Dredge Plume Modelling Report

ESSP Scenario 7.2.1

CLIENT: Leichhardt Salt Pty Ltd

STATUS: Rev 2

REPORT NUMBER: 24MET199/ R240475

LECHHARDT DOCUMENT NUMBER: ESSP-EN-14-TRPT-0049

ISSUE DATE: 21 March 2025

O2 Metocean PTY LTD | ABN 29 630 318 848| www.o2marine.com.au

Important Note

This report and all its components (including images, audio, video, text) is copyright. Apart from fair dealing for the purposes of private study, research, criticism or review as permitted under the *Copyright Act 1968*, no part may be reproduced, copied, transmitted in any form or by any means (electronic, mechanical or graphic) without the prior written permission of O2 Metocean.

This report has been prepared for the sole use of the **Leichhardt Salt Pty Ltd** (herein, 'the Client' or 'Leichhardt'), for a specific site (herein 'the site'), and the specific purpose specified in Section 1 of this report (herein 'the purpose'). This report is strictly limited for use by the client, to the purpose and site and may not be used for any other purposes.

Third parties, excluding regulatory agencies assessing an application in relation to the purpose, may not rely on this report. O2 Metocean waive all liability to any third-party loss, damage, liability or claim arising out of or incidental to a third-party publishing, using or relying on the facts, content, opinions or subject matter contained in this report.

O2 Metocean waive all responsibility for loss or damage where the accuracy and effectiveness of information provided by the client or other third parties was inaccurate or not up to date and was relied upon, wholly or in part in reporting.

This report contains maps that include data that are copyright to the Commonwealth of Australia (Geoscience Australia) 2006 and Microsoft Corporation Earthstar Geographics SIO (2022).

Maps are created in GDA2020 MGA zone 50 (EPSG:7850) coordinate reference system, unless otherwise stated, and are not to be used for navigational purposes. Positional accuracy should be considered as approximate.

O2 Metocean (An O2 Marine Company)
ABN 29 630 318 848

Head Office – Perth, Western Australia

11 Mews Road FREMANTLE WA 6160

T 1300 219 801 | info@o2marine.com.au

Version Register

Version	Status	Author	Reviewer	Approver	Date
Rev A	O2M Internal use only	J.O.C.	-	-	-
Rev B	Draft for Client Review	J. Owen-Conway	S. Morillo	S. Morillo	17/Jan/2025
Rev 0	Awaiging for figures	J. Owen-Conway	S. Morillo	S. Morillo	02/Feb/2025
Rev 1	Minor updates included	J. Owen-Conway	S. Morillo	S. Morillo	18/Feb/2025
Rev 2	For Client use	J. Owen-Conway	S. Morillo	S. Morillo	21/Mar/2025

Transmission Register

Controlled copies of this document are issued to the persons/companies listed below. Any copy of this report held by persons not listed in this register is deemed uncontrolled. Updated versions of this report if issued will be released to all parties listed below via the email address listed.

Name	Email Address
Regina Flugge	Regina.flugge@leic.com.au
Laurie Huck	Laurie.Huck@leic.com.au
Phoebe Ranford	pranford@prestoncolsulting.com.au

Changes from Previous Versions

Changes beyond amendment of typographical and formatting errors, or adjustment of text for clarity are listed below.

Section	Change
-	-

Acronyms, Abbreviations and Definitions

Acronyms & Abbreviations	Definitions
3D	Three-Dimensional
AHD	Australian Height Datum
B	Contribution due to suspended sediments to underwater light attenuation
BCH	Benthic Communities and Habitats
BH	Borehole
CSD	Cutter Suction Dredge
DHI	DHI Group
DLI	Daily Light Integral, also Integrated Daily Light
DSN	Dredge Science Node
EIA	Environmental Impact Assessment
EP Act	*Environmental Protection Act 1986*
EPA	Environmental Protection Authority
EPBC Act	*Environmental Protection and Biodiversity Conservation Act 1999*
ESD	Environmental Scoping Document
ESSP / the Project	Eramurra Solar Salt Project
FM	Flexible Mesh
HD	Hydrodynamic
I	Light intensity
I_0	Light intensity immediately below the sea surface
IMO	Insitu Marine Optics
k	Light attenuation coefficient
K_d	Downwelling light attenuation coefficient (function of light wavelength)
k_{d490}	Light attenuation coefficient at 490 nm wavelength
k_{PAR}	Light attenuation coefficient applicable to the full PAR spectrum
K_w	Light attenuation coefficient in clear ocean) water, for a particular light wavelength
$K_{w, PAR}$	Light attenuation coefficient in clear ocean) water, applicable to the full PAR spectrum
MIKE	MIKE Software by DHI

Acronyms & Abbreviations	**Definitions**
MNES	Matters of National Environmental Significance
MS	Ministerial Statement
Mtpa	Million tonnes per annum
MT	Mud Transport
NTU	Nephelometric Turbidity Unit
O2M	O2 Marine
O2Me	O2 Metocean (an O2 Marine Company)
PAR	Photosynthetic Active Radiation
PSD	Particle Size Distribution
ρ_b	Dry bulk density of a material
ρ_{dry}	Dry bulk density of marine sediments, general
SSC	Suspended Sediment Concentration
TSS	Total Suspended Solids
The Proposal	The ESSP (Project) at the proposal stage.
WA	Western Australia
WAMSI	Western Australian Marine Science Institute
X_{clay}, X_{silt}, X_{sand}	Percentages of clay, silt, and sand based on the PSD of each geological stratum
z	Depth below the sea surface (positive down)
ZoI	Zone of Influence
ZoHI	Zone of High Impact
ZoMI	Zone of Moderate Impact

Executive Summary

Leichhardt Salt Pty Ltd (Leichhardt) proposes to construct and operate the Eramurra Solar Salt Project (ESSP), a solar salt project with an annual average production capacity of 5.2 million tonnes per annum (Mtpa), and up to 6.8 Mtpa deposited in a low rainfall year, of high-grade salt (sodium chloride (NaCl) from seawater). The salt will be produced using a series of concentration ponds and crystallisers with a processing plant, transport corridor, stockpiling and export from the Cape Preston East Port (the Proposal). Dredge material will be disposed of onshore in decantation ponds within the Ponds and Infrastructure Development Envelope and offshore using hopper barges.

To minimise the potential environmental impacts associated with the proposed action, Leichhardt have iteratively refined the ESSP dredge and disposal program, drawing on feedback received from the EPA and insights and expertise from a wide range of disciplines. This report presents the sediment plume transport and dispersion assessment for Leichhardt's dredging and disposal program under ESSP Scenario 7.2.1, with an upper estimate of dredging and disposal volume of 398,000 m^3. This work expands upon the sediment plume transport modelling study for the ESSP Scenario 7.2, also conducted by O2Me for Leichhardt (O2Me 2023a). Key refinements to the dredging and disposal program under ESSP Scenario 7.2.1 relative to Scenario 7.2, aimed at reducing the amount of Proposal-generated fines released in the water column, are as follows:

- Increased certainty of the estimated dredge volume, with a minimum dredging requirement of 230,000 m^3 and a maximum of 398,000 m^3 which enhances operational safety.
- Repositioned dredge footprint to minimise dredging into the Calcrete sediment to significantly reduce the generation of fine particles available for suspension.
- Revised disposal regime redirecting the disposal of dredged material from the southern channel extent and berth pocket (up to 234,000 m^3) to onshore, thereby eliminating two significant dredge plume sources while dredging in these regions: overflow from hopper barges and disposal offshore. The improvement cannot be implemented in the Northern channel extent due to engineering, operational, and safety limitations.

The program examined in this study includes:

Aspect	Description
Dredge methodology	Cutter suction dredger (CSD)
Dredge volume	**Base Case** = 230,000 m^3 **High Volume Case**: 398,000 m^3
Disposal methodology	**Preferred Option**: Combination of onshore and offshore dredge material disposal, with southern channel and berth pocket disposed onshore and northern channel disposed offshore using hopper barges. **Alternative Option**: All material disposed offshore.
Dredging Schedule	Occurs between June and September, with 21 hr of effective dredging operations a day, 7-days a week, with 1-week break approximately mid-way through the dredging program.

O2Me adopted a nested approach to numerical modelling, which allowed for higher numerical resolution in the region of interest. Boundary conditions (fluxes and water levels) for the local model were derived from O2Me's regional Pilbara Model described in O2Me (2022a). Surface stress and barometric pressure were extracted from the European Centre for Medium Range Weather Forecasts ERA5 model. Four types of sediment plume sources were considered: the spill at the dredging site, the hopper barge overflow during loading or the onshore disposal tailwater discharge (dependent on disposal activity at that time), the offshore disposal and erosion of disposed material. Modelling was conducted using DHI's Mike 3 HD/FM/MT suite of models.

The dredge area was split into three zones: southern channel extent, berth pocket deepening and northern channel extent. Each zone was modelled with a uniform Particle Size Distribution (PSD) representative of the material within that zone. The representative PSD for each zone was based on the borehole and surficial PSD data collected within and surrounding each zone. Four sediment fractions were defined in the far-field model to represent material within the dredge cut that are < 250 µm in particle size: clay, silt, fine sand (lower) and fine sand (upper). All larger material (> 250 µm) do not contribute to dredge plume and settle near the source when released into the water column. Above background suspended sediment concentration (SSC) was modelled, and background SSC was added to the modelling results during post processing.

Leichhardt's increased confidence in the design of the dredging and dredge material disposal campaign has enabled the relaxation of a highly conservative numerical modelling assumptions used in the ESSP Scenario 7.2. The assumption of hindered settling of fines fractions has been replaced with the industry-standard approach of constant settling velocities.

A range of light attenuation models were tested to select a fit-for-purpose model of benthic light. A spectral diffuse attenuation model developed specifically for Cape Preston was adopted in the conversion of SSC to light attenuation coefficient for use in the Daily Light Integral (DLI) calculations. A discrete 3D approach was adopted for light attenuation through a vertical variation in SSC such that light attenuation was calculated separately for each of the 10-layers modelled. The light attenuation relationship was also applied discretised in wavenumber space using a relationship defined for Cape Preston for 20 nm increments of wavelengths within the Photosynth Active Radiation (PAR) band. The light model was qualitatively validated by comparing the Zone of Moderate Impact (ZoMI) derived for ambient conditions, to the coral habitats identified in the subtidal benthic communities and habitats (BCH).

Impacts to BCH are the primary consideration for the Environmental Impact Assessment (EIA) of dredge and disposal plumes. The dominant light- and SSC-sensitive BCH communities in the Cape Preston region are corals and seagrass, though filter feeders and macroalgae are also found. Assessment of the sediment plume fate in terms of spatial extent of SSC and benthic light (i.e. DLI) was conducted for the maximum dredge volume simulations for both disposal options. The Zone of Influence (ZoI), Zone of High Impact (ZoHI) and ZoMI were determined by analysing model results as running mean values of SSC (including background SSC), derived DLI, and the combined effects of SSC and DLI, as recommended in the EPA (2021) guidance for EIA of dredge plume modelling, applied to corals and seagrass.

Analysis of the modelling results for the higher volume case and both disposal options, revealed that:

- Moderate and High impact criteria for Seagrass (ZoMI and ZoHI) was not exceeded.
- Moderate Impact criteria for Corals (ZoMI) was exceeded for possible thresholds only:

  - The possible ZoMI associated with 100% offshore disposal is 6.47 ha in total area and intersects with 0.94 ha of coral habitat
  - The possible ZoMI associated with onshore and offshore disposal is 0.12 ha in total area and intersects with 0.06 ha of coral habitat
- High impact criteria for Corals (ZoHI) was not exceeded (indirect impacts considered, only).

Leichhardt is committed to the minimisation of dredge and disposal impacts associated with the ESSP, and through iterative project refinement which has incorporated feedback received from the EPA, the estimated impacts to BCH associated with the maximum dredge volume for both disposal options have been minimised, so that they are restricted to being within and closely nearby the dredge footprint.

A formal EIA was excluded from this report.

Contents

Tables

Figures

1. Introduction

1.1. Project Overview

Leichhardt Salt Pty Ltd (Leichhardt) proposes to construct and operate the Eramurra Solar Salt Project (ESSP), a solar salt project with an annual average production capacity of 5.2 million tonnes per annum (Mtpa), and up to 6.8 Mtpa deposited in a low rainfall year, of high-grade salt (sodium chloride (NaCl) from seawater). The salt will be produced using a series of concentration ponds and crystallisers with a processing plant, transport corridor, stockpiling and export from the Cape Preston East Port (the Proposal). The concentration ponds and crystallisers will be located on mining leases.

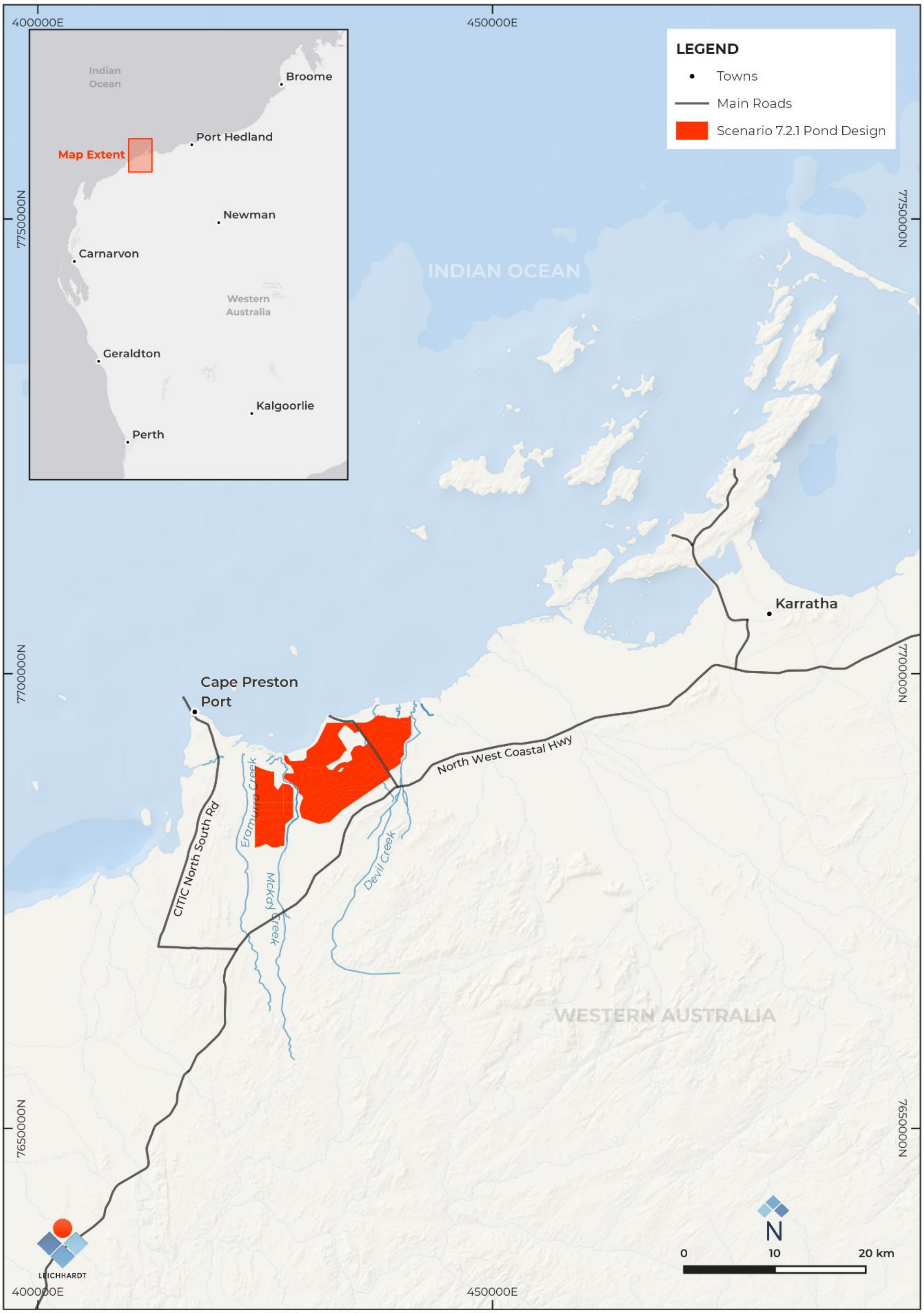
The export of salt is proposed to be via a trestle jetty. The jetty and associated stockpiles will be located at the Cape Preston East Port approved by Ministerial Statement (MS) 949. Dredging of the proposed channel and berth pocket will be undertaken as part of this Proposal. Dredged material will be disposed of both at an offshore disposal location and onshore within the Ponds and Infrastructure Development Envelope. The Cape Preston East Port jetty and associated stockpiles are excluded from the proposal.

Bitterns will be transported by pipeline attached to the trestle jetty structure and discharged via a diffuser located off the trestle jetty.

The proposal is located in the western Pilbara region of WA, approximately 55 km west-southwest of Karratha (Figure 1 and Figure 2). The summary project description is detailed in Table 1.

Table 1: Short Summary of the Proposal

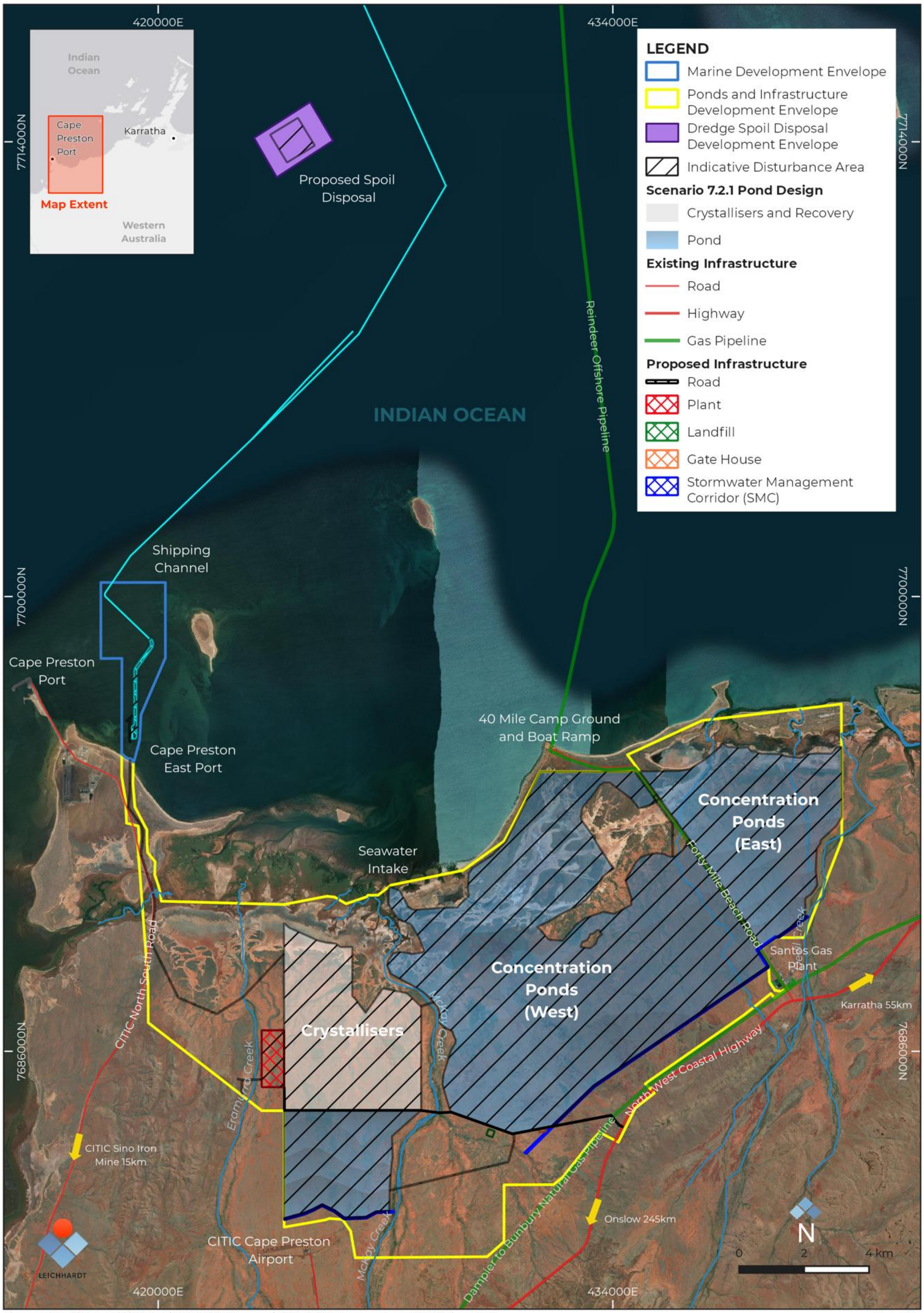
Project Title	Eramurra Solar Salt Project
Proponent Name	Leichhardt Salt Pty Ltd
Short Description	Leichhardt Salt Pty Ltd (Leichhardt) is seeking to develop a solar salt project in the Cape Preston East area, approximately 55 km west-southwest of Karratha in WA (the Proposal). The Proposal will utilise seawater and evaporation to produce a concentrated salt product for export. The Proposal includes the development of a series of concentration ponds, crystallisers and processing plant. Supporting infrastructure includes bitterns outfall, drainage channels, product dewatering facilities, desalination plant, pumps, pipelines, power supply, access roads, administration buildings, workshops, laydown areas, landfill facility, communications facilities and other associated infrastructure. The Proposal also includes dredging at the Cape Preston East Port with disposal of dredge material at an offshore location and onshore within the Ponds and Infrastructure Development Envelope.



Document Path: X:\Project_ESS\ESS_Jobs\J00081 - ERD_Document\J0081_F_ERD_Figures.qgz, Layout: J00081_ContextMap

Created By: GIS

Figure 1: Regional location of the Proposal (ESSP 7.2.1)



Document Path: X:\Project_ESS\ESS_Jobs\J00081 - ERD_Document\J0081_F_ERD_Figures.qgz, Layout: J00081_Scenario721

Created By:
SamWilson

Figure 2: Development Envelopes (ESSP 7.2.1)

1.2. Purpose of this report

The need for a dredge plume dispersion modelling study is outlined in Items 10, 11, 12, 17, and 40 of the Environmental Scoping Document (ESD) (Preston Consulting 2022), reproduced in Table 2.

Table 2: Work required for the assessment of the ESSP related to potential impacts to Benthic Communities and Habitats (BCH) and Marine Environmental Quality attributable to the ESSP which require a dredge plume dispersion modelling study (ESD, Preston Consulting 2022)

ESD Item Number	Environmental Factor	Work required
10	BCH	Undertake a dredge plume dispersion modelling study, utilising local conditions and proposed dredge sediment characteristics, to understand potential impacts to BCH resulting from dredge and spoil disposal activities. Model outcomes will be interpreted against the appropriate thresholds for the relevant BCH. Dredge plume modelling must consider the recommendations within Sun, Branson and Mills (2020): Guidelines on dredge plume modelling for environmental impact assessment. Prepared for Dredging Science Node, Western Australian Marine Science Institution, Perth, WA. 37 pp and EPA's Technical Guidance – Environmental impact assessment of marine dredging proposals.
11	BCH	If the dredge plume dispersion modelling identifies potential impacts on coral BCH, then […]
12	BCH	If the dredge plume dispersion modelling identifies potential significant impacts to macroalgae (including Sargassum) and/or bluespotted emperor recruitment BCH, then […]
17	BCH	Prepare a Dredging Spoil and Disposal Monitoring and Management Plan (DSDMMP) […]. The DSDMMP will consider the results of dredge plume modelling […]
40	Marine Environmental Quality	Undertake a dredge plume dispersion modelling study, utilising local conditions and proposed dredge sediment characteristics to understand potential impacts to marine environmental quality resulting from dredge and spoil disposal activities.

The purpose of this report is to describe the dredge plume modelling study undertaken by O2 Metocean (O2Me) on behalf of Leichhardt to support the evaluation of the effects of Project attributable changes on the Key Environmental Factors 'Benthic Communities and Habitats' (BCH) and 'Marine Environmental Quality', required to inform the assessment of environmental impacts from the ESSP as specified in the ESD (Preston Consulting, 2022).

1.3. Objective

The objective of this study was to provide:

1. An informed prediction of the potential fate of sediments mobilised during dredging and sea dumping associated with the ESSP
2. Provide data (zones of impact) to support the EIA of the ESSP.

1.4. Scope of Work

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

1. Conduct a desktop review of the proposed dredge methodology, available geotechnical information and water quality reports.
2. Derive sediment flux inputs for three-dimensional (3D) far-field (transport distances greater than a few hundred metres) numerical assessment based on the above.
3. Conduct a 3D far-field numerical assessment of dredge and dredge spoil disposal plume dispersion under varied environmental conditions.
4. Estimate the effect of the dredge plume on benthic light.
5. Generate zones of impact and a zone of influence in accordance with the Environmental Protection Authority of WA (EPA) Technical Guidance for the Environmental Impact Assessment of Marine Dredging Proposals (EPA, 2021) for the purpose of environmental impact assessment for the environmental conditions modelled.

Assessment of the environmental impact caused by the dredge and spoil disposal sediment plumes in this document is limited to the indirect impacts (i.e. in the far-field, also known as 'passive' impact). Direct physical impact inside the dredge footprint and immediate surroundings (near-field, also known as 'dynamic') is excluded from this assessment.

1.5. Exclusions and Limitations

Excluded from the scope of work, and therefore this report, is the following:

- Assessment of benthic habitats
- Impact assessment for benthic habitat that does not have any component related to dredging (such as the high impact assessment for seagrasses which is dependent on viable seedbank presence rather than any parameter related to dredging)
- Assessment of direct physical impact inside the dredge footprint and immediate surroundings.

1.6. Definitions and Conventions

Directional convention: Throughout this report, wind and wave directions will assume the standard meteorological convention of 'coming from', while currents will retain the standard oceanographic convention of 'flowing to'.

Directional Acronym Conventions: When describing the directionality of metocean parameters (such as wind, waves and currents), acronyms for direction are used in the report. For example, a wind direction may be described as SSE instead of a south-southeast. The exceptions to this convention include:

- when describing direction within a header
- when describing a proper noun (such as ‘Southwest Regnard Island’ or ‘Southwest Trade Winds’)
- when describing the direction that is not related to measured data or metocean parameters (such as describing a location for example ‘southern Australia’).

1.7. Reports of Relevance

A set of reports have been prepared to address items identified in the ESD related to the dredge plume program. A base hydrodynamic model (O2Me 2022a) capable of reproducing ambient waves, currents, and water levels E of Cape Preston was validated with locally acquired data (O2Me 2022b, 2022c). The base model was then adjusted to answer specific questions related to the EIA of the ESSP, such as dredge and dredge disposal plume dispersion modelling to assist with the assessment of impacts to BCH (O2Me 2025, this document).

2. Proposed Dredging Program

2.1. Program Refinement

Since 2022, Leichhardt have iteratively refined the ESSP dredge and disposal program, drawing on insights and expertise from a wide range of disciplines, including water technology specialists, dredge contractors, geomorphologists, port operations experts, hydraulic engineers, and more. Through the refinement phase, Leichhardt has worked to thoughtfully incorporate feedback from the EPA, specifically to enhance clarity of the proposed action and minimise modelling conservatism associated with program or data uncertainty. Key refinements incorporated to Scenarios 7.2 and the most recent 7.2.1 since 2022's ESSP Scenario 6.2 are summarised in Table 3.

This report describes the modelling methodology and dredge plume fate and transport results associated to Scenario 7.2.1.

Table 3: Historical dredge and disposal program refinement

ESSP Scenario	Refinement of dredge and disposal program and/or modelling approach
6.2	• Initial dredging program adopted for hydrodynamic modelling. • Dredging of 314,000 m^3 of material with offshore disposal.

7.2
([1])
	• Dredge footprint relatively unchanged compared to Scenario 6.2, with the exemption of a change to the berth pocket.
	• Dredge and disposal volume conservatively increased to 400,000 m^3 to account for unplanned over-dredge, channel widening for safe navigation, etc.
	• Offshore disposal ground 'Spoil Ground C' selected.
	• Enhanced interpretation of modelling results to more effectively delineate impact zones caused by benthic light reduction:
	  ◦ Validation of the light attenuation model by assessing the alignment between the boundaries of 'natural zones of impact' and BCH mapping. Natural zones of impact are defined as areas affected by light reduction due to naturally occurring suspended sediment, based on the assessment criteria for light reduction for corals, .
	  ◦ Zones of impacts due to ESSP dredge and disposal activities delineated for areas outside the naturally impacted zones.

7.2.1
([2])
	• Southern end of dredge footprint shifted northward by approximately 50 m to:
	  ◦ Integrate natural depressions in the bathymetry into the design to minimise dredging volumes.
	  ◦ Practically eliminate the need to dredge into the calcrete layer and therefore substantially reduce the generation of fines material.
	• Substantial reduction of fine material overflow (both at dredging and disposal sites) by incorporating onshore disposal during dredging of the southern-channel and berth pocket into the design.
	• Replacement of the ultra-conservative 'hindered settling' modelling assumption with the industry-standard 'constant settling' technique.

---

[1] Investigated in O2Me (2023a)

[2] This report.

2.2. Dredging and Disposal Program associated to ESSP Scenario 7.2.1

Leichhardt estimate that the total volume required to be removed to meet the ESSP Scenario 7.2.1 refined navigational channel, turning basin, and berth pocket design is 230,000 m^3. This volume is referred to as 'Base Case'. Design berth pocket and navigational channel dredge depths for the Base Case are 4.5 m CD and 6.7 m CD, respectively. Over-dredge and channel deepening or widening to accommodate for navigational safety recommendations may result in a larger dredge volume. Therefore, in this modelling exercise two dredge volumes were considered:

- **Base Case**: Leichhardt's best estimate of 230,000 m^3 considered the minimum dredge volume required to achieve the design; and
- **High Volume Case**: Upper limit dredge volume of 398,000 m^3, which accounts for the Base Case and the following increments:
    - Channel widening at the channel bend location (58,000 m^3)
    - Channel deepening by 0.3 m (54,000 m^3)
    - Berth pocket widening (9,000 m^3)
    - Expansion of turning area (18,000 m^3)
    - Over dredging allowance of 0.3 m (29,000 m^3)

Leichhardt opted to dredge the navigational channel, turning basin, and berth pocket with a Cutter Suction Dredger (CSD). The extents of each segment are shown in Figure 3.

To assist Leichhardt with their dredge and disposal program definition and better inform the EIA, two dredge material disposal options were considered in this study:

- **Disposal Option A**: 100% of material disposed offshore (as it was the case for Scenario 7.2, O2Me 2023a) to account for the possibility of onshore disposal location being technically unfeasible; or
- **Disposal Option B** (preferred): A combination of onshore and offshore dredge material disposal:
    - Southern channel and berth pocket: disposed onshore via pipeline.
    - Northern channel: disposed offshore using hopper barges

In summary, four dredging cases were considered:

- Base Case – Disposal Option A (230,000 m^3 offshore)
- Base Case – Disposal Option B (178,500 m^3 onshore and 51,500 m^3 offshore)
- High Volume Case – Disposal Option A (398,000 m^3 offshore)
- High Volume Case – Disposal Option B (234,500 m^3 onshore and 163,500 m^3 offshore)

The program is scheduled to be completed within a 30-week period, inclusive of:

- Equipment mobilisation: 4-weeks
- Setup of infrastructure (decant ponds, dredge spoil pipelines and pumps etc): 6-weeks
- Dredge and disposal operation: up to 20-weeks

The selected dredge and disposal window (June to September) has been developed to contain all works, including onshore disposal decanting, outside of the cyclonic season and have considered minimising impacts to marine mammals. The dredge and disposal operation will run 24 hours a day, 7-days a week, with one weeks intermission (no production) to allow for dredge equipment relocation to the northern channel extent (approximately mid-way through the dredging schedule).

Key parameters pertaining to the proposed dredging programs are given in Table 4.

Table 4: Dredge and disposal program.

Parameter	Base (Minimum)	Maximum	Notes
Dredge Volume	230,589m^3	397,658 m^3	Base Case and Maximum Case accounting for navigational safety and over-dredging.
Dredge equipment	CSD		Considerations made for cutter suction, trailer suction and backhoe dredging equipment. CSD selected as optimal equipment.
Dredge rate	140 – 183.75 m^3/hr		Calculated based on Leichhardt's estimated total weekly dredging volumes, assuming 24 hr continuous operations. Actual volumes vary depending on disposal location (onshore pumping or offshore shipping), dredging depth, and other factors.
Dredge schedule	Daily operations that align with the adopted dredge rate for the duration of each dredging option.		Modelled as a continuous dredging operation.
Duration of dredging	56 days	102 days	Duration of dredging program based on 21 hr effective dredging per day. The 3 hr of daily down time allow for equipment maintenance, inspections and stop-work due to marine fauna presence.
Disposal method	Two methods considered: • Disposal Option A • Disposal Option B		Based on the anticipated volumes that will be extracted from the southern-extent channel, berthing pocket, and northern channel, approximately 78% and 59% of the total dredge material will be disposed onshore for the Base Case and High-Volume Case, respectively.
Disposal location	Disposal Option A: • Spoil Ground C [116.272E, 20.671S] Disposal Option B: • Spoil Ground C for northern-extent channel • Onshore for southern-extent channel and berthing pocket		• Disposal locations shown in Figure 3. • The offshore disposal site is located approximately 19 km from the berth pocket of the proposed dredging site at the following coordinates. • The proposed onshore disposal site is immediately south of the ESSP. Material will be decanted at this onshore disposal site, and tailwater discharged nearby. The exact location of the tailwater discharge is yet to be defined, but it will be in close proximity to [116.225E, 20.8465S], where it was modelled.
Disposal frequency	• Onshore portion = Constant • Offshore portion = 8 hours		Offshore portion estimated based on dredge rate, sediment bulking factor, loading times, transit times, and disposal times for a split hopper barge.

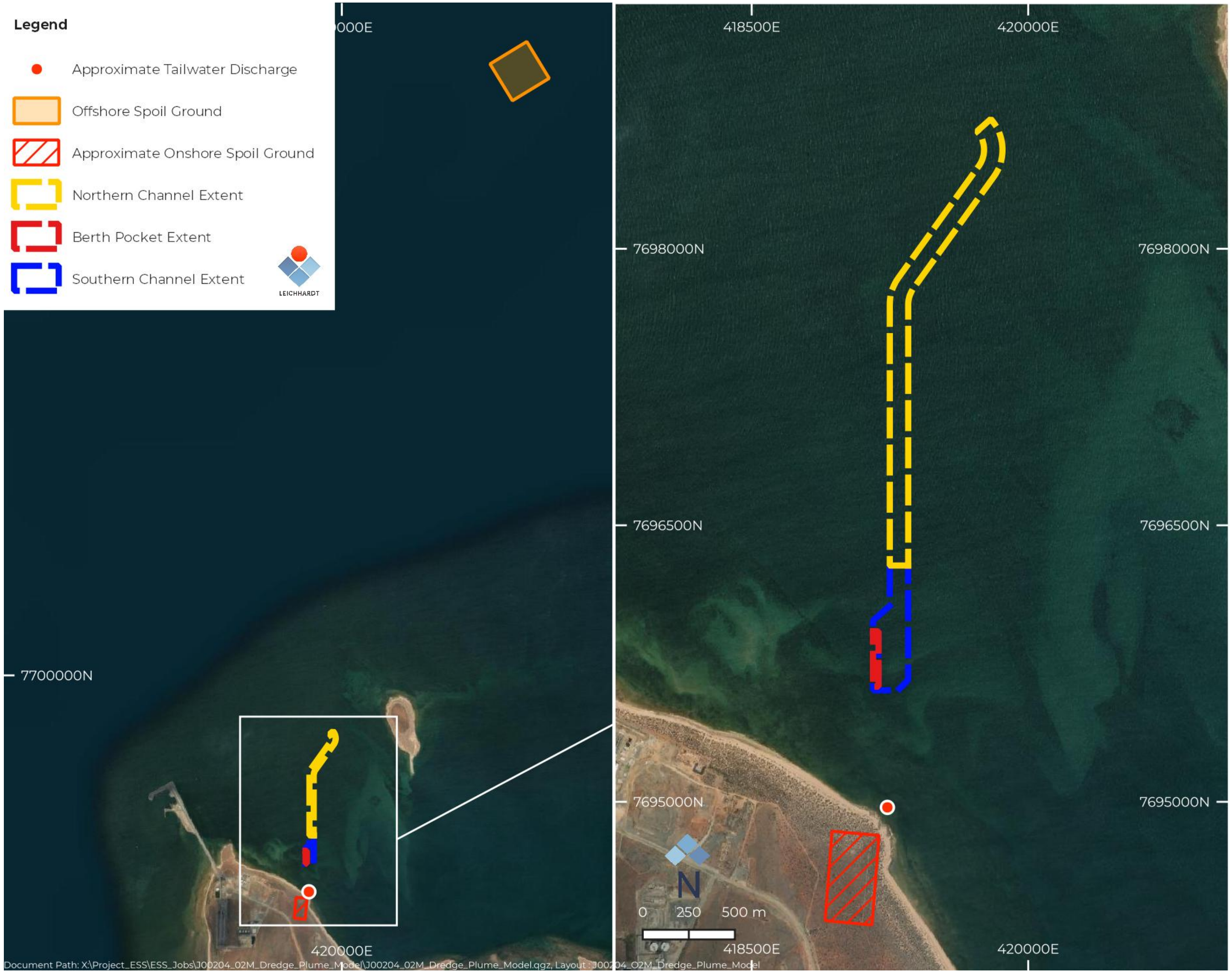


Figure 3 ESSP Offshore and approximate Onshore Spoil Ground and Tailwater Discharge Locations

3. Background

3.1. Oceanographic Context

The site of the proposed ESSP is W of the Regnard Bay on the western Pilbara Shelf. The Pilbara is an arid region with pronounced wet and dry seasons, influenced by the Indonesian-Australian monsoon and the meridional migration of the equatorial and subtropical pressure belts. The wet season (November-April) is characterised by high temperatures, higher than average rainfall, and lower atmospheric pressures (over the land). The dry season (May-October) is characterised by warm temperatures, clear skies, limited thunderstorm activity, very low rainfall, and higher atmospheric pressures.

The greatest impact of seasonality on dredge plumes is likely the variable wind patterns. During the SE monsoon (approximately during the dry season), winds are predominantly easterly to southerly, coincident with the trade winds. During the NW monsoon (approximately during the wet season) winds are predominantly W to SW. These seasonal trends are modulated year-round by a diurnal land-sea breeze system, which intensifies in the wet season. The region is exposed to tropical storms and cyclones during the wet season. The Karratha to Onslow coastline is the section of the Australian coast that is most prone to cyclones, with one cyclone making landfall every two years on average. Cyclones affecting the Pilbara typically form in the tropical waters between the Kimberley and the Timor Sea and intensify as they propagate westward and poleward, though tracks of significant cyclones impacting Cape Preston within the last 30 years are varied. In addition to tropical storms, troughs of low pressure also bring rain, strong winds, and sharp changes in wind direction.

For greater detail on the oceanographic context of both the regional setting and Regnard Bay, including weather, geomorphology, water levels, ocean currents, and waves, refer to the metocean data interpretation report (O2Me 2022c).

3.2. Sedimentological Context

Little is known of the sedimentology of Regnard Bay other than that the region is characterised by a lack of fine material. Geological sediment accumulation rates on the Holocene inner shelf and the mid-shelf to seawards appear very low, as evidenced by the large areas of patchy sediment and cemented rocks at or near-surface. It is likely, therefore, that these shelves do not supply fine sediment to the region. The likely predominant sources are the Maitland River catchment and the local bedrock present on the inner shelf. Neither source would result in large quantities of fine 'muddy' sediments within the bay. The high tidal flats to the S are a suspected source of muddy sediments but are likely a lessor contributor to the overall mass flux. There would be some local marine production (shells) in Regnard Bay, but this would not produce fines in high quantity.

Review of recently collected oceanographic data suggests that sediment resuspension surrounding the promontory headland is generally limited in its local availability, even under a fast current and large wave climates (O2Me 2022d). The presence of tropical cyclones likely also affects fine sediment composition within the bay. Cyclones are associated with very energetic sediment resuspension but also net drift currents which can flush otherwise protected coastal areas. The coincidence of these two processes provides a potential mechanism for export of mud which would lead to a further reduction in fine material.

3.3. Geotechnical investigations

Data from two geotechnical investigations were made available to O2Me for input into this study:

- SKM 2013 Investigation
- O2 Marine 2021 Sediment Sampling

Relevant sample sites from these studies with reference to the dredging footprint are presented in Figure 4.

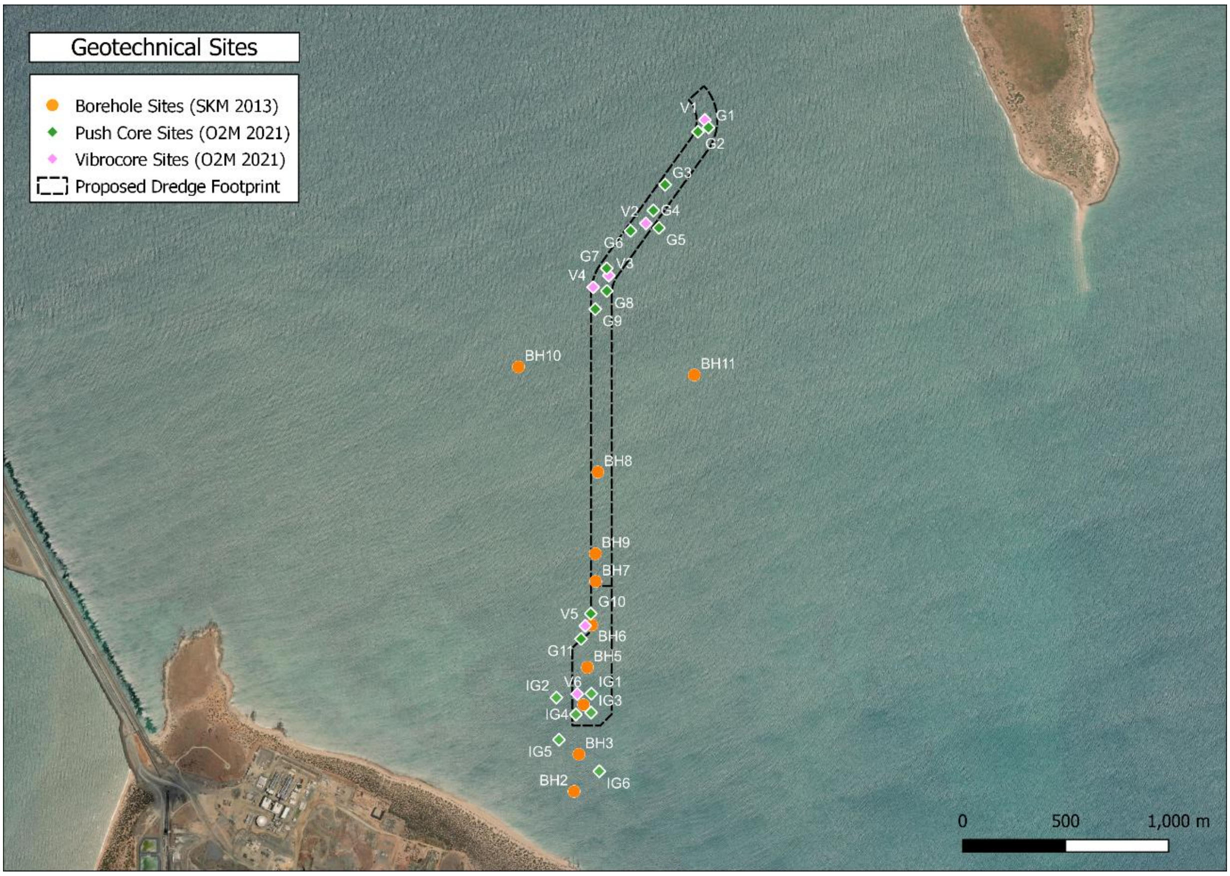


Figure 4 Geotechnical Sites

3.3.1. SKM 2013 investigation

The geotechnical investigation of SKM (2013) consisted of eleven boreholes in the vicinity of the dredge pocket, and surficial sediment samples (0 to 20 cm below the local seabed elevation) at each borehole location.

The study classified layers within the boreholes according to five (5) distinct geological strata:

1. Sandy coastal deposit
2. Calcrete
3. Fericrete
4. Basalt
5. Dacite.

and three ‘material classes’:

1. Sandy Coastal Deposit:

   Very loose to medium dense sand (geological stratum 1) layer ranging from 0.5 m to 6.0 m thick, with principal soil types consisting of sand, silt and gravel with shells and coral fines.

2. Intermediate secondary rock layer:

   Consisting of calcrete (geological stratum 2) and ferricrete (geological stratum 3) rock layers with very low to low strength (often with silty, gravelly and cobble layers).

3. Igneous rock layer:

   Consisting of dacite (geological stratum 4) and basalt (geological stratum 5).

SKM (2013) estimated the thickness of each geological stratum in the vicinity of the dredge pocket (where the bulk of the dredging would occur) by linear approximation of boreholes 1-9 (Figure 5). Particle size distribution (PSD) analysis undertaken by SKM in 2013 was reported for select samples at each borehole and surficial samples. The results of SKM’s PSD analysis have been reproduced in Table 5 and Table 6 respectively ([3]).

Borehole logs and images for boreholes 3 to 7, relevant to this study, have been reproduced from SKM (2013) and can be found in Appendix A. Boreholes 1, 2, 8 and 9 are either far from the proposed dredging channel (boreholes 1 and 2) or in regions where the seabed is lower than the dredging target (boreholes 8 and 9).The logs and images Appendix Ahave been trimmed to the top 5 m to only reflect the geological strata encountered above the target channel and berth pocket depths.

---

[3] Basalt and Dacite samples are not reported in this report as these are beyond dredge depth.

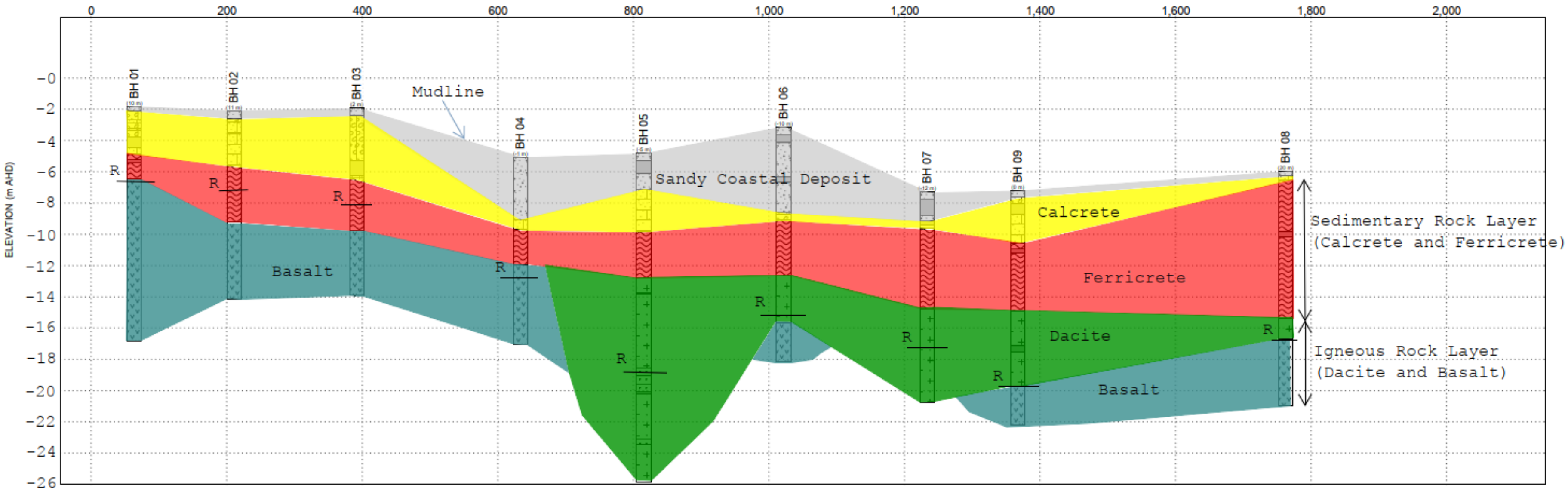


Figure 5: Borehole 1 to borehole 8 interpolation providing an approximate S to N cross section of geological layers within the channel alignment (reproduced from SKM, 2013)

Table 5: SKM (2013) Borehole PSD results for varying geological strata

Borehole	Geological Stratum	% Clay and cobbles (> 2.36 mm)	% Sand (0.75 µm 2.36 mm)	% Fines (< 0.75 µm)
BH01	Gravelly Sand	55	38	7
BH02	Sand	39	56	5
BH02	Calcrete	17	36	47
BH03	Ferricrete	62	22	16
BH04	Sand	1	94	5
BH06	Sand	2	92	6
BH07	Ferricrete	21	47	32
BH08	Ferricrete	38	43	19
BH09	Ferricrete	18	47	35

Table 6: SKM 2013 surficial (top 20 cm) PSD at each borehole location

Borehole	Clay (< 2 µm)	Silt (2 µm to 63 µm)	Fine Sand (63 µm to 250 µm)	Medium Sand (250 µm to 500 µm)	Coarse Sand (500 µm to 2000 µm)	Coarse Material (> 2000 µm)
BH01	0.33	2.86	2.57	10.64	47.13	36.46
BH02	0	2.04	1.37	38.4	43.04	15.13
BH03	0.02	2.88	5.48	41.14	44.93	5.55
BH04	0.37	2.42	1.87	31.13	63.32	0.89
BH05	0	1.83	8.14	58.3	31.41	0.32
BH06	0	0.67	20.55	75.68	3.02	0.07
BH07	0.3	2.39	3.13	7.02	41.05	46.12
BH08	0.27	2.25	2.77	6.97	51.95	35.78
BH09	0.57	5.08	3.7	4.02	39.91	46.71
BH10	0.06	1.52	12.9	44.41	38.84	2.26
BH11	0.25	1.54	50.97	42.04	4.73	0.47

3.3.2. O2 Marine 2021 sediment sampling

O2M (2021) collected 23 surficial sediment samples within and around the proposed dredge footprint. Results of PSD analysis for these samples are reproduced in Table 7.

Table 7: PSD analysis for O2 Marine (2021) surficial sediment samples

Site ID	Clay % (< 4 µm)	Silt % (4-62 µm)	Fine Sand % (62-250 µm)	Medium Sand % (250-500 µm)	Coarse Sand % (500-2000 µm)	Gravel % (> 2000 µm)
G1	0.67	3.79	27.21	34.78	31.78	1.77
G2	0.95	4.16	17.73	32.65	41.83	2.68
G3	0.36	2.77	15.3	44.59	35.57	1.41
G4	0.82	3.92	11.44	25.99	50.83	6.99
G5	0.21	1.75	29.36	37	26.16	5.51
G6	0.65	3.65	13.71	37.23	40.71	4.05
G7	0.06	2.57	10.98	41.66	32.47	12.26
G8	0	0	19.49	38.19	38.04	4.28
G9	0	0	21.66	41.29	31.21	5.84
G10	0	0	25.74	56.86	16.88	0.51
G11	0	0	22.25	55.81	14.83	7.1
V1	0.25	1.9	12.66	32.99	42.89	9.31
V2	0.74	4.56	28.21	32.19	28.29	6.01
V3	0	0	20.71	50.17	27.9	1.22
V4	0.26	2.18	16.3	35.75	40.7	4.81
V5	0	0	8.01	53.18	37.95	0.86
V6	0	0	19.41	66.69	13.78	0.13
IG1	0	0	4.62	59.55	35.36	0.47
IG2	0	0	3.29	59.12	37.31	0.28
IG3	1.63	13.5	9.89	18.55	52.47	3.96
IG4	4.08	22.89	14.51	16.2	35.83	6.5
IG5	0.42	4.36	5.75	41.5	40.5	7.47
IG6	0.44	3.73	2.43	36.57	54.93	1.89

3.4. Suspended solids concentration

Background water quality assessment was conducted by O2M (2022). Seasonal median Suspended Sediment Concentration (SSC) values from site NCP05 located in the vicinity of the proposed ESSP turning basin are reproduced in Table 8. For a more detailed description of the water quality assessment, including additional statistics, please refer to O2M (2022).

Table 8: Background SSC (O2 Marine 2022)

Period	Background Concentration (SSC)
Winter	0.47 mg/L
Summer	1.31 mg/L

3.5. Underwater light attenuation

The EPA (2021) guideline suggests assessment of impact on BCH through thresholds on both SSC and integrated daily light (DLI) availability. The former may be derived directly from sediment transport numerical models while the latter requires a relationship between light attenuation and particles suspended in water. Light attenuation in the ocean is best modelled by a Beer-Lambert type exponential decay law (Equation 1):

Equation 1: $I(z) = I_0\, e^{-kz}$

where z is the depth below the sea surface (positive down), I is the light intensity, I_0 is the intensity of light immediately below the sea surface, and k is the light attenuation coefficient often expressed as a function of TSS or SSC.

Several relationships between TSS or SSC and k have been developed for WA waters. For example, the EPA (2021) quotes Fearns et al's (2019) piece-wise relationship for k_{d490} (the light attenuation coefficient at 490 nm wavelength):

Equation 2: $k_{d490} = 0.0212 + 0.0774\,(TSS)$ for $TSS < 3$ mg/L

Equation 3: $k_{d490} = (-0.865) + 1.018\ln(TSS)$ for $TSS \geq 3$ mg/L

Similarly, MScience (2009) conducted two marine optics surveys in August 9-11, 2009, and October 5-6, 2009, between Thevenard Island and Onslow. The relation between TSS and k that they found is shown in Equation 4, where the subscript PAR (Photosynthetic Active Radiation) indicates that the relation is applied to the full PAR spectrum.

Equation 4: $k_{PAR} = 0.022 + 0.035\,(TSS)$

MScience (2019) derived another empirical relationship between k and SSC applicable to the full PAR spectrum using data collected in the Dampier Archipelago. This relationship was tuned to a very narrow depth range, low SSC range, and it was valid for October only as it did not account for seasonal availability of insolation, reflection, and refraction at the sea surface. O2Me generalised the MScience (2019) relationship for use outside of October and for a greater depth range by means of a generalised linear regression. The approach required application of a theoretical model for solar radiation, reflection, and refraction at the ocean's surface. From this approach, O2Me derived the relationship:

Equation 5: $k_{PAR} = K_{w,PAR} + 0.041\,(SSC)$

Assuming SSC ≈ TSS, the slope in Equation 5 (0.041) is comparable to the slope derived by Mscience (2009) for Ashburton (Equation 4).

The coefficient $K_{w,PAR}$ in Equation 5 reflects the attenuation in clear (zero SSC) water. Fitting to the results of Mscience (2019), $K_{w,PAR} \approx 0.1$ m^{-1}. Following Smith and Baker (1981), this corresponds to attenuation of yellow light in clear ocean water and aligns with what would be expected in 4-5 m depths, the depths the MScience (2009) relation was derived for. However, extrapolation of such value to deeper waters would be incorrect, as the availability of these longer light wavelengths reduces there. It is noted that MScience (2009) report a much lower $K_{\mathrm{w,PAR}} = 0.022$ m^{-1} for PAR in deeper waters (order ten metres) than MScience (2019). According to Smith and Baker (1981), such $K_{w,PAR}$ value corresponds approximately to the least attenuated 490 nm wavelength in clear ocean water. Therefore, a piece-wise empirical parameterisation was proposed based on the two datasets (MScience 2009 and MScience 2019):

Equation 6: $k_{PAR} = 0.1 + 0.041\ (SSC)$ for depths $z \leq 5$ m

Equation 7: $k_{PAR} = 0.022 + 0.041\ (SSC)$ for depths $z > 5$ m

Equation 2 to Equation 7 assume light attenuation is independent of light wavelength. Given that the opposite is true (i.e. light attenuation is wavelength dependent, refer to Fearns et al 2019), O2Me engaged Insitu Marine Optics (IMO) on behalf of Leichhardt to produce a spectral diffuse attenuation model using data gathered in the vicinity of Cape Preston. The model was developed using 26 turbidity and hyperspectral irradiance profiles collected between Steamboat Island and the Fortescue River mouth over two separate monitoring periods (June 15-17, 2020 and June 15, 2021). IMO first derived the below linear relationship between turbidity in NTU and SSC in mg/L:

Equation 8: $SSC = 1.17(NTU)$

A linear relationship between turbidity and diffuse downwelling light attenuation coefficient (K_d) of the form:

Equation 9: $k_d = K_w + B(NTU)$

was sought, where the subscript d represents a given wavelength from the light spectrum, B the contribution due to suspended sediments as captured by nephelometers, and K_w the attenuation in clear water. B and K_w are wavelength dependent. Combining Equation 8 and Equation 9, the following expression was obtained:

Equation 10: $k_d = K_w + \frac{B(SSC)}{1.17}$

IMO (2022) summarised the variation of the coefficients in Equation 10 over the PAR spectrum in Figure 6. For further details pertaining to the derivation of this relationship, please refer to IMO (2022) in Appendix A.

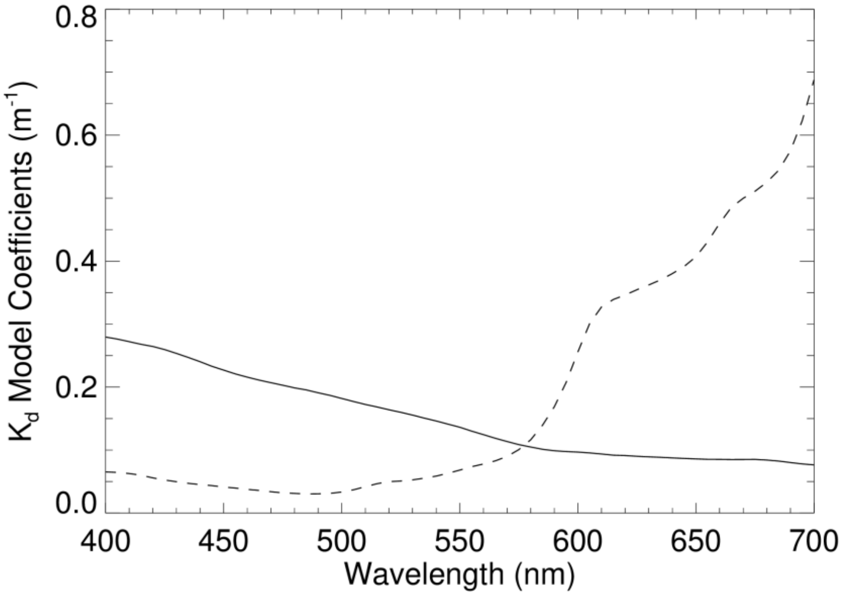


Figure 6: Light spectral coefficients of Equation 9: solid line = B, dashed line = $K_{w,\,PAR}$ (Source: IMO 2022: Appendix A)

O2Me considers the IMO (2022) model the best available information for modelling benthic light along the Cape Preston coast, as the relationship considers all wavelengths within the PAR spectrum, and it was derived using data collected near the proposed ESSP site. O2Me notes, however, that it does have limitations for application to dredge plume modelling, namely:

- It does not span very high turbidity levels that may be encountered in dredge plumes
- It was derived for ambiently suspended particles, not deep buried sediments that may be encountered during dredging (a limitation impossible to overcome prior to undertaking the dredging campaign, regardless of the light attenuation model used)
- It is not derived from data collected during different seasons (two periods in June only)
- Sediments are known to vary over relatively short distances.

Appropriateness of the light attenuation relationships presented in this section is discussed in Section 4.2.9, in the context of the EPA (2021) guidelines.

3.6. Benthic habitats

Impacts on BCH are the primary consideration for the EIA of dredge plumes. The dominant light and SSC sensitive BCH in the vicinity of the ESSP are corals and seagrass, though filter feeders and macroalgae are also found (Figure 7, refer to O2M 2025 and the references therein).

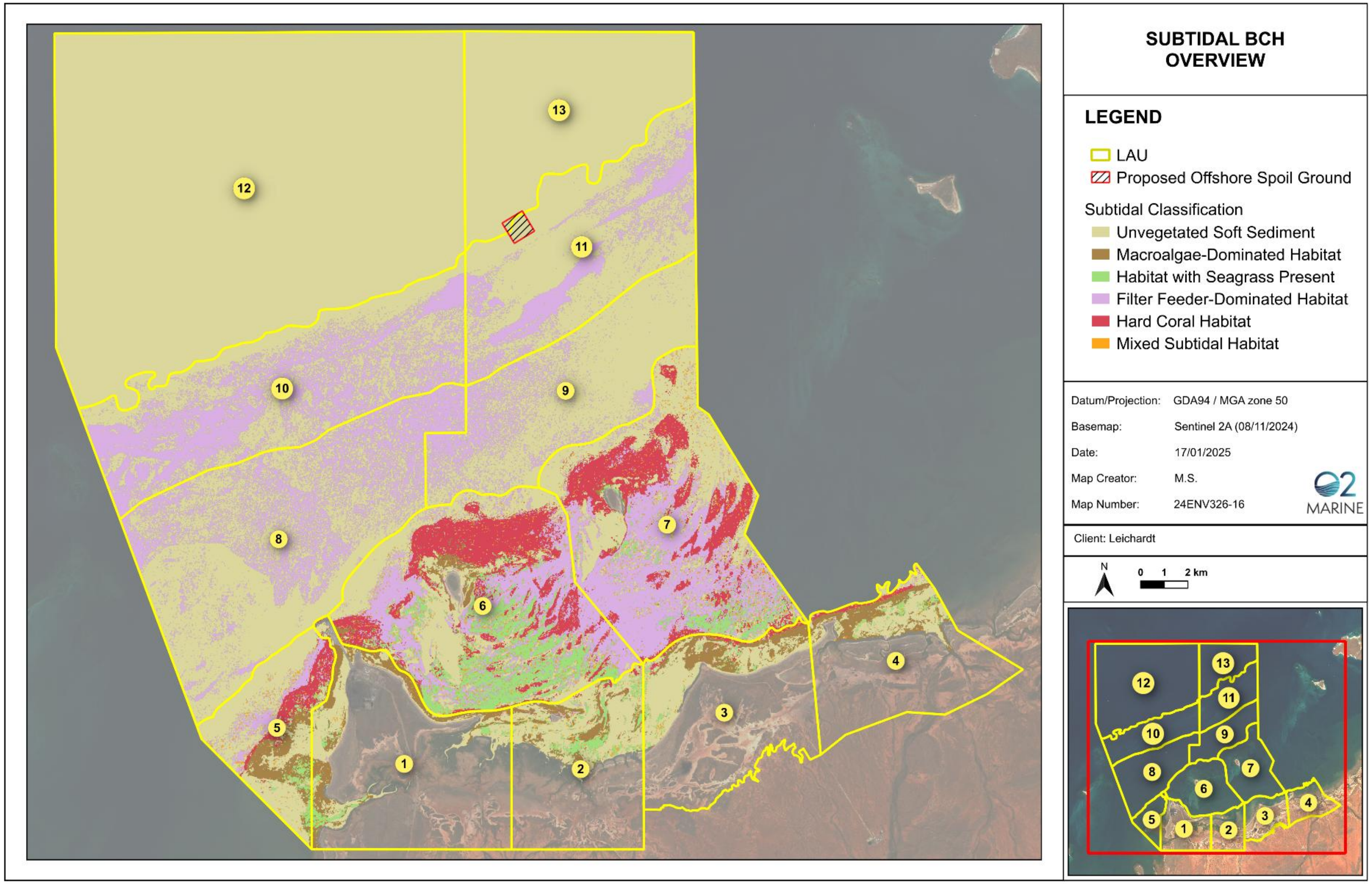


Figure 7: Subtidal BCH survey map (reproduced from O2M 2025)

3.7. Regulatory framework for impact assessment

Dredge plume assessments are relevant to both *the Environmental Protection and Biodiversity Conservation Act 1999* (EPBC Act) and *Environmental Protection Act 1986* (EP Act), which aim to support environmentally sustainable development while protecting environmental values, including biodiversity.

3.7.1. 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.

3.7.2. EP Act guidance

The EP Act is the primary legislation that governs EIA and environmental protection in WA. EIA in WA is conducted by the 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 "Technical Guidance – Environmental impact assessment of marine dredging proposals" (EPA 2021). The guidance describes an impact zonation scheme (Table 9), and the appendices in EPA (2021) offer the guideline trigger values for each of these zones.

Table 9: EPA (2021) Impact zonation scheme

Zone	Description based on EPA (2021)
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 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 where 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 from indirect impacts ([4]) of dredging is predicted to be irreversible. "Serious damage" means a damage to benthic communities or their habitats that is effectively irreversible or where any recovery, if possible, is expected to take more than five years after the dredging activities are completed.

---

[4] Direct impacts are excluded from this assessment, refer to 'Objective' in Section 1.3.

For assessing the impact on corals, the EPA (2021) guideline values for the ZoMI ‘possible’, ZoMI ‘probable’, ZoHI ‘possible’ and ZoHI ‘probable’ were adopted. Impacts on seagrass due to light reduction also adopted the EPA (2021) guideline values, in this case for *Halophila ovalis* for the ZoMI ‘possible’, and a conservatively modified threshold taken from the EPA (2021) guidelines for the ZoMI ‘possible’ for the same species for ZoMI ‘probable’[5]. Moderate impact on seagrass due to burial, and high impact on seagrass due to seedbank availability, fall outside of this scope of work.

Although the trigger values recommended in the EPA (2021) guideline are not reproduced in this report, the approach for assessing impact to corals and seagrass is laid out in Table 10.

The EPA also expects proponents to present an assessment of a Zone of Influence (ZoI) for a dredging activity. Unlike for the impact assessment, the EPA does not provide an assessment scheme for determining the ZoI, rather states that the boundary of the ZoI should represent a point beyond which the dredge plume is not discernible from background conditions and that this area can be large.

For this study, O2Me have defined the criteria for the ZoI as being any area that at any point during the program experiences a concentration of ≥ 1 mg/L background SSC anywhere in the water column. This is a highly conservative threshold in which the plume would unlikely be visually discernible, where detectable impacts to stable BCH would be highly improbable, and where change with respect to background could only be observed in the field with appropriately selected control sites and instrumentation.

---

[5] EPA (2021) guideline does not include a threshold for ZoMI ‘probable’ for *Halophila ovalis*, hence guidance from environmental specialists working on the ESSP was sought: doubling the ZoMI ‘possible’ threshold for *Halophila ovalis* from three to six weeks was recommended (C Lane, pers. comm.).

Table 10: Usage of EPA (2021) Appendix A guidelines to predict the impacts of dredging on corals and seagrass[6]

BCH category	Zone	Subcategory	Guideline description
Corals	ZoMI	Light Reduction and SSC combined (massive and foliose corals)	Based on moving average of both DLI and SSC dropping below and exceeding a threshold value respectively. Three separate averaging windows given for each of possible and probable effects. For a given averaging window, both the DLI and SSC criteria must be triggered simultaneously to be considered an overall breach of the guidance. The trigger of any averaging window constitutes an overall breach of the guidance. ** While no specific guidance is given, we interpret SSC to mean near-bed SSC, as protection of BCH is sought, and the threshold is based around depositional effects.*
		Light Reduction (all corals)	Based on moving average of DLI dropping below a threshold value. Three separate averaging windows were utilised for both possible and probable impacts as per EPA (2021) guidelines. When the running mean of DLI for any window drops below the respective thresholds, a zone is triggered. ** While no specific guidance is given, areas that trigger under light reduction thresholds without the presence of dredge activity (ambient light reduction) are excluded from being dredging impact related zones. For a given location, a trigger in the light reduction thresholds is considered a result of dredging impact if:* • *The location does not naturally exceed the light reduction thresholds outside of dredging activity; and* • *A (modelled) plume is present anywhere within the water column at the point in time where a trigger of the light reduction thresholds occurs. Conservatively, the modelled plume is deemed 'present' when the modelled concentration is SSC > 0.1 mg/L.*
	ZoHI	Light Reduction and SSC combined (All corals)	Based on moving average of DLI dropping below a threshold, SSC exceeding a threshold, and Sediment Deposition exceeding a threshold. Three separate averaging windows were utilised for both possible and probable impacts as per EPA (2021) guidelines. The guidance is not clear on whether these should be

---

[6] Guideline description has only been provided for the coral and seagrass species that were assessed as part of this study

BCH category	Zone	Subcategory	Guideline description
			triggered contemporaneously to be considered an overall breach of the guidance, however, for consistency with the ZOMI, it was assumed they should be. The triggering of any of the three averaging windows constituted an overall breach of the guidance. ** While no specific guidance is given, we interpret SSC to mean near-bed SSC, as protection of BCH is sought, and the threshold is based around depositional effects.*
Seagrass	ZoMI	Light Reduction (*Halophila ovalis*)	The possible ZoMI (*Halophila ovalis*) is based upon the two-week moving average of DLI dropping below a threshold for DLI, consecutively for a given duration. ** As it was the case for light reduction on corals ZoMI, areas that trigger under light reduction thresholds without the presence of dredge activity (ambient light reduction) are excluded from being dredging-impact related zones. For a given location, a trigger in the light reduction thresholds is considered a result of dredging impact if a (modelled) plume is present anywhere within the water column at that point in time.* ** Note that EPA (2021) is not explicit on whether the 2-week average period should be discrete or rolling. O2Me have adopted a rolling average.*
	ZoHI	All Seagrass	ZoHI for seagrass are defined based on viable seedbanks within the triggered ZoMIs. Delineation of ZoHI is therefore beyond the scope of this study.

3.8. 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 around the world and set recommendations for standard practice for modelling including clarity of model input parameters to be selected (Sun et al 2016). The work undertaken by WAMSI paved the way for a guideline for dredge plume modelling for the purpose of EIA (Sun et al 2020), which emphasised the need for a standardised approach to estimate source terms for dredge plume modelling (in the absence of field datasets). WAMSI have encouraged the use of an approach set out by Becker et al (2015) in estimating source terms, which has been adopted in this study.

Source term estimation is particularly complex where rock exists within the dredging layers (such as the calcrete layer encountered at the Project site, Figure 5). Complexity arises as mechanical disturbance, such as that caused by the mechanical fracturing of limestone calcrete by a CSD, may lead to generation of fine-grained material and their release into the marine environment. The process for quantification and estimation of this fine material is poorly understood yet requires parameterisation in dredge modelling.

Mills and Kemps (2016) note that dredging of limestone using a CSD may produce particles in the range of very fine silts to small rocks. Their review included a case study of CSD dredging of limestone within WA in which water samples taken close to the cutter head featured predominantly particles less than 40 µm in size. The exact PSD generated, however, is likely affected by material strength, excavation rate, as well as cutterhead geometry and power, and cannot be precisely quantified in the early stages of an EIA. Whilst the Mills and Kemps (2016) study does not provide an estimate of a PSD caused through CSD disturbance of all rock layer types, its findings (large amount of fines generation) align with the PSD conducted on a mechanically disturbed sample of calcrete at BH02 (Section 3.3.1), which noted 47% of fines in the sample. Such findings from Mills and Kemps (2016) support the conclusion that the PSD for calcrete at BH02 (Section 3.3.1) is an appropriate estimate of the PSD for particles in the plume from calcrete dredged using a CSD.

4. Methods

This section outlines the model that was adopted to simulate the dredge and spoil disposal program presented in Section 2.2. O2Me adopted a nested approach to hydrodynamic modelling, where boundary conditions to a local 3D sediment transport model were extracted from a regional hydrodynamic model. Modelling was conducted using the DHI Group MIKE FM/HD/MT suite of models.

4.1. Hydrodynamic model

4.1.1. The HD module

The DHI MIKE FM hydrodynamic (HD) module (3D with 10 sigma layers) was selected for this application (refer to DHI 2021a). For details on the underlying equations and assumptions, model set up, and hydrodynamic model validation, the reader is referred to O2Me (2022a).

4.1.2. Regional model

Boundary conditions for the 'local' numerical mesh used in the sediment transport model were extracted from O2Me's Adapted Pilbara model (Figure 8) – also referred to as 'Regional model', described fully in O2Me (2022a).

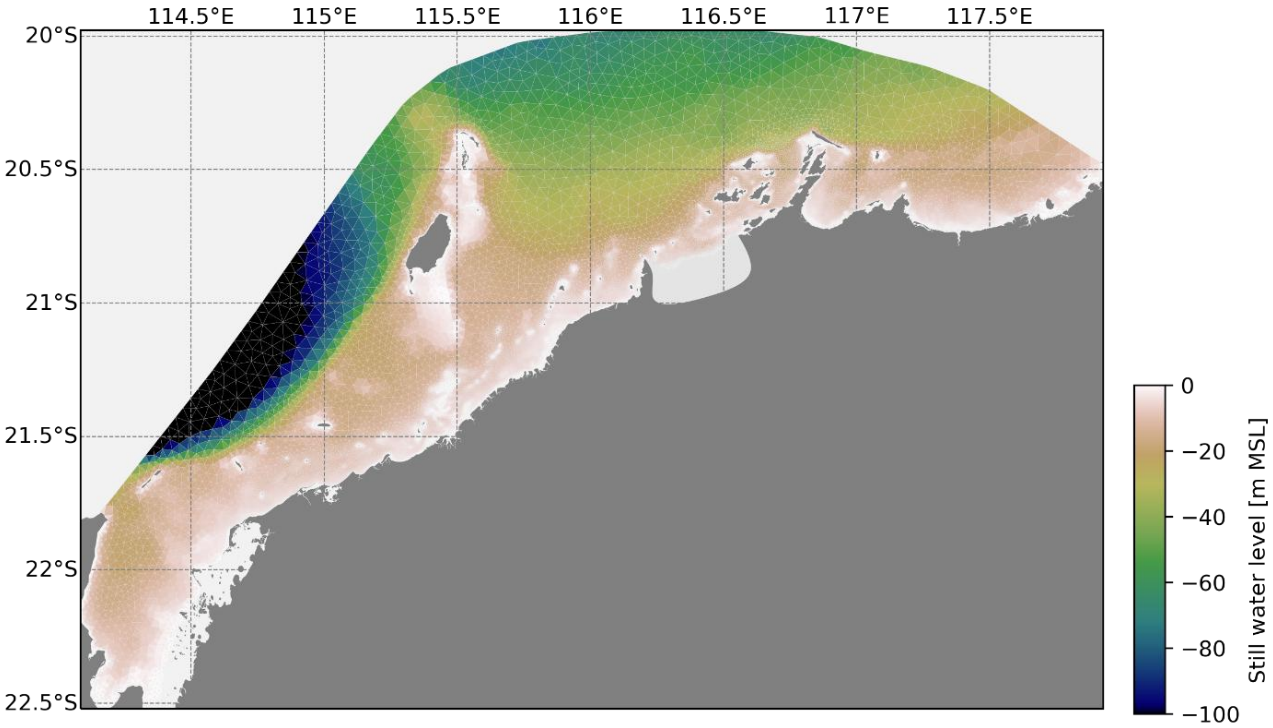


Figure 8: Numerical mesh of the Pilbara tidal model (O2Me 2022a) used to derive boundary conditions for the local sediment transport model shown in Figure 9

4.1.3. Local Regnard Bay model

The numerical mesh for the 3D 'local' model used in the dredge plume modelling study extends from the NE of Barrow Island to Legendre Island, with an offshore boundary located approximately 50 km off the coast of Cape Preston (Figure 9), reaching depths of approximately -50 m AHD. The domain was discretised with triangular elements, ranging from 3 km offshore to 50 m around the dredge location and proposed spoil ground (Figure 9). The vertical grid consisted of 10 vertical layers, with a sigma layer scheme utilised across the whole domain. The bathymetry and numerical solver are described in O2Me (2022a). Open boundaries were forced with fluxes and water levels extracted from the Adapted Pilbara model (Figure 8: O2Me 2022a), and surface stress and barometric pressure were extracted from the European Centres for Medium Range Weather Forecasting ERA5 model. Density stratification was not accounted for. The model is capable of simulating the known dominant physical oceanographic processes in the region (Dr R Steedman, 2022 – independent review of O2Me's modelling approach of the ESSP included as an Appendix to O2Me 2022a).

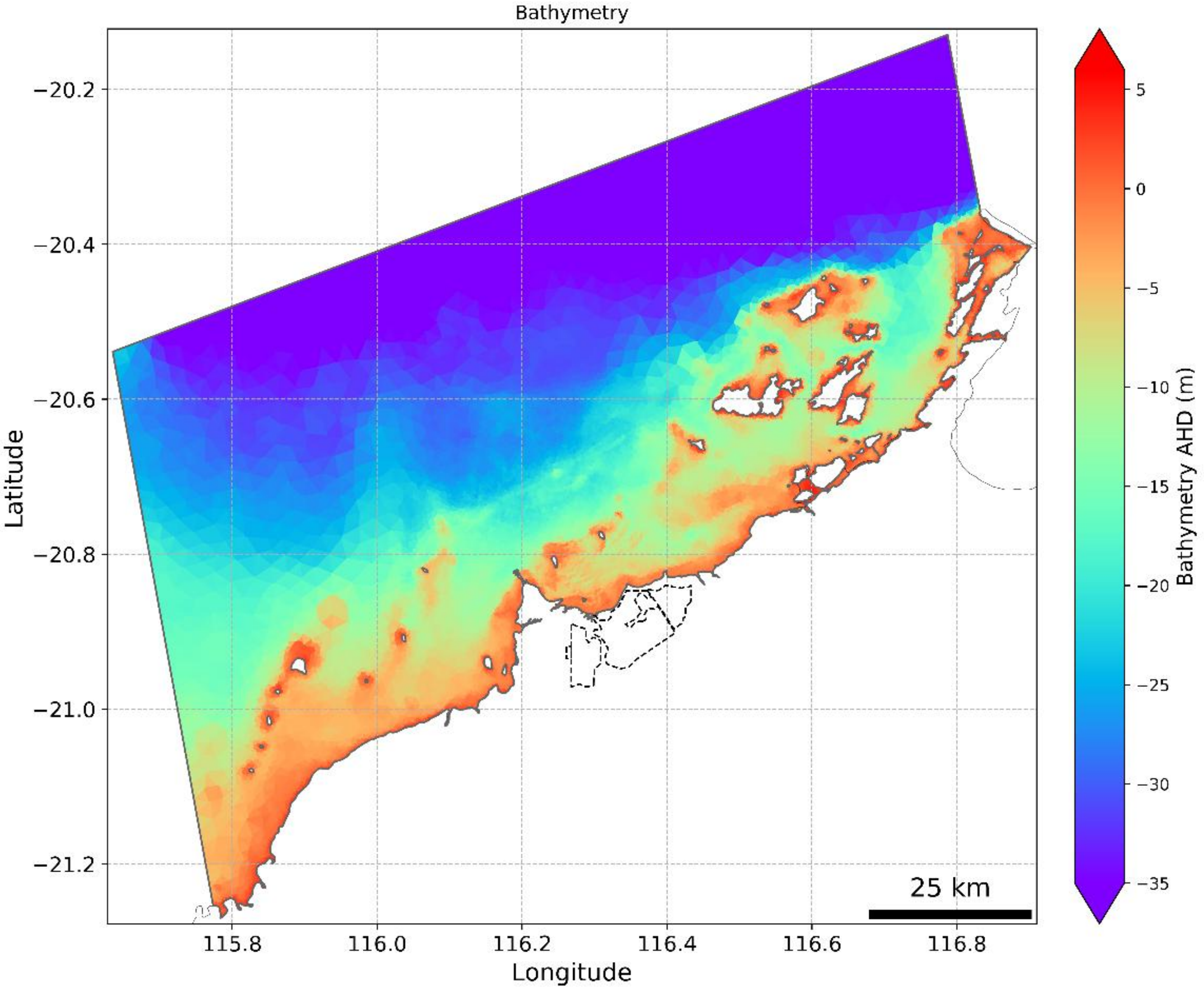


Figure 9: Numerical mesh for the local sediment transport model.

4.2. Sediment transport model

4.2.1. The MT module

Sediment transport was investigated with the Mike 3 Mud Transport (MT) module from the DHI suite of modules. DHI's MT 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. If activated, the erosion follows 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).

It is noted that direct impacts are not assessed in this report.

The sediment transport module was only applied to the local hydrodynamic model of Regnard Bay described in Section 4.1.3.

4.2.2. Solution method

The sediment transport equations were decoupled from the hydrodynamic equations; a common hydrodynamic modelling technique adopted in far-field sediment plume studies to increase flexibility during project execution. High-order schemes were used in both the temporal and spatial discretisations. Eulerian schemes at the grid-scales required for large spatio-temporal assessments of interest in this study (~100 km and ~months) are known to be diffusive. There is a trade-off between model accuracy and the scales in time and space that can be resolved, hence the adopted approach is in line with Sun and Branson (2018) recommendations.

Dynamic update of the bed was not considered necessary, as this only affects the hydrodynamics of the immediate dredging footprint which in turn is small with respect to the areas which are ultimately considered for environmental impact assessment. Further, dynamic effects due to bed changes during dredging are limited to the near-field zone which is not assessed here (refer to Section 1.4).

4.2.3. Simulated dredge scenarios

An estimated dredge and disposal schedule was prepared by Leichhardt for both the base scenario (minimum volume) and high-volume scenario (maximum volume). The high-level schedule consisted of:

- Dredge and disposal activity starting in June;
- Dredge and disposal activity finishing in August and September for the base scenario and high-volume scenario respectively;
- Dredging to begin at the southern extent of the footprint with onshore disposal activities, followed by the northern channel extent with offshore disposal activities; and
- Dredging rates to vary between the southern channel extent (183.75 m^3/hr) and the northern channel extent (140 m^3/hr).

The modelled period for the base and maximum volume scenarios were selected to conform to the above description (Table 11), and to align with previous modelling conducted by O2Me for earlier revisions of the ESSP.

Wind and tide extracted from the hydrodynamic results at the dredge footprint between June 2021 and September 2021 (Figure 10) display a variable forcing period. The first half of the modelled period was dominated by an easterly trade wind pattern, and the second half by a transitional wind pattern. For more details on these events, see O2Me (2022a) and O2Me (2022c).

Table 11: Dredge plume modelling scenarios and modelled dredging periods

Dredge plume model scenario	Modelled dredging period	Representative of
Base Case – Disposal Option A	10/06/2021 – 05/08/2021	Minimum dredge volume with 100 % offshore disposal
Base Case – Disposal Option B	10/06/2021 – 05/08/2021	Minimum dredge volume with a combination of offshore and onshore disposal
High Volume Case – Disposal Option A	03/06/2021 – 13/09/2021	Maximum dredge volume with 100 % offshore disposal
High Volume Case – Disposal Option B	03/06/2021 – 13/09/2021	Maximum dredge volume with a combination of offshore and onshore disposal

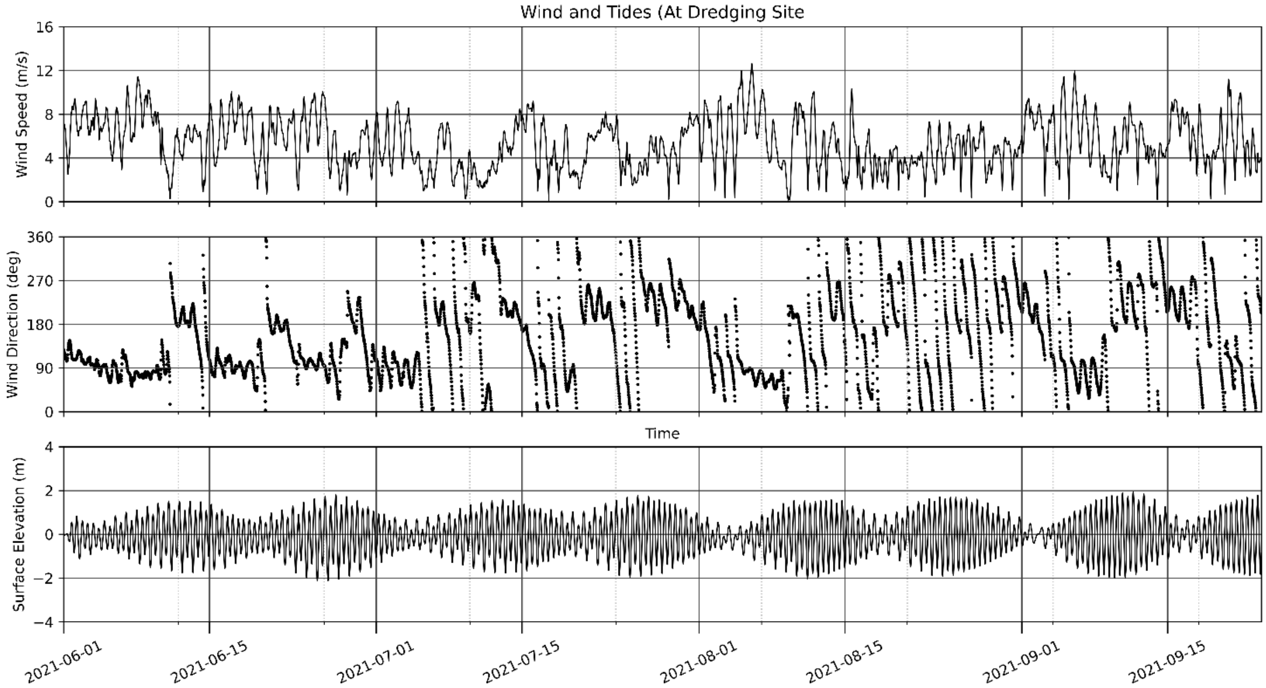


Figure 10: Wind and surface elevation during the Base scenario and High-Volume scenario at the proposed dredge site.

4.2.4. Spatial representation of the dredge footprint

The dredge footprint was split into three zones. The number of zones and boundary among them were evaluated by consideration of the available geotechnical information, the proposed dredge geometry, and proposed dredge methods. The need for precision was assessed against the relative importance of other known areas of uncertainty – a process requiring professional judgement. The three modelled zones (Figure 11) were:

- Zone 1: The southern channel extent
- Zone 2: The berth pocket deepening
- Zone 3: The northern channel extent.

Vertical layering was not considered necessary for this level of assessment, owing to the relatively shallow target depth and uncertainty over the exact dredge sequencing.

The volume of material within each dredging zone varies between the Base Case and High-Volume Case, as defined in Table 12.

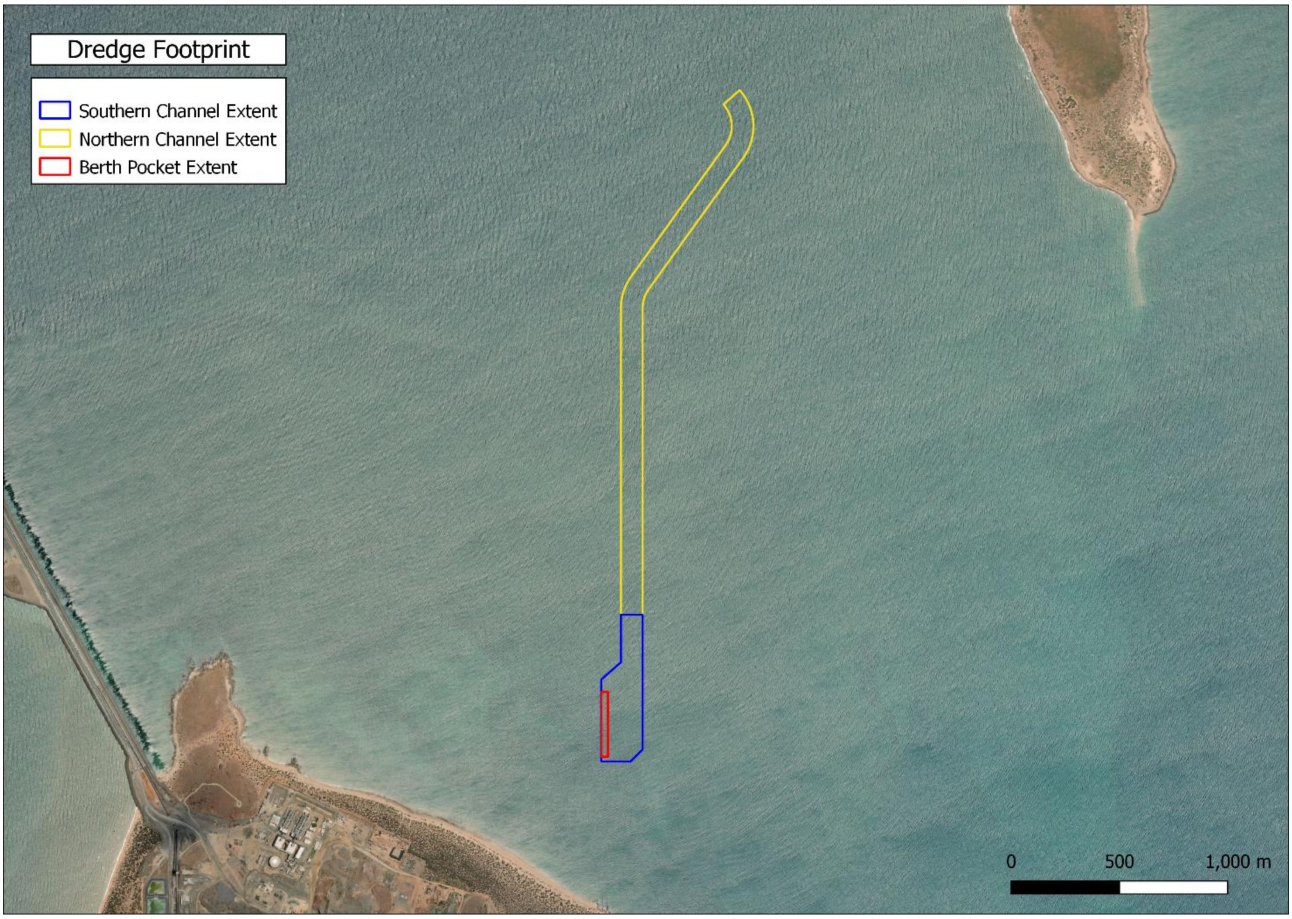


Figure 11: Dredge Model Zones

Table 12 Dredging volume within each zone

Dredge model zone	Base case	High Volume Case
Southern Channel Extent	160,005 m^3	206,864 m^3
Berth Pocket Deepening	18,870 m^3	27,555 m^3
Northern Channel Extent	51,714 m^3	163,239 m^3

4.2.5. Temporal progression of the cutter suction dredger

Through liaison between Leichhardt and O2Me, several assumptions about the dredging pattern were made:

1. At any point in space, dredging will continue until the target depth is reached before the dredger moves on (i.e. single pass dredging)
2. The CSD was assumed to have a reach of up to 5 m to either side
3. The order in which zones will be dredged is:
    a. Southern channel extent (onshore disposal)
    b. Berth pocket deepening (onshore disposal)
    c. Northern channel extent (offshore disposal)
4. For each zone, dredging will begin at the SW corner. The dredger will advance northward by alternating one W to E pass, followed by an E to W pass, and so forth
5. The CSD will dredge at a constant rate, thus it will progress more slowly in areas requiring more dredging (where the seabed is farther from target dredge depth).

4.2.6. Representation of dredge material

The spatial variability of dredged particles for modelling was simplified as follows:

1. Defining a representative particle size distribution for the dredge material within each distinct zone.
2. Defining a representative dry bulk density for the dredge material within each distinct zone; and
3. Defining the settling velocity model.

4.2.6.1. Representative particle size distribution

First, a standardisation of the different classifications from various laboratory analyses described in Section 3.3 was adopted, corresponding to the fractions:

- Coarse Material (Gravel, cobbles, rocks etc): particle diameter > 2000 µm
- Coarse Sand: 2000 µm > particle diameter > 250 µm
- Fine Sand (upper): 250 µm > particle diameter > 150 µm
- Fine Sand (lower): 150 µm > particle diameter > 62 µm
- Silt: 62 µm > particle diameter > 2 µm
- Clay: 2 µm > particle diameter.

Next, for each dredge zone, the representative PSD was calculated as follows:

1. Determine what percentage of the material is located within each geological strata (e.g. Zone *X* has 75% in sandy coastal deposit (SCD) and 25 % in calcrete).
2. Calculate an average PSD for each geological strata identified in (1), using only the samples that are within or neighbouring the zone (e.g. calculate a representative PSD_{SCD} and $PSD_{calcrete}$ for Zone *X*).
3. Calculate a weighted PSD using (1) and (2) above (e.g. $PSD_{zone\ X}$ = 0.75*PSD_{SCD}+ 0.25*$PSD_{calcrete}$).

Here, borehole samples along the channel length are deemed representative of the channel width (horizontal homogeneity assumption).

The resulting PSD for each zone are shown in Table 13. For further detail regarding the application of the above methodology, Table 13the reader is referred to Appendix B.

The percentage of fines (silt and clay) within the berth pocket deepening zone is substantially higher than in the other two zones due to encroaching on the calcrete and ferricrete layers. However, this zone has a substantially smaller dredging volume (Table 12), accounting for only ~8% of the total dredge material. Of this, half is within the sandy coastal deposit layer, meaning dredging into the calcrete and ferricrete layers represents approximately 4% of the total dredge material.

Table 13: PSD of representative material for scenarios

Zone	% Clay (< 2µm)	% Silt (2 µm-62 µm)	% Fine Sand (lower) (62 µm-150 µm)	% Fine Sand (upper) (150 µm-250 µm)	% Coarse Sand (250 µm -2000 µm)	% Gravel (> 2000 µm)
Southern Channel Extent	0.16	4.37	1.35	11.01	77.03	6.08
Berth Pocket Deepening	2.87	24.12	5.04	6.35	50.20	11.42
Northern Channel Extent	0.06	2.65	3.08	15.49	73.65	5.09

4.2.6.2. Representative dry bulk density

All material fractions were used to estimate the dry bed density, and hence the total mass of each fraction to be removed. Each modelled fraction was assigned a single representative settling velocity as a required input into the DHI model.

The mass flux (in kg/hr) of dredge material was estimated as the product of the volumetric dredge rate (in m^3/hr) and a dry bulk density (kg/m^3). The dry bulk density (ρ_{dry}) of the marine sediment and calcareous gravel materials were therefore estimated by van Rijn and Barth (2018). In the absence of organic material, ρ_{dry} is estimated with Equation 11.

Equation 11: $$\rho_{dry} = \left[400\left(\frac{X_{clay}}{100}\right) + 800\left(\frac{X_{silt}}{100}\right) + 1600\left(\frac{X_{sand}}{100}\right)\right]$$

Here X_{clay}, X_{silt} and X_{sand} are the percentages of clay, silt, and sand based on the PSD of each geological stratum. Note that in this definition, sand is defined as any material with a particle size greater than the upper limit of silt. The representative dry density for each zone was calculated using a weighted average whereby the percentage of each geological stratum that contributes as material for that zone has been used as the weights. A different dry density was used for each zone. These representative dry densities for each zone are shown in Table 14.

Table 14: Dry density of model dredge material

Geological Stratum	ρ_{dry} (kg/m^3)
Southern Channel Extent	1563.12
Berth Pocket Deepening	1372.60
Northern Channel Extent	1578.40

4.2.6.3. Settling velocity

Only the four fractions below 250 µm (clay, silt and fine sand fractions) were included as far-field source terms; other larger particles do not contribute to the dredge plume and settle near the source when released into the water column.

Constant settling velocities of each modelled sediment fraction, a DHI MT module input, were estimated using Stoke's law (Sun et al 2016; DHI 2021b) and are given in Table 15. Neither flocculation nor hindered settling were considered.

Table 15: Settling velocities

Sediment fraction	Settling velocity (m/s)
Fine sand (upper)	0.024903
Fine sand (lower)	0.0083664
Silt	0.000885
Clay	0.000004

4.2.7. Spill Sources

Four distinct spill sources were considered, of which vary depending on the nature of the dredge and disposal activity (Table 16).

Assumptions related to source term definition closely follow the WAMSI guidelines for source term estimation (Sun et al, 2020, Becker et al, 2015 and Mills and Kemp, 2016).

Table 16 Modelled far-field spill sources

Source	Method	Far-field Contribution	Basis for selection
Dredging	CSD	3% of all fine sand, silt and clay, with the spill released near the seabed (bottom model layer). Where rock layers are encountered (Berth Pocket dredging), this source term is increased to 5%, in line with findings detailed in Section 3.8	The quantity of release is informed by Becker et al. (2015) Table 1 and Sun et al. (2020) Table 2. The distribution of the release is informed by Becker et al.
Dewatering/ Overflow	CSD material pumped to onshore settlement ponds.	2 % of silt and clay within the dredged material to be spilled at the tailwater discharge site following the onshore disposal (post decanting)	No guidance provided by Becker et al (2015) or Sun et al. (2020). The percentage of fines discharged with the tailwater followed SKM (2006) section 3.2.6.1.
	CSD material for offshore disposal	9 % of silt and clay with the spill to be distributed evenly in the water column at the dredger's location	The quantity of release is informed by Becker et al. (2015) Table 1 and Sun et al. (2020) Table 2. The distribution of the release is informed by Becker et al. (2015).
Offshore disposal	CSD material for offshore disposal	10 % of all silt, clay and fine sand, with 30 % of this spill to be distributed evenly within the water column (due to stripping) and the remaining 70 % to be occur near the seabed (due to bottom collapse).	The quantity of the release is informed by Becker et al. (2015) Table 1 and Sun et al. (2020) Table 2. The distribution of the release is informed by Gensheimer (2010) and Johnson and Fong (1995).
Erosion of disposed material	CSD material for offshore disposal	5% of the disposed clay, silt and fine sand to be placed in near the seabed.	Quantity and distribution of the release was informed by the Woodside Project (RPS, 2022).

4.2.8. Ambient Suspended Sediment Concentration

Modelling ambient SSC requires parameterisation of bed erosion terms, open boundary conditions including any terrestrial inputs, and their change relative to environmental forcing conditions.

In the absence of such parameterisation, the more simplistic (industry standard) approach to modelling ambient SSC was adopted whereby the 'Winter' background SSC (Table 8), consistent with the dredging schedule, was added to the 'above background' modelled SSC during post-processing before interpretation of potential environmental impact.

4.2.9. Selection of an Appropriate Light Model

Modelling benthic light according to the Beer-Lambert law (Equation 1) based on empirical evidence of the relationship between light attenuation and SSC or TSS, a methodology suggested by the EPA (2021), is riddled with uncertainties. The use of k_{PAR} (see Equation 4 to Equation 7) has been historically pervasive along the Pilbara Coast (e.g. MScience 2009, and MScience 2019) despite it ignoring the different rates of light attenuation for different bands of the PAR spectrum.

A wavenumber approach such as that adopted by IMO (2022) in deriving Equation 10 is considered more robust (refer to Fearn et al 2019). Unfortunately, the lack of field data variability in the dataset used to derive Equation 10 cannot be ignored and, as a result, the expression conservatively[7] results in greater light attenuation with depth, and higher sensitivity to small changes in SSC, than other relationships adopted in similar EIAs for dredging programs in the Pilbara prepared for the EPA.

In addition, none of the relationships discussed in Section 3.4 account for changes in particle size, shape, or type during different environmental forcing events (storms, surface runoffs, etc.) – a well-known shortcoming of applying a single expression to modelling benthic light. Further, application of the Beer-Lambert law requires accurate representation of incident solar radiation, reflection, and refraction at the ocean's surface, all difficult to forecast with certainty.

Yet, the application of a single relationship between k and TSS or SSC in EIAs of dredging programs is widely accepted (refer to EPA 2021) and was adopted for this analysis. Given the uncertainty surrounding the use of any of the proposed light models, O2Me have developed a validation exercise to demonstrate that the locally derived IMO (2022) relationship provides a suitable estimation of benthic light for the purposes of EIA of the Project.

4.2.9.1. Approach

The light attenuation calculation accounted for three-dimensional variation in modelled SSC. DLI was calculated across the model domain with consideration of:

- Spatially and temporally variable solar elevation
- Reflection and refraction of light at the sea surface
- Spatially and temporally variable total water depth and mean path length of solar radiation
- Vertically variable SSC and variable light attenuation coefficient for different wavelengths of light.

A discrete 3D approach was taken where light attenuation was calculated separately for each of the 10 model layers. The light attenuation relationship was also applied discretised in wavenumber space using the relationship defined in Equation 10 and Figure 6 for 20 nm increments of wavelengths within the PAR band. This was achieved by assuming that the total incident light shall be divided evenly between each representative wavelength band (i.e. a flat spectrum within PAR). Whilst this flat spectrum is not a perfect descriptor of incident solar spectrum in the Pilbara, O2Me believe this is a conservative measure as typical spectra have greater energy at intermediate PAR wavelengths (where the light attenuation coefficient would be lower in a dredge plume).

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. A constant reduction of 15% over the entire simulation was adopted.

---

[7] Relative to results of the assessment criteria defined in Section 3.7.2 using other light attenuation models introduced in Section 3.4.

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 – a technicality required with the DHI suite of models.

4.2.9.2. Validation

ZoMI for coral[8] was derived for the ambient condition (no-dredging) by applying the IMO (2022) light attenuation model to the naturally occurring SSC (as per Section 4.2.8) according to the assessment criteria for light reduction for corals (Table 10). The derived ZoMI demarks the zone where corals would be naturally impacted by light reduction and therefore unlikely to survive. Comparison of this naturally triggered ZoMI to the coral habitats identified in the subtidal BCH survey (O2M, 2023a) is presented in Figure 12 for the period spanning the base scenario and high volume scenarios (June 2021 to September 2021).

An agreement between the naturally occurring ZoMI boundary (approximately along the -10 m AHD isobath) derived using the IMO (2022) light attenuation model and the northern-most extent of the coral BCH patches is observed in Figure 12. This agreement qualitatively validates the light attenuation model adopted for this study, including:

- The selection of 0.47 mg/L ambient SSC for the model scenarios (discussed in sections 3.4 and 4.2.8)
- The selection of the IMO (2022) light attenuation model as a function of depth and SSC (discussed in sections 3.4 and 4.2.9)
- The 15% subsurface PAR reduction model (section 4.2.9.1)
- The DLI thresholds (discussed in 3.7.2 and 4.2.9.1).

---

[8] Coral communities are typically more sensitive than seagrass to reduced light conditions.

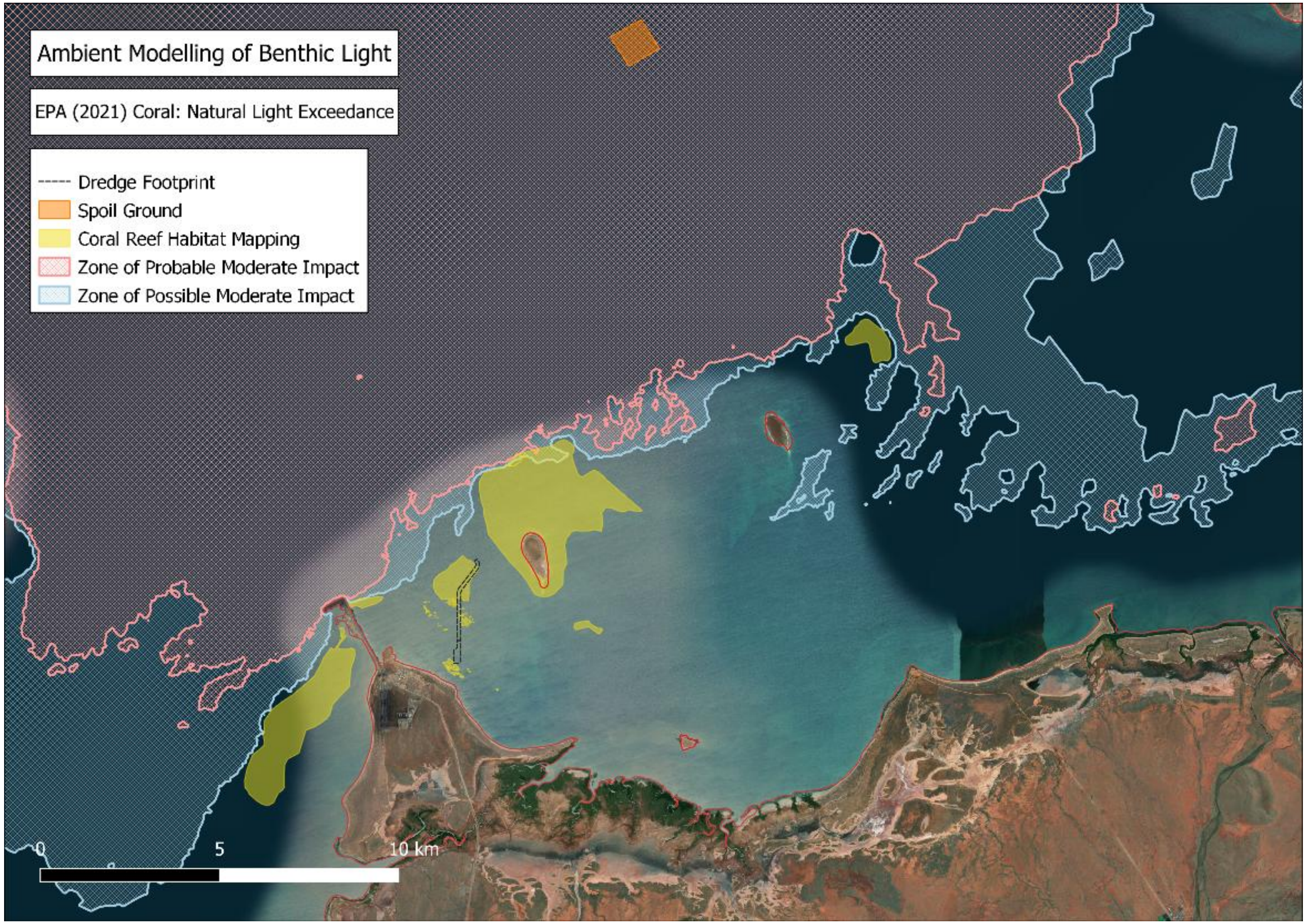


Figure 12: Natural ZoMI computed during the simulated dredging timeline (no dredge and disposal action) overlaying the subtidal coral BCH (O2M, 2023a)

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 Section 6.

For each disposal option, the environmental impact is presented for the largest (worst) potential environmental impact scenario. For both disposal option A and B, this was the High-Volume Case.

5.1. General plume behaviour

The maximum suspended sediment (both in vertical layering and time) for each model cell was calculated and compiled together to produce the maximum SSC map for the Base Case (Figure 13) and High-Volume Case (Figure 14). The maximum SSC maps do not reflect the extent of the sediment plume at any specific instant in time. Rather, they provide for a depiction of the scale, spread, and attenuation from discharge point of the sediment concentrations observed in each simulation.

Modelling results revealed a relatively low initial SSC at source and a rapid decrease in SSC with increasing distance from the dredging and disposal sites, driven by:

- The particle size of the discharged material, which contains a high proportion of find sand that settles quickly and closer to the source compared to silt and clay.
- The type of dredger considered, since CSD release material at its head near the seabed. Any material release near the seabed takes much shorter time to reach the seabed than when it is discharged at surface layer, for example via split hopper barge overflow.
- The type of disposal method, with a substantial reduction in generated SSC when onshore disposal is considered.

High ‘above background’ concentrations of >10 mg/L SSC were restricted to within or near the dredging footprint, which tended to oscillate along a north-westerly to south-easterly plane, in agreement with tidal currents. The low concentrations signal (<2 mg/L SSC) composed of the smaller particle fractions travelled further away, primarily aligning with wind driven current flows.

Owing to the very low fines content in the dredged material (typically < 1% clay and < 5 % silt, refer to Section 4.2.6), the extent and concentration of the modelled suspended sediment was rather similar for all four cases considered. Other notable observations may be summarised as follows:

- Base Case (Figure 13):
  - Both disposal options lead to similar size (areal extent) and severity (SSC) at the Offshore Spoil Ground C, which suggests that most of the material settles within 8-hours, the time spanning between two consecutive disposal events.
  - Barge overflow at the dredging site is the primary factor contributing to a broader spread of the sediment plume at the dredging site. Consequently, Disposal Option B, which assumes no overflow while dredging the southern channel and berth pocket, is expected to result in the smallest impact zones compared to Disposal Option A.
  - The tailwater discharge included in the Disposal Option B introduces an additional source of SSC south of the dredge footprint. Although this plume reaches >10 mg/L SSC, its contribution to the SSC footprint is relatively small and practically negligible.

- High Volume Case (Figure 14):
  - Key observations made earlier regarding the extent of the sediment plume when comparing the two disposal methods are also applicable to the High-Volume Case too.
  - The sediment plume generated in the High Volume Case affects a larger areal extent compared to the Base Case.

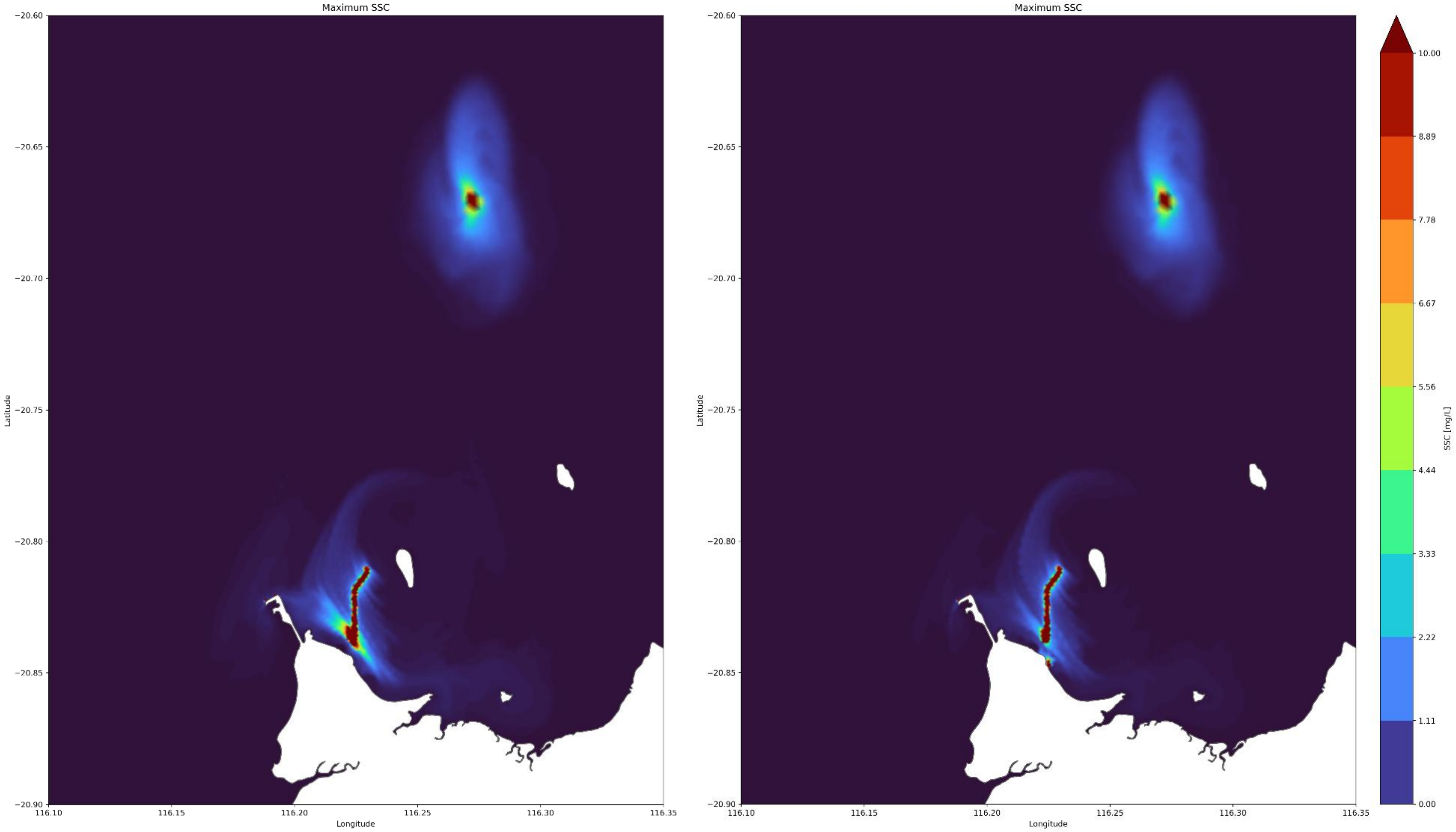


Figure 13: Maximum SSC Maps for Base Case with Disposal Option A (left) and Disposal Option B (right)

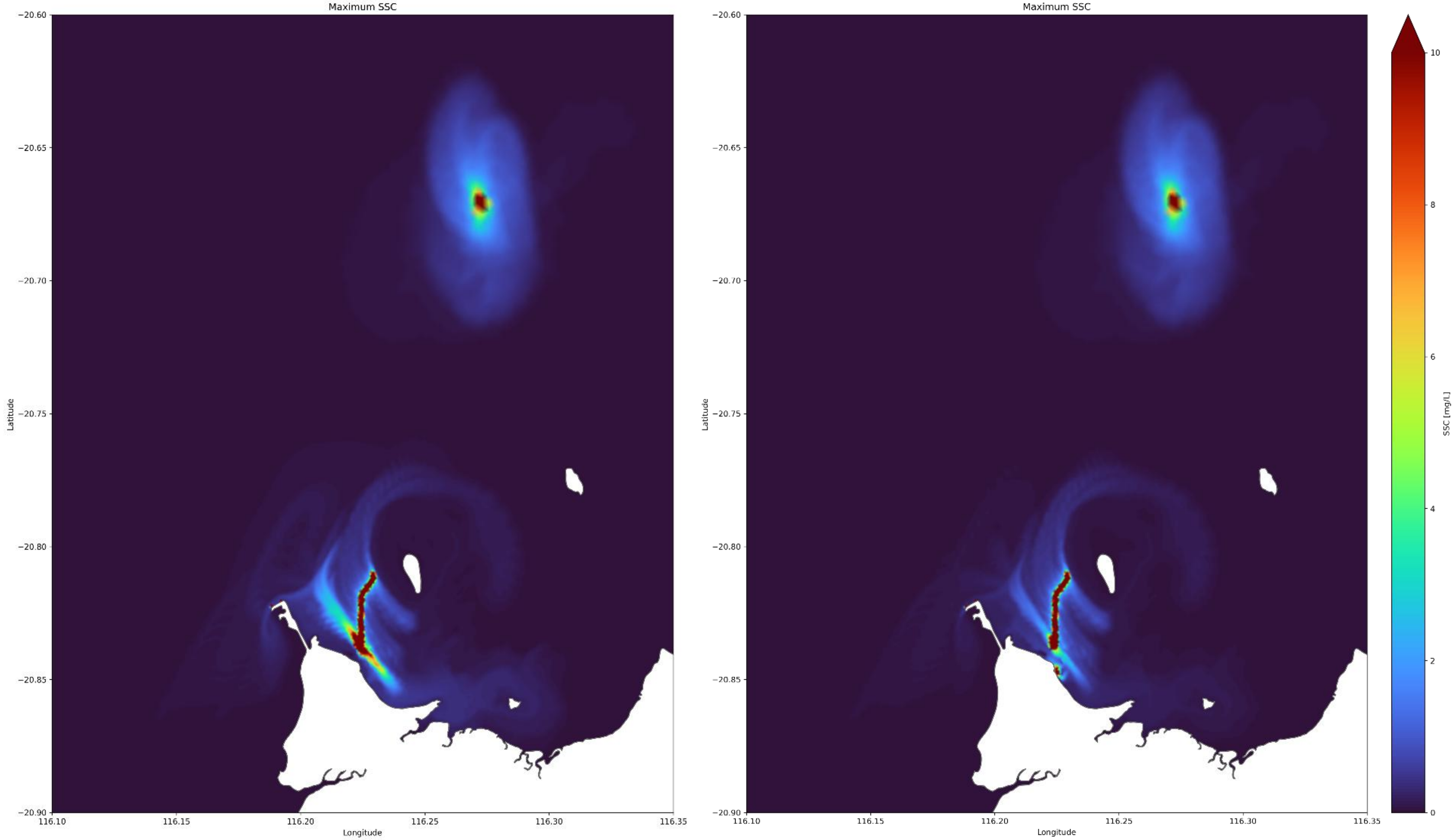


Figure 14: Maximum SSC Maps for High Volume Case with Disposal Option A (left) and Disposal Option B (right)

6. Potential environmental impact

A discussion on the potential for ecological stress is presented next, using the guidance described in Sections 3.7 and 3.8 and the method for the application of this guidance outlined in Sections 4.2.8 and 4.2.9.

The assessment for coral impact and seagrass impact has been conducted separately, with separate maps of the respective zones being produced. Therefore, this discussion must not be considered a formal environmental impact assessment.

Since the behaviour of the sediment plumes arising from the 'Base Case' and 'High-Volume Case' is similar but the areal extent of the plumes is larger for the 'High-Volume Case', the zones of impact are shown for the largest (worst) sediment plume scenario.

6.1. Zone of Influence

The Zone of Influence has been calculated for:

- High Volume Case – Disposal Option A (Offshore only): Figure 15
- High Volume Case – Disposal Option B (Onshore and Offshore): Figure 16

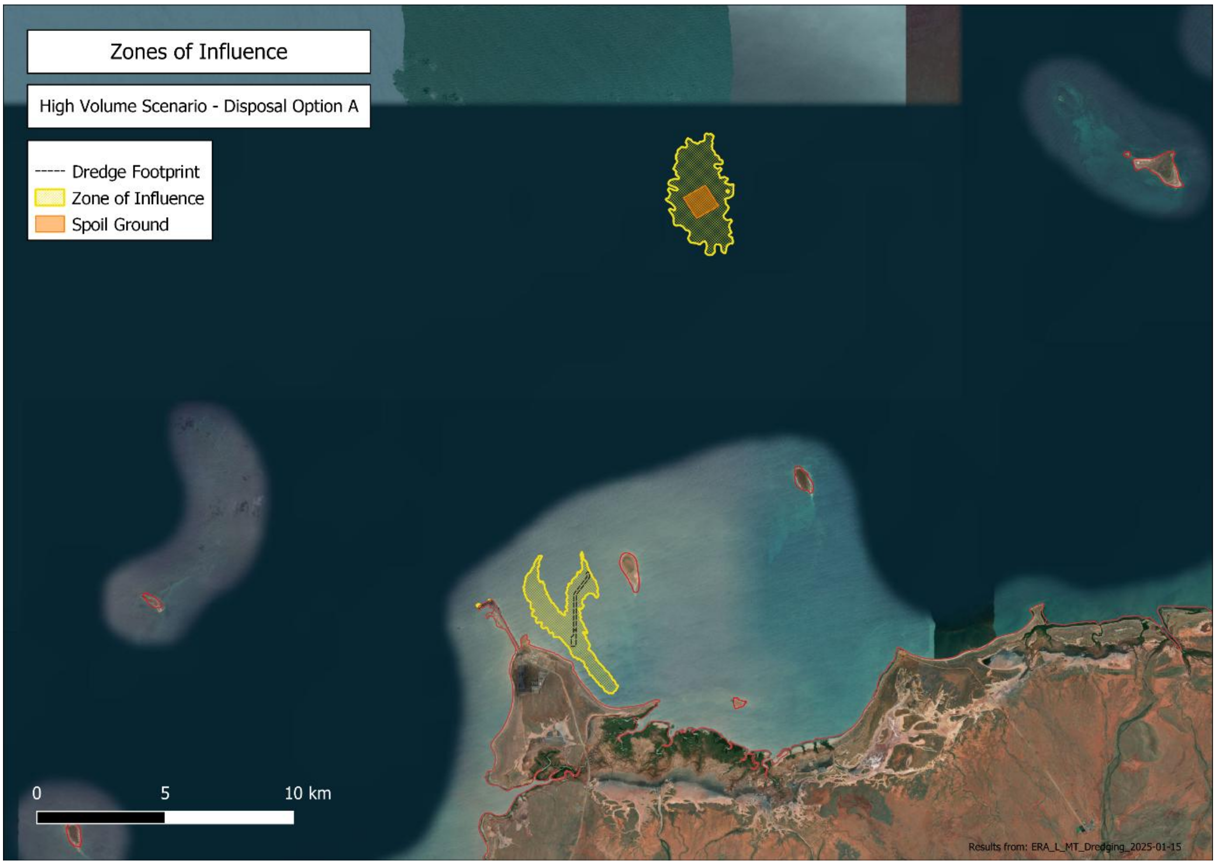


Figure 15 Zone of Influence: High Volume - Disposal Option A (Offshore Only)

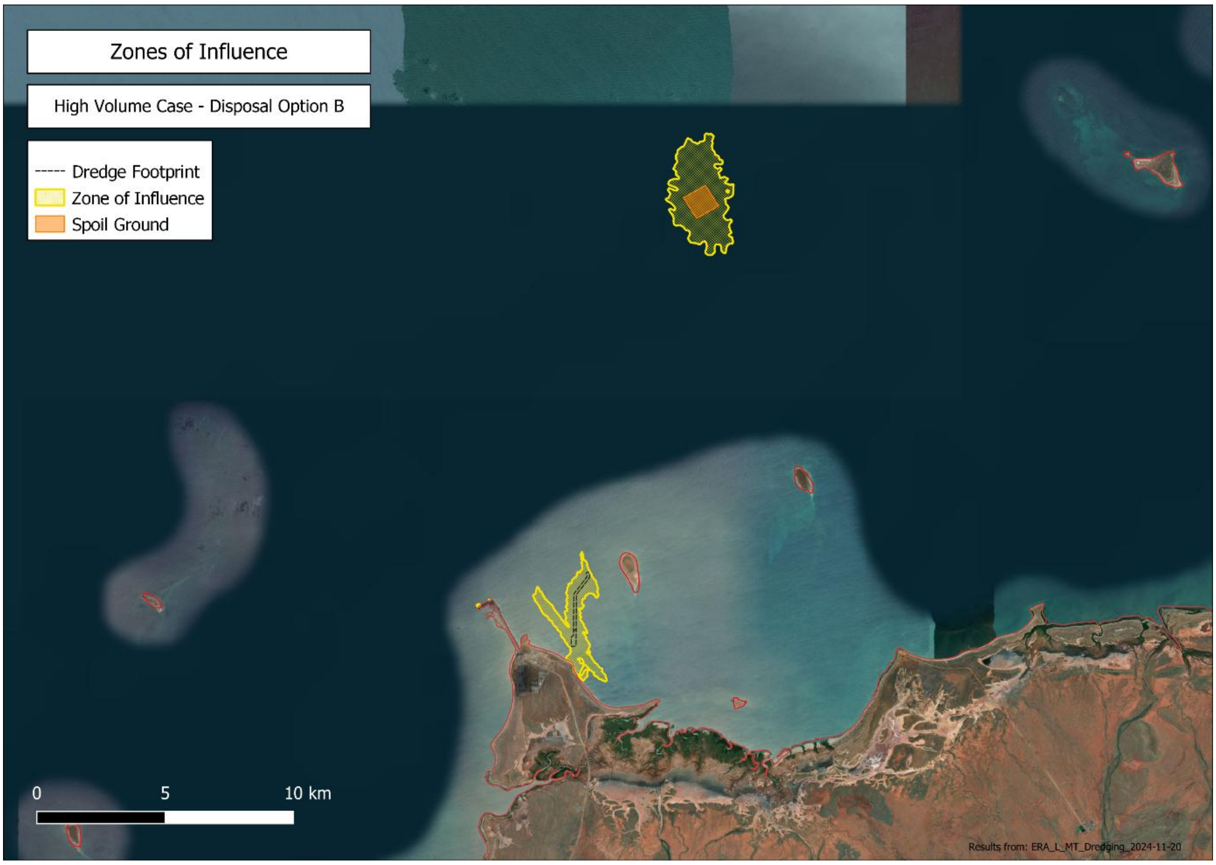


Figure 16 Zone of Influence: High Volume - Disposal Option B (Onshore & Offshore)

6.2. Zones of Impact

For both Disposal Option A and Disposal Option B:

- Moderate and High impact criteria for Seagrass (ZoMI and ZoHI) was not exceeded
- Moderate impact criteria for Corals (ZoMI) was exceeded for possible thresholds only.
- High impact criteria for Corals (ZoHI) was not exceeded.

The possible ZoMI for corals is shown in Figure 17 and Figure 18 for Disposal Option A and Disposal Option B, respectively. The following comments apply to these zones of impact:

- The possible ZoMI associated with Disposal Option A (6.47 ha in area) is larger than those for Disposal Option B (0.12 ha in area). The relative increase in ZoMI area associated with Disposal Option A is attributable to the additional sediment spilled nearby the dredging site as a result of the CSD overflow/dewatering process.
- The possible ZoMI associated with Disposal Option A intersects with 0.94 ha of coral habitat
- The possible ZoMI associated with Disposal Option B intersects with 0.06 ha of coral habitat

Table 17 summarises the area of intersection between the zones of impact and all mapped BCH. Note that for BCH that do not have an associated assessment criteria (e.g. macroalgae), the zones of impact to coral have been assumed for area calculations.

Table 17 Area of mapped BCH that intersect with modelled zones of impact (hectares)

Habitat	Disposal Option A		Disposal Option B	
	Moderate Impact (ha)	High Impact (ha)	Moderate Impact (ha)	High Impact (ha)
Hard Coral	0.94	0.00	0.06	0.00
Seagrass	0.00	0.00	0.00	0.00
Macroalgae Dominated	0.00	0.00	0.00	0.00
Filter Feeder Dominated	5.42	0.00	0.06	0.00
Mixed Subtidal	0.11	0.00	0.00	0.00
Unvegetated Soft Sediment	0.00	0.00	0.00	0.00

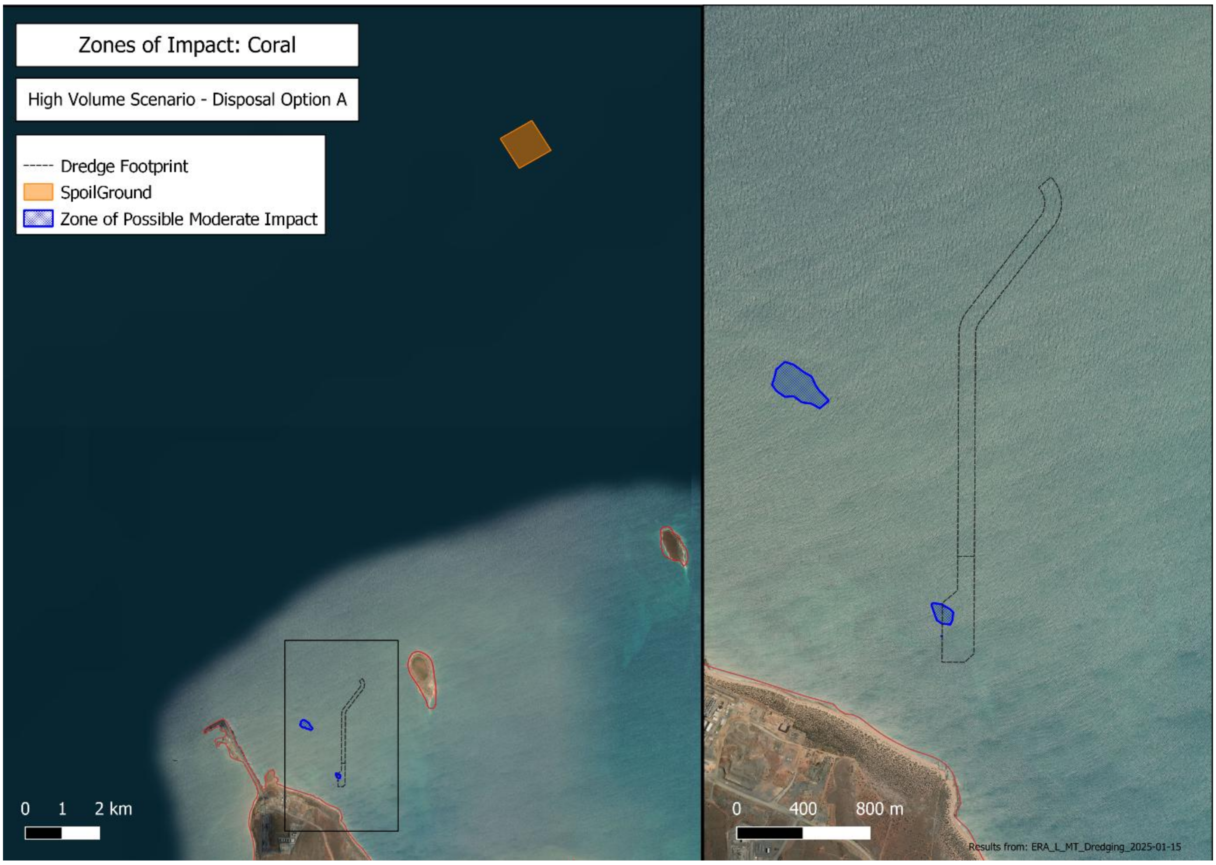


Figure 17 High Volume Case - Disposal Option A: Zones of Impact (Coral)

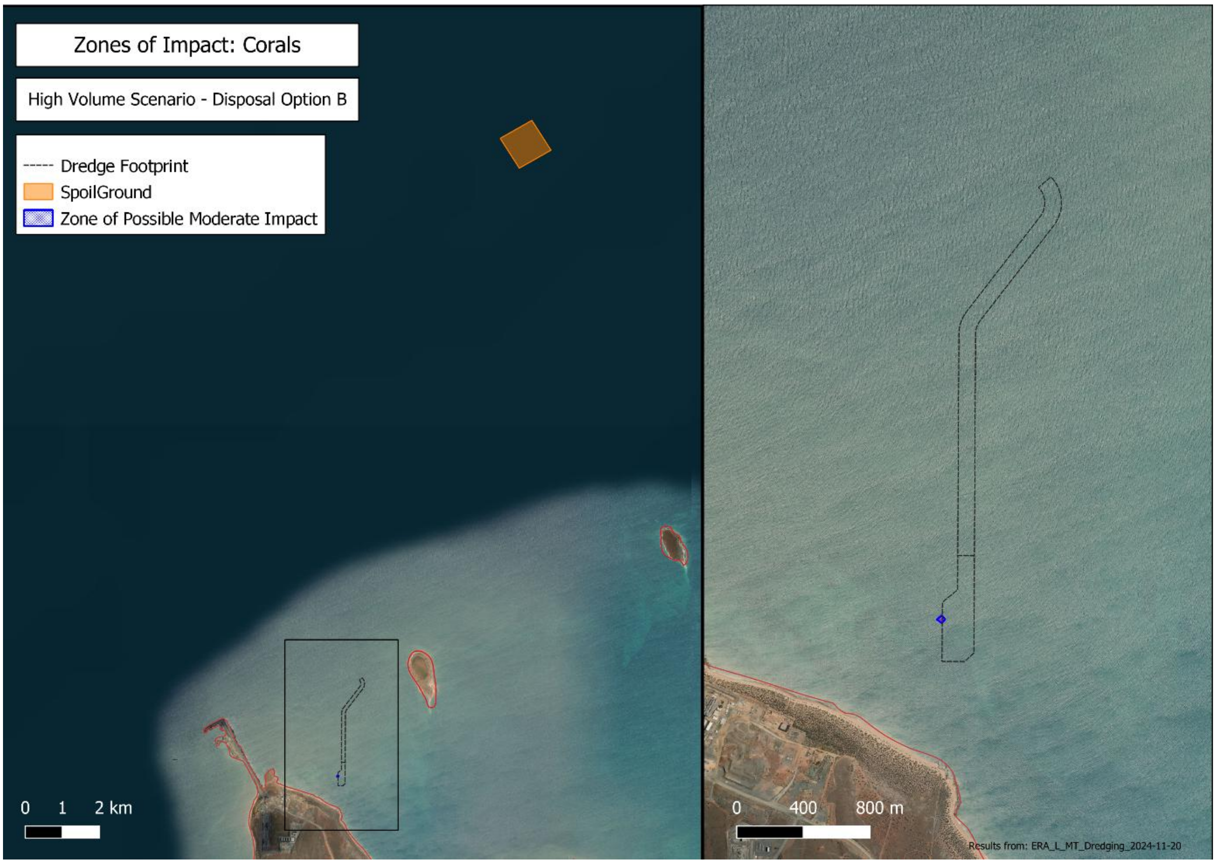


Figure 18: High Volume Case - Disposal Option B: Zones of Impact (Coral)

7. Conclusion

Since 2022, Leichhardt have iteratively refined the ESSP port channel design, associated dredge works and dredge spoil placement and disposal program. The iterative process drew on feedback received from the EPA and insights and expertise from a wide range of disciplines. Key refinements focused on reducing the load of Proposal-generated fines released into the water column. For the latest ESSP Scenario 7.2.1, dredging volumes were refined to include a base design representative of the best current information and a potential high-volume design which accounts for risk factors and data uncertainties. The dredge footprint and berth pocket were also moved north to minimise dredging into the Calcrete sediment, and the disposal method adapted to (preferably) include onshore disposal of material dredged near the coast.

Numerical modelling of SSC was conducted for the base and high-volume dredging cases, as well as for the two disposal options considered by Leichhardt, resulting in four (4) combinations of dredge and disposal conditions of the ESSP Scenario 7.2.1. The largest zones of impact were observed for the high-volume case scenario and were therefore conservatively adopted for this discussion, as using the smaller zones from the base case could not be justified. Results were analysed as per the EPA (2021) guidance for EIA of dredge plume modelling on corals and seagrass. Minimal environmental impact to BCH from the refined dredge and disposal program are expected, and may be summarised as follows:

- Moderate and High impact criteria for Seagrass (ZoMI and ZoHI) were not exceeded.
- Moderate impact criteria for Corals (ZoMI) was exceeded for possible thresholds only:
  - The possible ZoMI associated with 100% offshore disposal is 6.47 ha in total area and intersects with 0.94 ha of coral habitat
  - The possible ZoMI associated with onshore and offshore disposal is 0.12 ha in total area and intersects with 0.06 ha of coral habitat
- High impact criteria for Corals (ZoHI) was not exceeded.

8. References

Becker J, Eekelen E, Van Wiechen J, De Lange W, Damsa T, Smolders T and Van Koningsveld M (2015) Estimating Source Terms for Far Field Dredge Plume Modelling. Journal of Environmental Management, vol. 149, pp. 282-293.

DHI (2021a) MIKE 21 & MIKE 3 Flow Model FM Mud Transport Module Scientific Documentation. Retrieved from MIKE 3 Documentation: https://manuals.mikepoweredbydhi.help/2021/MIKE_3.htm.

DHI (2021b) MIKE 3 Flow Model FM Mud Transport User Guide. Retrieved from MIKE 3 Documentation: https://manuals.mikepoweredbydhi.help/2021/MIKE_3.htm.

EPA (Environmental Protection Authority) (2021) Technical Guidance – Environmental impact assessment of marine dredging proposals. Joondalup, WA 6919: Department of Water and Environmental regulation.

Fearns P, Dorji P, Broomhall M, Chedzey H, Symonds G, Mortimer N, Branson P, Contardo S, Shimizu K, Sun C (2019) Plume Characterisation – Field Studies. Report of Theme 3 – Project 3.2.1, prepared for the Dredging Science Node, Western Australian Marine Science Institution, Perth, Western Australia, 300 pp.

Gensheimer RJ (2010) Dynamics of particle clouds in ambient currents with application to open-water sediment disposal. Master of Science, Department of Civil and Environmental Engineering, Massachusetts Institute of Technology, Cambridge, MA.

IMO (Insitu-Marine Optics) (2022) Spectral Diffuse Attenuation Model for the Cape Preston Coast, Perth, WA.

Johnson, BH and Fong, MT (1995) Development and Verification of Numerical Models for Predicting the Initial Fate of Dredged Material Disposed in Open Water. Report 2. Theoretical Developments and Verification Results. Army Engineer Waterway Experiment Station, Vicksburg, MS.

Mills D, and Kemps H (2016) Generation and release of sediment by hydraulic dredging: a review. Report of Theme 2 – Project 2.1. Prepared for the Dredging Science Node (DSN), Western Australian Marine Science Institution (WAMSI), pp. 97, Perth, WA.

MScience (2009) Wheatstone LNG Development: Baseline Water Quality Assessment Report November 2009. Prepared for URS Corporation, Report No. MSA134R3, Perth, WA.

MScience (2019) Woodside Scarborough Dredging Threshold Levels for Model Interrogation, Appendix D of the Woodside Scarborough Dredging and Spoil Disposal Management Plan, Report No. SA0006AH0000002, Perth, WA.

O2 Marine (O2M), 2021, Eramurra Solar Salt Project: Sediment Analysis, O2 Marine Report R210087, Fremantle 6160, Western Australia. Report prepared for Leichhardt Salt Pty Ltd.

O2 Marine (O2M), 2022, Eramurra Solar Salt Project: Water Quality Analysis Report, O2 Marine Report R210120,Fremantle 6160, Western Australia. Report prepared for Leichhardt Salt Pty Ltd.

O2 Marine (O2M), 2023a, Eramurra Solar Salt Project: Subtidal Benthic Communities and Habitat, O2 Marine Report R210228, Fremantle 6160, Western Australia. Report prepared for Leichhardt Salt Pty Ltd.

O2 Marine (O2M), 2025, Eramurra Solar Salt Project: Subtidal Benthic Communities and Habitat, O2 Marine Report R210228, Revision 6, Fremantle 6160, Western Australia. Report prepared for Leichhardt Salt Pty Ltd.

O2 Metocean (O2Me) (2022a) Eramurra Solar Salt Project: Base Hydrodynamic Model, O2 Marine Report R210323, Fremantle 6160, Western Australia. Report prepared for Leichhardt Salt Pty Ltd.

O2 Metocean (O2Me) (2022b) Eramurra Solar Salt Project: Metocean Field Data Collection Programme: Data Report, O2 Marine Report R200219, Fremantle 6160, Western Australia. Report prepared for Leichhardt Salt Pty Ltd.

O2 Metocean (O2Me) (2022c) Eramurra Solar Salt Project: Metocean Data Interpretation, O2Me Report R210389, Fremantle 6160, Western Australia. Report prepared for Leichhardt Salt Pty Ltd.

O2 Metocean (O2Me) (2022d) Eramurra Solar Salt Project: Coastal Process Study to Support BCH Assessment, O2Me Report R210391, Fremantle 6160, Western Australia. Report prepared for Leichhardt Salt Pty Ltd, November 2022.

O2 Metocean (O2Me) (2023a) Eramurra Solar Salt Project: Dredge Plume Modelling, O2Me Report R210324, Fremantle 6160, Western Australia. Report prepared for Leichhardt Salt Pty Ltd.

O2 Metocean (O2Me) (2025) Eramurra Solar Salt Project Scenario 7.2.1: Dredge Plume Modelling, O2Me Report R240475, Fremantle 6160, Western Australia. Report prepared for Leichhardt Salt Pty Ltd.

Preston Consulting (2022) Eramurra Solar Salt Project: Environmental Scoping Document. Document Number WV03015. Revision 2a.

RPS (2022). Scarborough Development Dredged Sediment Dispersion Modelling. Document No. MAW0753J.002. Revision 3. Report prepared for Woodside Energy.

SKM (Sinclair Knight Merz) (2006) Dredging Program for the Dampier Port Upgrade. Document Number MW03712-SKM-EO-ME-5001, Revision 2a, Perth, WA.

SKM (Sinclair Knight Merz) (2013) Cape Preston Marine Geotechnical Investigation - Summary of Results. Document Number MW03712-SKM-EO-ME-5001, Perth, WA.

Smith, RC, and Baker, KS (1981) Optical properties of the clearest natural waters (200–800 nm). Applied optics, 20(2), 177-184.

Steedman R (2022) A review O2Metocean Base Hydrodynamic Model of Cape Preston East Leichhardt Salt Pty Ltd, (proposed) Eramurra Solar Salt Project, 14 July 2022.

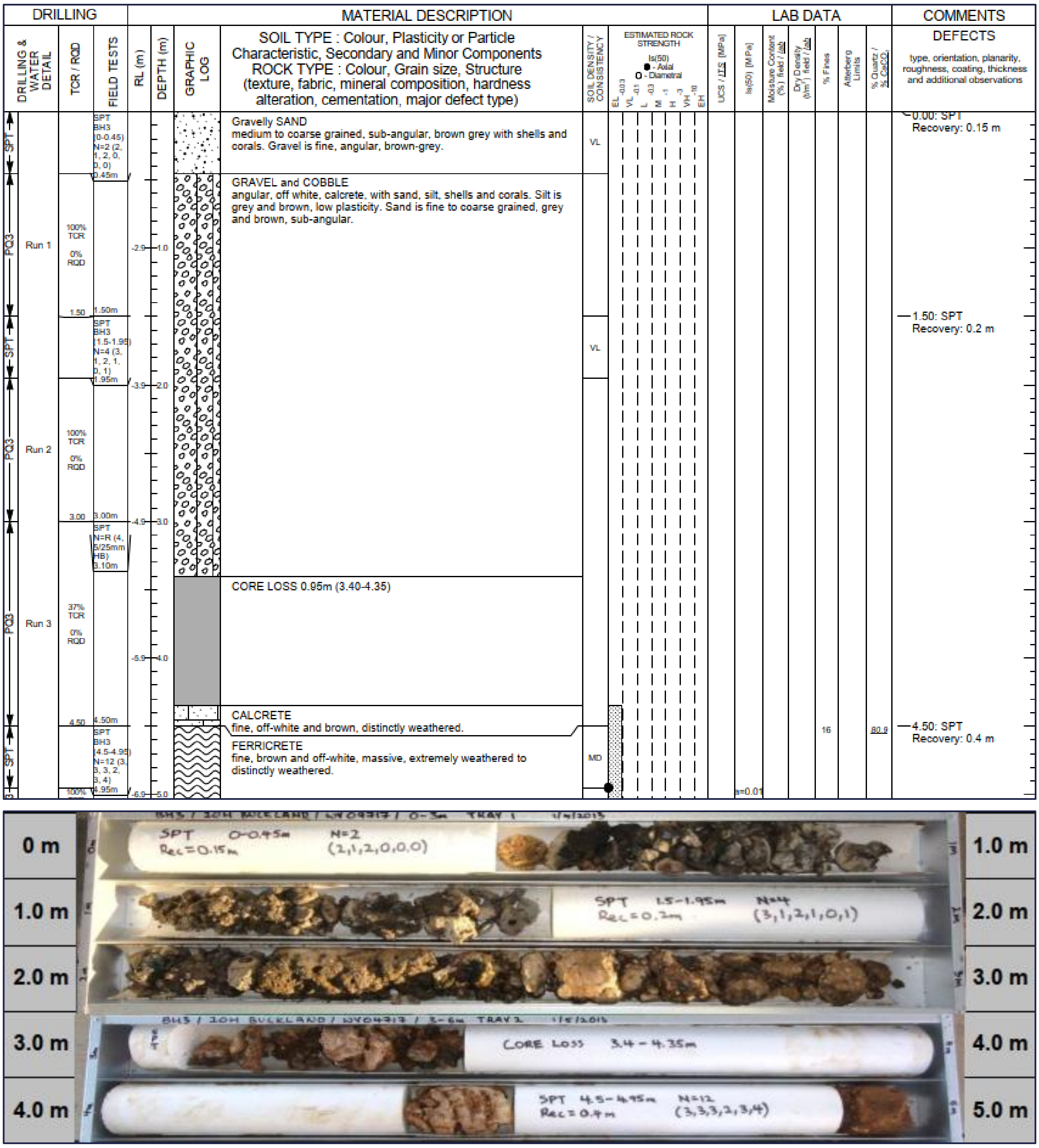
Sun C, and Branson P (2018) Numerical modelling of dredge plumes. Report of Theme 3 - Project 3.4. Prepared for the Dredging Science Node, Western Australian Marine Science Institution, Perth, WA.

Sun C, Branson P, and Mills D (2020) Guideline on dredge plume modelling for environmental impact assessment. Western Australian Marine Science Institution (WAMSI), Perth, WA.

Sun C, Shimizu K, and Symonds G (2016) Numerical Modelling of Dredge Plumes: A Review. Western Australian Marine Science Institution (WAMSI) and CSIRO Oceans and Atmosphere Flagship, Perth, WA.

van Rijn L, and Barth R (2018) Settling and Consolidation of Soft Mud Layers. Journal of Waterway, Port, Coastal and Ocean Engineering (ASCE), vol. 145, pp. 27-45.

Appendix A. SKM 2013 Borehole 03 to Borehole 07 (0 m to 5 m)



DRILLING				MATERIAL DESCRIPTION						LAB DATA							COMMENTS
DRILLING & WATER DETAIL		TCR / RQD	FIELD TESTS	RL (m)	DEPTH (m)	GRAPHIC LOG	SOIL TYPE : Colour, Plasticity or Particle Characteristic, Secondary and Minor Components ROCK TYPE : Colour, Grain size, Structure (texture, fabric, mineral composition, hardness alteration, cementation, major defect type)	SOIL DENSITY / CONSISTENCY	ESTIMATED ROCK STRENGTH Is(50) ● - Axial O - Diametral EL -0.03 VL -0.1 L -0.3 M -1 H -3 VH -10 EH	UCS / ITS (MPa)	Is(50) (MPa)	Moisture Content (%) field / lab	Dry Density (t/m³) field / lab	% Fines	Atterberg Limits	% Quartz / % CaCO3	DEFECTS type, orientation, planarity, roughness, coating, thickness and additional observations
SPT			SPT BH3 (0-0.45) N=2 (2, 1, 2, 0, 0, 0) 0.45m				Gravelly SAND medium to coarse grained, sub-angular, brown grey with shells and corals. Gravel is fine, angular, brown-grey.	VL									0.00: SPT Recovery: 0.15 m
PQ3	Run 1	100% TCR 0% RQD		-2.9	1.0		GRAVEL and COBBLE angular, off white, calcrete, with sand, silt, shells and corals. Silt is grey and brown, low plasticity. Sand is fine to coarse grained, grey and brown, sub-angular.										
SPT		1.50	1.50m SPT BH3 (1.5-1.95) N=4 (3, 1, 2, 1, 0, 1) 1.95m	-3.9	2.0			VL									1.50: SPT Recovery: 0.2 m
PQ3	Run 2	100% TCR 0% RQD															
PQ3	Run 3	3.00 37% TCR 0% RQD	3.00m SPT N=R (4, 5/25mm HB) 3.10m	-4.9	3.0												
				-5.9	4.0		CORE LOSS 0.95m (3.40-4.35)										
							CALCRETE fine, off-white and brown, distinctly weathered.							16		80.9	
SPT		4.50 100%	4.50m SPT BH3 (4.5-4.95) N=12 (3, 3, 3, 2, 3, 4) 4.95m	-6.9	5.0		FERRICRETE fine, brown and off-white, massive, extremely weathered to distinctly weathered.	MD	●		a=0.01						4.50: SPT Recovery: 0.4 m

Figure 19 BH03: 0m to 5m. Extracted from Appendix C of SKM (2013)

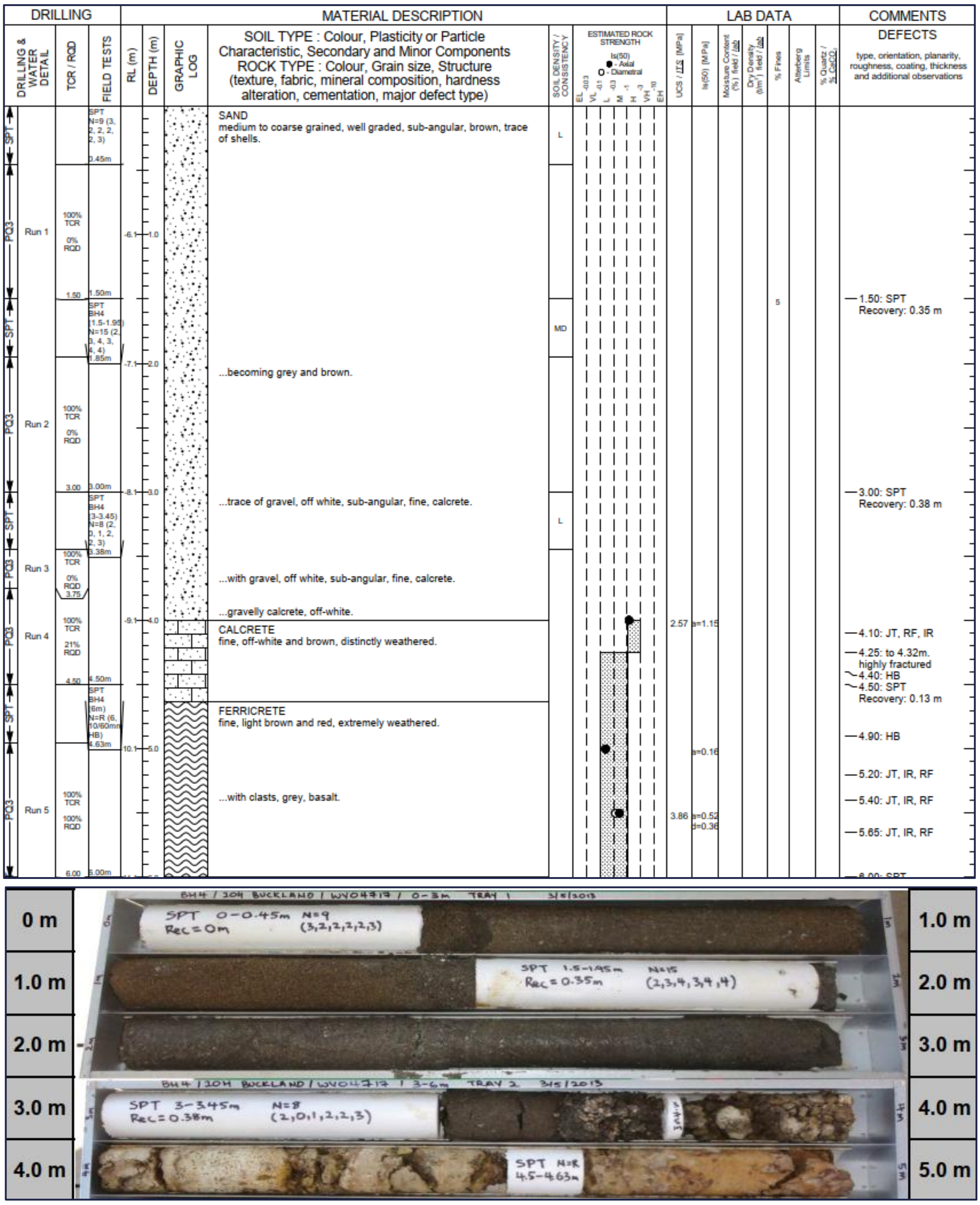
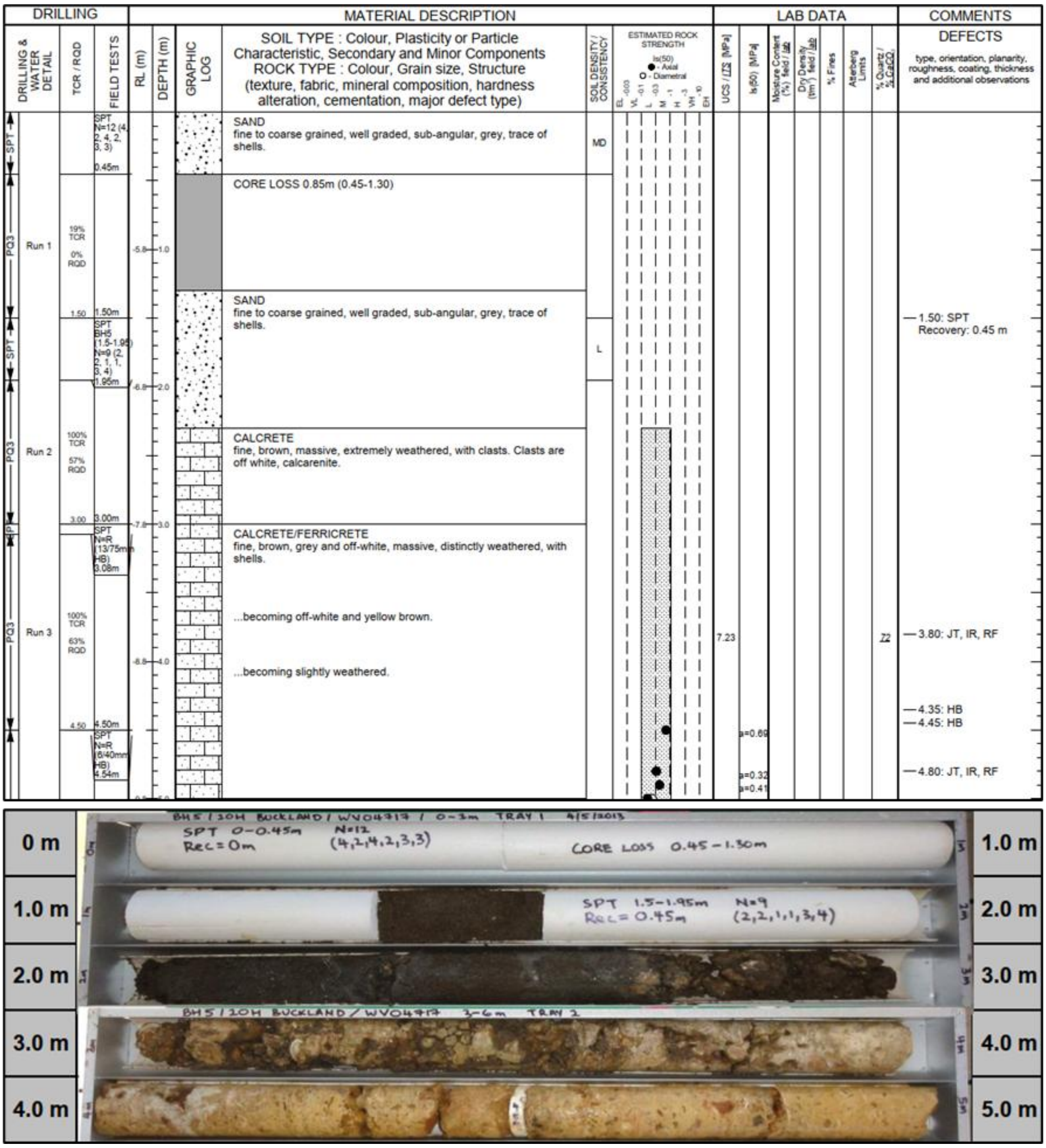
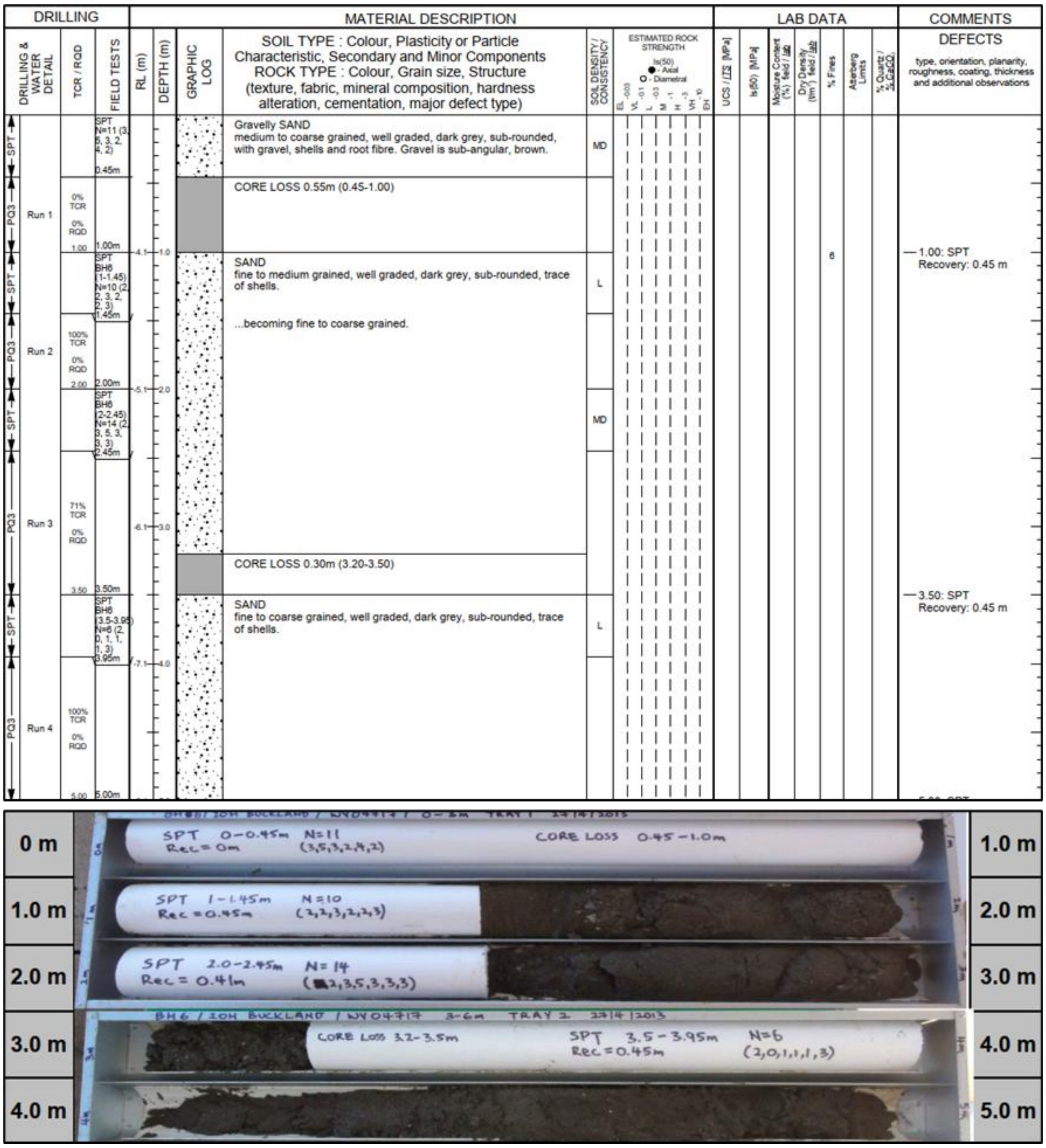


Figure 20 BH04: 0m to 5m. Extracted from Appendix C of SKM (2013)



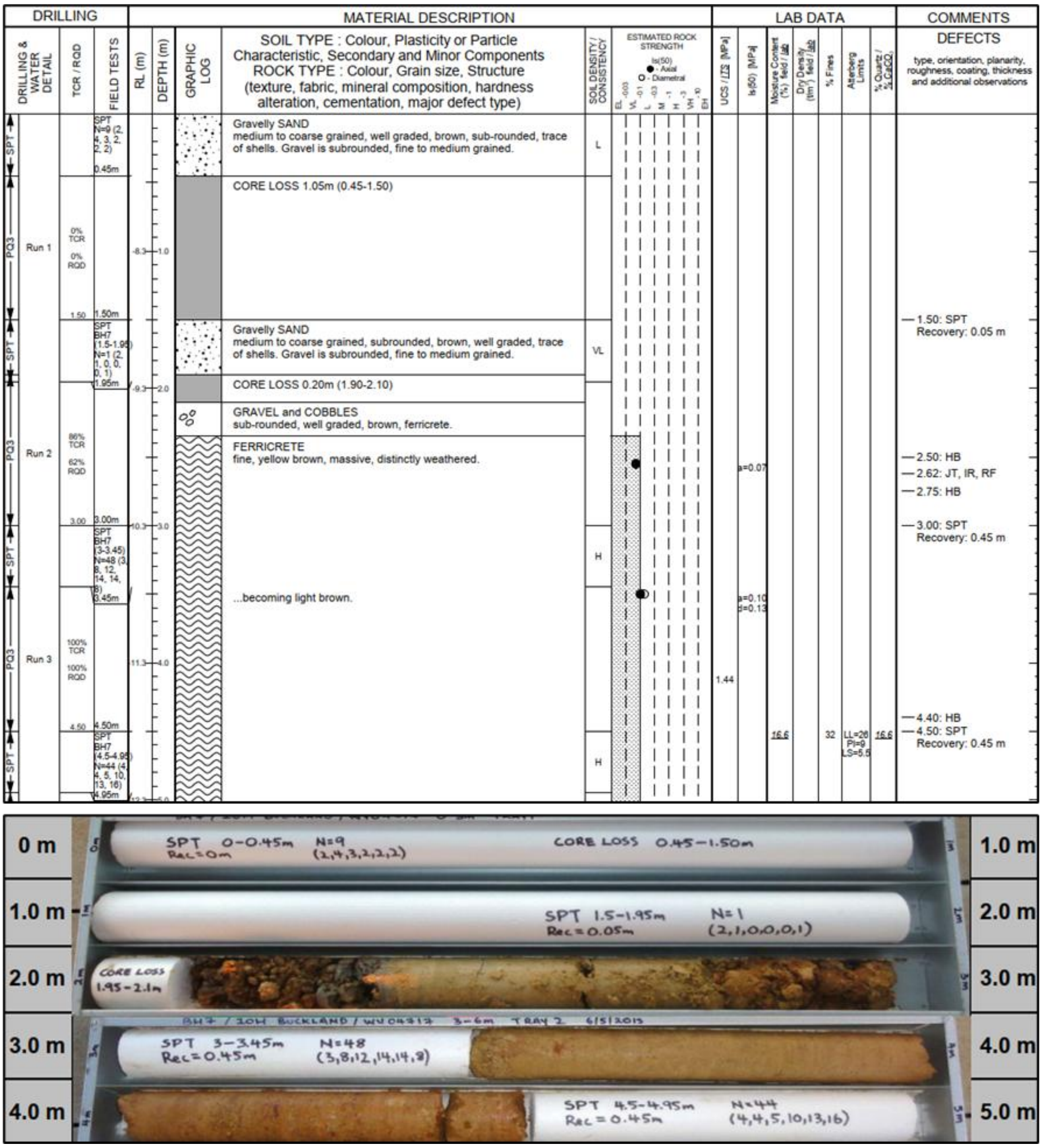
DRILLING			MATERIAL DESCRIPTION					LAB DATA							COMMENTS
DRILLING & WATER DETAIL	TCR / RQD	FIELD TESTS	RL (m)	DEPTH (m)	SOIL TYPE : Colour, Plasticity or Particle Characteristic, Secondary and Minor Components ROCK TYPE : Colour, Grain size, Structure (texture, fabric, mineral composition, hardness alteration, cementation, major defect type)	SOIL DENSITY / CONSISTENCY	ESTIMATED ROCK STRENGTH Is(50) ● - Axial ○ - Diametral (EL, VL, L, M, H, VH, EH)	UCS / ITS [MPa]	Is(50) [MPa]	Moisture Content (%) field / lab	Dry Density (t/m³) field / lab	% Fines	Atterberg Limits	% Quartz / % CaCO3	DEFECTS type, orientation, planarity, roughness, coating, thickness and additional observations
SPT		SPT N=12 (4, 2, 4, 2, 3, 3) 0.45m			SAND fine to coarse grained, well graded, sub-angular, grey, trace of shells.	MD									
PQ3 Run 1	19% TCR 0% RQD		-5.8	1.0	CORE LOSS 0.85m (0.45-1.30)										
SPT	1.50	1.50m SPT BH5 (1.5-1.95) N=9 (2, 2, 1, 1, 3, 4) 1.95m	-6.8	2.0	SAND fine to coarse grained, well graded, sub-angular, grey, trace of shells.	L									1.50: SPT Recovery: 0.45 m
PQ3 Run 2	100% TCR 57% RQD				CALCRETE fine, brown, massive, extremely weathered, with clasts. Clasts are off white, calcarenite.										
SPT	3.00	3.00m SPT N=R (13/75mm HB) 3.08m	-7.8	3.0	CALCRETE/FERRICRETE fine, brown, grey and off-white, massive, distinctly weathered, with shells.										
PQ3 Run 3	100% TCR 63% RQD		-8.8	4.0	...becoming off-white and yellow brown. ...becoming slightly weathered.			7.23	a=0.69 a=0.32 a=0.41					72	3.80: JT, IR, RF 4.35: HB 4.45: HB 4.80: JT, IR, RF
SPT	4.50	4.50m SPT N=R (6/40mm HB) 4.54m													

Figure 21 BH05: 0m to 5m. Extracted from Appendix C of SKM (2013)



DRILLING & WATER DETAIL	TCR / RQD	FIELD TESTS	RL (m)	DEPTH (m)	GRAPHIC LOG	MATERIAL DESCRIPTION SOIL TYPE : Colour, Plasticity or Particle Characteristic, Secondary and Minor Components ROCK TYPE : Colour, Grain size, Structure (texture, fabric, mineral composition, hardness alteration, cementation, major defect type)	SOIL DENSITY / CONSISTENCY	ESTIMATED ROCK STRENGTH Is(50) ● - Axial O - Diametral EL .003 VL .01 L .03 M .1 H .3 VH 10 EH	UCS / UTS [MPa]	Is(50) [MPa]	Moisture Content (%) field / lab	Dry Density (t/m³) field / lab	% Fines	Atterberg Limits	% Quartz / % CaCO₃	COMMENTS DEFECTS type, orientation, planarity, roughness, coating, thickness and additional observations
SPT		SPT N=11 (3, 5, 3, 2, 4, 2) 0.45m				Gravelly SAND medium to coarse grained, well graded, dark grey, sub-rounded, with gravel, shells and root fibre. Gravel is sub-angular, brown.	MD									
PQ3 Run 1	0% TCR 0% RQD 1.00	1.00m	-4.1	1.0		CORE LOSS 0.55m (0.45-1.00)										
SPT		SPT BH6 (1-1.45) N=10 (2, 2, 3, 2, 2, 3) 1.45m				SAND fine to medium grained, well graded, dark grey, sub-rounded, trace of shells.	L						6			1.00: SPT Recovery: 0.45 m
PQ3 Run 2	100% TCR 0% RQD 2.00	2.00m	-5.1	2.0		...becoming fine to coarse grained.										
SPT		SPT BH6 (2-2.45) N=14 (2, 3, 5, 3, 3, 3) 2.45m					MD									
PQ3 Run 3	71% TCR 0% RQD 3.50	3.50m	-6.1	3.0		CORE LOSS 0.30m (3.20-3.50)										3.50: SPT Recovery: 0.45 m
SPT		SPT BH6 (3.5-3.95) N=6 (2, 0, 1, 1, 1, 3) 3.95m	-7.1	4.0		SAND fine to coarse grained, well graded, dark grey, sub-rounded, trace of shells.	L									
PQ3 Run 4	100% TCR 0% RQD 5.00	5.00m														

Figure 22 BH06: 0m to 5m. Extracted from Appendix C of SKM (2013)



DRILLING

MATERIAL DESCRIPTION

LAB DATA

COMMENTS

DRILLING & WATER DETAIL | TCR / RQD | FIELD TESTS | RL (m) | DEPTH (m) | GRAPHIC LOG

SOIL TYPE : Colour, Plasticity or Particle Characteristic, Secondary and Minor Components
ROCK TYPE : Colour, Grain size, Structure
(texture, fabric, mineral composition, hardness alteration, cementation, major defect type)

SOIL DENSITY / CONSISTENCY | ESTIMATED ROCK STRENGTH Is(50) ● - Axial O - Diametral

UCS / ITS [MPa] | Is(50) [MPa] | Moisture Content (%) field / lab | Dry Density (t/m³) field / lab | % Fines | Atterberg Limits | % Quartz / % CaCO3

DEFECTS
type, orientation, planarity, roughness, coating, thickness and additional observations

Gravelly SAND
medium to coarse grained, well graded, brown, sub-rounded, trace of shells. Gravel is subrounded, fine to medium grained.

CORE LOSS 1.05m (0.45-1.50)

Gravelly SAND
medium to coarse grained, subrounded, brown, well graded, trace of shells. Gravel is subrounded, fine to medium grained.

CORE LOSS 0.20m (1.90-2.10)

GRAVEL and COBBLES
sub-rounded, well graded, brown, ferricrete.

FERRICRETE
fine, yellow brown, massive, distinctly weathered.

...becoming light brown.

—1.50: SPT
Recovery: 0.05 m

—2.50: HB

—2.62: JT, IR, RF

—2.75: HB

—3.00: SPT
Recovery: 0.45 m

—4.40: HB

—4.50: SPT
Recovery: 0.45 m

Figure 23 BH07: 0m to 5m. Extracted from Appendix C of SKM (2013)

Appendix B. Application of Representative PSD Methodology

For each dredge zone, the representative PSD was calculated as follows:

Step 1: Determine what percentage of the material is located within each geological strata

- Southern Channel Extent: The target dredge depth of 4.5 m CD can be approximated to 6.93 AHD using the tidal planes for 'NCP05' derived in O2Me (2022c). Mapping the dredging extent over the SKM borehole interpolation (orange area in Figure 24) concluded that the southern channel extent dredge material is entirely composed of the sandy coastal deposit layer[9].
- Berth Pocket Deepening: The target dredge depth of 6.7 m CD can be approximated to 9.13 AHD using the tidal planes for 'NCP05' derived in O2Me (2022c). Mapping the dredging extent over the SKM borehole interpolation (purple area in Figure 24) concluded that the southern channel extent dredge material is 48% sandy coastal deposit, 51% calcrete and 1% ferricrete.
- Northern Channel Extent: The target dredge depth 4.5 m CD (6.93 m AHD) is to extend further north than the northern most SKM borehole (borehole 8). The target dredging depth is either above the existing seabed or no more than ~0.5 m deeper than the existing seabed (Figure 25). Hence, the region can be well represented by surficial samples (100 % sandy coastal deposit).

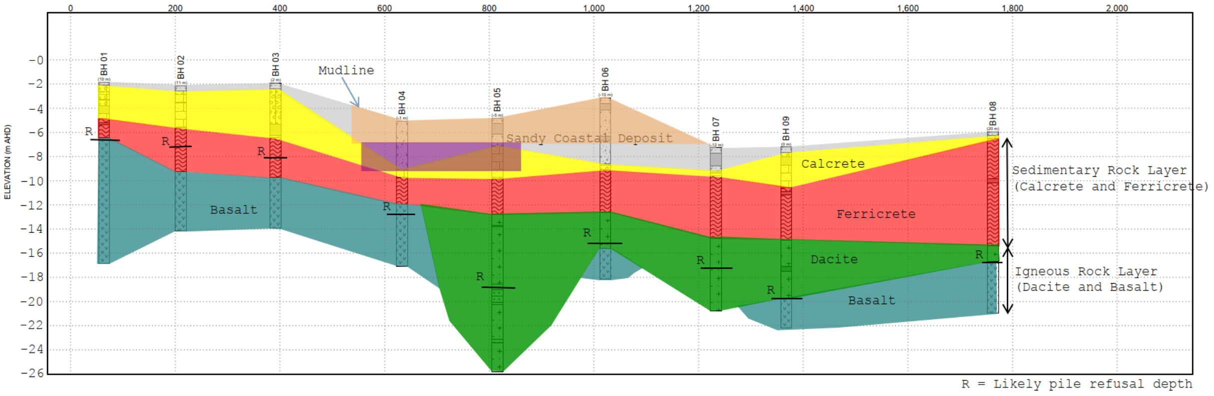


Figure 24 southern channel extent (orange) and berth pocket deepening (purple) dredging extent overlaying the SKM (2013) borehole interpolation

---

[9] ~0.3% of the overlayed area encroaches Calcrete and given this very small magnitude and the simplistic linear interpolation applied to the SKM borehole interpolation, this has been rounded to the nearest percent (0 % calcrete) for the purpose of PSD derivation.

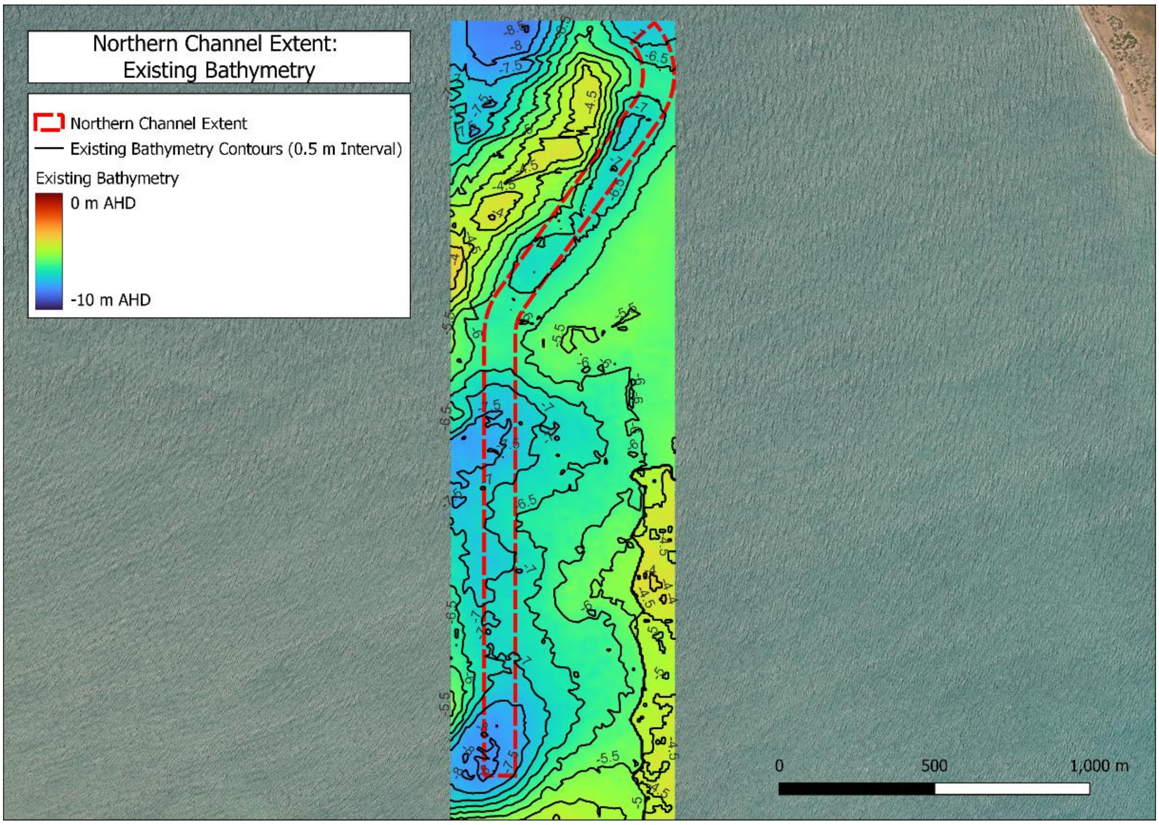


Figure 25 Northern Channel Extent: Existing Bathymetry

Step 2: Calculate an average PSD for each geological strata identified in (Step 1), using only the samples that are within or neighbouring the zone

The following samples from Section 3.3.1 and Section 3.3.2 were selected and averaged as follows:

- Southern Channel Extent:
  - Sandy coastal deposit average PSD included SKM and O2M samples at sites BH4, BH5, BH6, BH7, V6, V5, G10, G11, IG1, IG4 and IG3.
- Berth Pocket Deepening:
  - Sandy coastal deposit average PSD included SKM and O2M samples at sites BH4, BH5, V6 and IG4
  - Calcrete average PSD included SKM samples at sites BH2 and BH7 (north and south of berth pocket)
  - Ferricrete average PSD included SKM sample at sites BH2 (only sample within Ferricrete layer)
- Northern Channel Extent:
  - Sandy coastal deposit average PSD O2M samples at sites G1, G2, G3, G4, G5, G6, G7, G8, G9, V1, V2, V3 and V4.

Step 3: Calculate a weighted PSD using (Step 1) and (step 2)

- Southern Channel Extent PSD= 1.0*PSDSCD+ 0.25*PSDcalcrete.
- Berth Pocket Deepening PSD= 0.48*PSDSCD+ 0.51*PSDcalcrete+ 0.01*PSDferricrete.
- Northern Channel Extent PSD= 1.0*PSD_{SCD}.

Appendix C. IMO 2022: Spectral Diffuse Attenuation Model for the Cape Preston Coast

In-situ Marine Optics

Unit 7, 6 Tidal Way Bibra Lake, WA 6163 www.insitumarineoptics.com info@insitumarineoptics.com

Spectral Diffuse Attenuation Model for the Cape Preston Coast

In-situ Marine Optics Pty. Ltd.

June 8, 2022

Acronyms, Abbreviations and Definitions

NTU	Nephelometric Turbidity Unit.
NIR	Near-Infra Red.
λ	Wavelength of Light (usually denoted in nm).
$K_d(\lambda)$	Diffuse attenuation coefficient of underwater irradiance (m^{-1}).
$E_d(\lambda)$	In-water Downwelling Irradiance ($Wm^{-2}nm^{-1}$).
$E_s(\lambda)$	In-air Downwelling Irradiance ($Wm^{-2}nm^{-1}$).
θ_{s_w}	Solar zenith angle in water (°).
z	Water Depth (m).
SSC	Suspended Solids Concentration ($mgl^{-}1$).

1 Methods

1.1 Input Data

In-situ in-water NTU and hyperspectral irradiance ($E_d(\lambda, z)$) profiles and in-air ($E_s(\lambda)$) reference measurements were collected by O2 Marine made in a variety of locations during two different field cruises from 15^{th} - 17^{th} June 2020 and 15^{th} of July 2021. In total, 26 complete profiles were made where all data sources were available. A summary of the input data can be found in Table 1.

1.2 Data Reduction

Firstly, the Beer-lambert Law was used to determine the full profile-averaged diffuse attenuation coefficient for each profile where all three NTU, E_d and E_s data were available (N=26). As atmospheric conditions fluctuated during the fieldwork, the In-water E_d measurements were normalised by the in-air reference E_s measurements prior to model fitting. Furthermore, to reduce the first-order effects of sun angle-dependent mean path-length on the $K_d(\lambda)$ model coefficients, the depth measurements for each profile were normalised by the cosine of the in-water solar zenith angle.

For every discrete wavelength measured by the In-situ Marine Optics μSpec hyperspectral radiometers, model coefficients $A(\lambda)$ and $K_d(\lambda)$ were determined over the depth range of 5cm below the surface, to the depth of roughly 0.5% surface irradiance (or 50cm from the seabed). The model coefficient $A(\lambda)$ is considered a residual and is discarded.

$$\frac{E_d(\lambda)}{E_s(\lambda)} = A(\lambda)e^{-K_d(\lambda)\left(\frac{z}{cos(\theta_{sw})}\right)}. \tag{1}$$

The next stage of data reduction involved comparing $K_d(\lambda)$ with the in-situ NTU data. As $K_d(\lambda)$ is a pseudo-vertically weighted measurement, and as most NTU profiles demonstrated well-mixed water columns, full-cast median NTU data was extracted for comparison with $K_d(\lambda)$. An example scatter plot comparison for 495nm is shown in Figure 1, along with the linear regression model fit. Linear regression model fits were performed for each available wavelength to determine the final spectral model coefficients $B(\lambda)$ and $C(\lambda)$ (see Equation 2).

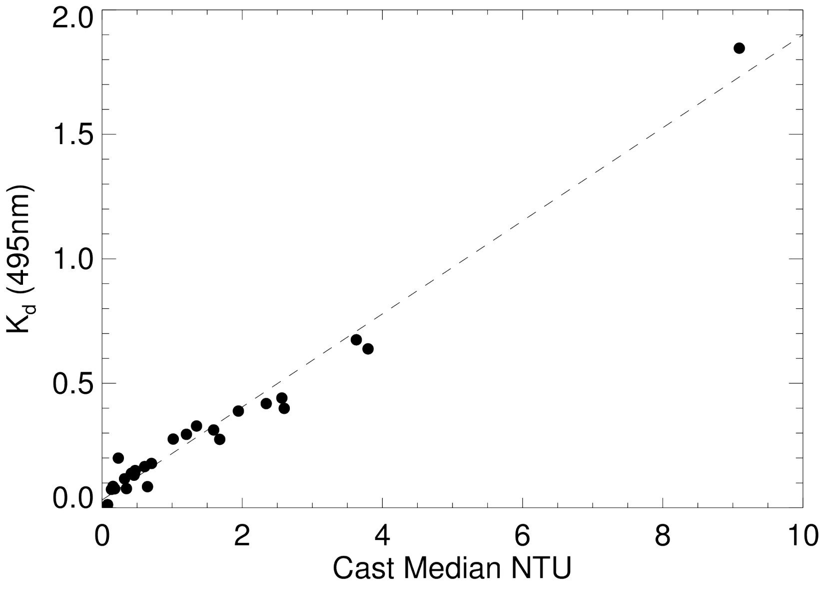


Figure 1: Example scatter plot of $K_d(495m)$ v.s. profile median NTU, with the linear regression model fit overplotted. The full set of coefficients are provided in MODEL.csv

$$K_d(\lambda) = B(\lambda)[NTU] + C(\lambda). \tag{2}$$

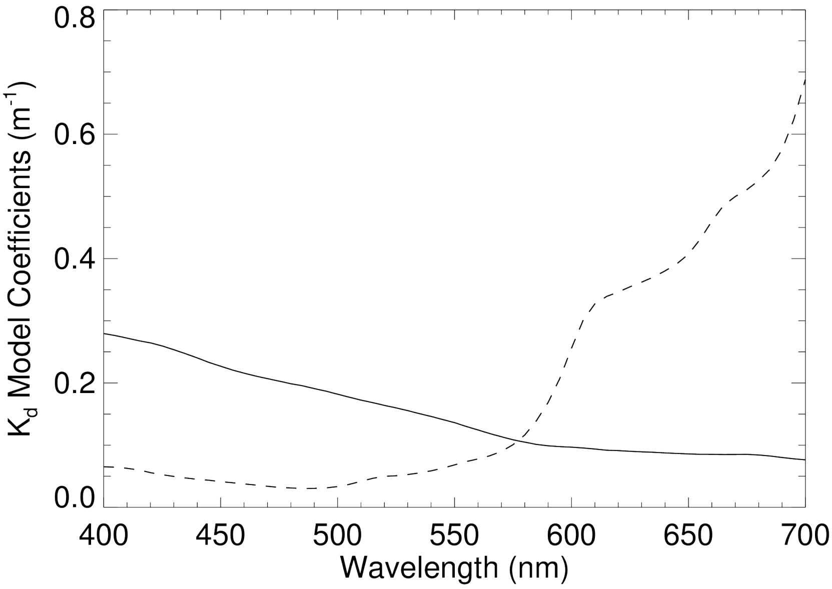


Figure 2: Final spectral model coefficients B (NTU-specific diffuse attenuation) shown in solid line and the residual non-particle background attenuation C (primarily driven by water absorption), shown in a dashed line. These coefficients are found in MODEL.csv

Finally, it is often desirable to convert NTU into SSC so that this relationship may be substituted into Eq.2 to yield a model based on SSC. Figure 3 shows the scatter plot of the surface averaged NTU v.s. water-sample based SSC measurements from the Cape Preston Coast fieldwork. Note the Y intercept on the SSC indicating methodological bias of approximately $2mgl^{-1}$. There are a few reasons why offsets such as these occur, primarily due to sample storage issues where bottles are contaminated and / or organisms grow and / or particles aggregate over time in storage prior to gravimetric processing. Given the NTU sensor was well calibrated and is a better indication of the particle concentration present in the water during the K_d measurements, the offset should be considered a residual and ignored if the intention is to numerically simulate particles of a given SSC. In this case, use of Eq. 3 which ignores the offset is appropriate.

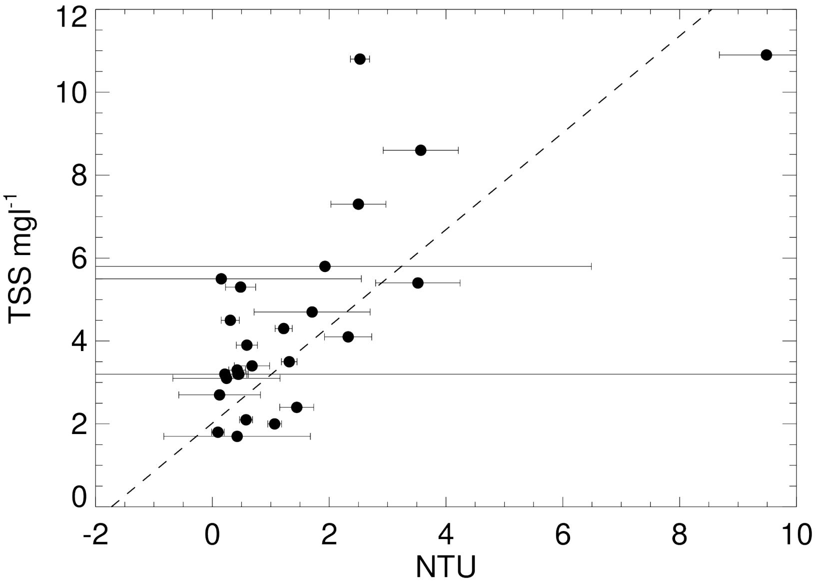


Figure 3: SSC vs NTU relationship. Model fit shown in dashed line.

$$SSC = 1.17[NTU] \tag{3}$$

2 Discussion

The spectral diffuse attenuation coefficients and resultant empirical model coefficients B and C determined here represent a first-order understanding of the spectral light attenuation encountered in the Cape Preston Coast during field sampling. The spectral shape of the NTU specific K_d is indicative of non-algal particle absorption, however there is a slight feature between 650nm and 700nm which indicative of chlorophyll absorption. The residual K_d is indicative of pure water absorption in the NIR region, with an exponential feature in the blue region which may be due to dissolved organics which don't correlate with NTU.

The data used for modelling had NTUs ranging from near zero, up to approximately 9 NTU, however most of the samples were taken in waters clearer than 4 NTU. Near full-profile $K_d(\lambda)$ were calculated from near surface down to 50cm from the seafloor or the 0.5% light level and as such, the depths used in the calculation varied from 1.4m down to approximately 11m.

It is not recommended to use these model coefficients to model conditions outside those experienced during the Cape Preston Coast field campaigns. For extrapolation purposes, a larger dataset would be required and more time consuming data reductions could be undertaken on the existing dataset which should yield greater accuracy when extrapolating to simulate dredge conditions.

Table 1: Summary of in-situ field measurements

Date	Time	θ_{s_w}	Latitude (S)	Longitude (E)	SSC (mgl^{-1})	YSI Surface NTU	IMO NTU Cast Median	K_d Calc. depth (m)	Comments
15/6/2021	11:31-11:50	13.2	$21^\circ15'9.95''$	$115^\circ49'1.89''$	10.8	2.0	2.6	-2.0	Ambient logger turned on;
15/6/2021	13:20-13:28	7.6	$21^\circ14'46.18''$	$115^\circ48'55.99''$	2.0	0.4	1.1	-1.5	Mid cloud cover
15/6/2021	13:40-13:50	7.6	$21^\circ12'40.45''$	$115^\circ47'12.96''$	4.3	0.5	1.3	-5.8	Clear patch in cloud
15/6/2021	14:10-14:20	17.6	$21^\circ8'15.1''$	$115^\circ47'31.65''$	2.4	-	1.7	-7.8	Glassy (reflectance high)
15/6/2021	14:40-14:50	17.6	$21^\circ5'58.59''$	$115^\circ47'8.15''$	2.1	-	0.7	-3.6	
15/6/2021	15:25	27.2	$20^\circ59'37.85''$	$115^\circ53'46.52''$	3.2	-	0.6	-7.3	
15/6/2021	16:00	35.8	$20^\circ59'46.6''$	$116^\circ2'38.16''$	4.1	1.5	2.5	-2.4	Overcast; Fortescue ramp
15/6/2021	16:50	35.8	$21^\circ0'22.76''$	$116^\circ5'57.67''$	10.9	7.4	9.2	-1.8	
16/6/2021	11:00-11:15	13.2	$20^\circ55'9.52''$	$116^\circ1'44.37''$	1.7	-	0.5	-4.6	Windy; Overcast
16/6/2021	12:45	3.4	$20^\circ51'47.24''$	$115^\circ55'14.82''$	2.7	-0.1	0.2	-6.4	Rough; Wind island?; Overcast
16/6/2021	13:00	7.7	$20^\circ51'38.68''$	$115^\circ53'48.39''$	1.8	-0.5	0.2	-8.7	Overcast
16/6/2021	16:05	35.8	$20^\circ58'26.92''$	$116^\circ5'39.91''$	4.7	1.0	1.9	-5.6	Overcast
17/6/2021	10:39	22.9	$20^\circ58'43.11''$	$116^\circ7'19.08''$	7.3	1.8	4.1	-2.9	Overcast/patchy
17/6/2021	11:00	22.9	$20^\circ57'20.29''$	$116^\circ9'15.34''$	3.5	1.0	1.4	-1.8	Patchy
17/6/2021	11:30	13.1	$20^\circ53'50.38''$	$116^\circ9'59.17''$	3.4	0.2	0.7	-2.8	Some clear sky overhead
17/6/2021	14:00	17.8	$20^\circ52'10.03''$	$116^\circ9'22.59''$	3.3	-	0.5	-11.9	Cloudy
17/6/2021	14:45	17.8	$20^\circ54'30.46''$	$116^\circ6'48.07''$	3.2	0.1	0.5	-7.3	Overcast
17/6/2021	15:17	27.3	$20^\circ59'59.02''$	$116^\circ6'7.04''$	5.4	2.4	3.9	-3.8	Overcast
15/7/2021	8:30	40.5	$20^\circ49'51.63''$	$116^\circ4'25.75''$	3.1	-	0.4	-4.2	NA
15/7/2021	8:59	40.5	$20^\circ52'4.99''$	$116^\circ4'59.47''$	5.5	-	0.3	-7.9	NA
15/7/2021	9:12	32.9	$20^\circ53'59.94''$	$116^\circ5'22.64''$	4.5	-	0.4	-8.2	NA
15/7/2021	9:26	32.9	$20^\circ55'57.83''$	$116^\circ5'33.42''$	5.3	-	0.5	-6.5	NA
15/7/2021	12:31	3.7	$21^\circ0'15.44''$	$116^\circ5'58.69''$	8.6	-	4.0	-4.2	NA
15/7/2021	12:40	3.7	$20^\circ59'45.53''$	$116^\circ6'19.22''$	5.8	-	2.1	-3.4	NA
15/7/2021	12:57	3.8	$20^\circ57'58.65''$	$116^\circ6'3.45''$	3.9	-	0.7	-6.0	NA
15/7/2021	13:45	6.6	$20^\circ56'56.47''$	$115^\circ56'13.33''$	3.2	-	0.4	-11.1	NA

METOCEAN
An O2Marine company

MARINE

WA Marine Pty Ltd trading as O2Marine
ACN 168 014 819
11 Mews Road Fremantle 6160
T: 1300 219 801
E: info@o2marine.com.au