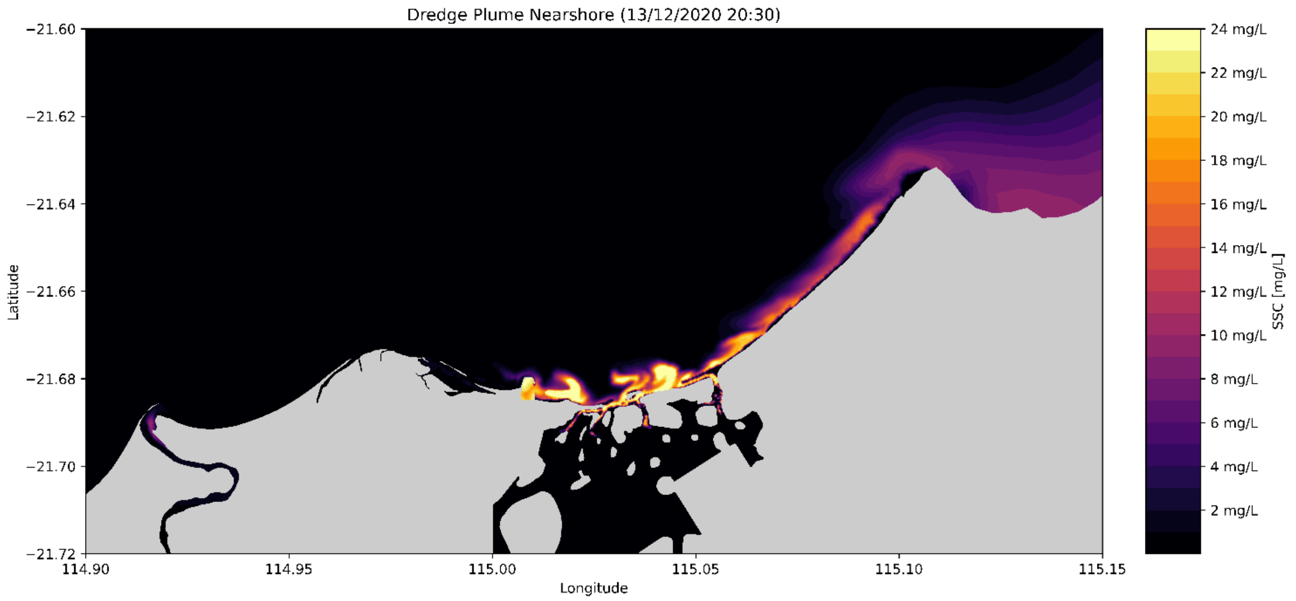


Figure 13 General behaviour plots. Top image presents a typical north-easterly drift during the simulation. Bottom image presents a typical westerly drift during the simulation. Note: These figures present the maximum above background SSC value within a water column is displayed for each location, during one given timestep.



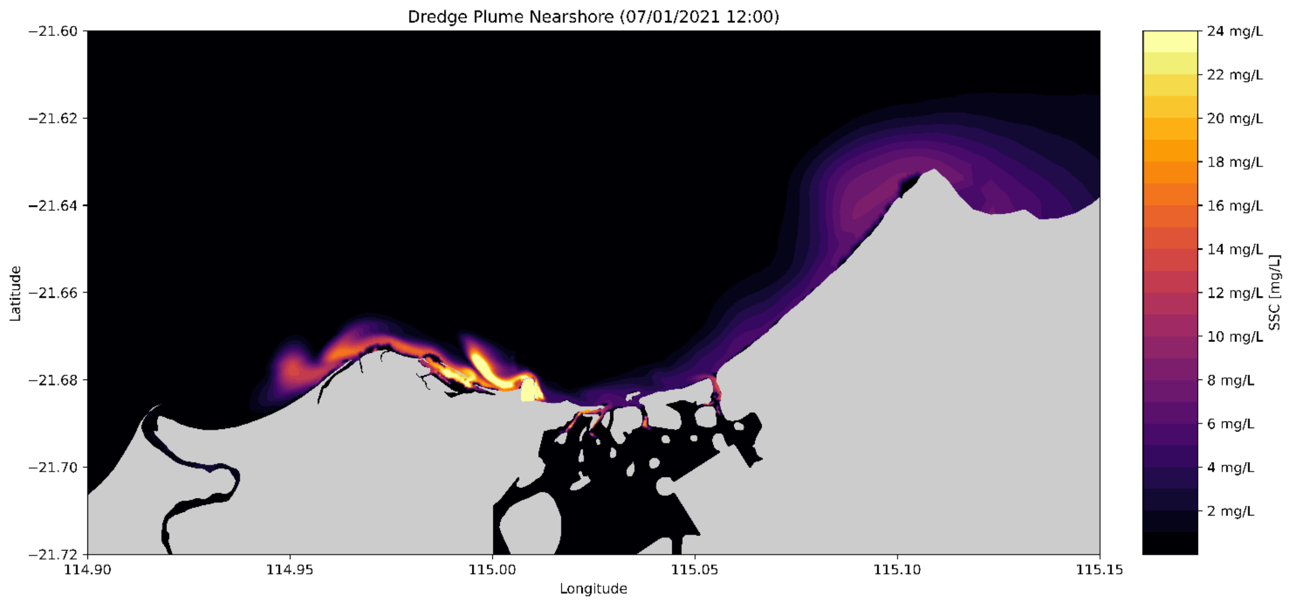


Figure 14 General behaviour plots. Top image presents a typical north-easterly drift during the simulation. Bottom image presents a shorter-term plume movement west of the MOF during the simulation. Note: These figures present the maximum above background SSC value within a water column is displayed for each location, during one given timestep.

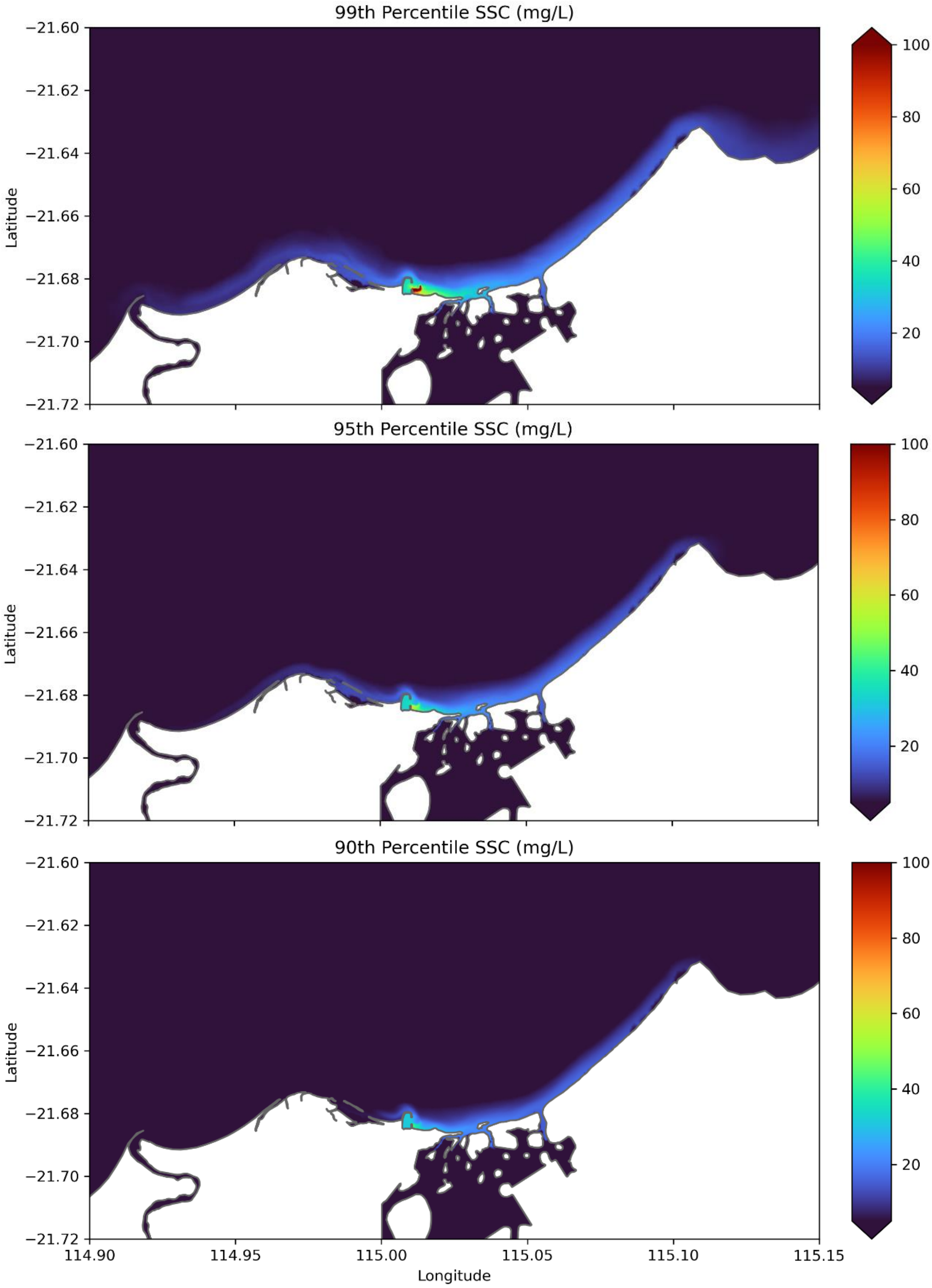


Figure 15 Scenario 1: SSC percentile plots (Note: the figure presents above background SSC, whereby the maximum total SSC within all vertical cells is presented). Top, middle, and bottom panels are the 99th, 95th and 90th percentiles, respectively. The contours in these maps cover a much larger area than the plume at any single point in time.

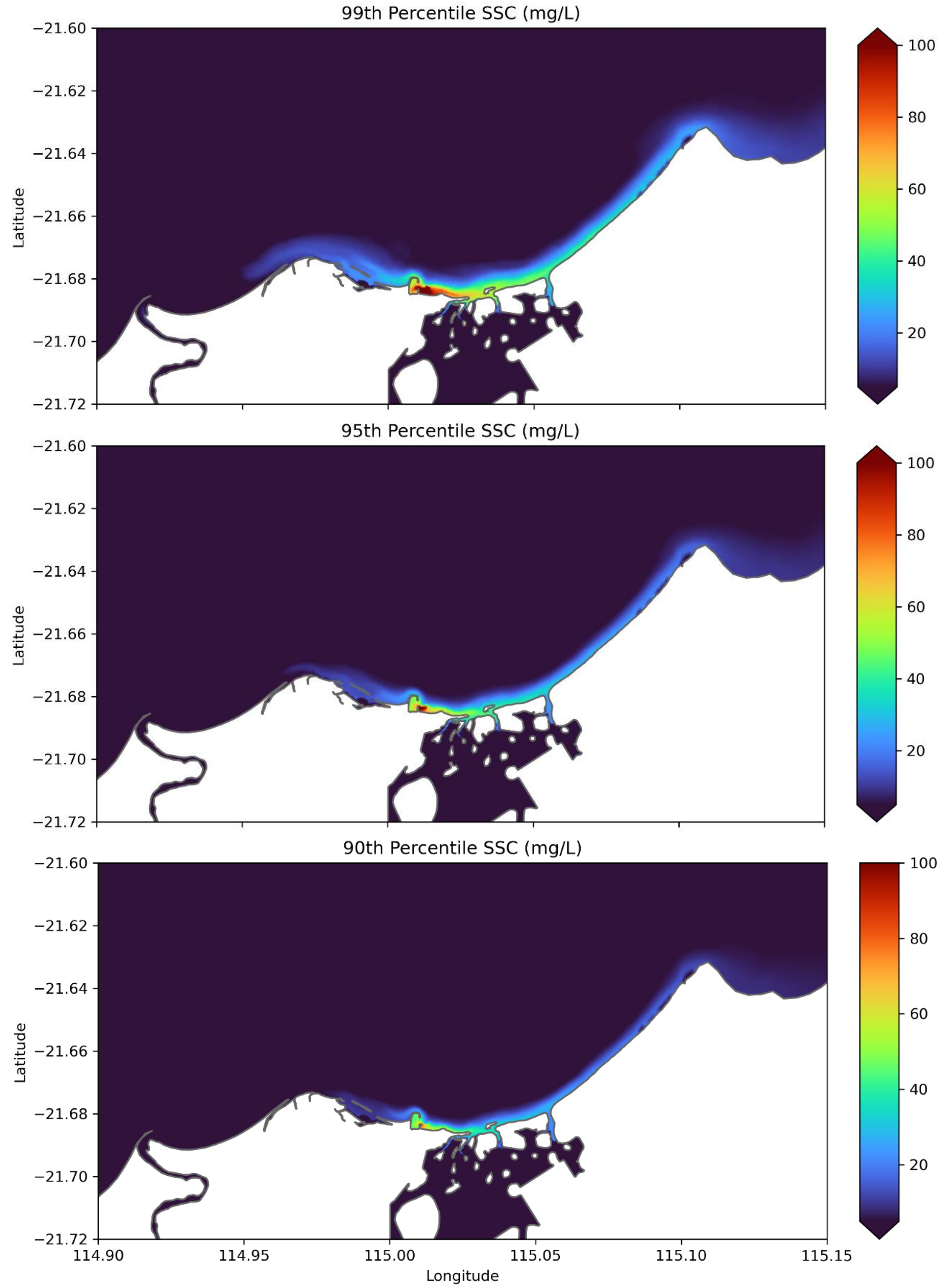


Figure 16 Scenario 2: SSC percentile plots (Note: the figure presents above background SSC, whereby the maximum total SSC within all vertical cells is presented). Top, middle, and bottom panels are the 99th, 95th and 90th percentiles, respectively. The contours in these maps cover a much larger area than the plume at any single point in time.

5.2. Qualitative description of disposal plume trajectory

99th percentile above background SSC plots at Spoil Ground C are presented for Scenarios 1 and 2 in Figure 17 and Figure 18 respectively.

The disposal placement and disposal erosion plumes differ in behaviour between Scenario 1 and 2. In Scenario 1, the 99th percentile above background SSC plume extends both north-easterly and south-westerly of the disposal site, whilst only a north-easterly direction is seen during Scenario 2. The plume behaviour is again consistent with prevailing wind conditions, and further emphasise the role that wind currents play on plume drift and spatial coverage. Both scenarios show a similar rate of decay in concentrations across the 99th to 90th percentile above background SSC plots, however in general the concentrations in Scenario 2 appear slightly higher than those in Scenario 1.

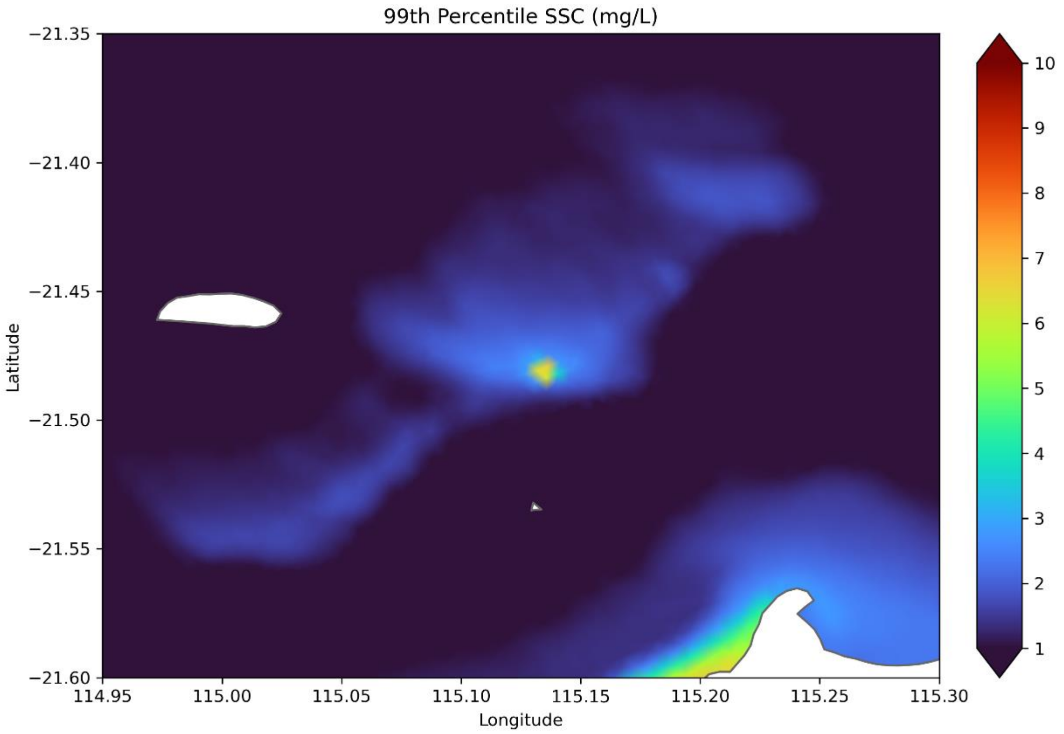


Figure 17 Scenario 1: 99th SSC percentile plots at disposal (Note: the figure presents above background SSC, whereby the maximum total SSC within all vertical cells is presented). The contours in these maps cover a much larger area than the plume at any single point in time.

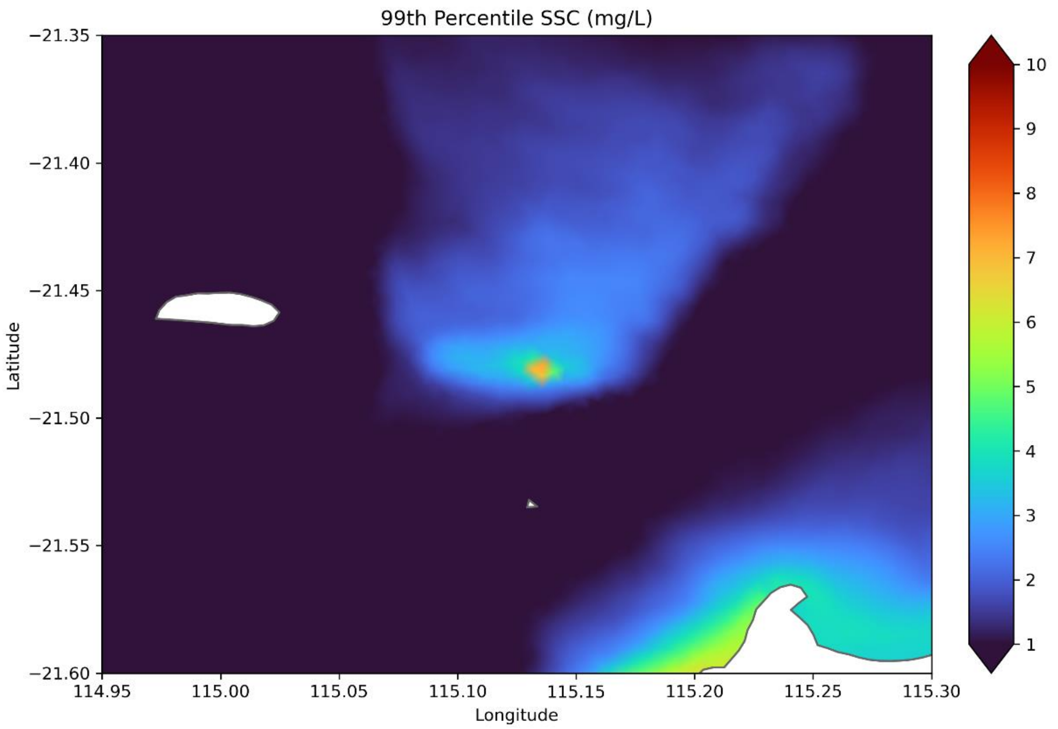


Figure 18 Scenario 2: 99th SSC percentile plots at disposal (Note: the figure presents above background SSC, whereby the maximum total SSC within all vertical cells is presented). The contours in these maps cover a much larger area than the plume at any single point in time.

6. Discussion: environmental impact assessment

6.1. Zone of Influence

The ZoI has been calculated according to Section 4.3. ZoI for Scenario 1 and 2 are shown in Figure 19 and Figure 20, respectively.

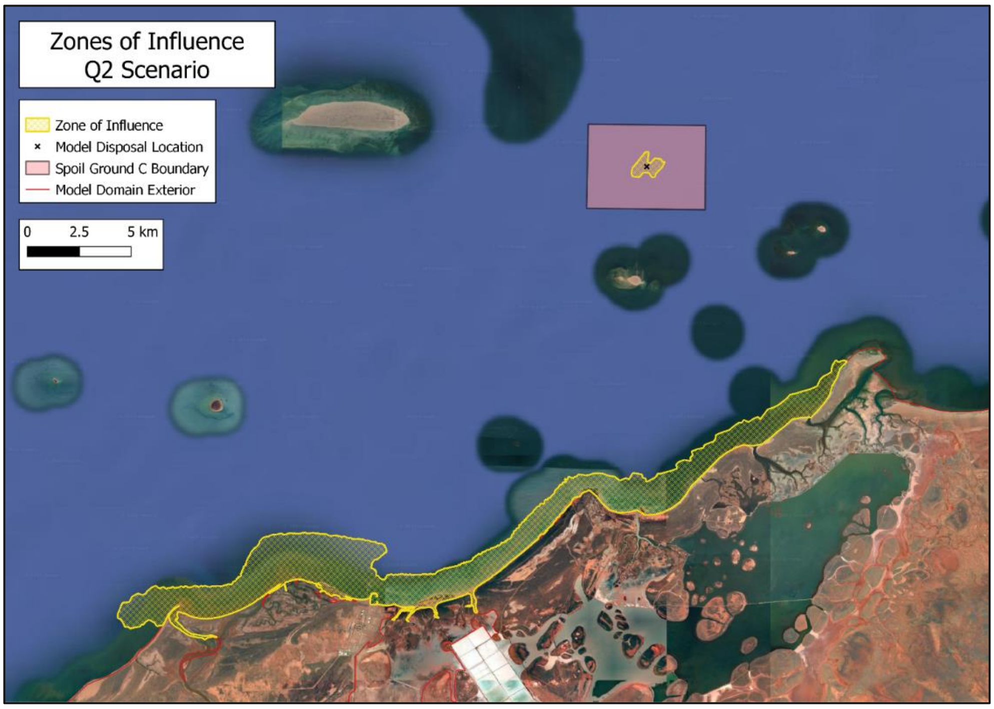


Figure 19 Scenario 1 (Q2 Scenario): Zone of Influence

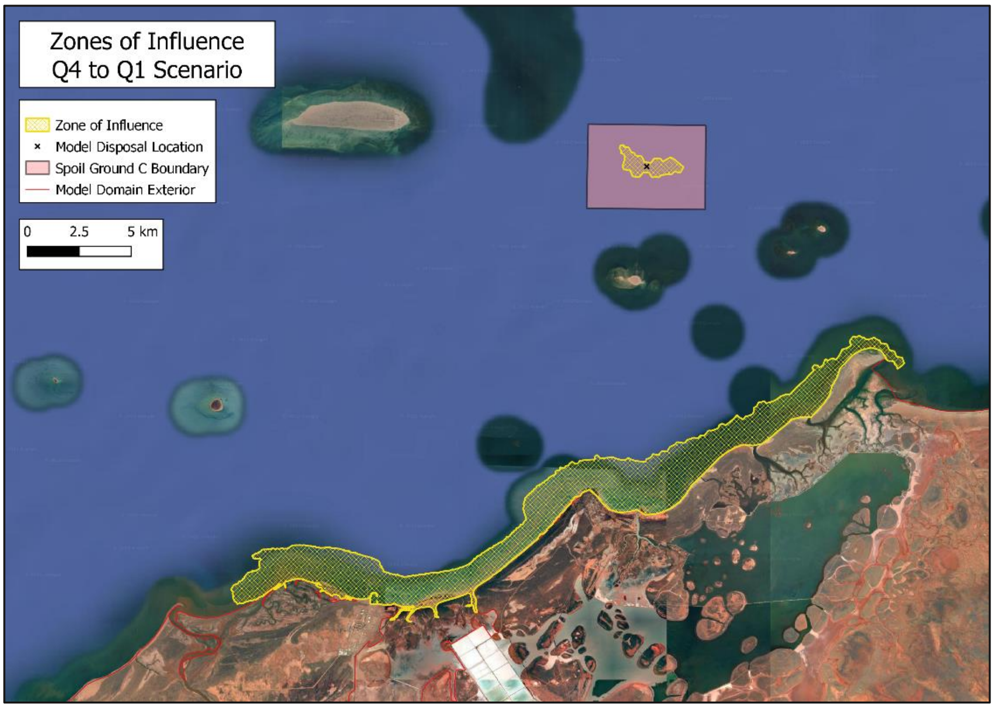


Figure 20 Scenario 2 (Q4 to Q1 Scenario): Zone of Influence

6.2. Zones of Impact

Zones of impact have been calculated using the assessment method defined in Section 4.3. Figure 21 and Figure 22 present the zones of impact for Scenario 1 and 2 respectively. There are no zones of impact (moderate or high) within the disposal ground footprints for neither Scenario 1 nor Scenario 2, thus Figure 21 and Figure 22 are cropped to the coastline).

Scenario 1 only produces a possible and probable ZoMI (no possible or probable ZoHI), which mainly surrounds the dredge footprint and MOF. The outer extent of the ZoMI is controlled by the DLI thresholds rather than the combination of SSC and DLI. The relative large patch of possible ZoMI just prior to Onslow corresponds to an area that does not experience high SSC (refer Figure 15), however it results from the DLI thresholds given its deeper bathymetry compared to its surroundings. The concentrations experienced in this patch of ZoMI is so small that the majority of this patch sits outside of the ZoI (i.e. the majority of this patch does not experience SSC concentrations greater than 5 mg/l during the simulation). Other small patches in the possible ZoMI observed along the coast between Ashburton and Onslow are bathymetry artifacts: they experience about the same mass passing through these locations however the volume of each cell is smaller, hence creating a higher concentration and significantly reducing DLI), but not being shallow enough at some timesteps to be removed by the depth cut-off described in Section 4.3.

Scenario 2 produces a possible and probable ZoMI that are similar in behaviour to those observed in scenario 1, however they are smaller. Scenario 2 also produces a possible ZoHI which is confined to a small area within and close to the dredge footprint. As it was the case in Scenario 1, the outer extent of the ZoMI is controlled primarily by the DLI thresholds alone. Whilst Scenario 2 produced higher concentrations than Scenario 1, the extra light availability during the December to January period results in slightly smaller ZoMIs than in Scenario 1. As the ZoHI is determined by a combination of SSC and DLI thresholds, the higher SSC concentrations from Scenario 2 lead to a smaller ZoHI in the dredge footprint than Scenario 1. The increased light availability during Scenario 2, also acts to reduce some of the patchy portions of the possible ZoMI that was observed in Scenario 1, most notably the lack of possible ZoMI just west of Onslow.

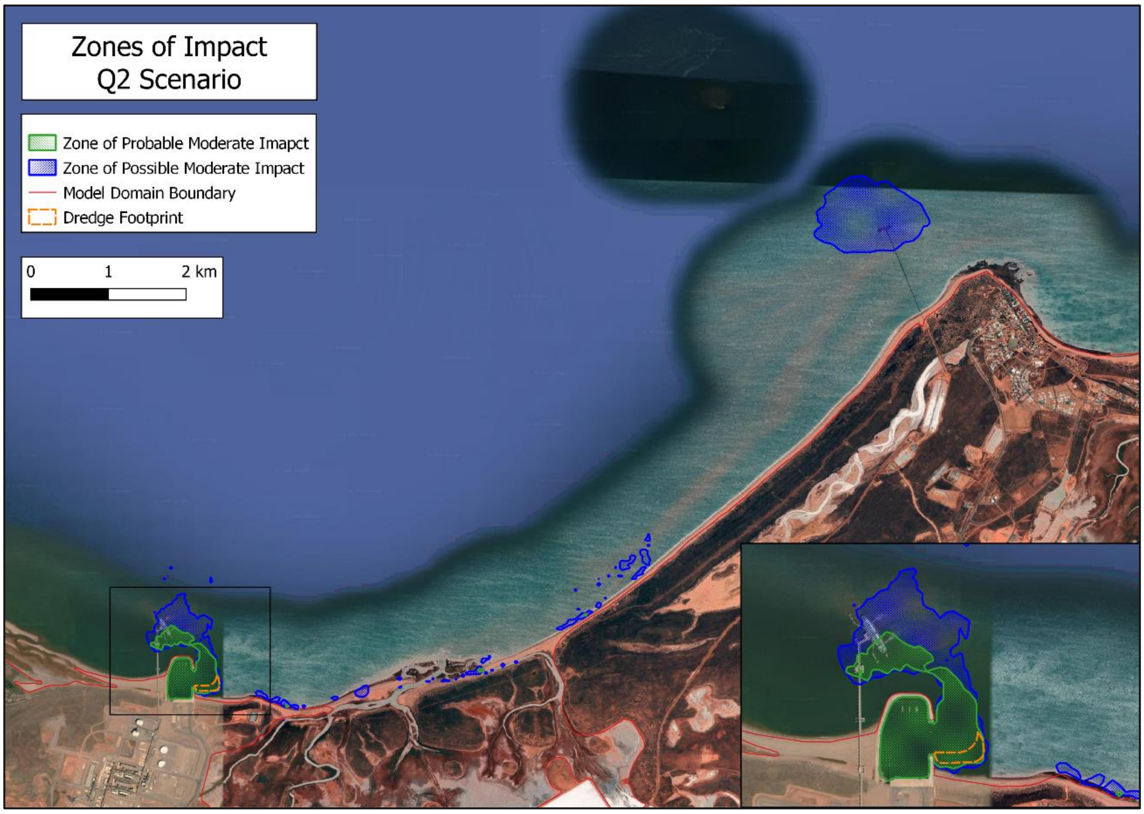


Figure 21 Scenario 1 (Q2 Scenario): Zones of Impact

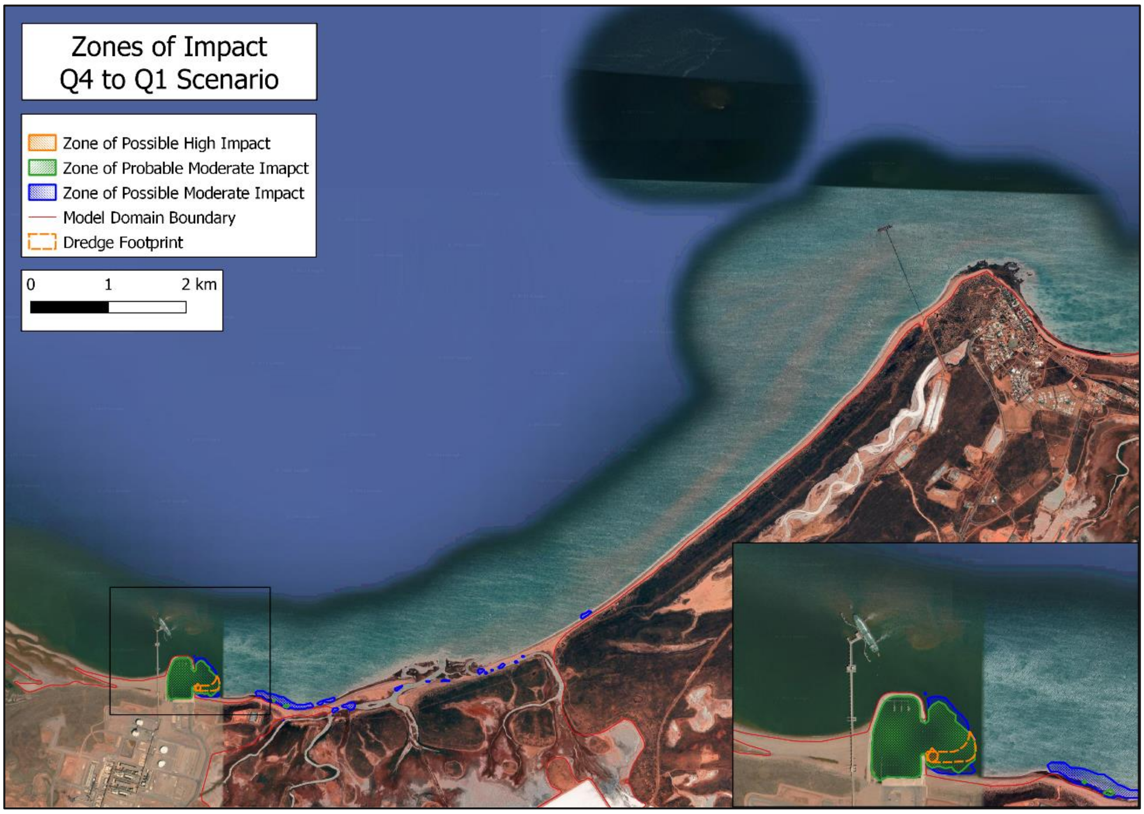


Figure 22 Scenario 2 (Q4 to Q1 Scenario): Zones of Impact

6.3. Comparison with past projects

6.3.1. Mardie project

The Mardie project featured similarities in terms of the dredge program, with both projects utilising a backhoe dredger with a hopper barge. Dredge rates were also comparable as the Mardie project simulated between 100 m3 and 125 m3 per hour in comparison with 112.5 m3 in this project. Similarities extend further to the model inputs as sediment fractions, sediment settling velocities, and plume spill rates also were close in magnitude between the two projects. We note that the spill rate for a hopper barge overflow was quite high in the Mardie project; O2M's review of available source term in the literature suggests that Baird's selected overflow terms are more in line with overflow from a hydraulic dredged material with high water content than a backhoe dredger, and thus O2M believe that the selection of a smaller overflow for the far-field source term of mechanically dredged material is more appropriate.

The zones of impact presented in the Mardie Project appear in scale with those of the AIP project, whereby in both cases they were relatively constrained to the dredge footprint.

6.3.2. Wheatstone LNG project

As expected, the zones of impact produced in the Wheatstone study are much larger than the zones of impact generated in the AIP project simulation; Wheastone's dredging program was considerably larger. Whilst the spatial extent cannot be entirely compared to this project, a similar behaviour of the sediment plumes is inferred from the spread of the zones of impact to the northeast and south westerly directions. Chevron (2016) also noted similar behaviour in response to the net drift of the zones of impact, being that the net drift is primarily driven by wind fields and therefore the seasonality in wind speed and direction can drive the spatial extent of the plume. This was evident in the general behaviour of both the plume and zones of impact in this study (AIP) which featured a plume/zone drift following the periodic wind driven currents.

6.4. Intersection of zones of impact and mapped benthic habitats

The intersection of zones of impact with the mapped BCH identified in O2 Marine (2021d) are presented graphically in Figure 23 and Figure 24 for Scenario 1 and 2, respectively. A conservative measure has been taken to list the entirety of the dredge footprint as a ZoHI, hence the ZoHI for Scenario 1 for which no modelled ZoHI (possible or probable) was detected, covers the dredge footprint only (Figure 23). Conversely, as a possible ZoHI was calculated for Scenario 2 using the EPA (2021) impact assessment method, the ZoHI in Figure 24 extends to the outermost extent of the combined dredge footprint and derived ZoHI using the EPA criteria.

Table 9 presents the calculated areas of overlap between the zones of impact and the BCH for both scenarios. Zones of impact from Scenario 1 overlaps predominantly with bare substrate, with some small overlap with the sand veneered limestone pavement and sand with sparse filter feeders (less than 1 ha of overlap each). Zones of impact from Scenario 2 only overlap with bare substrate, with areas of intersection being smaller than those in Scenario 1.

Table 9 Zone of impact intersection with BCH for both modelled scenarios. (Note: intersection areas have been rounded up to the closest whole number)

Scenario	Zone of Impact	Bare Substrate (ha)	Sand Veneered Limestone Pavement (ha)	Sand with Sparse Seagrass (ha)	Sand with Sparse Filter Feeders (ha)	Coral (ha)
1 (Q2)	Moderate (Possible)	156	1	-	1	-
	Moderate (Probable)	40	-	-	-	-
	High	3	-	-	-	-
2 (Q4 to Q1)	Moderate (Possible)	8	-	-	-	-
	Moderate (Probable)	26	-	-	-	-
	High	3	-	-	-	-

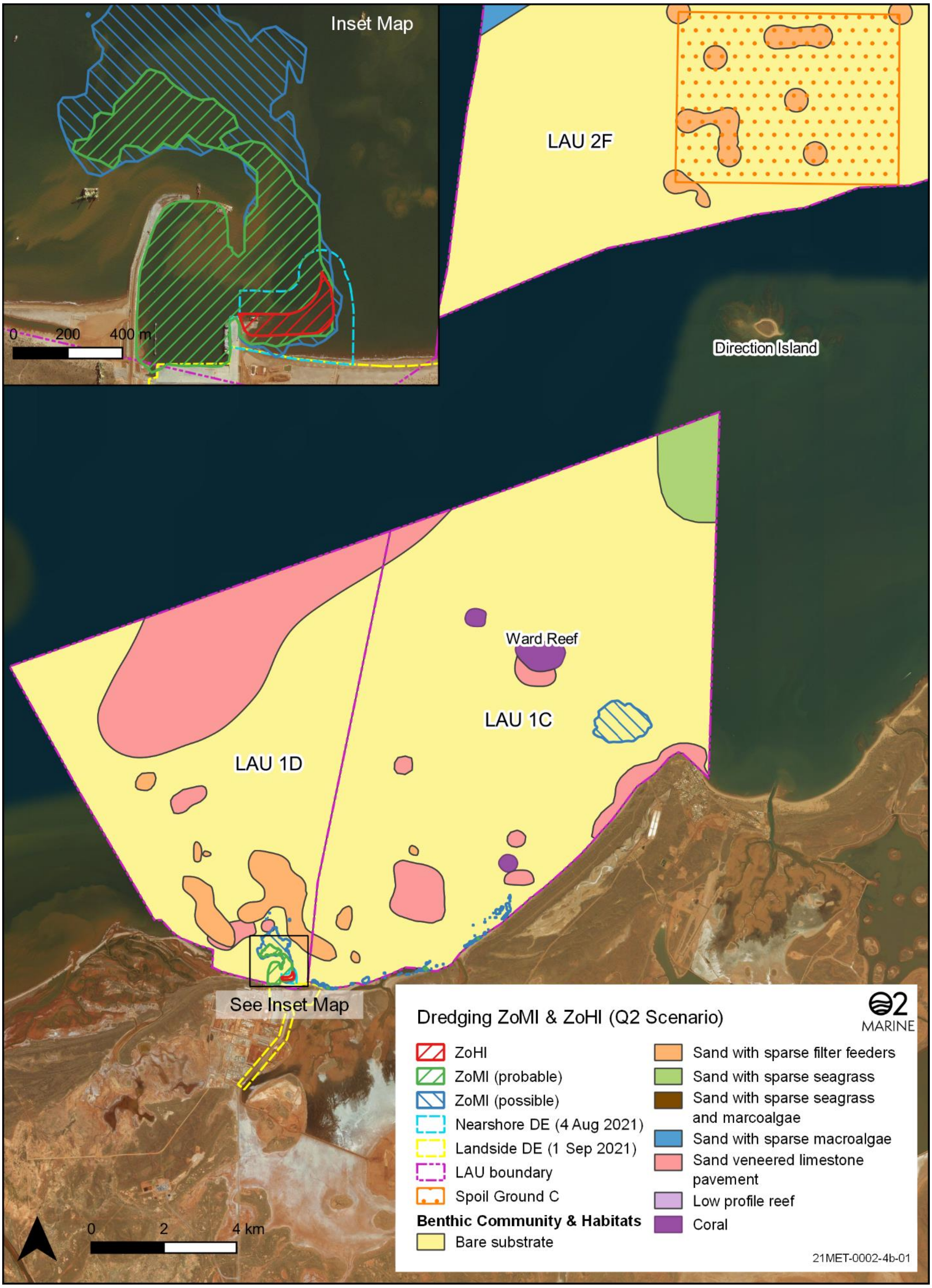


Figure 23 Scenario 1 (Q2) zones of impact intersection with BCH

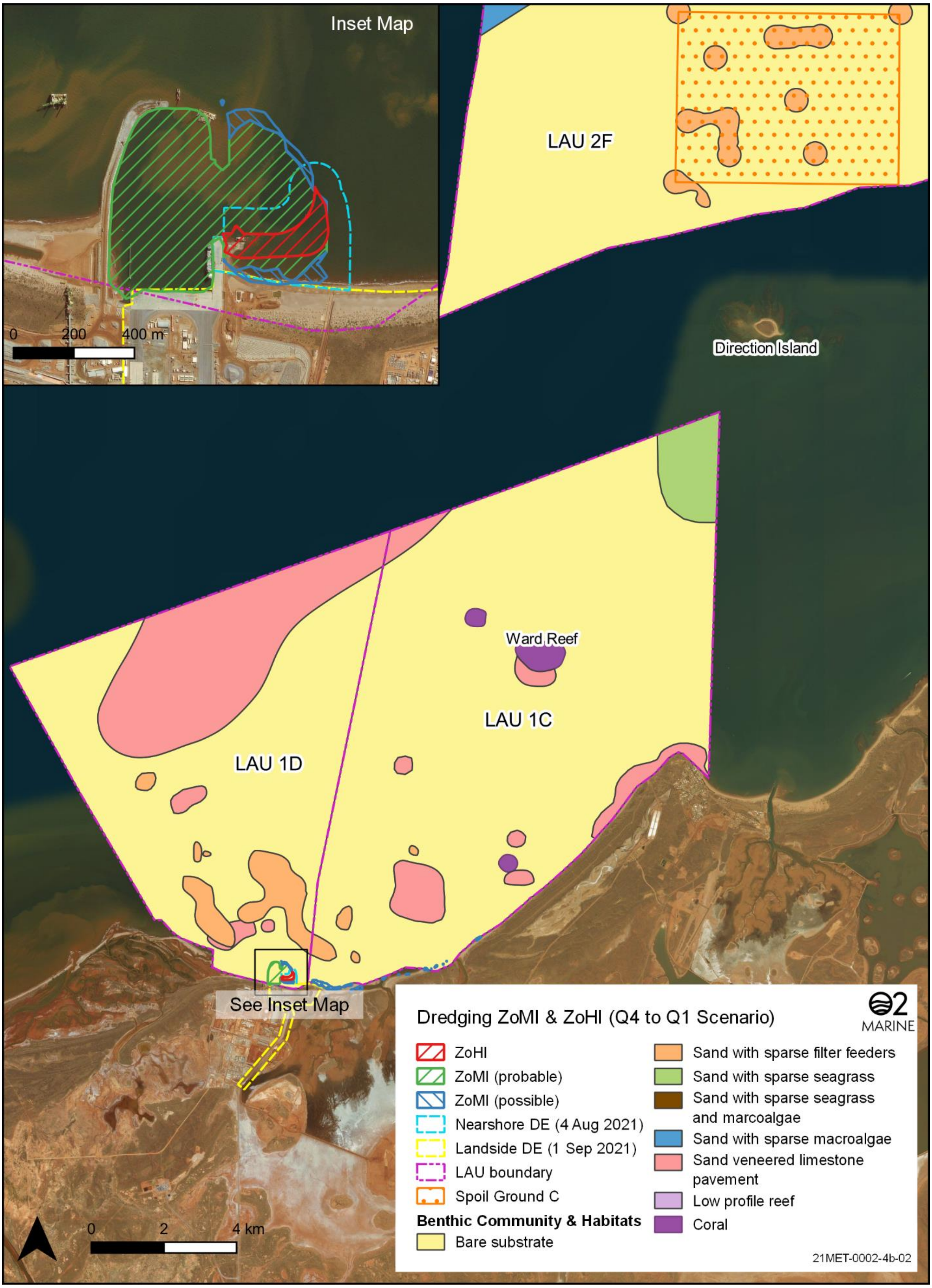


Figure 24 Scenario 2 (Q4 to Q1) zones of impact intersection with BCH

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