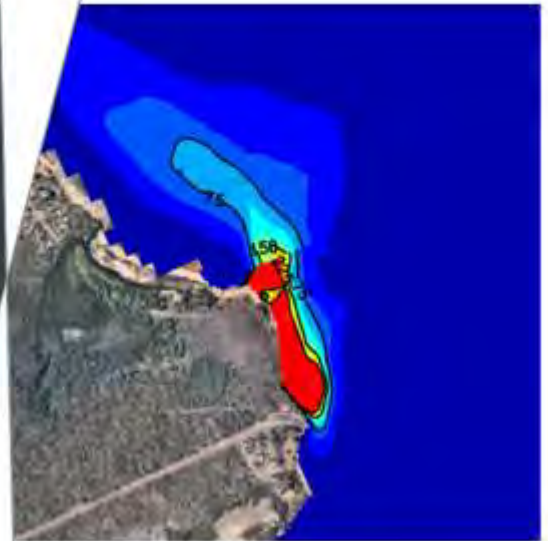


Sediment Transport Report

New Marine Facilities to Service
Mandorah and Cox Peninsula

ZMD01890



Prepared for
Department of Infrastructure, Planning and
Logistics

16 February 2023

Contact Information

Cardno (NT) Pty Ltd
ABN 78 078 713 934

Level 6
93 Mitchell Street
Darwin NT 0800
Australia

www.cardno.com

Phone +61 8 8942 8200
Fax +61 8 8942 8211

Document Information

Prepared for Department of Infrastructure,
Planning and Logistics

Project Name New Marine Facilities to
Service Mandorah and Cox
Peninsula

File Reference SER_SedimentTransport

Job Reference ZMD01890

Date 16 February 2023

Version Number Rev 3

Author(s):

Hadi Sadeghian
Principal Coastal Engineer

Cory Smith
Senior Coastal Engineer

Leo Reith
Coastal Engineer

Approved By:

Daniel Strickland
Principal Coastal Engineer

Effective Date 16/02/2023

Date Approved 16/02/2023

Document History

Version	Effective Date	Description of Revision	Prepared by	Reviewed by
Rev A	7/12/2021	Draft for DIPL review	HS / CS / LR	CS / DRS
Rev 1	20/02/2022	Final	HS / CS / LR	CS / DRS / DIPL
Rev 2	03/02/2023	Draft for inclusion in SER	HS / CS / LR	CS / DRS
Rev 3	16/02/2023	Final for inclusion in SER	HS / CS / LR	DRS / DIPL

© Cardno. Copyright in the whole and every part of this document belongs to Cardno and may not be used, sold, transferred, copied or reproduced in whole or in part in any manner or form or in or on any media to any person other than by agreement with Cardno.

This document is produced by Cardno solely for the benefit and use by the client in accordance with the terms of the engagement. Cardno does not and shall not assume any responsibility or liability whatsoever to any third party arising out of any use or reliance by any third party on the content of this document.

Our report is based on information made available by the client. The validity and comprehensiveness of supplied information has not been independently verified and, for the purposes of this report, it is assumed that the information provided to Cardno is both complete and accurate. Whilst, to the best of our knowledge, the information contained in this report is accurate at the date of issue, changes may occur to the site conditions, the site context or the applicable planning framework. This report should not be used after any such changes without consulting the provider of the report or a suitably qualified person.

Table of Contents

1	Introduction	1
	1.1 Project Background	1
	1.2 Purpose and Structure of this Document	3
2	Existing Information and Inputs	5
	2.1 Metocean Conditions	5
	2.2 Water Quality	5
	2.3 Sediment Properties	7
	2.4 Data Gaps	8
3	Field Investigations	9
	3.1 Seabed sediment sampling	9
	3.2 Additional Investigations for the SER	11
4	Numerical Modelling Systems	12
	4.1 Delft3D Modelling System	12
	4.1 SWAN Wave Modelling System	12
	4.2 Morphological Modelling System	12
	4.3 LITPACK Modelling System	13
5	Nearshore Sediment Transport and Morphology Assessment	14
	5.1 Introduction	14
	5.2 Modelling Simulations	14
	5.3 Morphological Inputs	15
	5.4 Sediment Transport Pathways	18
	5.5 Sedimentation Plots	18
6	Harbour Basin Siltation Assessment	30
	6.1 Methodology	30
	6.2 Results	30
7	Shoreline Evolution Assessment	31
	7.1 Introduction	31
	7.2 Sediment Data	31
	7.3 Longshore Sediment Transport Modelling (LITDRIFT)	32
	7.4 Shoreline Evolution Modelling (LITLINE)	35
	7.5 Model Validation	38
8	Dredging and Disposal Sediment Transport Assessment	40
	8.1 Introduction	40
	8.2 Model Setup	40
	8.3 Disposal site	43
	8.4 Results	45
9	Conclusions and Project Implications	50
	9.1 Nearshore Sediment Transport and Morphology	50

	9.2	Harbour Siltation	50
	9.3	Shoreline Evolution	50
	9.4	Dredge Plume Dispersion	51
10		References	52

Appendices

Appendix A	Field Logs
Appendix B	Sediment Sampling COC
Appendix C	Sediment Sampling Results
Appendix D	Dredge Plume Dispersion Modelling Results

Tables

Table 3-1	Analytical schedule - PSD	9
Table 3-2	Median Particle Diameter (D ₅₀)	11
Table 7-1	Potential Longshore Sediment Transport Rates along Profile	34
Table 7-2	Accretion and erosion rates	38
Table 8-1	Production / spill rates	41
Table 8-2	Scenario inputs	42
Table 9-1	Accretion and erosion rates	51

Figures

Figure 1-1	Site locality	2
Figure 2-1	Inpex Ichthys water quality monitoring locations (Inpex, 2014)	5
Figure 2-2	Turbidity measurements at monitoring sites relevant to Mandorah – Inpex Ichthys Project (Cardno, 2015)	6
Figure 2-3	Darwin Harbour NTU vs TSS relationship – Inpex Ichthys Project (Cardno, 2014)	7
Figure 3-1	PSD sample sites	10
Figure 5-1	The location of wave extraction point used to define the representative modelling scenarios	16
Figure 5-2	Monthly wave roses at the extraction location based on CSIRO hindcast wave data (1979 to 2019)	17
Figure 5-3	Total sediment load transport vectors: 1-month, wet season	19
Figure 5-4	Total sediment load transport vectors: 1-month, dry season	20
Figure 5-5	Total sediment load transport vectors: 1-month, shoulder season (wet to dry)	21
Figure 5-6	Total sediment load transport vectors: 1-month, shoulder season (dry to wet)	22
Figure 5-7	Total sediment load transport vectors: 2-weeks, storm	23
Figure 5-8	Baseline sediment deposition: 1-month wet season	24
Figure 5-9	Change in bed level: 1-month, wet season	25
Figure 5-10	Change in bed level: 1-month, dry season	26

Figure 5-11	Change in bed level: 1-month, shoulder season (wet to dry)	27
Figure 5-12	Change in bed level: 1-month, shoulder season (dry to wet)	28
Figure 5-13	Change in bed level: 2-weeks, storm	29
Figure 6-1	Turbidity time series at Mandorah Station	30
Figure 7-1	Location of sediment samples collected for particle size distribution	31
Figure 7-2	The Location of considered profile at the Proposed Mandorah Harbour Site	32
Figure 7-3	The Bathymetry of Profile used for Litdrift Modelling	32
Figure 7-4	Schematic showing the effect of changes in shoreline orientation on longshore transport (DHI, 2020).	33
Figure 7-5	Q- α Curve for Selected Profile	34
Figure 7-6	LITLINE profile locations	36
Figure 7-7	LITLINE profile cross sections	36
Figure 7-8	Shoreline evolution results	37
Figure 7-9	Extent of potential shoreline change	38
Figure 8-1	Location of proposed disposal site	44
Figure 8-2	95 th Percentile TSS depth averaged concentrations for Scenarios 1 (neap) and 5 (spring).	46
Figure 8-3	95 th Percentile TSS depth averaged concentrations for Scenarios 2 (neap) and 6 (spring).	46
Figure 8-4	95 th Percentile TSS depth averaged concentrations for Scenarios 3 (neap) and 7 (spring).	47
Figure 8-5	95 th Percentile TSS depth averaged concentrations for Scenarios 4 (neap) and 8 (spring).	47
Figure 8-6	Sedimentation deposition thickness mapping Scenarios 1 (neap) and 5 (spring).	48
Figure 8-7	Sedimentation deposition thickness mapping Scenarios 2 (neap) and 6 (spring).	48
Figure 8-8	Sedimentation deposition thickness mapping Scenarios 3 (neap) and 7 (spring).	49
Figure 8-9	Sedimentation deposition thickness mapping Scenarios 4 (neap) and 8 (spring).	49
Figure 9-1	Areas of potential shoreline change	51

1 Introduction

1.1 Project Background

The existing Mandorah Jetty and Boat Ramp are key infrastructure facilities servicing the Mandorah, Wagait and Belyuen communities, as well as visitors to the area from Darwin and surrounds. Mandorah Jetty supports the only ferry service from Darwin to the Cox Peninsula. The Mandorah boat ramp is located just south of the Jetty, with both facilities sharing a common onshore carpark facility.

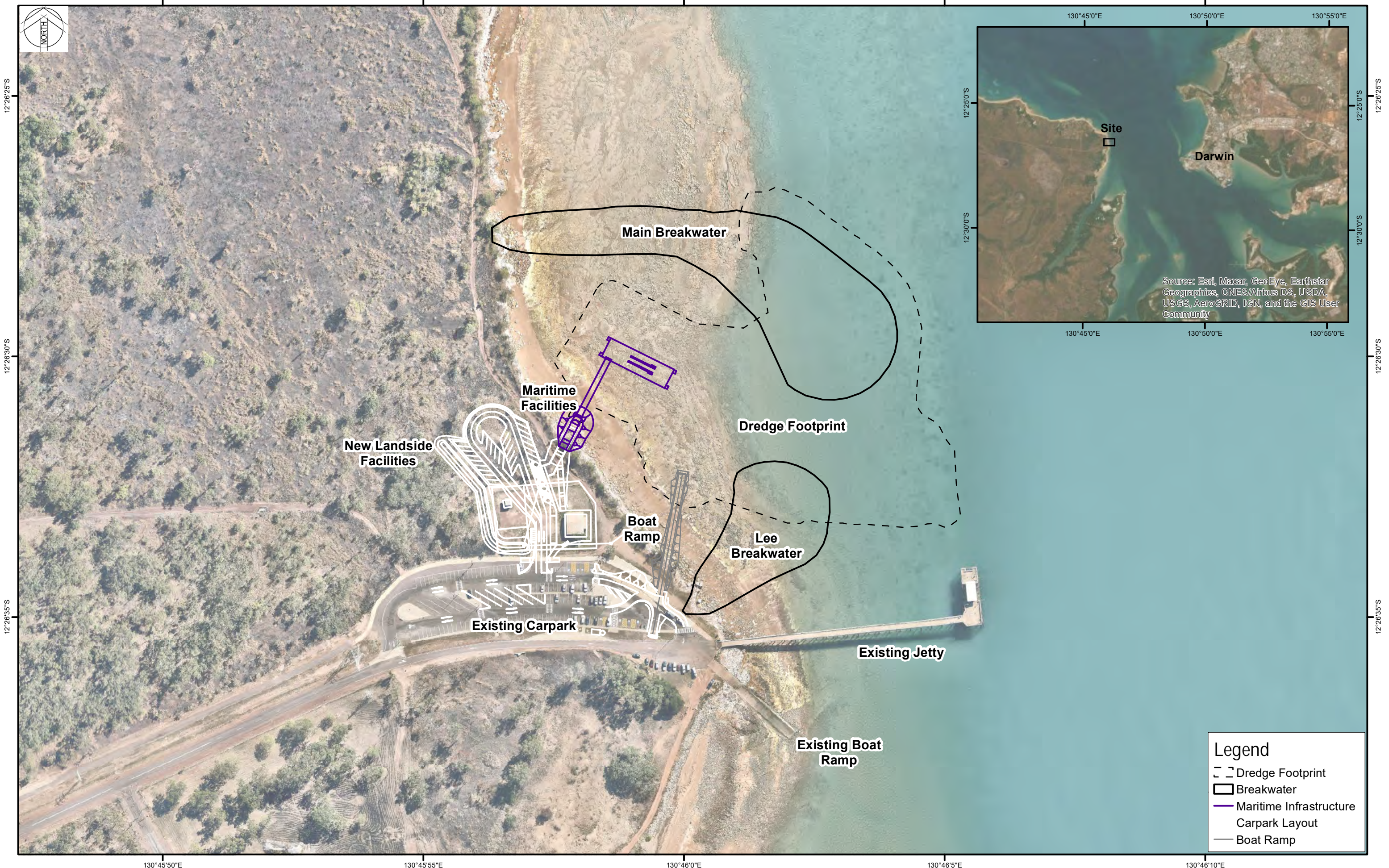
Previous studies (e.g. Jacobs, 2016 and 2019) identified shortcomings in the design of the existing facilities, such as Disability Discrimination Act (DDA) non-compliance of the existing Jetty, and investigated various options to improve the ferry berthing facility and boat ramp. The Department of Infrastructure, Planning and Logistics (DIPL) commissioned Cardno to develop and assess options for new marine facilities at Mandorah. The key project objectives included selection and design of a facility that:

- > Addresses issues faced by the existing Mandorah Jetty and boat ramp. These issues include the highly exposed nature of the site, DDA non-compliance, passenger safety issues and safety and sedimentation issues of the existing boat ramp;
- > Minimises construction and whole-of-life costs;
- > Allows for uninterrupted ferry service operation during construction; and
- > Provides a safe and enjoyable passenger experience.

DIPL and Cardno have now developed, assessed and designed a preferred option for new marine facilities at Mandorah. The facilities comprise a dredged basin, two large breakwaters, boat ramp, gangway and pontoon, and onshore ferry terminal and parking facilities (**Figure 1-1**).

1.1.1 Site Location

Mandorah is located near the eastern tip of the Cox Peninsula in the Northern Territory, approximately six kilometres to the west of Darwin. Access to Mandorah from Darwin is via the regular ferry service, or by driving approximately 120 km along the road network.



Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Legend

- Dredge Footprint
- Breakwater
- Maritime Infrastructure
- Carpark Layout
- Boat Ramp

SITE LOCALITY
 MANDORAH MARINE FACILITIES
 SEDIMENT TRANSPORT REPORT
 FIGURE 1-1

© Cardno Limited All Rights Reserved.
 This document is produced by Cardno Limited solely for the benefit of and use by the client in accordance with the terms of the retainer. Cardno Limited does not and shall not assume any responsibility or liability whatsoever to any third party arising out of any use or reliance by third party on the content of this document.

Date
 11/01/2022
 Size
 A3
 Scale



1.2 Purpose and Structure of this Document

The purpose of this *Sediment Transport Report* is to describe the investigation, modelling and implications of sediment transport processes that are relevant to the projects site and proposed project. The report summarises and assesses existing information relating to sediment transport through desktop review. The key sediment transport processes relevant to the project are harbour siltation, sedimentation and dredge plume dispersion. These processes have implications for design and construction, operations and environmental impact assessment.

The document has been structured as follows:

- > This Section (1) introduces the project and context and purpose of this report;
- > **Section 2** details existing data and information relevant to sediment transport in the vicinity of the project site and relevant to the project;
- > **Section 3** describes further field investigations undertaken as part of the project to fill relevant data gaps;
- > **Section 4** describes the numerical modelling systems applied to understand the influence of the proposed project on sediment transport and fate;
- > **Section 5** details the assessment of the influence of the proposed project on nearshore sediment transport processes and morphology;
- > **Section 6** details the assessment of harbour siltation relevant to the proposed project;
- > **Section 7** details the assessment of how the shoreline will evolve following construction of the proposed project;
- > **Section 8** details the assessment of dredging and disposal sediment plume dispersion relevant to the proposed project; and
- > **Section 9** outlines the conclusions of the investigations and their implications in terms of the overall project.

1.3 Reference Documents

Various investigations and studies have been carried out as part of the overall development and design project to date. This report documents a component of these investigations. The following documents are referenced in, or should be given due consideration when reading, this report:

- > Directly relevant:
 - *Supplementary Environmental Report* (Stantec, 2023a): This document has been prepared to detail additional investigations and environmental risk assessment in addition to the *Environmental Referral Report* (see below). The report addresses the EPA's Direction to Provide Additional Information.
 - *Environmental Referral Report* (Cardno, 2022a): This document provides the necessary details to refer the project to the NT EPA. This *Sediment Transport Report* is an appendix to the referral document, providing the necessary context for assessing risk to the marine environment associated with sediment transport from the project;
 - *Metocean Report* (Cardno, 2023): Details the metocean information and investigations for the project site that inform design of the new proposed infrastructure. The report details the underlying physical metocean processes that drive sediment transport processes that have been described in this report;
 - *Marine Environment Report* (Cardno, 2022b): Details the marine environment (including physical properties related to sediment) and ecology relevant to the project site. The results of sediment transport investigations are important for understanding potential impacts to the marine environment detailed in the report;
 - *SAP Implementation Report* (Cardno, 2022f): Details marine sediment quality investigations undertaken to understand any contamination within the dredging and disturbance area and guide proper handling and disposal of dredge material; and

- *Dredging and Spoil Disposal Management Plan (DSDMP)* (Stantec, 2023b): Defines the dredging actions and necessary controls to avoid or minimise risk for, and impact to, the marine environment.
- > Relevant to the overall project:
 - *Design Report* (Cardno, 2022c): Details the design requirements, basis, inputs, calculations and outcomes for the new proposed infrastructure;
 - *Geotechnical Report* (Cardno, 2022d): Details the geotechnical information and investigations for the project site that inform design of the new proposed infrastructure;
 - *Terrestrial Environment Report* (Cardno, 2022e): Details the terrestrial environment and ecology relevant to the project site, similar to the function of the report for the marine environment; and
 - *Construction Environmental Management Plan (CEMP)* (Stantec, 2023c): Defines likely construction activities and controls required to avoid or minimise environmental impact.

2 Existing Information and Inputs

2.1 Metocean Conditions

To properly understand sediment transport processes at the site, a detailed and comprehensive understanding of the site's metocean conditions must first be obtained. This is achieved by developing numerical models (e.g. hydrodynamic and wave) and validating and calibrating these with data collected data (e.g. wave, currents and water level). The project's *Metocean Report* (Cardno, 2023) provides comprehensive details of the metocean modelling and input data, and should be reviewed to understand the conditions underpinning sediment transport assessment in this report.

2.2 Water Quality

Baseline water quality, in terms of turbidity or suspended sediment concentration, is well understood at the project site, with monitoring being conducted continuously for over 2 years during the INPEX Nearshore Environmental Monitoring Program. Continuous near-bed turbidity (NTU) records collected (15 min interval) at site directly offshore Mandorah (MAN_01), as well as two sites within Woods Inlet (WOD_01 and WOD_02). Other sites of relevance include:

- > Charles Point (CHP_02), alongshore to the west north west of the site; and
- > Fanny Bay (FAN_01 and FAN_02), where turbidity data can be compared to observed siltation rates for the Cullen Bay Ferry Facility.

Site locations are depicted in **Figure 2-1** and the turbidity datasets for the monitoring period are shown in **Figure 2-2**.



Figure 2-1 Inpex Ichthys water quality monitoring locations (Inpex, 2014)

Total suspended solids (TSS) and particle size distribution (PSD) samples for correlation with NTU values were also collected throughout Darwin Harbour by Cardno for the Ichthys Project. These were combined to develop a relationship between TSS and NTU, which was used to approximate ambient TSS concentrations at the site. This relationship is plotted in **Figure 2-3**. The relationship was then further refined to be site specific through dedicated data collection for this project (see **Section 3.2**).

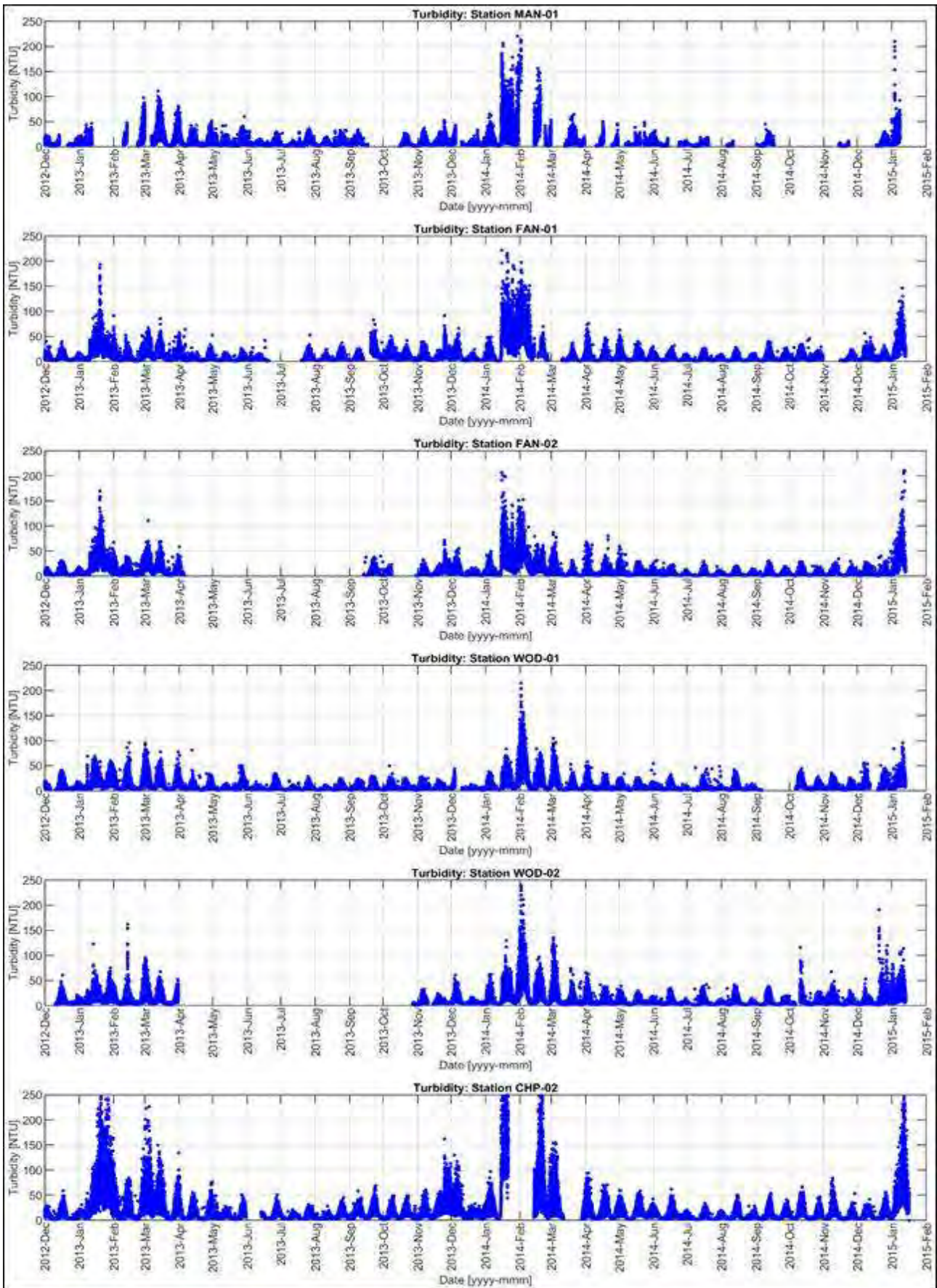


Figure 2-2 Turbidity measurements at monitoring sites relevant to Mandorah – Inpex Ichthys Project (Cardno, 2015)

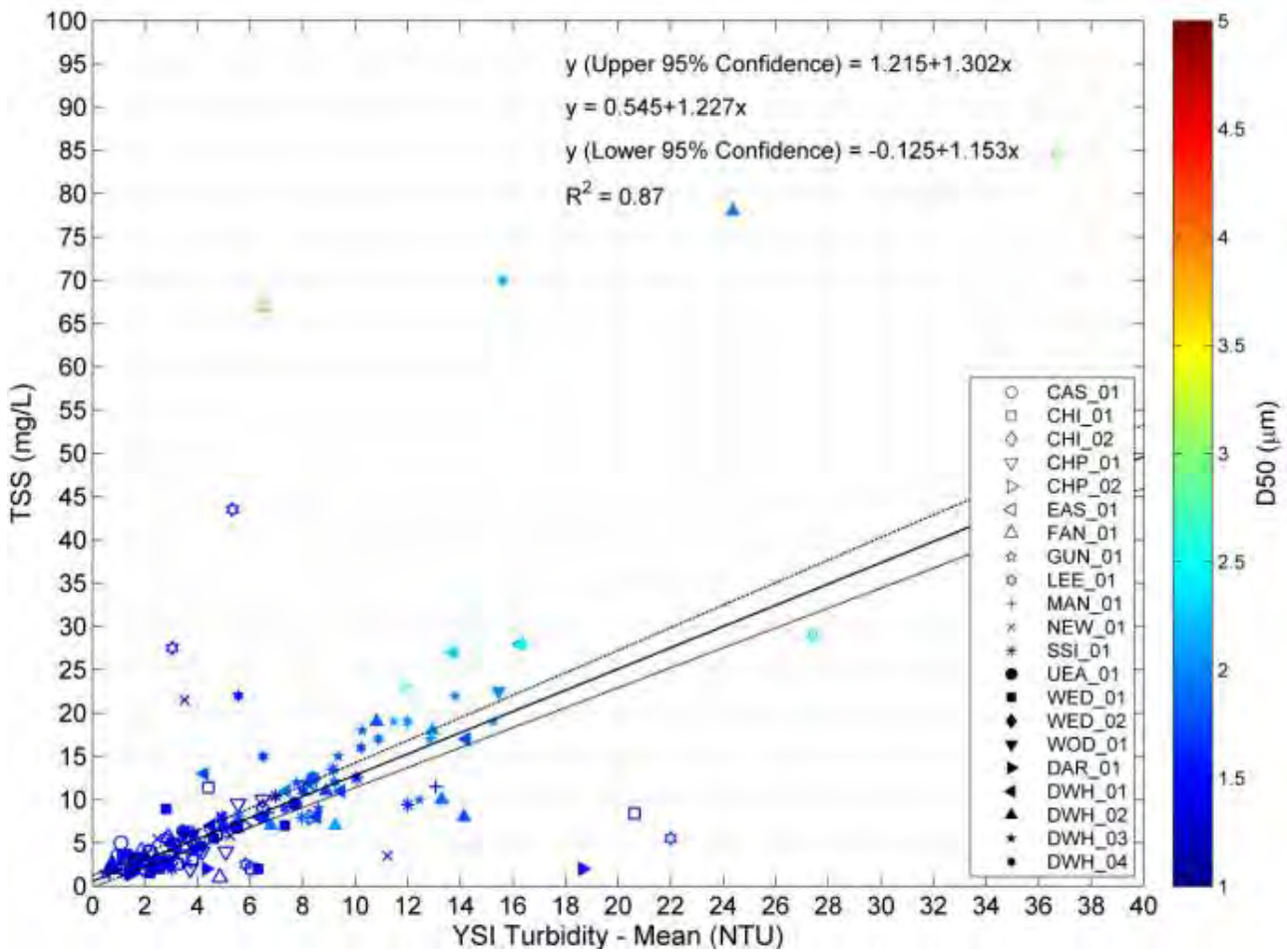


Figure 2-3 Darwin Harbour NTU vs TSS relationship – Inpex Ichthys Project (Cardno, 2014)

2.3 Sediment Properties

2.3.1 Historical

Existing historical data relating to the properties of surficial sediments within the proposed dredge area is limited. Four samples were collected by Douglas Partners (2016). These results indicate that sands and marine sediments (silts and gravelly sand) overlay very low to low strength (with some Medium strength bands) rocks of the Darwin Member and extremely low strength meta-siltstone (which underlies that Darwin Member at the landward end of the development).

2.3.2 Geotechnical Investigations (Cardno, 2022d)

Cardno undertook a detailed geotechnical investigation, as well as sediment sampling and analysis, within the project footprint in 2019. Detailed assessment of the physical and chemical properties of sediments sampled in the area are found in the *SAP Implementation Report* (Cardno, 2022f) and geological properties are detailed in the *Geotechnical Report* (Cardno, 2022d). Field logs are also provided in **Appendix A**.

2.3.2.1 Profile Description

- > There is limited marine bed sediment in the area, the deepest refusal depth for push coring was 0.8 metres and for most sample locations the refusal depth was less than 0.5 metres; and
- > Field observations noted unconsolidated sediment largely as marine SAND, dark grey.

2.4 Data Gaps

The key data gap identified with respect to sediment transport processes, following review of historical information and execution of geotechnical and sediment quality sampling in the project footprint, was an understanding of sediment properties in the nearshore areas adjacent the proposed project. The nature of this sediment is a required input to understand longshore sediment transport processes at the site. Further field investigations (**Section 3**) were undertaken to fill this data gap.

3 Field Investigations

3.1 Seabed sediment sampling

3.1.1 Aims and Objectives

The purpose of this additional sediment sampling was to characterise the PSD of available sediment adjacent to, but outside, the project area to inform longshore sediment transport assessment.

3.1.2 Survey Area

Sediment sampling sites were selected to represent the nature of available sediment in the littoral zone, to the north and south of the project site. Sediment sampling locations are depicted in **Figure 3-1**.

3.1.3 Sampling Methods

The scope of work undertaken as part of the longshore drift assessment was carried out in accordance with the following guidelines, to the extent relevant to an assessment of this nature:

- > Australian Standard 2003. Method of testing soils for engineering purposes. Method 3.6.3: Soil classification tests—Determination of the particle size distribution of a soil—Standard method of fine analysis using a hydrometer. AS 1289.3.6.3-2003.
- > NAGD 2009. National Assessment Guidelines for Dredging. Commonwealth of Australia, Canberra, 2009.

Sediment sampling was carried out between 3 March 2020 and 11 March 2020 by trained and experienced staff to ensure that the correct sampling procedures were followed. Surface samples were collected at 11 sampling sites (4 beach samples and 7 seabed samples) employing a grab sampling method.

3.1.4 Quality Assurance and Control Measures

Quality control procedures were followed in accordance with guidelines for sampling presented in the methodology *Soil classification tests—Determination of the particle size distribution of a soil—Standard method of fine analysis using a hydrometer. Australian Standard (AS 1289.3.6.3-2003)*.

Samples were collected directly into appropriately labelled zip-lock bags and delivered to the laboratory under Chain of Custody documentation (**Appendix B**).

3.1.5 Analytical Methods

All soil analysis was undertaken by ALS Global Laboratories (Sydney) [National Association of Testing Authorities (NATA) accreditation number 825].

The analytical schedule for particle size distribution are presented in **Figure 3-1**.

Table 3-1 Analytical schedule - PSD

Material	Volume	Total Samples	Sample ID	Laboratory Schedule
Sediment	1 x 500mL bag per sample.	11	MS1-4, MBS1-7	11 samples for PSD by hydrometer

3.1.6 Results

The median particle diameter (D_{50}) from each PSD sample is presented below in **Table 3-2**. Laboratory results and analysis are presented in **Appendix C**.



MS1

MS2

MS4

MBS1

MBS2

MBS3

MBS4

MS3

MBS5

MBS6

MBS7

Legend
PSD Sample Locations

Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community



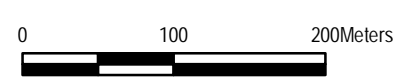
West Perth, Western Australia

© Cardno Limited All Rights Reserved.
This document is produced by Cardno Limited solely for the benefit of and use by the client in accordance with the terms of the retainer. Cardno Limited does not and shall not assume any responsibility or liability whatsoever to any third party arising out of any use or reliance by third party on the content of this document.

Date
17/11/2021

Size
A3

Scale
1:5,000



PSD SAMPLING LOCATIONS

MANDORAH MARINE FACILITIES
SEDIMENT TRANSPORT REPORT

FIGURE 3-1

Table 3-2 Median Particle Diameter (D_{50})

Sediment Sample	D_{50} (mm)
Onshore Samples	
MBS1	0.694
MBS2	1.041
MBS3	1.104
MBS4	1.827
MBS5	1.437
MBS6	1.222
MBS7	0.695
Offshore Samples	
MS1	0.150
MS2	0.146
MS3	0.288
MS4	0.184

3.2 Additional Investigations for the SER

As part of additional investigations required to inform the project's *Supplementary Environmental Report* (SER) (Stantec, 2023a), additional field investigations were undertaken that are relevant to informing sediment transport assessment. Details of these investigations are provided in the SER and are summarised as follows:

- > Collection of water samples for total suspended solids (TSS) analysis alongside turbidity (NTU) readings. This data was used to improve the NTU vs TSS relationship at the site. This sampling and analysis, as well as the refined relationship, is presented in the SER (Stantec, 2023a). Given the long-term NTU dataset available at Mandorah, this allows an estimate sediment movement in the water column to be achieved, helping to validate modelling of such fluxes; and
- > Additional high-resolution (multibeam) survey was undertaken for the project's nearshore area. This data was collected to improve understanding of the benthic habitat in the nearshore area, which informed understanding of sediment availability for sediment transport modelling.

4 Numerical Modelling Systems

4.1 Delft3D Modelling System

The Delft3D hydrodynamic modelling system has been utilised in this study. It is a world leading hydrodynamic, sediment transport and water quality modelling system developed by Deltares in The Netherlands. It has been extensively utilised by Cardno at sites around Australia and internationally. The Delft3D modelling system can be used to simulate tides, wind, pressure and wave forcing, stratification, sediment transport, dredge material dispersion and water quality. Delft3D is comprised of several modules that provide the facility to undertake a range of studies. All studies generally begin with the Delft3D-FLOW module. From Delft3D-FLOW, details such as velocities and water levels along with density, salinity and temperature (where required), can be provided as inputs to the other modules.

Many nearshore areas include shallow inter-tidal regions; consequently, Delft3D includes a robust and efficient wetting and drying algorithm to handle this process. Delft3D includes a Domain Decomposition (DD) capability to facilitate computation by having fine grids at nearshore locations or areas of interest where bathymetric and structure details vary significantly and coarser offshore grids where a larger model extent is required, but seabed bathymetric changes are generally smaller. This procedure allows efficient modelling to be undertaken without sacrificing resolution where it is needed.

The project's Metocean Report (Cardno, 2023) provides details on the hydrodynamic model applied to this project and should be reviewed to understand the conditions underpinning sediment transport assessment in this report.

4.1 SWAN Wave Modelling System

The wave model Cardno applied in this study is based on the third-generation wind/wave modelling system, SWAN, which is incorporated as a module into the Delft3D modelling system. This model was developed at the Delft Technical University and includes wind input (local sea and developing storm cases), combined sea and swell, offshore wave parameters, refraction, shoaling, non-linear wave-wave interaction, a full directional spectral description of wave propagation, bed friction, white capping, currents and wave breaking. SWAN also includes phase-averaged diffraction based on the model of Holthuijsen et al (2007).

SWAN includes a nested grid capability that allows coarser grids in deeper water and finer grids in shallow water where better definition of seabed form and depth variation are needed, and may use the same or different grids from those used in the hydrodynamic modelling. Output from the model includes significant wave height, dominant wave direction, spectral peak and mean periods and (optionally) the full directional wave spectra. It can be coupled with Delft3D to include the inter-action between waves and tidal/wind driven flows. For cyclones the non-steady-state version is applied so that the spatially and temporally varying cyclonic wind-fields are included in wave development and propagation.

The project's Metocean Report (Cardno, 2023) provides details on the wave model applied to this project and should be reviewed to understand the conditions underpinning sediment transport assessment in this report.

4.2 Morphological Modelling System

The module applied to the sediment transport analyses is the Online Sediment Module with the Van Rijn (2004) sediment transport module – cohesionless sediment. This system makes it possible to undertake time-series sediment transport modelling using combined tide, wind and wave processes. The bed levels, water levels and currents within the wave module are updated every 30 minutes and the calculated wave conditions (wave heights and radiation stress maps) are used for the next hydrodynamic phase.

Changes in currents and water levels then affect wave process calculations in the next wave model step and those new outcomes are then used in the next hydrodynamic and morphological steps. It is based on the Van Rijn (2004) sediment transport algorithm. This algorithm incorporates time varying flow conditions in the calculation of bed roughness and reference concentrations.

4.3 LITPACK Modelling System

In order to investigate the morphological response of the Mandorah shoreline, the LITPACK coastal processes modelling system developed at the Danish Hydraulics Institute was applied. LITPACK includes a number of modules. The modules applied in this study were LITDRIFT and LITLINE.

LITLINE is the shoreline plan-form, evolution module of LITPACK and applies the Pelnard-Consideré 1-line method of analysis. It can include shoreline structures such as the Mandorah breakwaters. It applies the computational results of LITDRIFT at a number of shoreline locations along a modelled section of shoreline. Curved-in-plan alignments are essentially modelled as a straight coastline, but with appropriate wave directions applied at the seaward ends of the profiles. An active beach face height extending from an adopted closure depth to the top of wave run-up is used to calculate the changes in the shoreline (at the position of the mean sea level contour)

5 Nearshore Sediment Transport and Morphology Assessment

5.1 Introduction

Construction of the maritime facilities at Mandorah has the potential to impact several NT EPA Environmental Factors including Landforms, Marine Ecosystems, Hydrological Processes and Culture and Heritage. Once installed, the breakwaters are expected to alter the local hydrodynamic and wave conditions, in turn, affecting patterns of sediment movement, deposition and re-suspension. In the nearshore area (defined as being beyond the intertidal zone) this is expected to result in changed sediment transport patterns and a reorganisation of available sediment, resulting in morphological change. The modelling system applied to understand changes in the nearshore area has been described in **Section 4.2**. Changes at the shoreline (e.g. beaches and intertidal) have been modelled by a different process, discussed in **Section 7**.

5.2 Modelling Simulations

Five general morphological modelling scenarios were investigated, selected to be representative of the most common seasonal metocean conditions that characterise the project area. This type of modelling is very computationally intensive, meaning the number of simulations and their durations need to be limited. The five scenarios were simulated for pre- and post-development conditions, and included the combined influence of waves, winds, and tides. These input parameters were required to describe the physical processes that are typically experienced on an annual basis at Mandorah. The scenario modelling approach has been adopted to optimise the simulation time. The five general morphological modelling scenarios investigated include:

- 1-month of typical dry season conditions;
- 1-month of typical wet season conditions;
- 1-month of typical shoulder season (wet to dry) conditions;
- 1-month of typical shoulder season (dry to wet) conditions; and
- 2-weeks of typical storm conditions.

An assessment of representative wave conditions to be applied to the morphological modelling was undertaken based on a 40-year synthetic wave hindcast covering the period from 1979 to 2019. The location of wave data extraction location at the project site is shown in **Figure 5-1**.

The monthly directional distribution of significant wave heights at the extraction location are presented in **Figure 5-2**. This distribution provided the basis for a visual assessment of representative modelling scenarios, which comprised a similar significant wave heights and frequency of occurrence to that of 40-year average. The representative periods applied to the morphological modelling are discussed below.

5.2.1 Dry Season

The period selected as representative of typical dry season conditions was 1st July 2016 through 31st July 2016. The wave conditions during this period are representative of the wave height experienced in dry season months, which are typically characterised by locally generated wind waves approaching the site from the south-east directional sector. Significant wave height during the simulation period rarely exceed 1.0 m and peak wave periods are typically less than 4 seconds.

5.2.2 Wet Season

The period selected as representative of typical wet season conditions was 1st January 2011 through 31st January 2011. The wave conditions during this period are representative of the wave height experienced in wet season months, which are typically characterised by a combination of locally generated wind waves and offshore swell. The distribution of wave conditions across the simulation period is relatively unidirectional, from the north-north-west, north, and north-north-east direction sectors. Conditions outside of these directional

sectors accounted for less than 25% of the simulation period. The largest significant wave heights across the observation period were associated with northerly swell, with a peak wave period exceeding 10 seconds.

5.2.3 Shoulder Season (Dry to Wet)

The period selected as representative of typical shoulder season (dry to wet) conditions was 1st October 2013 through 31st October 2013. The wave conditions during this period are representative of the wave height experienced in shoulder season (dry to wet) months, which are typically characterised by relatively calm conditions and a shift from the prevailing south-east directional sector to the northern directional sectors. Peak wave periods across the simulation period rarely exceeded 4 seconds.

5.2.4 Shoulder Season (Wet to Dry)

The period selected as representative of typical shoulder season (wet to dry) conditions was 1st April 2008 through 30th April 2008. The wave conditions during this period are representative of the wave height experienced in shoulder season (wet to dry) months, which are somewhat omnidirectional between the north-north-west and south-south-east directional sectors. The largest wave heights across the simulation period approached the site from the north-north-east, while peak wave periods were associated with the northerly directional sectors, attributed to the longer fetches outside of Beagle Gulf.

5.2.5 Storm Conditions

The period selected as representative of typical storm conditions was 12th February 2011 through 28th February 2011. The storm period experienced sustained significant wave heights in the order of 5.0 m at the offshore modelling boundary, with accompanying peak wind speeds exceeding 21 m/s.

5.3 Morphological Inputs

Marine sediments within the vicinity of Mandorah primarily comprise fine to coarse grained, cohesive alluvial/residual sandy-clay, overlying rock varying in weathering and strength. The results from the geotechnical field investigations, bathymetric surveys, and aerial imagery have been interpreted to describe the spatial distribution of sediment availability to be incorporated in the morphological model. Non-erodable areas have also been described, such as the nearshore porcellanitic shelf.

The general sediment composition has been defined as non-cohesive, with a median sediment diameter of 180 μm . The sediment composition has been specified to represent a sandy clay mix. The sand fraction has been specified as 70% of the overall sediment composition and the clay fraction has been selected as 30% of the composition. Coarser grained sediments recovered from the geotechnical field investigations have been excluded from the morphological modelling simulations, given their low mobility. The assumptions of sediment composition and availability are considered to be conservative, such that the modelling's demonstrated sediment movement may be exaggerated. This is required as a precautionary approach to assessing potential environmental impact, but also ensures that modelling demonstrates potential movement of sediment that the project will induce.



Figure 5-1 The location of wave extraction point used to define the representative modelling scenarios

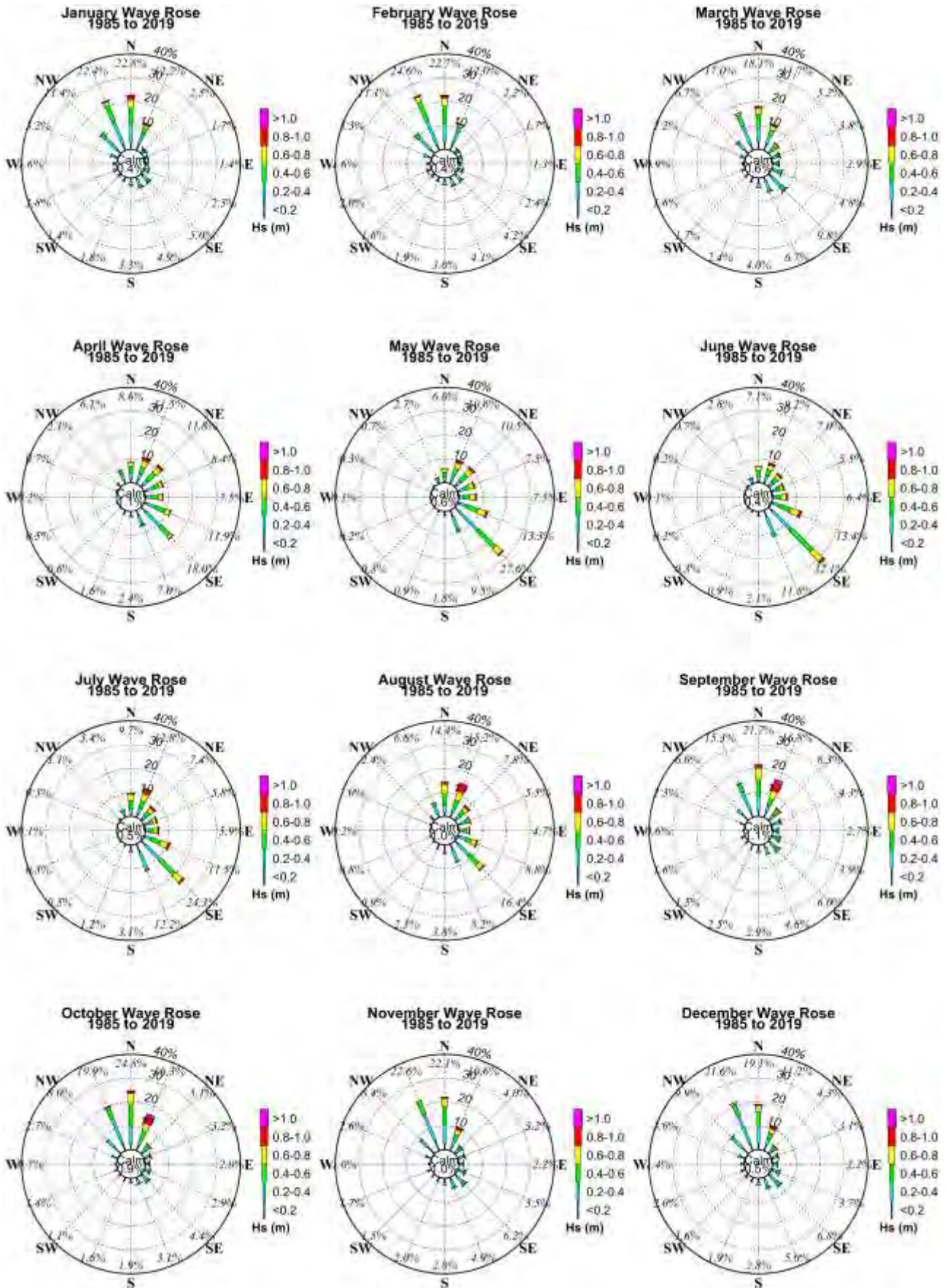


Figure 5-2 Monthly wave roses at the extraction location based on CSIRO hindcast wave data (1979 to 2019)

5.4 Sediment Transport Pathways

To investigate the potential sediment transport pathways, and the likely source(s) of the sediment that may be mobilised at Mandorah, the east/west and north/south directed sediment transport rates predicted by the model have been integrated over the simulation period. This provides an indication of the net sediment transport rate and its corresponding direction across the simulation periods. **Figure 5-3** to **Figure 5-7** present the net sediment transport vectors for the post development conditions across the five morphological modelling scenarios investigated.

The potential sediment transport pathways indicate the residual direction and intensity of the sediment flux, should sediment be available on the seabed. These pathways suggest that sediment transport pathways at the site are generally consistent throughout the year, indicating strong dependency between morphological response and tidal currents. The majority of strong sediment mobility occurs offshore from the proposed harbour, in water depths exceeding approximately 10 m. Notable areas of high sediment mobility include the water column adjacent to the nearshore reef immediately north of harbour. Conversely, the potential sediment transport pathways show low sediment mobility in the nearshore area, surrounding the proposed harbour.

5.5 Sedimentation Plots

Morphological simulations across the five modelling scenarios were undertaken to investigate the combined influence of tides, wind and waves on local sedimentation and erosion patterns. An initial investigation was carried out to validate the morphological modelling results, based on available bathymetric datasets within the modelling domain. The bathymetric datasets used for comparison were dated approximately three-years apart, at similar times in the annual cycle (September 2017 and October 2022). A comparison of the surveys shows that the nearshore seabed is relatively stable, with very localised elevation changes rarely exceeding ± 0.2 m.

An example of the modelled baseline (pre-development) net sediment deposition, across the wet season is provided in **Figure 5-8** below. Comparisons between the five morphological simulations suggest that seasonality has minimal impact on sedimentation and erosion patterns. This is likely attributed to tidal currents being the dominant mechanism for sediment resuspension and transport in the area.

Figure 5-9 to **Figure 5-13** present pre- and post-development difference plots of net sedimentation and erosion across the five morphological modelling scenarios investigated. Changes to local sedimentation and erosion patterns, attributed to the harbour, are relatively small and localised. There is also minimal seasonal variability, as demonstrated by the comparable results across the five morphological simulations. During all modelling simulations, net changes to the seabed elevation were observed prior to the end of the modelling period. This indicates that the seabed reaches a state of morphological equilibrium, based on available sediment volumes within the modelling domain, relatively rapidly.

Notable changes, attributed to the harbour, include an accumulation of sediment to the north of the northern breakwater. At times, this material may be expected to be deposited at the entrance of the harbour, with some localised scour also expected near the harbour entrance. The interaction between the breakwater structures and net northerly currents, during both ebb and flood flows, creates a less energetic 'shadow' in the (tidal) lee of the northern breakwater. Such environments are conducive of low sediment mobility, leading to the accumulation of material on the seabed. Based on the modelling results and comparisons between bathymetric surveys taken three-years apart, at similar times in the annual cycle, these changes are anticipated to occur relatively soon following construction of the harbour.

The morphological modelling focuses on the potential for sediment redistribution within the vicinity of the proposed harbour. Other sediment loads, which may be transported into the harbour, such as the settlement of ambient suspended sediment (siltation) are not processes that are accounted for by this morphological modelling. An empirical estimate of such sediment loads has been provided in **Section 6**, below.

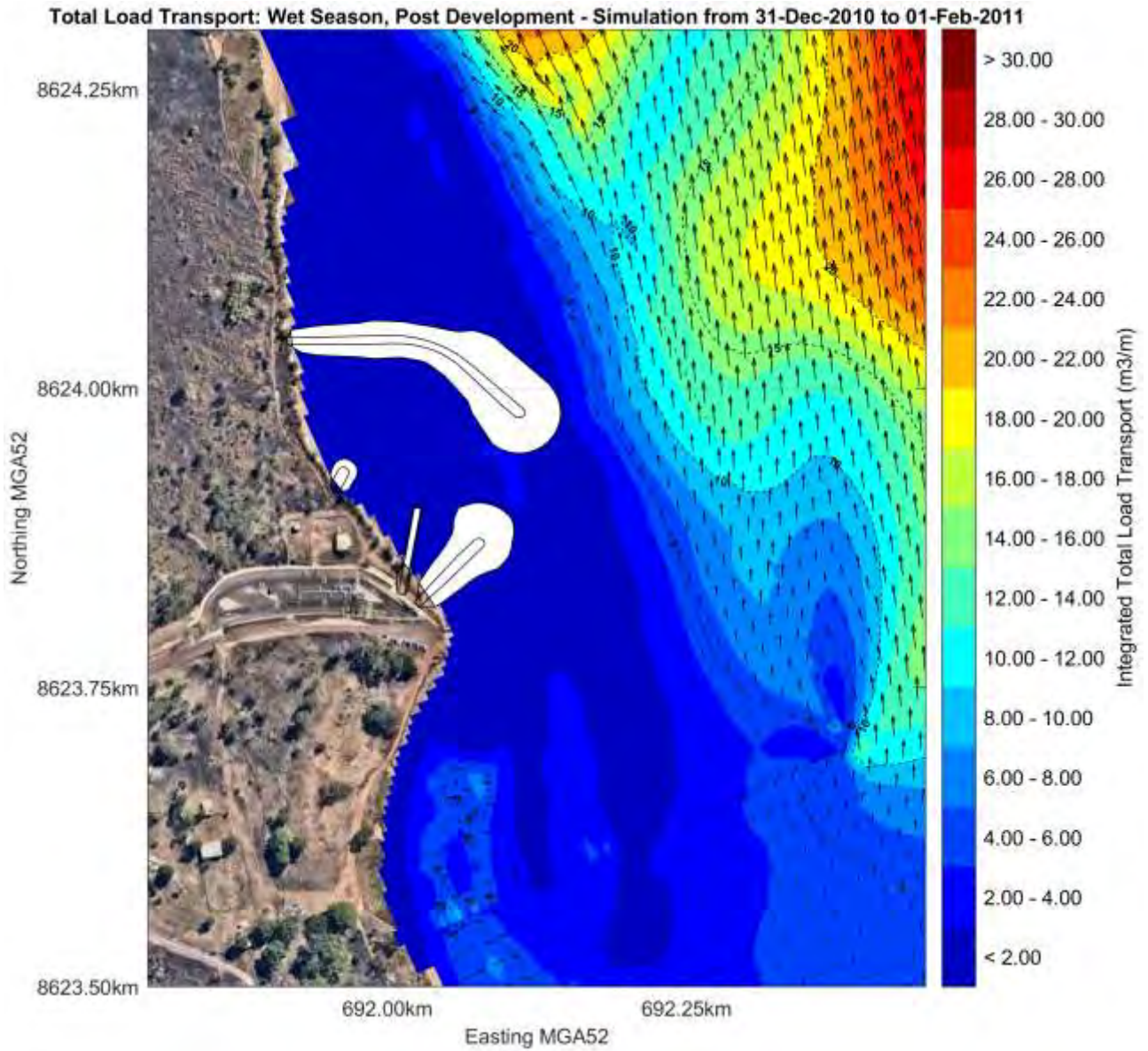


Figure 5-3 Total sediment load transport vectors: 1-month, wet season

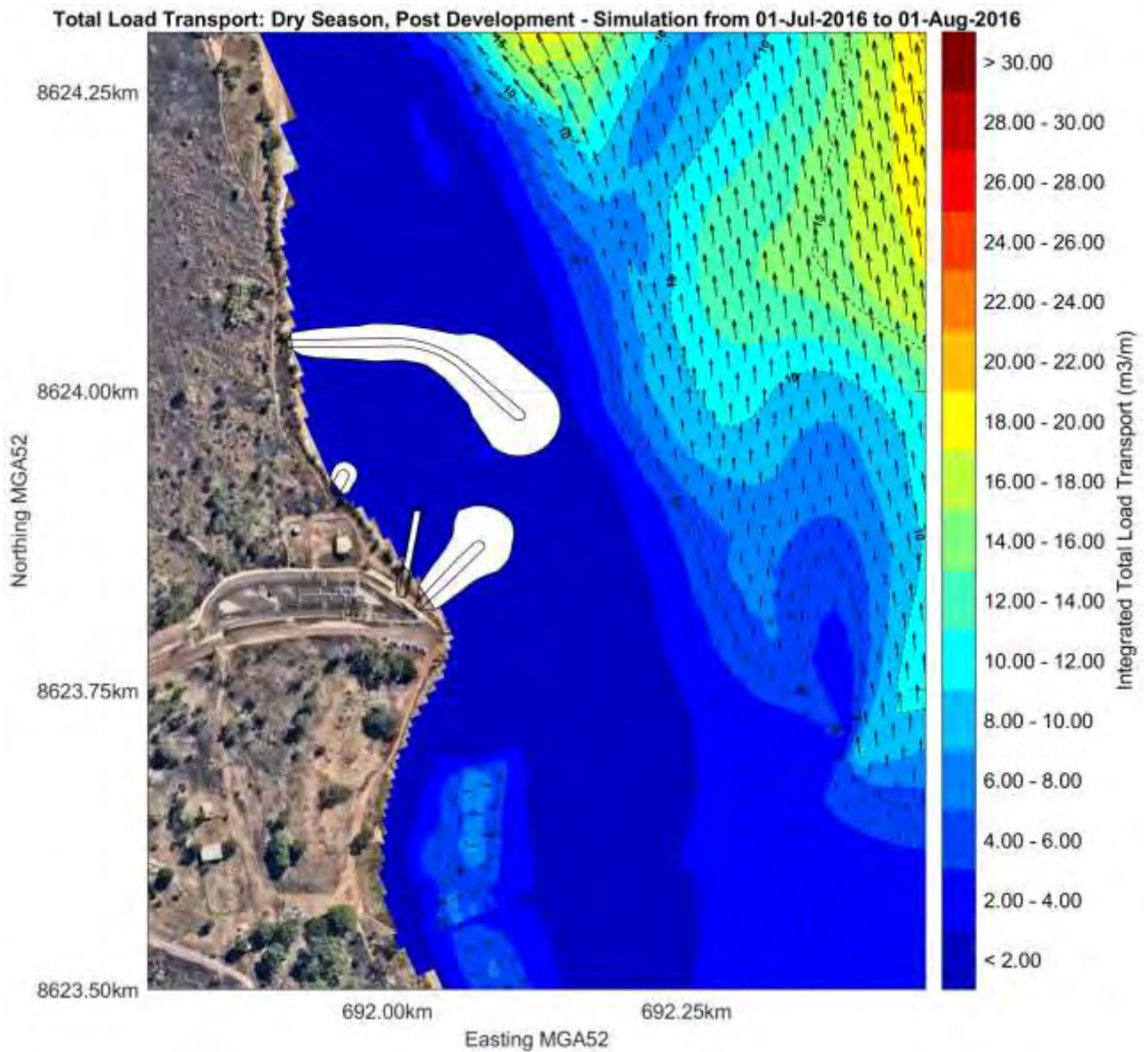


Figure 5-4 Total sediment load transport vectors: 1-month, dry season

Total Load Transport: Shoulder Season - Wet to Dry, Post Development - Simulation from 31-Mar-2008 to 01-May-2008

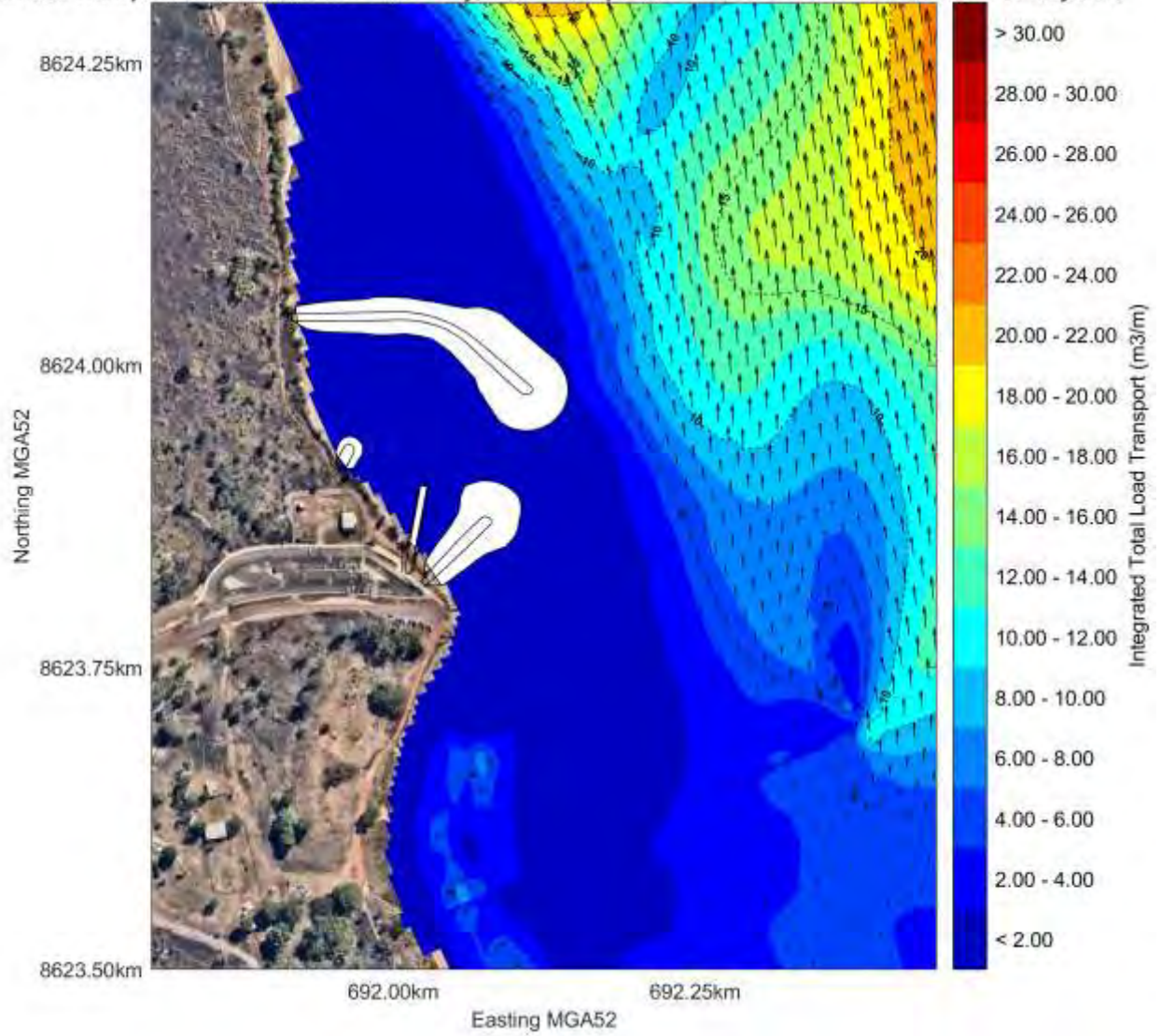


Figure 5-5 Total sediment load transport vectors: 1-month, shoulder season (wet to dry)

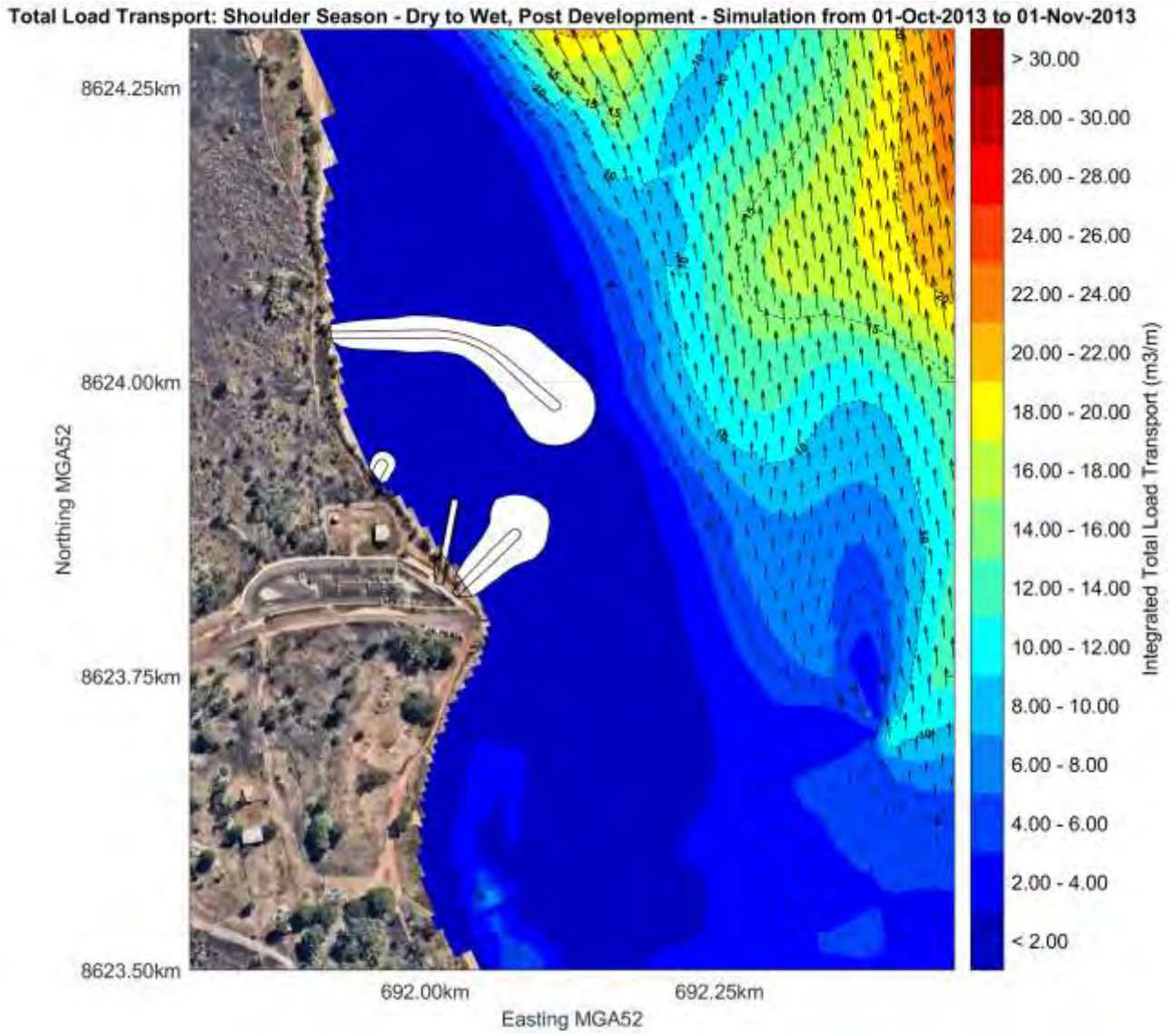


Figure 5-6 Total sediment load transport vectors: 1-month, shoulder season (dry to wet)

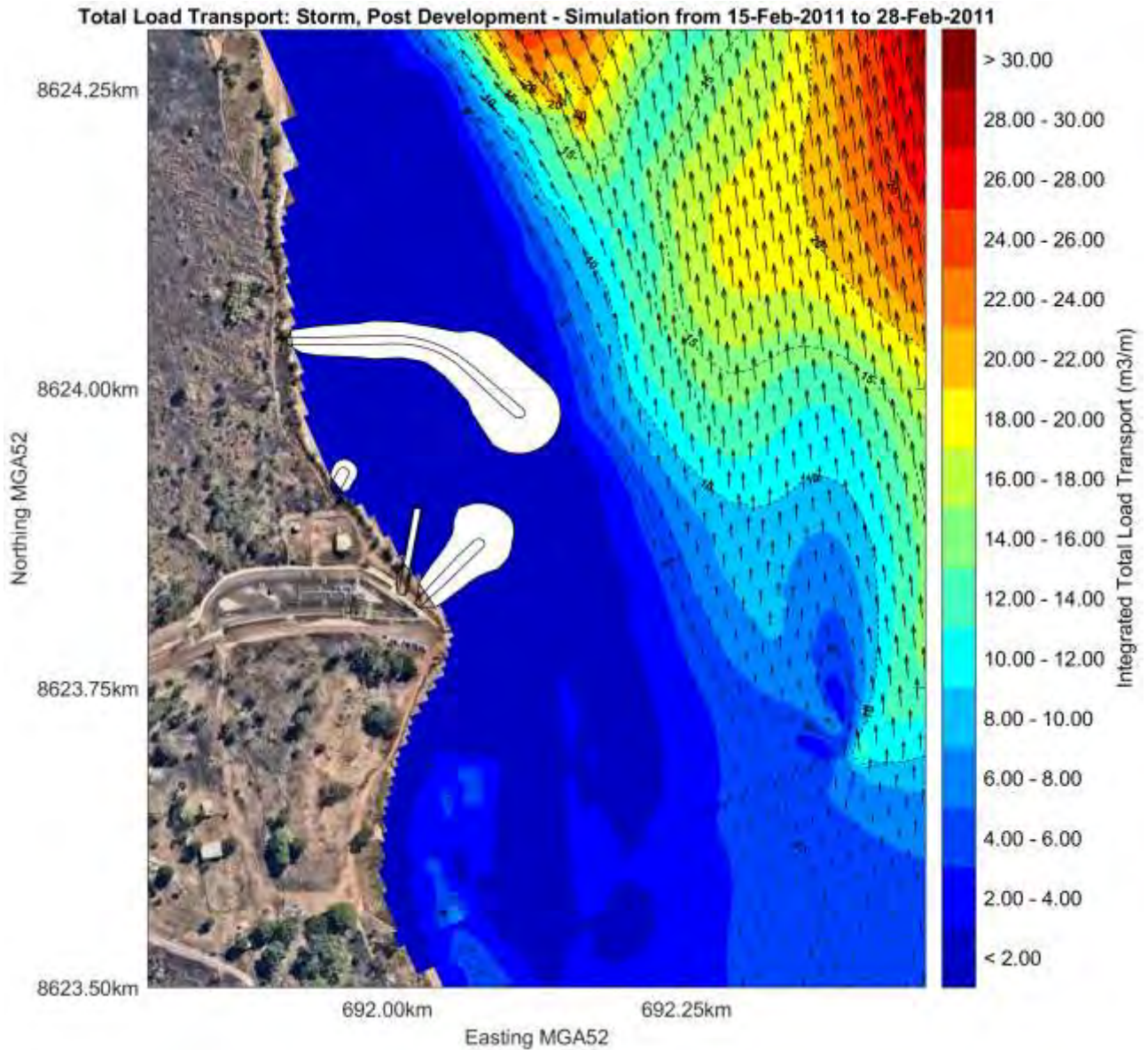


Figure 5-7 Total sediment load transport vectors: 2-weeks, storm

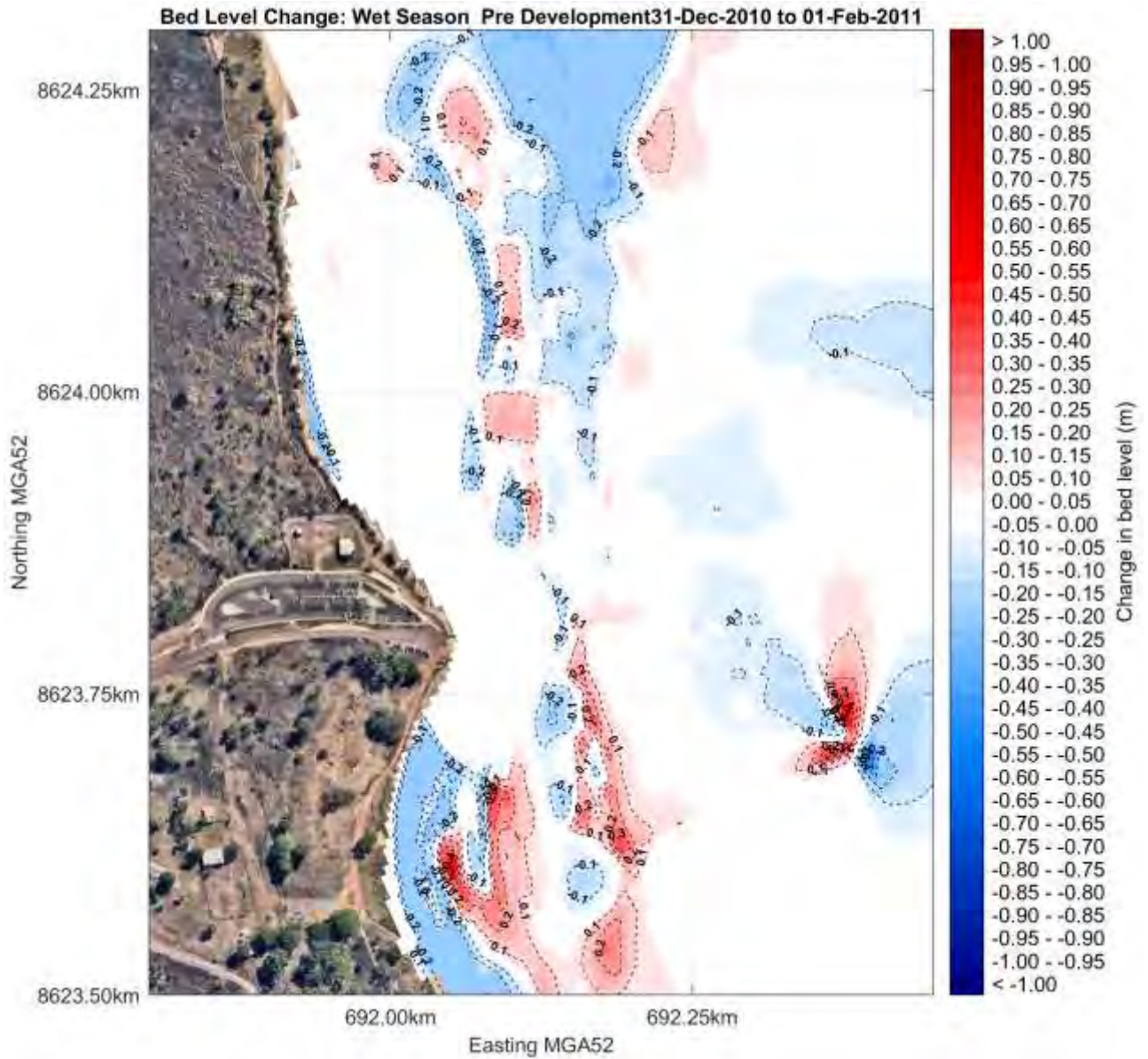


Figure 5-8 Baseline sediment deposition: 1-month wet season

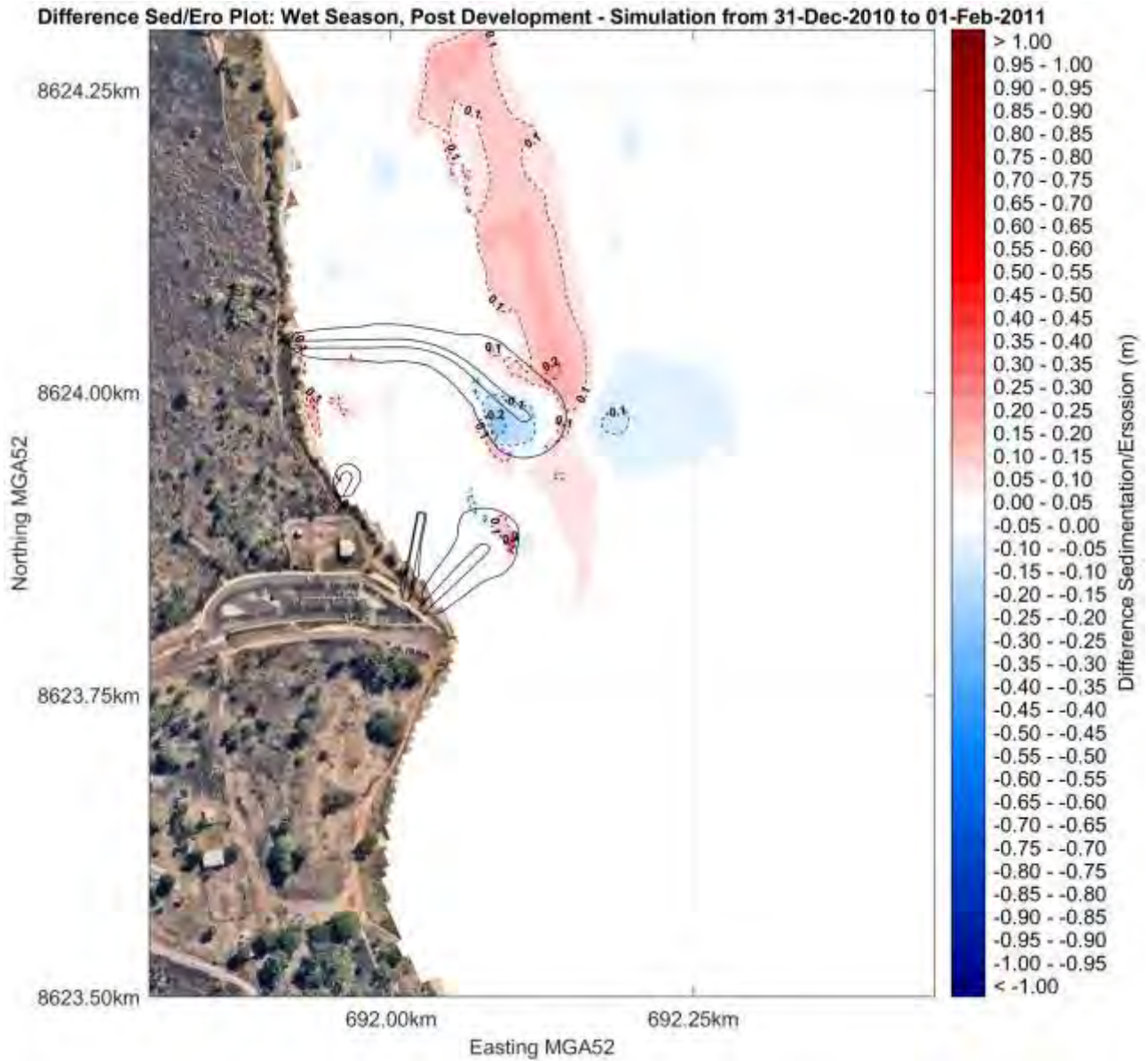
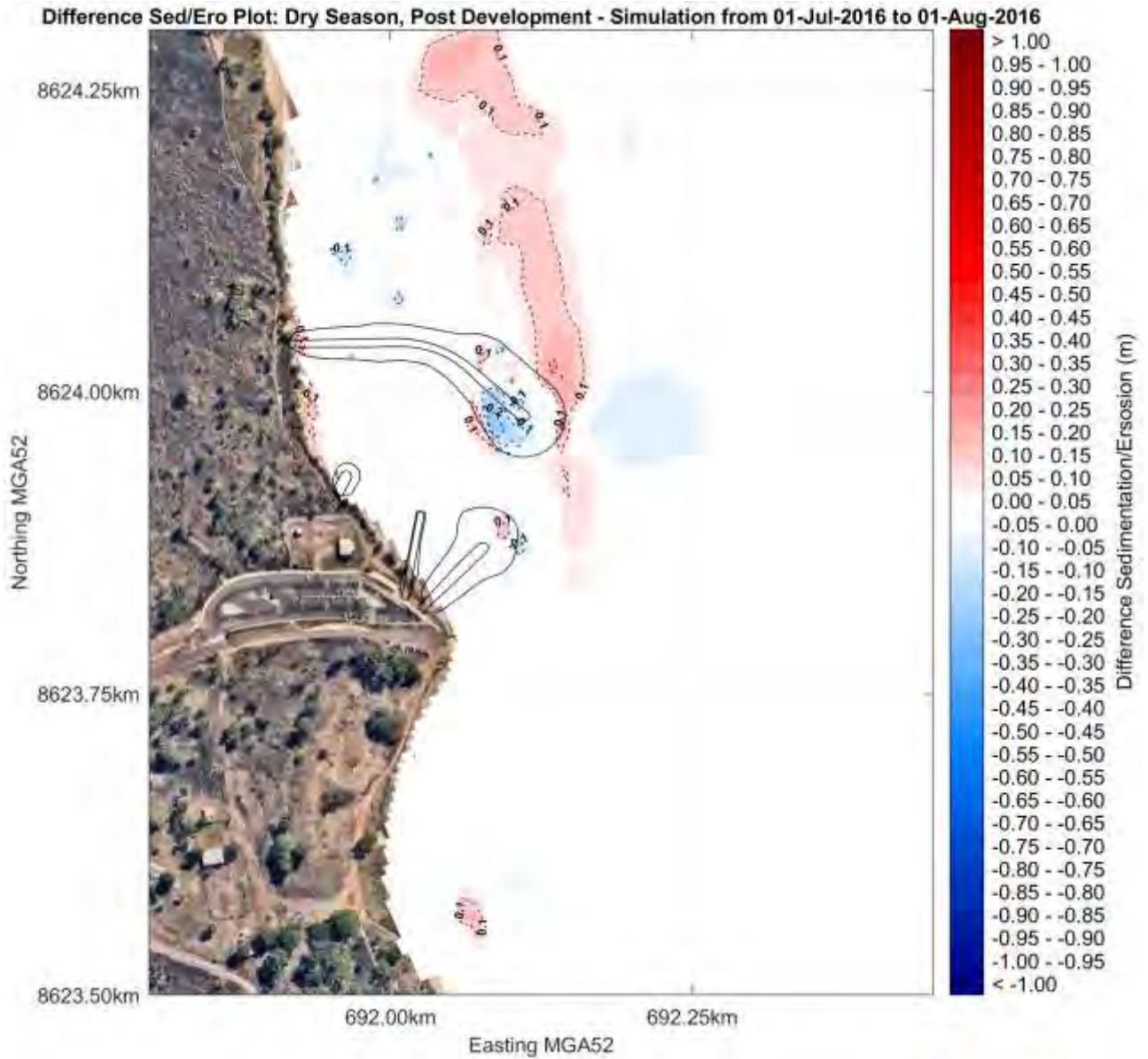


Figure 5-9 Change in bed level: 1-month, wet season



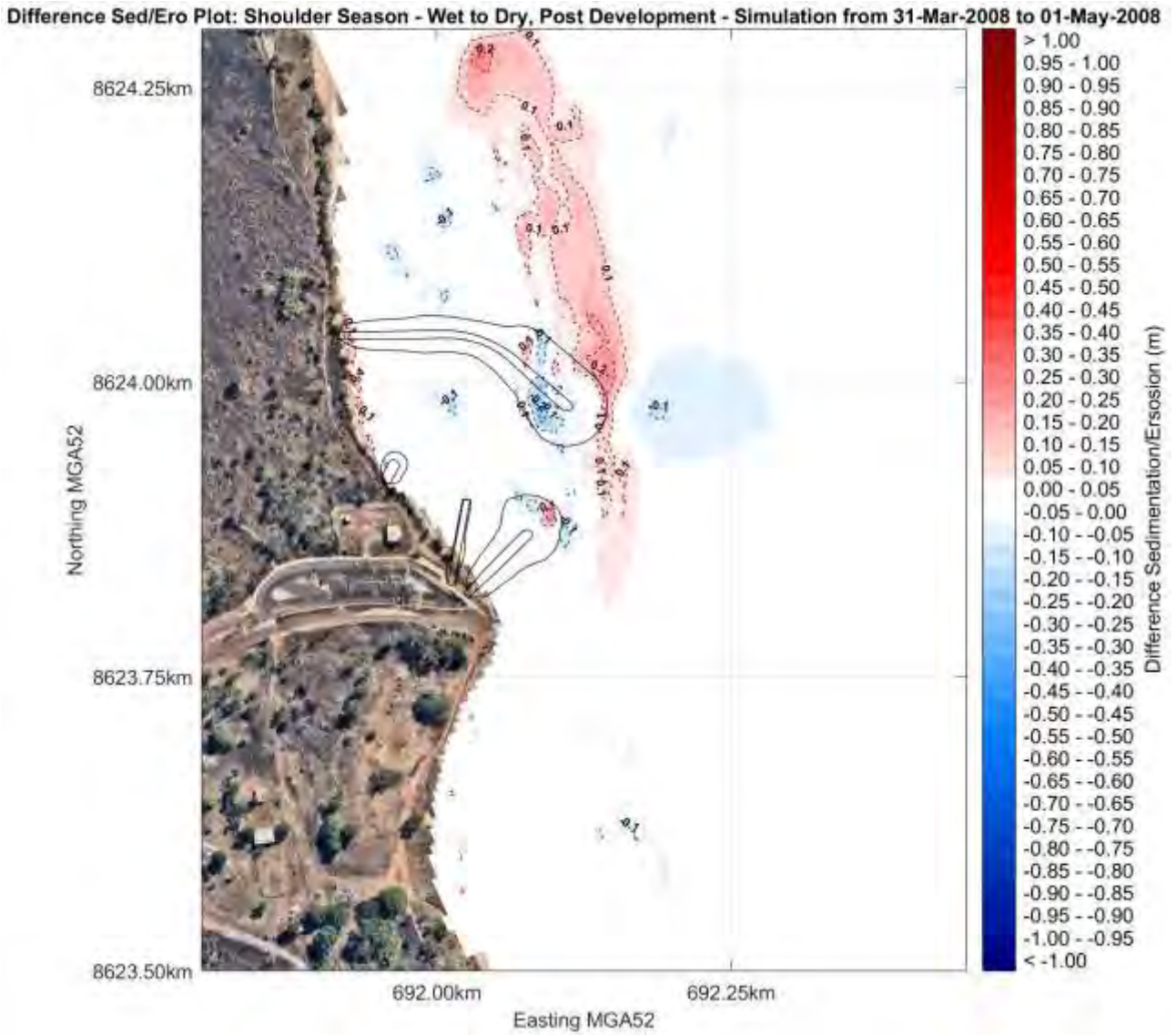
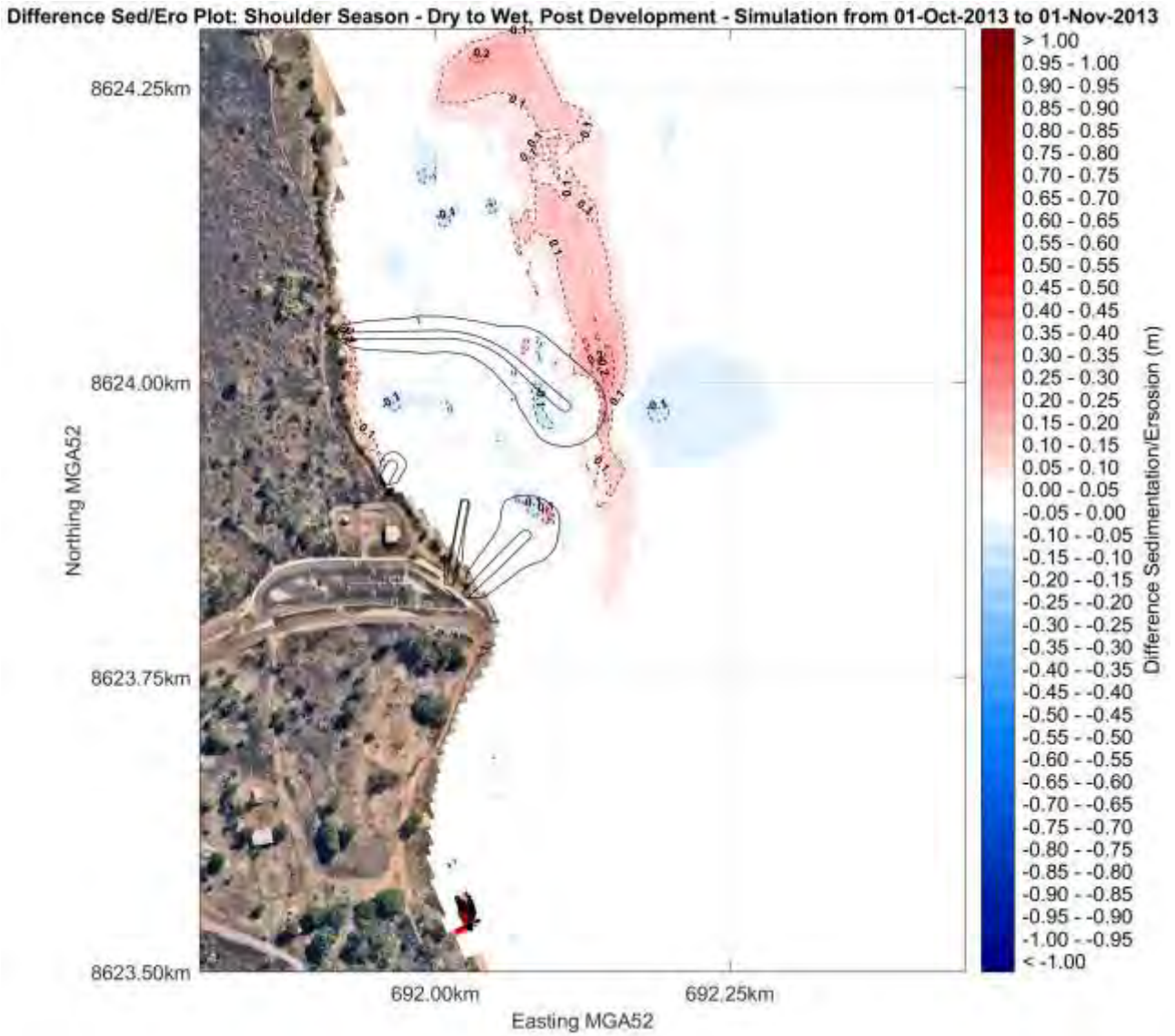


Figure 5-11 Change in bed level: 1-month, shoulder season (wet to dry)



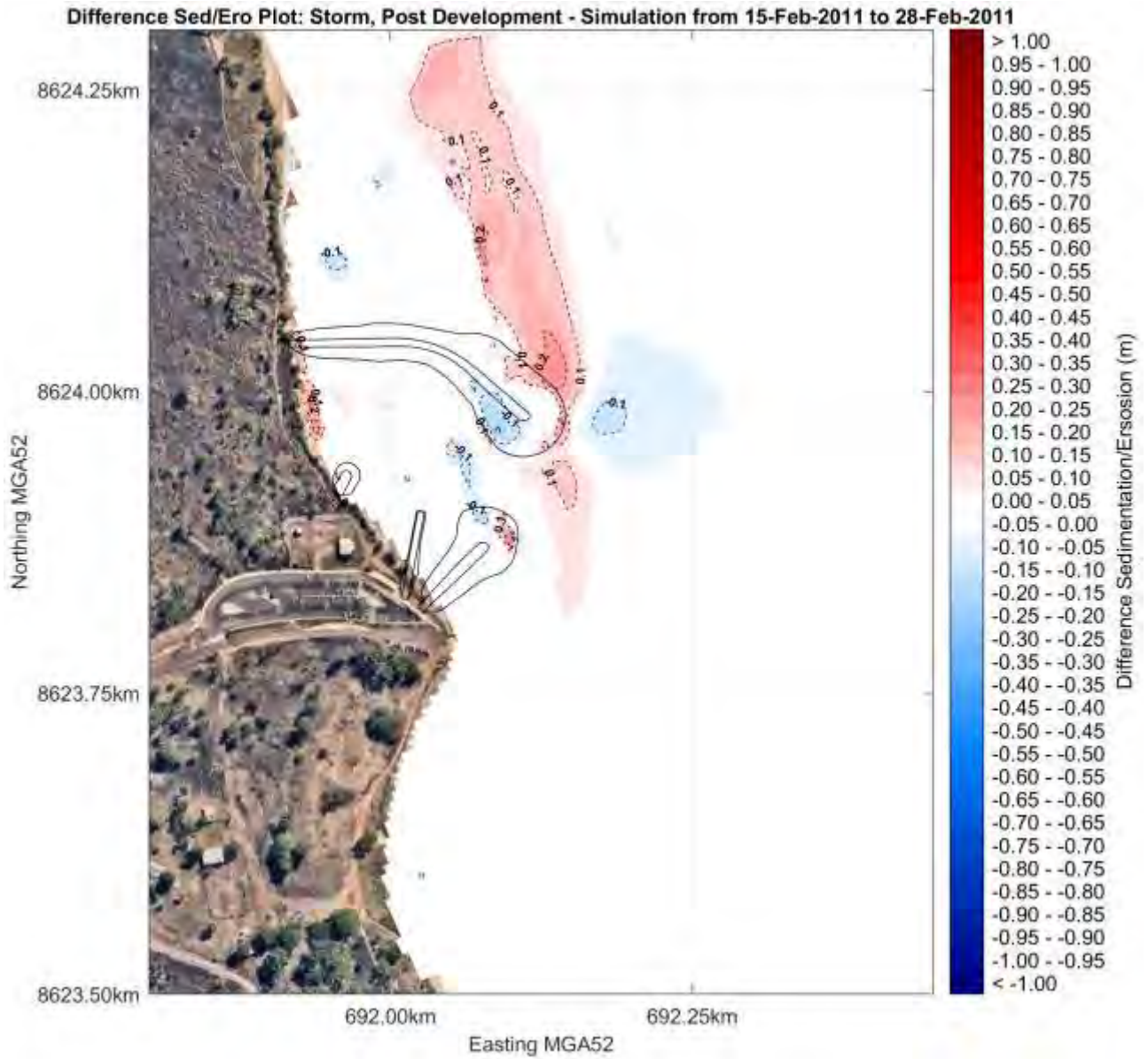


Figure 5-13 Change in bed level: 2-weeks, storm

6 Harbour Basin Siltation Assessment

6.1 Methodology

An estimation of the annual siltation inside the harbour basin, for the harbour design, has been derived based on the theory of Van Rijn (2012a). This involved using measured water levels, currents and turbidity data, together with the proposed harbour characteristics (total surface area, entrance width and entrance configuration) to calculate the exchanged volume of water and suspended sediment. This assessment includes variable concentrations throughout the year to estimate sedimentation rates within the proposed harbour basin.

The sedimentation estimates are based on the conversion of turbidity measurements to concentration of suspended sediment at Mandorah, collected during the Inpex Ichthys Project (Cardno, 2015) (**Figure 6-1**).

Water levels and current velocities corresponding to the period of suspended sediment measurements outside the harbour were estimated using the hydrodynamic modelling results, detailed in the *Metoccean Report* (Cardno, 2023). Siltation estimates were then calculated for the harbour by applying Van Rijn’s method for the period between January 2013 to January 2015. A sedimentation estimate has been calculated every 5 minutes.

6.2 Results

Using an effective average settling velocity of 0.202 mm/s (which is based on the measured suspended sediment particle size distribution during recorded by Cardno), the yielding sedimentation rate is approximated as 210 mm/yr. This corresponds to a trapping efficiency of 0.24.

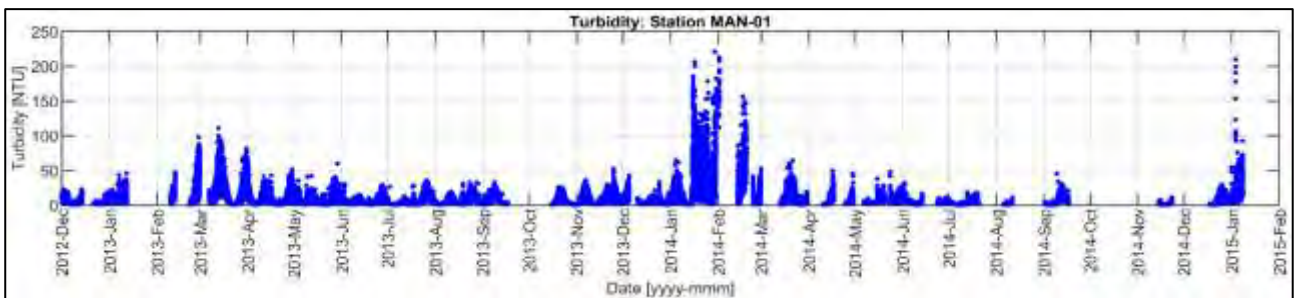


Figure 6-1 Turbidity time series at Mandorah Station

Note that this estimate is likely to be a conservative assessment of harbour siltation, as:

- > The sedimentation volume is based on a dry bulk density of 350 kg/m³. This represents freshly deposited mud, and will consolidate over time as more sediment is deposited above it, which will double (or more) over time, halving the volume;
- > The turbidity measurements were collected during a large-scale dredging campaign in Darwin Harbour, which may include elevated turbidity levels due to the dredging works; and
- > The passage into and out of the harbour by the ferry, and to a lesser extent, recreational vessels, will stir up freshly deposited sediment, thereby reducing the amount of sediment retained in the harbour.

7 Shoreline Evolution Assessment

7.1 Introduction

Construction of the maritime facilities at Mandorah has the potential to create a need for ongoing shoreline management, to avoid to impact several NT EPA Environmental Factors including Landforms, Culture and Heritage and Hydrological Processes. Once installed, the breakwaters will act as a barrier to local longshore sediment transport processes. This may result in areas experiencing sustained accretion and erosion adjacent to the facilities, altering the shape of the shoreline. It may also lead to a more dynamic shoreline (i.e., seasonal changes) nearby the harbour breakwaters.

The purpose of this investigation is to examine the likely effects of the proposed harbour works on the regional shoreline and to estimate any ongoing maintenance requirements. This requires the estimation of long-term, longshore sediment transport rates in the region near the harbour and application of these in appropriate numerical modelling.

Longshore Sediment Transport (LST) and subsequent, shoreline evolution calculations were undertaken using the LITDRIFT and LITLINE modules of the DHI LITPACK Littoral Processes FM modelling system. These modules simulate the sediment transport (net and gross) under time-varying wave, water level, and currents conditions across realistic shore normal seabed profiles that are based on survey and spatially variable sediment characteristics.

7.2 Sediment Data

Sediment samples were collected approximately 200 m to the south of the existing jetty, where sediment was available at the shoreline. Yellow dots shown in **Figure 7-1** indicate each sediment sampling point. Average D50 of these sediment samples was 1.221mm. This value was used as input for the LITPACK sediment transport modelling, to characterise the grain size of sediment in the littoral zone.



Figure 7-1 Location of sediment samples collected for particle size distribution

7.3 Longshore Sediment Transport Modelling (LITDRIFT)

Cardno initially undertook longshore sediment transport modelling using the LITDRIFT module of the LITPACK coastal processes modelling system developed by the Danish Hydraulics Institute. It is used internationally for assessment of coastal processes. LITDRIFT computes longshore sediment transport from a time-series of wave and water level parameters. Natural beach profiles, graded sediments, currents, wind and local roughness can be included. Generally, the highest transport rate occurs in the breaking wave zone. For this analysis, LITDRIFT modelling has been undertaken for a pre-development scenario to estimate the potential LST rates at the Mandorah harbour site.

7.3.1 Model Setup

7.3.1.1 Profiles

For this study, longshore sediment transport has been modelled for one (1) shore normal profile as indicated in **Figure 7-2**. The bathymetric details of these profiles have been derived from the consolidated bathymetric and topographic data, and are presented in **Figure 7-3**.



Figure 7-2 The Location of considered profile at the Proposed Mandorah Harbour Site

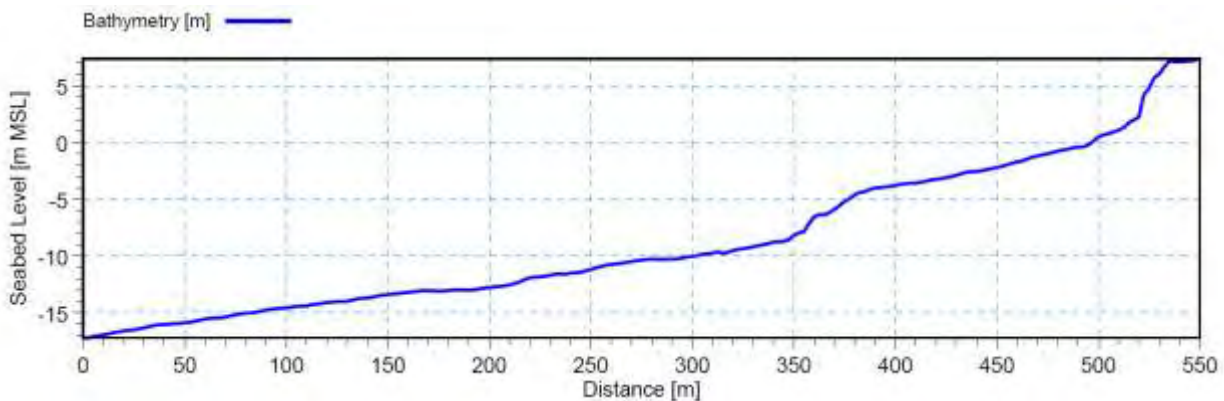


Figure 7-3 The Bathymetry of Profile used for Litdrift Modelling

7.3.1.2 Shore Normal Direction

A key input to the sediment transport assessment is the direction of the normal to the shoreline. For this analysis, shore normal direction is taken at 90°N based on the nearshore contours.

7.3.1.3 Duration

This initial analysis is undertaken using an individual scenario events approach, using 34 years (1985-2019) of wave climate data developed from SWAN wave modelling for the selected shore normal location, and its corresponding hindcast water level from the developed Delft3D hydrodynamic model constituents.

7.3.2 Modelling Results

7.3.2.1 Q-Alpha Curves

Longshore transport is highly sensitive to the orientation of the shoreline normal. A change in the shoreline normal will affect the angle between the approaching waves and the shoreline normal, which is one of the key parameters for longshore sediment transport. This is illustrated in **Figure 7-4**, in which a coastline is shown for two different shoreline orientations. Waves are in both cases approaching the shoreline from the east. The beach in the left panel has a shoreline normal towards south-east which causes longshore transport towards south (indicated by the blue arrow). The shoreline normal in the right panel is oriented towards north-east, which causes transport towards north (indicated by the blue arrow).

Changes to shoreline orientation occur naturally in response to seasonal variations in the wave climate and in response to long term trends in erosion/deposition. The shoreline orientation will in particular change if changes to the upstream sediment supply occur. e.g., if sediment is blocked at a point along the shoreline, then the downstream shoreline will turn up against the predominant waves such that the longshore transport on the downstream beach is also zero. The calculated longshore transport is then shown as a function of the shoreline orientation thus forming a so-called Q- α curve.

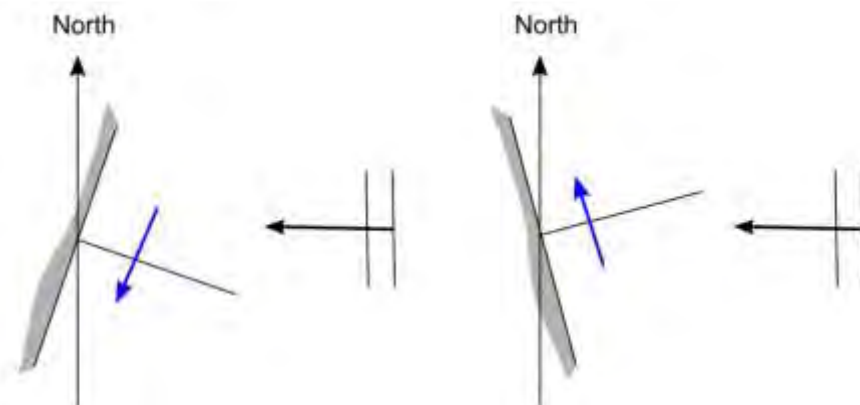


Figure 7-4 Schematic showing the effect of changes in shoreline orientation on longshore transport (DHI, 2020).

Figure 7-5 shows the Q- α curve for the analysed profile. The figure shows both the variation of the potential gross-transport (red curve) and the potential net transport (blue curve). Note that the gross-transport and net transport are to be defined positive for transport towards the south and negative towards the north.

The figures show that the net transport is generally towards the south.

The slope of the net transport i.e., the change in net transport per degree change in shoreline orientation, gives a measure of the sensitivity of the net transport to changes in shoreline orientation. The sensitivity of the net transport to changes in shoreline orientation is around 330 m³/deg near the present orientation, and ranges from 51 to 354 m³/deg.

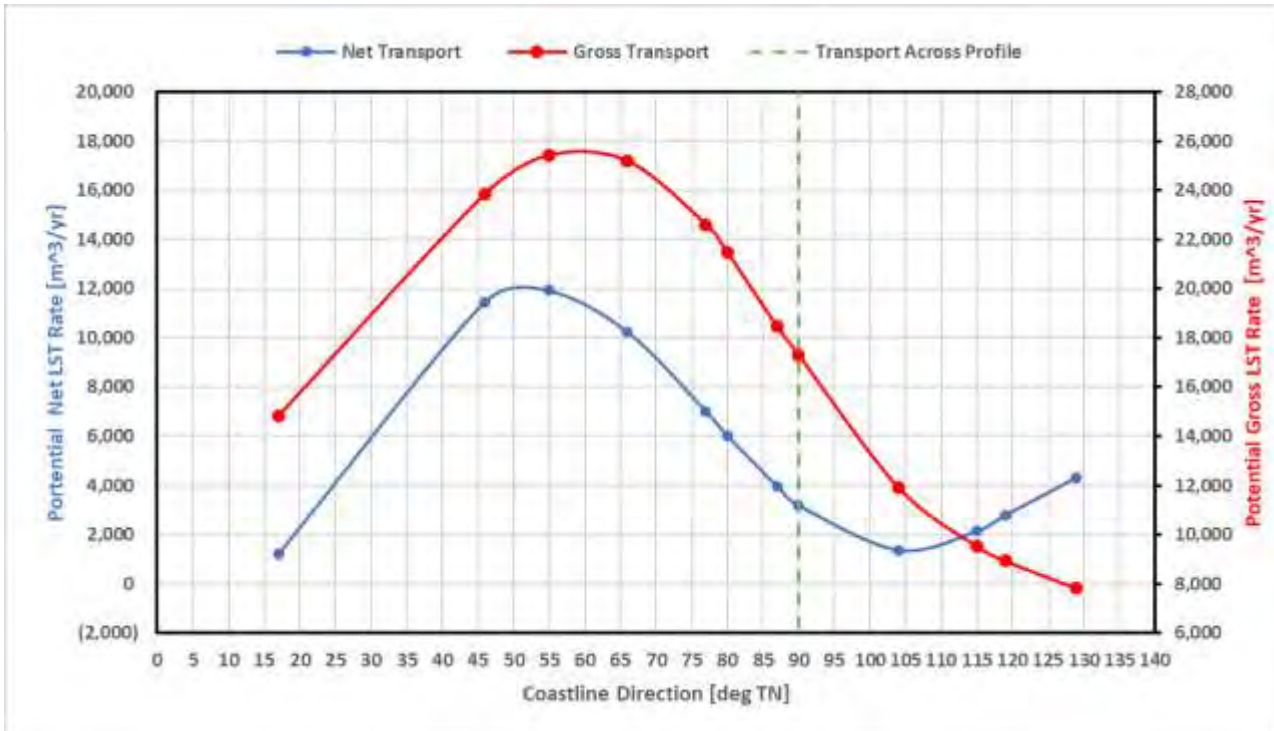


Figure 7-5 Q-α Curve for Selected Profile

7.3.3 Potential Longshore Sediment Transport Rates

As the shoreline orientation at the site is variable, the peak sediment transport rates have been assumed from the Q-α curve to define the potential longshore transport at the site. This equates to an approximate net southerly transport of 12,000 m³/year, as described in **Table 7-1**. Noting that the shore normal direction varies from about 55° to 130° at the site, the net-transport rate is likely to be lower than this, between 2,000 and 12,000 m³/year. Furthermore, the proposed structures do not extend to the length of the modelled profile, although the majority of littoral drift is expected to occur where they are situated.

Table 7-1 Potential Longshore Sediment Transport Rates along Profile

Potential Rate	Rate [m³/yr]
Net Transport	12,000
Gross Transport	25,000

7.3.4 Shoreline Evolution Investigation

The construction of coastal structures such as shore connected breakwaters as proposed at Mandorah will alter the coastlines sediment transport regime. Based on a review of historic imagery this shoreline appears to have been relatively (dynamically) stable over the last 10 years, and would be considered to be in equilibrium for the existing wave climate and tidal regime.

The breakwaters will essentially block longshore sediment transport, which as a result of this, the shoreline will accrete on the updrift side, with commensurate erosion on the downdrift side. The extent and rate of shoreline changes updrift of the harbour have been estimated utilising the analytical solution of equation of motion and continuity in the alongshore direction, along with the potential net transport rates estimated using LITDRIFT. Whilst the investigation gives an estimate for net longshore sediment transport rates, which can be used to estimate accretion and erosion volumes, the following uncertainties exist with regards to the model outcomes:

- > The assessment assumes a continuous, straight shoreline and only interprets results to estimate potential accretion volumes, it does not model the effects of the breakwaters themselves; and

- > This investigation has used potential sediment transport, which assumes there is sufficient available sand for these rates to occur. However, based on the available bathymetric data as well as the geological features of the study area, it appears that there is a lot of shallow rock in the area. This means that the sediment transport rates presented in this report and used for this assessment are likely larger than what is occurring.

Following review of the project's *Environmental Referral Report* (Cardno, 2022a), and given the limitations described above, the EPA has requested more sophisticated shoreline evolution modelling be undertaken as part of the *Supplementary Environmental Report* (Stantec, 2023a). LITLINE has been applied to fulfill this requirement.

7.4 Shoreline Evolution Modelling (LITLINE)

Cardno has undertaken shoreline evolution modelling using the LITLINE module of the LITPACK coastal processes modelling system developed by the Danish Hydraulics Institute. It is used internationally for assessment of coastal processes. LITLINE simulates the coastal response to gradients in the longshore sediment transport capacity as a result of natural features and coastal structures computes shoreline evolution.

LITLINE is the shoreline plan-form, evolution module of LITPACK and applies the Pennard-Considered 1-line method of analysis. The model included shoreline structures such as the Mandorah breakwaters, applying the computational results of LITDRIFT at a number of shoreline locations along a modelled section of shoreline. Curved-in-plan alignments are modelled as a straight coastline, but with appropriate wave directions applied at the seaward ends of the profiles. An active beach face height extending from an adopted closure depth to the top of wave run-up is used to calculate the changes in the shoreline (at the position of the mean sea level contour).

7.4.1 Model Setup

7.4.1.1 Profiles

For this study, shoreline evolution has been modelled using two representative shore normal profiles as indicated in **Figure 7-6**. The bathymetric details of these profiles have been derived from the consolidated bathymetric and topographic data and are presented in **Figure 7-7**.



Figure 7-6 LITLINE profile locations

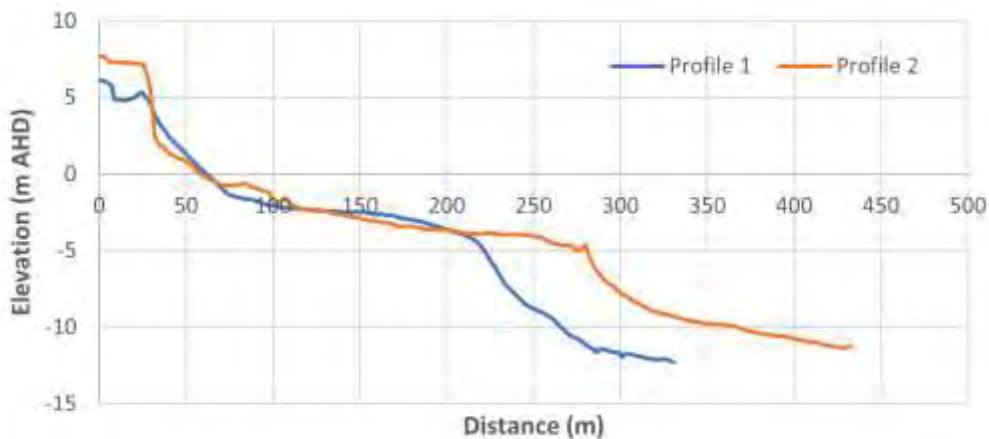


Figure 7-7 LITLINE profile cross sections

7.4.1.2 Shore Normal Direction

A key input to the sediment transport assessment is the direction of the normal to the shoreline. For this analysis, shore normal direction is taken at 90°N based on the nearshore contours.

7.4.1.3 Duration

The LITLINE models were run for a period of 10 years (2000–2010), using wave climate data developed from SWAN wave modelling for the selected shore normal location, and corresponding hindcast water level from the developed Delft3D hydrodynamic model constituents.

7.4.2 Modelling Results

Two scenarios were run for the ten year period in LITLINE, modelling both the existing coastline without the facility and the coastline with the proposed facility installed - including the breakwaters acting as barriers to longshore sediment transport. The model assumes an entirely sandy (erodable) coastline, which is not the case for portions of the coastline in the project area. Given areas of rock present along the shoreline, the output results are then adjusted so that erosion ceases inland where rock barriers are present (above highest astronomical tide). This is the case for the shoreline directly to the south of the proposed facility. Any supply deficit modelled for this area is accounted for by being shifted southwards – the direction of longshore drift.

The initial 'shoreline' applied in the models (shown in **Figure 7-8**) has been derived based on a combination of survey data (approximately mean high water springs) and recent aerial imagery that demonstrates the active upper limit of the beach. **Figure 7-8** displays the output change in shoreline, with and without installation of the marine facilities, after the ten year model period.

A widened beach profile north of the facilities is due to the main breakwater disrupting the net southerly transport of sediment. The accretion to the north of the facilities reduces the sand feed available to the south, resulting in a small area of erosion approximately 350 m south of the lee breakwater. It should be noted that the substantial erosion shown on the beach to the south of the facility in **Figure 7-8** has resulted from the modelling both with and without the structures. I.e., it is a result of the 10-year period of coastal conditions or the assumptions related to sediment mobility, rather than the influence of the structures. Although this may indicate that the 10-year modelled period is not typical, it is useful to conservatively assess the changes that the harbour may induce.

Predicted shoreline change to the south of the facility is also uncertain, due the presence of rock in the area. Geotechnical information collected at the project site suggests underlying rock may be present at the back of the beach (i.e., beyond the visible rock directly south), inhibiting the modelled erosion from occurring in reality. The 'down-drift' effects of the proposed maritime facilities on the surrounding shoreline are limited to within 400 m south of the lee breakwater, due to coastal structures and a sharp change in shoreline orientation. Model outputs presented that are beyond 400m south are unrealistic, due to the change in shoreline angle and man-made structures not being properly accounted for in the model.



Figure 7-8 Shoreline evolution results

7.4.3 Shoreline Change Volumes

Accretion and erosion volumes have been estimated for each area displayed in **Figure 7-9**. Zones represent the area bounded by the change in shoreline position between existing and proposed conditions model runs. Volumes were derived using topographic data (beach slope) and calculated areas, tabulated in **Table 7-2**. Volumes are expressed as an annual change, averaged over the 10-year modelling period to remove interannual variability.

Table 7-2 Accretion and erosion rates

Zone	Rate [m ³ /yr]
Accretion – North of facilities	1,300 – 1,900
Erosion – South of facilities	200 - 600



Figure 7-9 Extent of potential shoreline change

7.5 Model Validation

Validation of long-term sediment transport modelling is difficult, given the lack ongoing monitoring data for the area of interest and the fact that the model predicts the effects of a significant shoreline change - i.e., there is no previous, similar scenario available for comparison at the site. The study area is fortunate to have some historical shoreline evolution data associated with small marina that was constructed approximately 400 m to the south of the project area, in the early 2000s. The results of this installation can be compared qualitatively with the proposed project’s model results. In undertaking this comparison, the following limitations must be stated:

- > Assessment of shoreline change over time is confounded by the low temporal resolution of aerial imagery, combined with the very high tidal range for the region. I.e., aerial imagery captures an instantaneous waterline position, which does not necessarily represent the mean shoreline (defined as the contour at 0 m AHD or MSL);

- > The historical structure is in a different location, with different shoreline orientation and intertidal bathymetry compared to the proposed facility;
- > The offshore extent of the historical structure is much less than that of the proposed main breakwater;
- > The permeability (in terms of sediment transport) is likely to be lower for the historical structure; and
- > Sand management may have occurred around the historical structure without this information being documented for consideration.

Assessment of approximately 10 years of information on shoreline change to the north of the historical structure appears to demonstrate accumulation to its north, though only in its direct vicinity. The change in shoreline is considerably less than that predicted to the north of the proposed main breakwater. This could potentially indicate that the rates of modelled transport are higher than those occurring in reality. Substantial erosion modelled to the south for both scenarios also supports this notion.

Given the uncertainty in the modelling and implications for potential environmental impact and ongoing sand management effort, it is recommended that routine monitoring of the shoreline position adjacent the facility be undertaken once it is constructed. Specific details of such monitoring are provided in the project's *Coastal Processes Monitoring and Management Plan* (Stantec, 2023d).

8 Dredging and Disposal Sediment Transport Assessment

8.1 Introduction

The potential impacts on the benthic communities and habitats (BCH) surrounding the proposed project during construction must be assessed, to inform management of potential environmental impact. A likely key impact on the environment could be caused by sediments brought into suspension during construction, dredging and disposal activities. Cardno have undertaken sediment plume dispersion modelling to predict the suspended sediment load and likely sedimentation within the surrounding marine environment due to construction activities. This model is based on Cardno's calibrated 3D hydrodynamic model (see Cardno, 2023). This section provides an overview of the modelling carried out to define the flow fields and current speeds within the study area as well as the fine sediment transport and dispersion model to simulate the advection-dispersion of the suspended sediments released as part of the construction, dredging and disposal activities. Brief details on the numerical model, model setups, basic assumptions and methodology are described below.

8.1.1 Hydrodynamic Modelling

The hydrodynamic modelling undertaken in this study was used to define the water level variations and currents around the study area. Details on the development of the hydrodynamic model can be found in the *Metocean Report* for the project (Cardno, 2023).

8.2 Model Setup

8.2.1 Inputs and assumptions

8.2.1.1 General assumptions

The dispersion modelling has been based on the following assumptions:

- > Rock has been assumed to be dredged simultaneously by backhoe dredge and land-based excavator. Unconsolidated sediments have been assumed to be dredged by a Cutter Suction Dredge (CSD);
- > Dredging volumes (for modelling purposes) were conservatively estimated based on geotechnical information. Total volume of unconsolidated sediment dredged = 30,000 m³ (conservative – likely less than 20,000 m³) and rock = 70,000 m³;
- > It has been assumed the dredging contractor prevents clumping of dredged soft sediment, and all disposed material is resuspended. This is a conservative approach for predicting the intensity of suspended solids and sedimentation outside of the disposal zone. If the contractor is unable to implement this control, and clumping does occur, sedimentation at the disposal site may be underpredicted by the modelling (while suspended sediment concentrations are overpredicted);
- > Maintenance dredging assessments in the harbour have been modelled assuming accumulated sediment to consist of fines only;
- > Construction times for rock structures have been estimated using schedule estimates of previous tender submissions;
- > During placement, rocks have been assumed to displace seabed sediment equal to 25% of their own volume. This has only been applied to the bottom layer of rock for each rock structure; and
- > It is predicted that if there are some stoppages during the dredging works (due to weather condition, equipment maintenance, etc.), the suspended sediment concentration and deposition thickness will be lessened. So, the scenario adopted in this study (assuming no work stoppages) is conservative.

8.2.1.2 Schedule

The modelling was based on the following schedule:

- > Runtime of each simulation varies by scenario (**Section 8.2.2**), this includes ~2-day model warm up time and ~2-days to allow any remaining fines in the water column time to settle;
- > Working hours vary by dredging/construction method and it has been conservatively assumed that works will occur seven days a week;
- > Construction production rates are based on schedule estimates in tender responses. Dredging production rates have been chosen based upon previous works within Darwin Harbour and examples in literature. **Table 8-1** tabulates adopted production rates; and
- > Partial overlap of dredging of rock and the construction of the main breakwater.

Table 8-1 Production / spill rates

Activity	Production rate	Source	Source spill rate (kg/s)	Disposal spill rate (kg/s)
Dredging of soft sediment (CSD)	200 m ³ /hr	DIPL, 2017	0.3	96.3
Dredging of rock (backhoe and landside excavator)	121.5 m ³ /hr	Bray, Bates & Land, 1996	1.8	N/A
Rock placement				
– Main Breakwater	– 300 m ³ /day	DIPL supplied information	– 0.260	N/A
– Lee breakwater	– 158 m ³ /day		– 0.140	
– Boat ramp	– 3.5 m ³ /day		– 0.003	
– Causeway	– 1.2 m ³ /day		– 0.001	
Disturbance of seabed				
– Main Breakwater	– 79 m ³ /day	DIPL supplied information	– 1.71	N/A
– Lee breakwater	– 104 m ³ /day		– 2.26	
– Boat ramp	– 1.0 m ³ /day		– 0.02	
– Causeway	– 1.2 m ³ /day		– 0.03	
Piling	1 pile/day	DIPL supplied information	0.2	N/A

8.2.1.3 Materials

- > Rock:
 - Fines content in rock: 1% by mass;
 - Spillage of fines from rock at source: 100%; and
 - Rock assumed to be disposed onshore.
- > Unconsolidated sediments:
 - Fines content in sediment: 30% by mass;
 - Spillage of fines from rock at source: 3%; and
 - All unconsolidated sediments assumed to be disposed of offshore.

8.2.1.4 Sediment Transport Parameters

A summary of the sediment transport parameters used for the dredge plume dispersion modelling are as follows. Sediments have been modelled as cohesive with transport parameters established based on typical values presented in literature and Cardno’s extensive experience.

- > Critical Bed Shear Stress for Deposition (Sedimentation): 0.08 N/m² (Whitehouse et. al., 2000)
- > Critical Bed Shear Stress for Erosion: 0.10 N/m² (Whitehouse et. al., 2000)
- > Erosion Parameter: 0.0001 kg/m²/s
- > Fresh Settling Velocity: 0.5 mm/s (INPEX Browse, Ltd., 2011)
- > Specific Density of Sediment Grains: 2650 kg/m³
- > Mean sediment diameter (D₅₀): 0.02 mm
- > Dry Bed Density of Deposited, Weakly to Medium Consolidated Sediment: 250 kg/m³ (1200 kg/m³ for Scenarios 1 & 5, see **Section 8.2.2**) (Van Rijn, 2012b)
- > Reference Density for Hindered Settling: 250 kg/m³ (1200 kg/m³ for Scenarios 1 & 5, see **Section 8.2.2**)

8.2.2 Scenarios

The model was split into several scenarios spanning the entire dredging and construction program for both a typical spring, and neap tide. Due to the long duration of Scenarios 3 and 7, 28 days were modelled out of a total expected construction time of 45 days. Suspended sediment intensity is expected to have stabilised after four weeks of construction with piling works completed in the first week of the model. Sedimentation rates feeding into other parts of the project have been scaled to reflect the full construction program. **Table 8-2** contains the variables altered in each of the eight scenarios modelled.

Table 8-2 Scenario inputs

Scenario	Description	Tidal cycle	Working hours	Model duration (days)	Percentage of program modelled
1	<ul style="list-style-type: none"> • Cutter suction dredge of soft sediments (30,000 m³); and • Offshore disposal (30,000 m³). 	Neap	<ul style="list-style-type: none"> • 8 hrs per day (excluding ~2 hr break for slack tide); and • 7 days a week. 	22	100%
2	<ul style="list-style-type: none"> • Backhoe dredge rock from barge (35,000 m³); • Land based excavation using long reach excavator from beach at low tide (35,000 m³); and • Construction of the main breakwater. 	Neap	<ul style="list-style-type: none"> • 8 hrs per day; and • 7 days a week. 	18	100%
3	<ul style="list-style-type: none"> • Construction of the main breakwater (potential overlap); • Construction of lee breakwater; • Construction of causeway and boat ramp; and • Installation of piles. 	Neap	<ul style="list-style-type: none"> • 8 hrs per day; and • 7 days a week. 	28	62.2%

4	<ul style="list-style-type: none"> • Maintenance dredging; and • Disposal of dredged material. 	Neap	<ul style="list-style-type: none"> • 12 hrs per day. 	4.5	100%
5	<ul style="list-style-type: none"> • Cutter suction dredge of soft sediments (30,000 m³); and • Offshore disposal (30,000 m³). 	Spring	<ul style="list-style-type: none"> • 8 hrs per day (excluding ~2 hr break for slack tide); and • 7 days a week. 	19	100%
6	<ul style="list-style-type: none"> • Backhoe dredge rock from barge (35,000 m³); • Land based excavation using long reach excavator from beach at low tide (35,000 m³); and • Construction of the main breakwater. 	Spring	<ul style="list-style-type: none"> • 8 hrs per day; and • 7 days a week. 	18	100%
7	<ul style="list-style-type: none"> • Construction of the main breakwater (potential overlap); • Construction of lee breakwater; • Construction of causeway and boat ramp; and • Installation of piles. 	Spring	<ul style="list-style-type: none"> • 8 hrs per day; and • 7 days a week. 	28	62.2%
8	<ul style="list-style-type: none"> • Maintenance dredging; and • Disposal of dredged material. 	Spring	<ul style="list-style-type: none"> • 12 hrs per day. 	4.5	100%

8.3 Disposal site

The modelled disposal site is located approximately 1.2 km north east of the dredge site with a depth of 13.5 m (**Figure 8-1**). Current speeds at the site are relatively high, reaching 1.5 m/s in a spring tide ebb flow and ~0.5 m/s in a spring tide flood flow - favourable conditions for the dispersal of sediment through the water column.



● DISPOSAL SITE
(692313, 8625139)

12°26'0"S

12°26'0"S

12°26'30"S

12°26'30"S



- Legend
- Proposed Disposal Site
 - ▭ Breakwater
 - - - Project Footprint

Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community



Darwin, Northern Territory

© Cardno Limited All Rights Reserved.
This document is produced by Cardno Limited solely for the benefit of and use by the client in accordance with the terms of the retainer. Cardno Limited does not and shall not assume any responsibility or liability whatsoever to any third party arising out of any use or reliance by third party on the content of this document.

Date
1/12/2021

Size
A3



PROPOSED DISPOSAL SITE

MANDORAH MARINE FACILITIES
SEDIMENT TRANSPORT REPORT

FIGURE 6-1

8.4 Results

The results of the dredge plume modelling are presented in terms of total suspended solids (TSS) and sediment deposition thickness. Increases in sediment concentrations and turbidity levels arising from the spillage of the dredged sediments from the backhoe / land-based dredge or CSD and construction activities may under certain conditions have adverse effects on marine flora and fauna by reducing light penetration into the water column and by physical disturbance. The risk of adverse impacts was assessed by evaluating concentrations of suspended fine sediments and sediment deposition thickness due to the dredging, disposal and construction activities, and comparing these to environmental guidelines (Stantec, 2023a). Note that the concentrations and sediment deposition thickness presented in this report should be interpreted as above background.

The severity of impact to ecological habitats resulting from increased suspended sediment concentrations and turbidity is highly dependent on the frequency and duration of exposure. By carrying out a probability of exceedance assessment, the spatial extent and concentration of depth averaged suspended sediments (above background) have been presented in terms of percentiles, ranging between the 25th and 95th percentiles.

For the purpose of viewing 'worst-case' suspended sediment concentrations and to ensure appropriate monitoring and mitigations are considered; 95th percentile plots have been presented in **Figure 8-2** to **Figure 8-5** for each scenario. Detailed model outputs for 25th, 50th, 80th and 90th percentiles are documented in **Appendix D**. Sediment deposition thickness for each scenario is presented in **Figure 8-6** to **Figure 8-9**.

Overall, magnitudes of suspended sediment concentrations are shown to be higher during the dredging of soft sediments using a CSD. When dredging soft sediment, TSS concentrations are higher at the disposal site than within the dredge footprint, although this may be overstated, due to the conservative assumption that no clumping of dredged material occurs. High TSS concentrations during backhoe / landside dredging are largely contained within the dredge footprint. This outcome is mainly attributed to the fact that current speeds in those areas are relatively low, so the suspended fine sediment does not disperse, and remains within the project area until the dredging construction works stop for the day.

Sedimentation occurs largely within, or in close proximity to, the dredge footprint due to low current speeds reducing dispersion of the sediment. Scenarios 4 and 8 show a wider sedimentation footprint due to all dredged material assumed to be fines during maintenance dredging, increasing dispersive effects. As no clumping of dredged material has been allowed for in the model, sediment deposition at the disposal site is likely underestimated if the dredging contractor is unable to prevent clumping (i.e., with appropriate water injection and mixing). It is recommended that the contractor includes suitable methods to prevent clumping and to ensure that environmental risk will be managed.

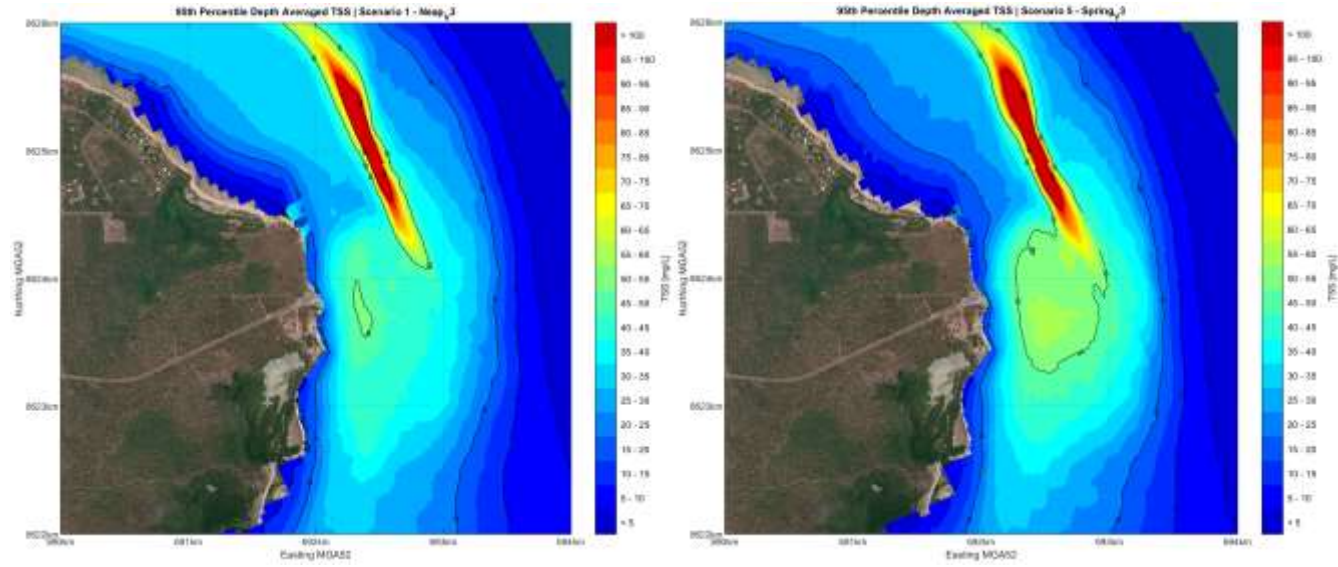


Figure 8-2 95th Percentile TSS depth averaged concentrations for Scenarios 1 (neap) and 5 (spring).

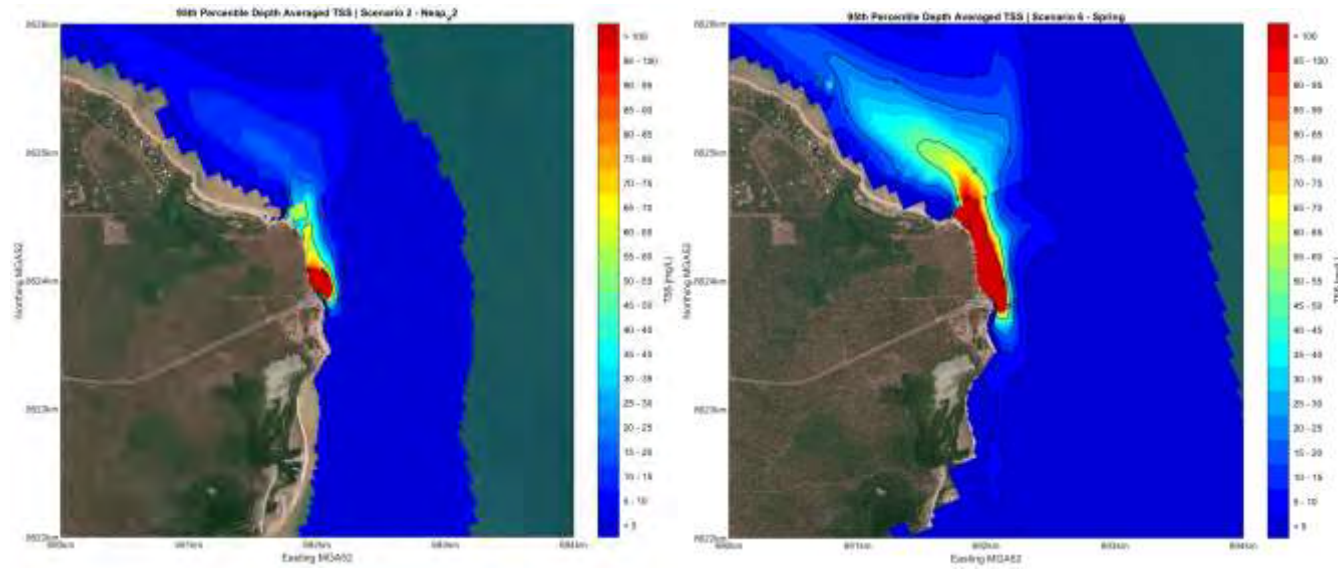


Figure 8-3 95th Percentile TSS depth averaged concentrations for Scenarios 2 (neap) and 6 (spring).

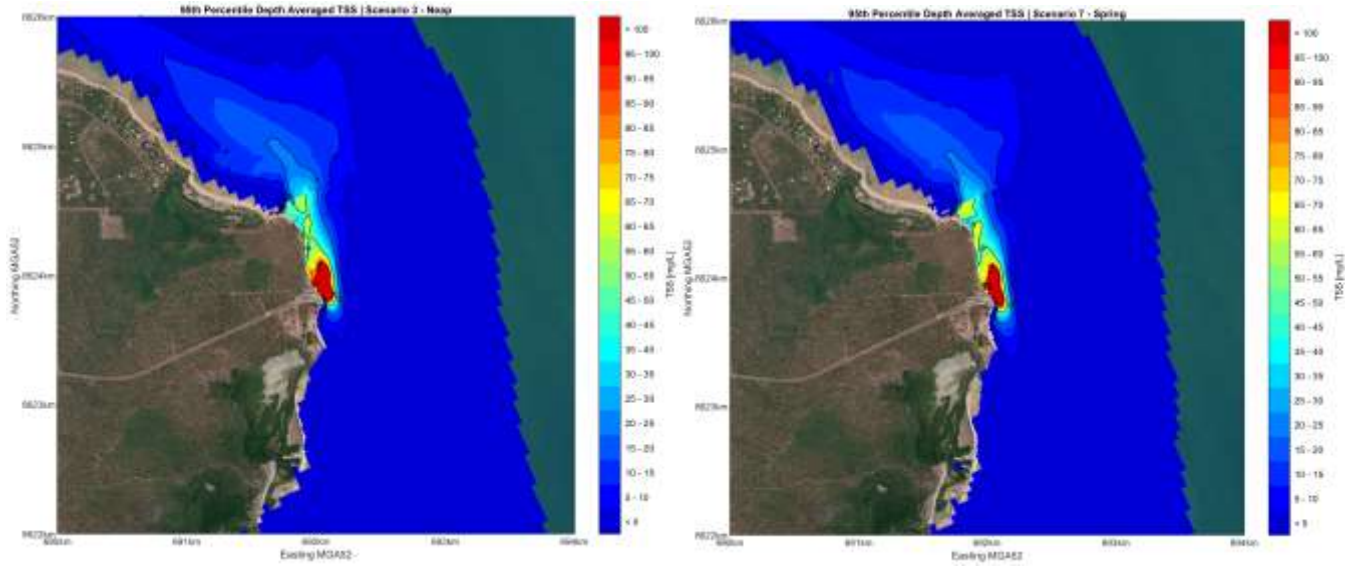


Figure 8-4 95th Percentile TSS depth averaged concentrations for Scenarios 3 (neap) and 7 (spring).

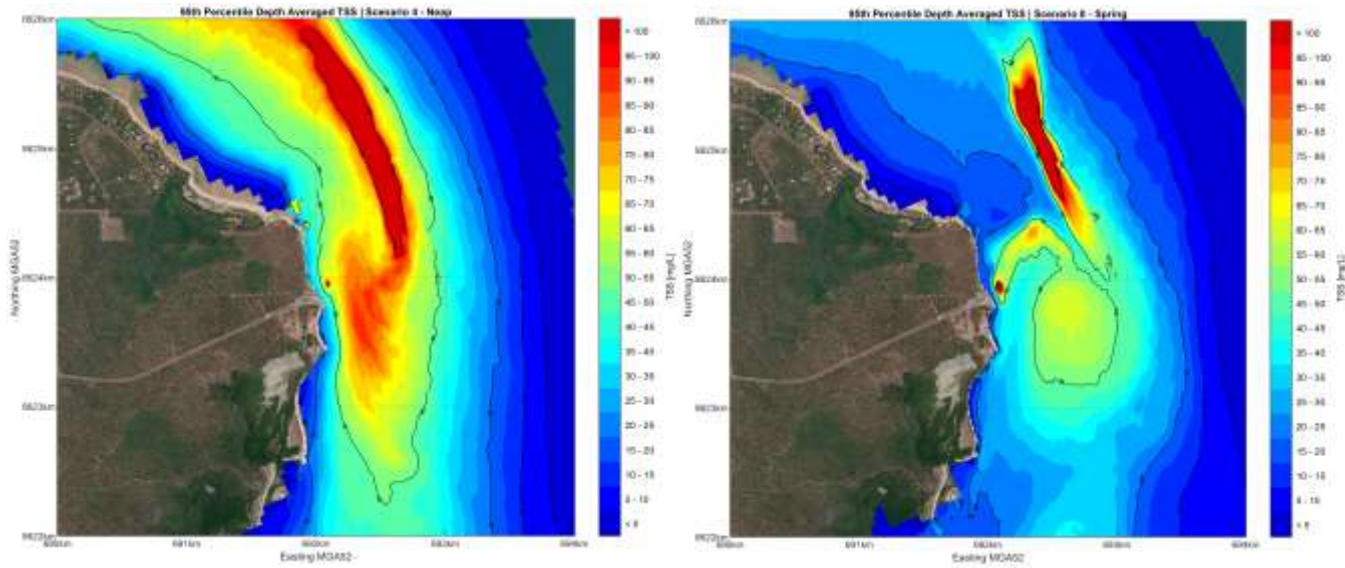


Figure 8-5 95th Percentile TSS depth averaged concentrations for Scenarios 4 (neap) and 8 (spring).

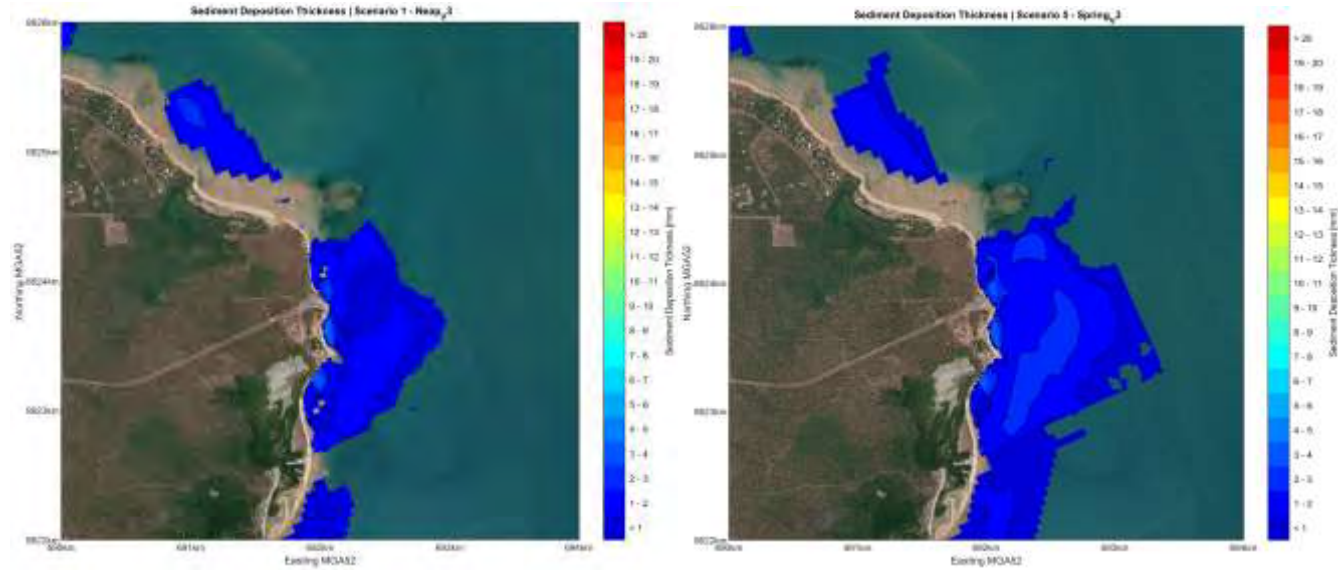


Figure 8-6 Sedimentation deposition thickness mapping Scenarios 1 (neap) and 5 (spring).

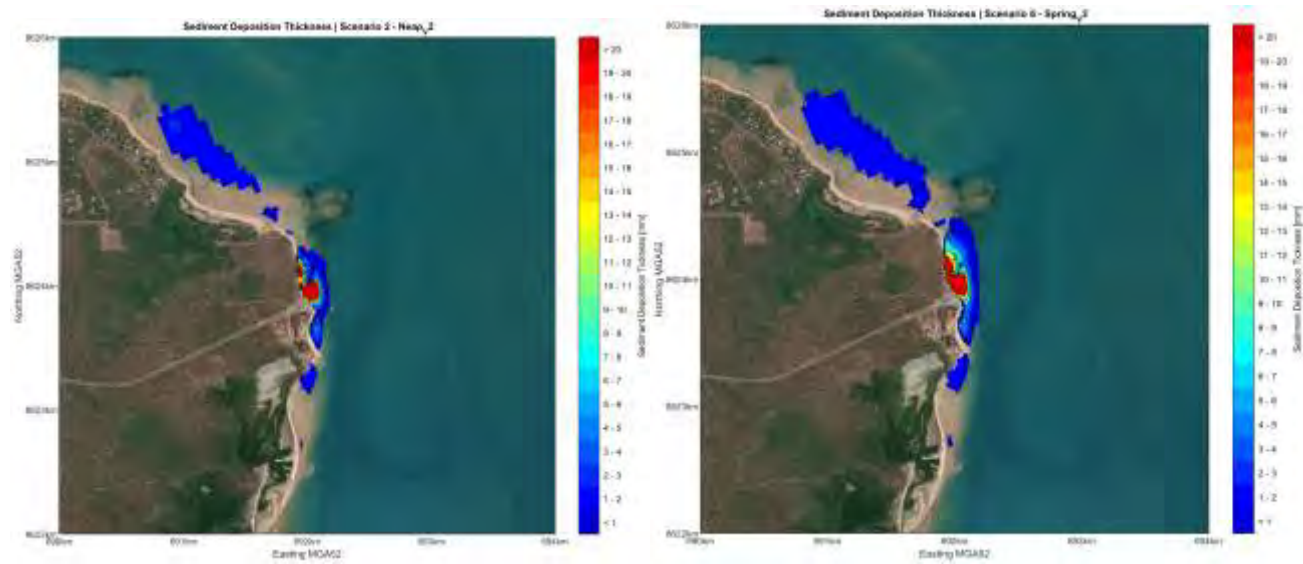


Figure 8-7 Sedimentation deposition thickness mapping Scenarios 2 (neap) and 6 (spring).

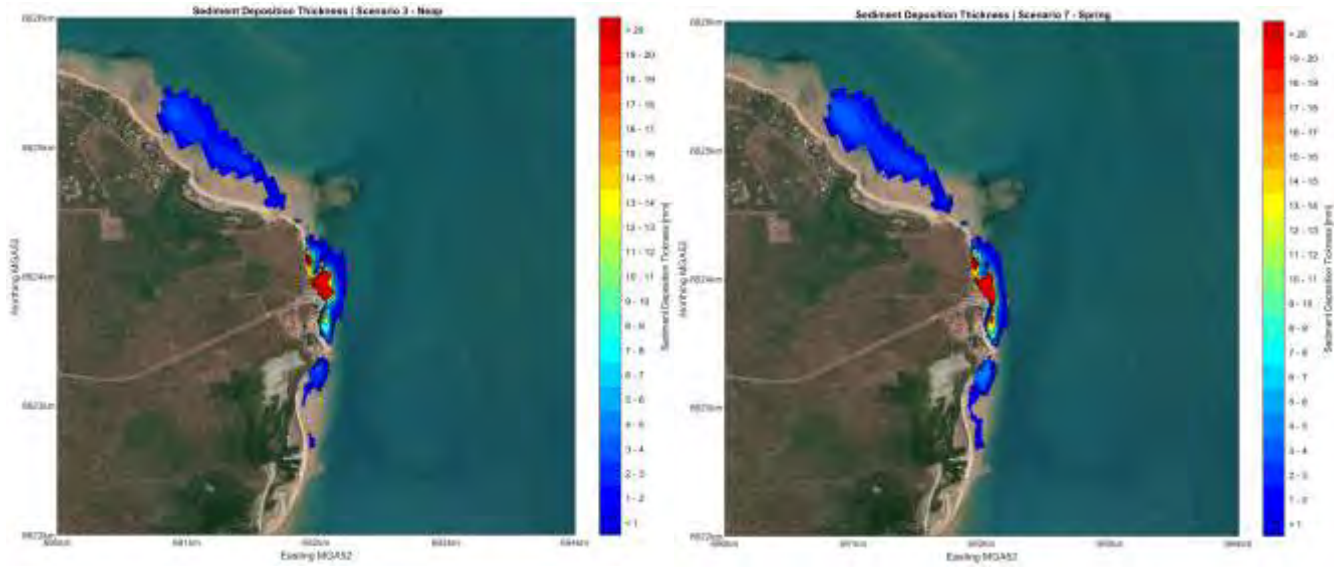


Figure 8-8 Sedimentation deposition thickness mapping Scenarios 3 (neap) and 7 (spring).

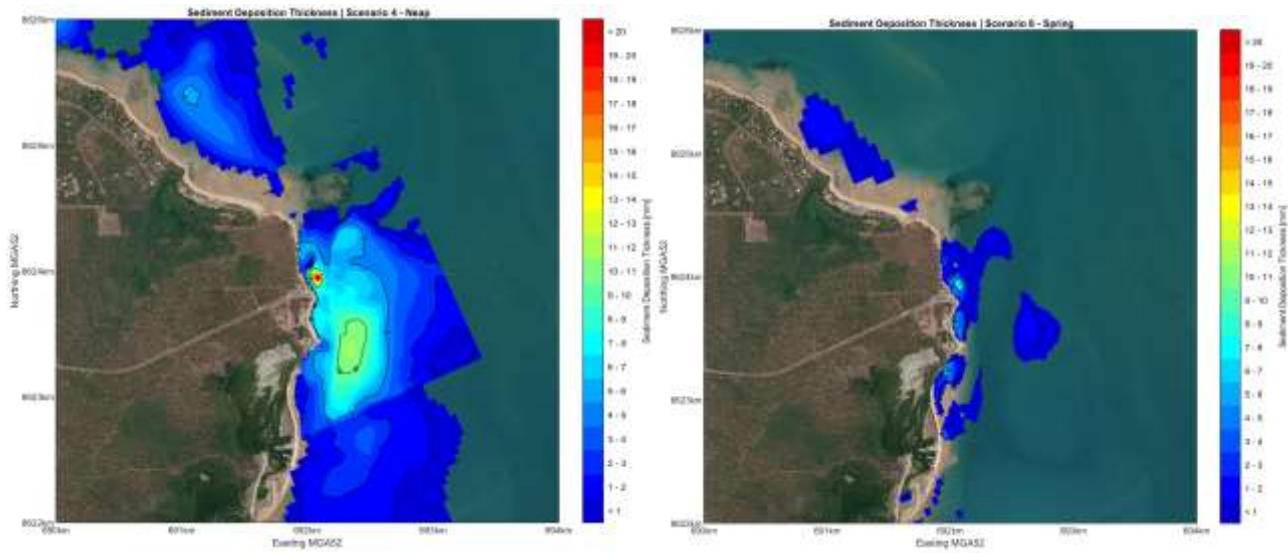


Figure 8-9 Sedimentation deposition thickness mapping Scenarios 4 (neap) and 8 (spring).

9 Conclusions and Project Implications

9.1 Nearshore Sediment Transport and Morphology

Morphological processes at Mandorah are influenced by a large range of combined water level, wind and wave conditions. Sediment resuspension and transport at the site is predominantly governed by northerly tidal currents, which are present during both ebb and flood flows in the nearshore waters adjacent the project site. These currents generally increase in magnitude with water depth, creating areas of strong sediment mobility offshore and areas of low sediment mobility nearshore.

The interaction between the harbour and local current circulations creates a sheltered environment in the lee of the northern breakwater, which is anticipated to result in an accumulation of sediment to the north of the main breakwater head. At times, this material may be expected to be deposited at the entrance of the harbour, which may require maintenance dredging to maintain desired bed levels within the proposed tolerances. Some scour is also expected around the breakwater heads, due to the focusing of passing currents.

9.2 Harbour Siltation

The breakwaters are designed to reduce wave and current conditions for the safe navigation of vessels, leading to an unavoidable decrease in velocities and increase in siltation. To maintain desired bed levels within the proposed tolerances, maintenance dredging will be required at regular temporal intervals. The sedimentation rate calculated provides an estimate of the length of maintenance dredging intervals required to keep bed levels within the siltation allowance of 0.3 m. Modelled sedimentation rates result in a maintenance dredging interval of 1.4 years.

$$\text{Maintenance Interval} = \frac{0.3 \text{ m}}{0.210 \text{ m/yr}} = 1.4 \text{ years}$$

This sedimentation rate is considered to be a conservative estimate due to the following:

- > The sedimentation volume is based on a dry bulk density of 350 kg/m³. This represents freshly deposited mud, and will consolidate over time as more sediment is deposited above it, which will double (or more) in density over time, halving the volume; and
- > The passage into and out of the harbour by the ferry, and to a lesser extent, recreational vessels, will stir up freshly deposited sediment, thereby reducing the amount of sediment retained in the harbour.

Hydrographic survey should be regularly undertaken upon the completion of construction of the marine facilities to quantify sedimentation rates within the basin. As the predicted sedimentation rate is likely conservative, measured sedimentation rates are expected to be lesser, extending the interval required between maintenance dredging campaigns.

It is more likely, due to the above, that maintenance dredging would be required approximately every 5 to 7 years. This is comparable with similar facilities within Darwin Harbour, for example Cullen Bay Ferry Terminal. Recommendations for ongoing survey to monitor harbour siltation are provided in the project's CPMMP (Stantec, 2023c).

9.3 Shoreline Evolution

Potential shoreline evolution once the facility is installed was assessed using metocean conditions from an historical 10-year period (2000–2010). The modelling was undertaken for both existing conditions at the site and proposed conditions with the inclusions of the breakwaters.

A widened beach profile north of the facilities is predicted due to the main breakwater disrupting the net southerly transport of sediment. The accretion to the north of the facilities reduces the sand feed available to the south, resulting in a small area of erosion approximately 350 m south of the lee breakwater. Predicted shoreline change to the south of the facility is also uncertain, due to the presence of rock in the area.

Accretion and erosion volumes have been estimated for each area displayed in **Figure 9-1**. Zones represent the area bounded by the change in shoreline position between existing and proposed conditions model runs. Volumes were derived using topographic data (beach slope) and calculated areas, tabulated in **Table 9-1**. Volumes are expressed as an annual change, averaged over the 10-year modelling period to remove interannual variability.

Table 9-1 Accretion and erosion rates

Zone	Rate [m ³ /yr]
Accretion – North of facilities	1,300 – 1,900
Erosion – South of facilities	200 - 600



Figure 9-1 Areas of potential shoreline change

Given the uncertainty in shoreline evolution modelling and implications for potential environmental impact and ongoing sand management effort, it is recommended that routine monitoring of the shoreline position adjacent the facility be undertaken once it is constructed. Specific details of such monitoring are provided in the project’s *Coastal Processes Monitoring and Management Plan* (Stantec, 2023d).

9.4 Dredge Plume Dispersion

The purpose of modelling the transport and fate of sediment during construction and dredging is primarily to understand associated environmental risk. The results presented in this report have been assessed in terms of environmental risk within the SER (Stantec, 2023a), with specific controls for this risk outlined in the DSDMP (Stantec, 2023b).

10 References

- AECOM, 2018, *Darwin Port Long Term Dredging Management Plan*. Report prepared by AECOM Australia Pty Ltd, Perth, for Darwin Port Operations
- ANZECC / ARMCANZ, 2000a, *Australian and New Zealand Guidelines for Fresh and Marine Water Quality, Volume 1: The Guidelines*. Australian and New Zealand Environment & Conservation Council and Agriculture & Resource Management Council of Australia & New Zealand, October 2000.
- Bray R.N., Bates A.D. & Land J.M , 1996, *Dredging: A Handbook for Engineers* 434 PP. Elsevier Butterworth Heinemann
- Cardno, 2019, *Gap Analysis Report – Design and Document New Marine Facilities to Service Mandorah and Cox Peninsula Communities* (T19-1198_R001_RevA_GA_Draft), prepared for DIPL on 7 October 2019.
- Cardno, 2020a, *Concept Design Options Report – Design and Document New Marine Facilities to Service Mandorah and Cox Peninsula Communities* (T19-1198_R006_RevB_ConceptOptions_Draft), prepared for DIPL on 7 February 2020.
- Cardno, 2020b, *Basis of Design – Design and Document New Marine Facilities to Service Mandorah and Cox Peninsula Communities* (T19-1198_R002_RevB_BoD_Draft), prepared for DIPL on 20 April 2020.
- Cardno, 2020c, *25% (Concept) Design Report – Design and Document New Marine Facilities to Service Mandorah and Cox Peninsula Communities* (T19-1198_R010_RevA_25Design_Draft), prepared for DIPL on 3 August 2020.
- Cardno, 2022a, *Environmental Referral Report: Design and Documentation New Marine Facilities to Service Mandorah and Cox Peninsula*. Prepared for the Department of Infrastructure, Planning and Logistics.
- Cardno, 2022b, *Marine Environment Report: Design and Documentation New Marine Facilities to Service Mandorah and Cox Peninsula*. Prepared for the Department of Infrastructure, Planning and Logistics.
- Cardno, 2022c, *Design Report: Design and Documentation New Marine Facilities to Service Mandorah and Cox Peninsula*. Prepared for the Department of Infrastructure, Planning and Logistics.
- Cardno, 2022d, *Geotechnical Report: Design and Documentation New Marine Facilities to Service Mandorah and Cox Peninsula*. Prepared for the Department of Infrastructure, Planning and Logistics.
- Cardno, 2022e, *Terrestrial Environment Report: Design and Documentation New Marine Facilities to Service Mandorah and Cox Peninsula*. Prepared for the Department of Infrastructure, Planning and Logistics.
- Cardno, 2022f, *SAP Implementation Report: Design and Documentation New Marine Facilities to Service Mandorah and Cox Peninsula*. Prepared for the Department of Infrastructure, Planning and Logistics.
- Cardno, 2023, *Metocean Report: Design and Documentation New Marine Facilities to Service Mandorah and Cox Peninsula*. Prepared for the Department of Infrastructure, Planning and Logistics.
- Commonwealth of Australia, 2009, *National Assessment Guidelines for Dredging*.
- Department of Infrastructure, Planning and Logistics (DIPL) 2017, *Notice of Intent Cullen Bay Ferry Terminal Dredging*. Northern Territory Government, Darwin, Northern Territory.
- Fortune, J., 2006, *The grainsize and heavy metal content of sediment in Darwin Harbour, Report No.: 14/2006D*, Aquatic Health Unit, Environmental Protection Agency, Department of Natural Resources, Environment and the Arts, Darwin, N.T., 74 pp. Available at: http://irm.nt.gov.au/data/assets/pdf_file/0007/16882/fortune_grainsize.pdf.
- Goda, Y., 2000, *Random Seas and Design of Maritime Structures*. 2nd Edition published by World Scientific.
- INPEX Browse, Ltd., 2011, *Ichthys Gas Field Development Project – Supplement to the Draft Environmental Impact Statement*. Report prepared by INPEX Browse, Ltd., Perth, Western Australia, for the

- Commonwealth Government, Canberra, ACT, and the Northern Territory Government, Darwin, Northern Territory.
- INPEX Browse, Ltd., 2011, *Ichthys Gas Field Development Project Draft Environmental Impact Statement*. Report prepared by INPEX Browse, Ltd., Perth, Western Australia, for the Commonwealth Government, Canberra, ACT, and the Northern Territory Government, Darwin, Northern Territory.
- INPEX Browse, Ltd., 2013, *Dredging and Spoil Disposal Management Plan – East Arm*. Report prepared by INPEX Browse, Ltd., Perth, Western Australia, for the Commonwealth Government, Canberra, ACT, and the Northern Territory Government, Darwin, Northern Territory.
- INPEX Browse, Ltd., 2014, *Dredging and Spoil Disposal Management Plan – Gas Export Pipeline*. Report prepared by INPEX Browse, Ltd., Perth, Western Australia, for the Commonwealth Government, Canberra, ACT, and the Northern Territory Government, Darwin, Northern Territory.
- IPCC, 2013, *Climate Change 2013: The Physical Science Basis – Summary for Policymakers, Technical Summary and Frequently Asked Questions*. Working Group 1 Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change
- Jacobs, 2016, *Mandorah Jetty and Boat Ramp - Assessment and Upgrade Concept Study Department of Infrastructure* (IW103400-ESO-RP-0001, T15-1406), prepared for DIPL on 15 September 2016.
- Jacobs, 2019, *Mandorah Jetty and Boat Ramp Engineering Studies, Coastal Modelling and Preliminary Design Report* (IW163900-003-CM-RPT-001, T17-1448), prepared for DIPL on 27 February 2019.
- Lyard, F., Lefevre, F., Letellier, T. & Francis, O., 2006, *Modelling the global ocean tides: modern insights from FES2004*. *Ocean Dynamics* 56, 394–415 (2006). <https://doi.org/10.1007/s10236-006-0086-x>
- Munksgaard NC, Kaestli M, Gibb K, Dostine P, Townsend S (2013). *Darwin Harbour Baseline Sediment Survey 2012*. Report to Aquatic Health Unit (Department of Land Resource Management). Charles Darwin University, Darwin.
- Northern Territory (NT) Environment Protection Authority (EPA), 2013, *Guidelines for the environmental assessment of marine dredging in the Northern Territory*. Northern Territory Environment Protection Authority, Darwin, Northern Territory.
- Northern Territory (NT) Environment Protection Authority (EPA), 2015, *Guideline for the Preparation of a Notice of Intent*, Northern Territory Environment Protection Authority, Darwin, Northern Territory.
- The State of Queensland, 2013, *Coastal hazard technical guide – Determining coastal hazard areas*. Prepared by Environmental Planning, Department of Environment and Heritage Protection. April 2013.
- Stantec, 2023a, *Supplementary Environmental Report: Mandorah Marine Facilities*. Prepared for the Department of Infrastructure, Planning and Logistics.
- Stantec, 2023b, *Dredging and Soil Disposal Management Plan Report: Mandorah Marine Facilities*. Prepared for the Department of Infrastructure, Planning and Logistics.
- Stantec, 2023c, *Construction Environmental Management Plan: Mandorah Marine Facilities*. Prepared for the Department of Infrastructure, Planning and Logistics.
- Stantec, 2023d, *Coastal Processes Monitoring and Management Plan: Mandorah Marine Facilities*. Prepared for the Department of Infrastructure, Planning and Logistics.
- URS Australia Pty Ltd. 2009. *Ichthys Gas Field Development Project: nearshore marine water quality and sediment study*. Report prepared by AUR Australia Pty Ltd, Perth, for INPEX Browse Ltd, Perth, Western Australia.
- URS 2011, *Ichthys Gas Field Development Project: summary of the long-term water-quality and program for Darwin Harbour*. Report prepared for INPEX Browse, Ltd, R1589, March 2011. Technical appendix S9 to INPEX (2011).
- Van Rijn, L., 2012a, *Harbour siltation and control measures*. <https://www.leovanrijn-sediment.com/>

Van Rijn L., 2012b, *Principles of Sedimentation and Erosion Engineering in Rivers, Estuaries and Coastal Seas, Netherlands*: Aqua Publications.

WA EPA, 2016 *Technical Guidance: Environmental Impact Assessment of Marine Dredging Proposals*

APPENDIX

A

FIELD LOGS

APPENDIX

B

SEDIMENT SAMPLING COC

13.04.20

ALS CHAIN OF CUSTODY		ALS Laboratory: please tick →		JACKAY 26 Highway Road Mackay QLD 4740 Ph: 07 4541 0177 E: mackay@als.com.au		NEWCASTLE 208 Gurn Road Warneck NSW 2304 Ph: 02 4989 6432 E: newcastle@als.com.au		SYDNEY 277-289 Woodsons Road Swanfield NSW 2194 Ph: 02 8724 4555 E: sydney@als.com.au											
CLIENT: Cardno (NT) Pty Ltd		TURNAROUND REQUIREMENTS: <input type="checkbox"/> Standard TAT (List due date) ✓		FOR LABORATORY USE ONLY (Circle)		<table border="1"> <tr> <td>Quality Seal Intact?</td> <td>Yes</td> <td>No</td> </tr> <tr> <td>Time for / from test bottles present upon receipt?</td> <td>Yes</td> <td>No</td> </tr> <tr> <td>Refrigeration / Storage Temperature on Arrival?</td> <td>Yes</td> <td>No</td> </tr> <tr> <td>Other comments:</td> <td colspan="2">3.2</td> </tr> </table>		Quality Seal Intact?	Yes	No	Time for / from test bottles present upon receipt?	Yes	No	Refrigeration / Storage Temperature on Arrival?	Yes	No	Other comments:	3.2	
Quality Seal Intact?	Yes	No																	
Time for / from test bottles present upon receipt?	Yes	No																	
Refrigeration / Storage Temperature on Arrival?	Yes	No																	
Other comments:	3.2																		
OFFICE: 93 Mitchell Street, Level 6, Darwin 0800		(Standard TAT may be longer for some tests e.g. Ultra Trace Elements)		COC SEQUENCE NUMBER (Circle)		COC: 1 2 3 4 5 6 7		OF: 1 2 3 4 5 6 7											
PROJECT: Mandorah Marine Facilities		ALS QUOTE NO.: EN02418		COUNTRY OF ORIGIN: AUSTRALIA															
PURCHASE ORDER NUMBER: DZ1810		CONTACT PH: 08 8481 0703		PROJECT MANAGER: Daniel Strickland		SAMPLER: Julian Brown		SAMPLER MOBILE: 0418830919											
RELINQUISHED BY: Julian Brown		RECEIVED BY: Sep M.		DATE/TIME: 01/04/20		DATE/TIME: 01/04/2020 1545		RECEIVED BY: Kim											
COC Emailed to ALS? YES		EDD FORMAT (or default): Exdat		DATE/TIME: Before 16:00 on date of sampling				DATE/TIME: 03.04.20											
Email Reports to: daniel.strickland@cardno.com.au		Email Invoice to: daniel.strickland@cardno.com.au						8Am											
COMMENTS/SPECIAL HANDLING/STORAGE OR DISPOSAL: Samples placed on ice after collection. 1 Jar and green bags frozen upon delivery at laboratory, 1 Jar and pulp bag refrigerated upon delivery at laboratory.																			
ALS USE ONLY		SAMPLE DETAILS MATRIX: Solid(S) Water(W)		CONTAINER INFORMATION		ANALYSIS REQUIRED including SUITES (NB, Suite Codes must be listed to attract suite price) Where Metals are required, specify Total (unfiltered bottle required) or Dissolved (field filtered bottle required).				Additional Information									
LAB ID	SAMPLE ID	DATE / TIME	MATRIX	TYPE & PRESERVATIVE (refer to codes below)	TOTAL Jars / Bags	PSD - All per test parameters on suite EN02418					Comments on likely contamination levels, dilutions, or samples requiring specific OC analysis etc.								
1	MBS7	11/03/2020	S		1	X					PSD by hydrometer as per Daniel. 3.4.2020 DJG								
2	MBS1	11/03/2020	S		1	X													
3	MBS2	11/03/2020	S		1	X													
4	MBS3	11/03/2020	S		1	X													
5	MBS4	11/03/2020	S		1	X													
6	MBS5	11/03/2020	S		1	X													
7	MBS6	11/03/2020	S		1	X													
8	MS1	3/03/2020	S		1	X													
9	MS2	3/03/2020	S		1	X													
10	MS3	3/03/2020	S		1	X													
11	MS4	3/03/2020	S		1	X													
					TOTAL	11	11	0	0										
Water Container Codes: P = Unpreserved Plastic; N = Nitric Preserved Plastic; ORC = Nitric Preserved ORC; SH = Sodium Hydroxide/Cd Preserved; S = Sodium Hydroxide Preserved Plastic; AG = Amber Glass Unpreserved; AP = Airtight Unpreserved Plastic																			
V = VOA Vial HCl Preserved; VS = VOA Vial Sodium Bisulfate Preserved; VS = VOA Vial Sulfuric Preserved; AV = Airtight Unpreserved Vial SG = Sulfuric Preserved Amber Glass; H = HCl preserved Plastic; HS = HCl preserved Spedation bottle; SP = Sulfuric Preserved Plastic; F = Formaldehyde Preserved Glass;																			
Z = Zinc Acetate Preserved Bottle; E = EDTA Preserved Bottle; ST = Sterile Bottle; ASS = Plastic Bag for Acid Sulphate Solts; U = Unpreserved Jar; LU = Lugol's Iodine Preserved Bottle; STT = Sterile Sodium Thiosulfate Preserved Bottle.																			

Environmental Division
Sydney
Work Order Reference
ES2011348



Telephone: 61-2-8794 0555

Subcon / Forward Lab / Split WO
Lab / Analysis: Newcastle
Organised By / Date: PSD 1-11
Relinquished By / Date: _____
Connote / Courier: _____
WO No: ES2011348
Attach By PO / Internal Sheet: _____

LAB OF ORIGIN:
DARWIN

APPENDIX

C

SEDIMENT SAMPLING RESULTS

Certificate of Analysis

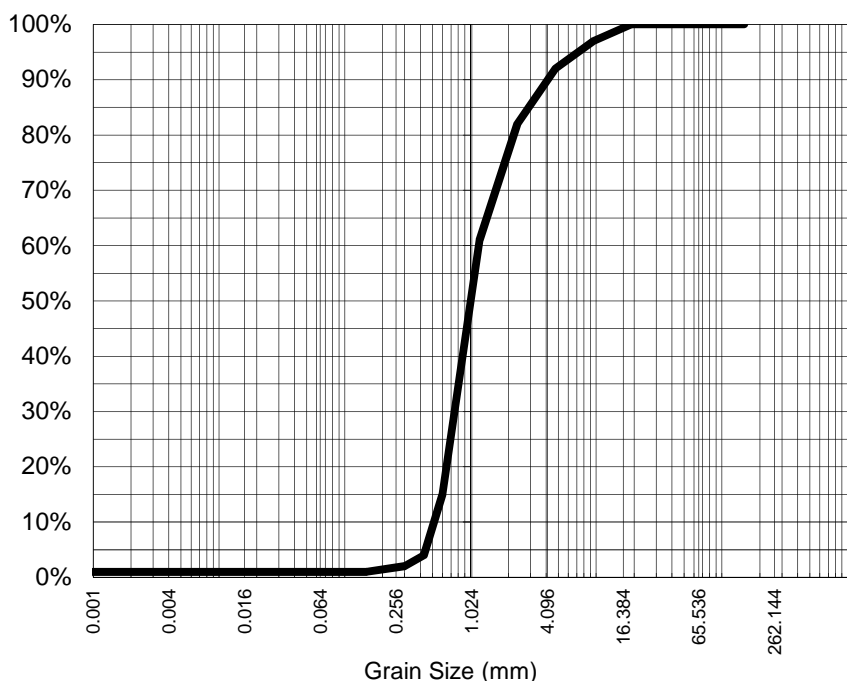
ALS Laboratory Group Pty Ltd
5/585 Maitland Road
Mayfield West, NSW 2304
pH 02 4014 2500
fax 02 4968 0349
samples.newcastle@alsenviro.com

ALS Environmental
Newcastle, NSW



CLIENT: DANIEL STRICKLAND **DATE REPORTED:** 9-Apr-2020
COMPANY: CARDNO (WA) PTY LTD **DATE RECEIVED:** 3-Apr-2020
ADDRESS: 222 Planet Street **REPORT NO:** ES2011348-003 / PSD
 Welshpool
 WA, Australia
PROJECT: Mandorah Marine Facilities **SAMPLE ID:** MBS2

Particle Size Distribution



Particle Size (mm)	% Passing
19.0	100%
9.50	97%
4.75	92%
2.36	82%
1.18	61%
0.600	15%
0.425	4%
0.300	2%
0.150	1%
0.075	1%
Particle Size (microns)	
57	1%
40	1%
28	1%
20	1%
15	1%
10	1%
7	1%
5	1%
1	1%

Median Particle Size (mm)*	1.041
----------------------------	-------

Analysis Notes

Samples analysed as received.

* Soil Particle Density required for Hydrometer analysis according to AS 1289.3.5.1—2006 was unable to be performed as insufficient sample was supplied by the client. Typical sediment SPD values used for calculations and consequently NATA endorsement does not apply to hydrometer. Median Particle Size is not covered under the current scope of ALS's NATA accreditation.

Sample Comments: AS1289.3.6.3 states that hydrometer analysis is not applicable for samples containing <10% fines (<75µm). Results should be assessed accordingly

Loss on Pretreatment NA

Sample Description: Sand, shells

Test Method: AS1289.3.6.2/AS1289.3.6.3

Soil Particle Density (<2.36mm)

NATA Accreditation: 825 Site: Newcastle
This document is issued in accordance with NATA's accreditation requirements. Accredited for compliance with ISO/IEC 17025. This document shall not be reproduced, except in full.

Analysed: 7-Apr-20

Limit of Reporting: 1%

Dispersion Method Shaker



Aleksandar Vujkovic
Laboratory Supervisor
Authorised Signatory

Certificate of Analysis

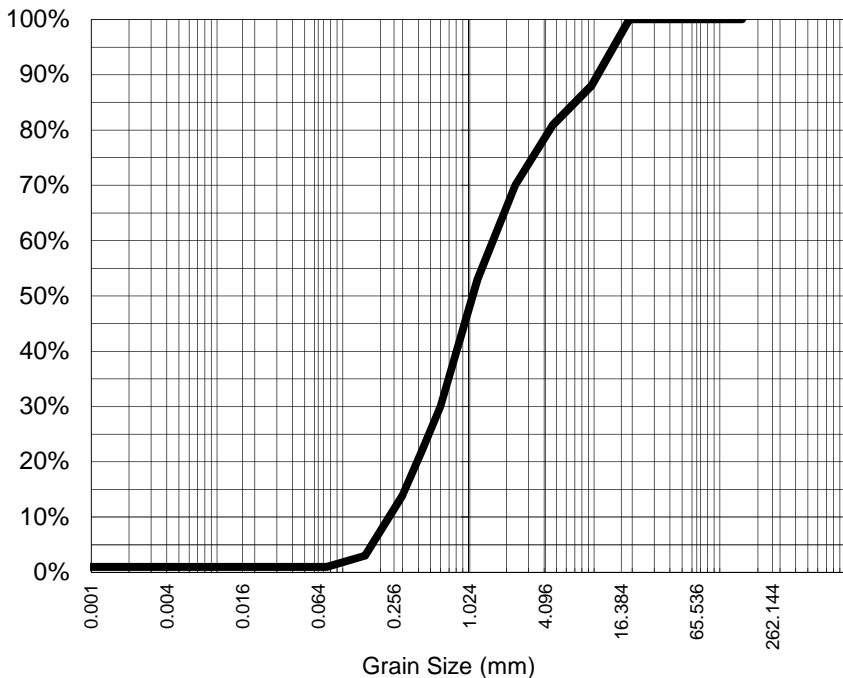
ALS Laboratory Group Pty Ltd
5/585 Maitland Road
Mayfield West, NSW 2304
pH 02 4014 2500
fax 02 4968 0349
samples.newcastle@alsenviro.com

ALS Environmental
Newcastle, NSW



CLIENT: DANIEL STRICKLAND **DATE REPORTED:** 9-Apr-2020
COMPANY: CARDNO (WA) PTY LTD **DATE RECEIVED:** 3-Apr-2020
ADDRESS: 222 Planet Street **REPORT NO:** ES2011348-004 / PSD
 Welshpool
 WA, Australia
PROJECT: Mandorah Marine Facilities **SAMPLE ID:** MBS3

Particle Size Distribution



Particle Size (mm)	% Passing
19.0	100%
9.50	88%
4.75	81%
2.36	70%
1.18	53%
0.600	30%
0.425	22%
0.300	14%
0.150	3%
0.075	1%
Particle Size (microns)	
57	1%
40	1%
28	1%
20	1%
15	1%
10	1%
7	1%
5	1%
1	1%

Median Particle Size (mm)*	1.104
----------------------------	-------

Analysis Notes

Samples analysed as received.

* Soil Particle Density required for Hydrometer analysis according to AS 1289.3.5.1—2006 was unable to be performed as insufficient sample was supplied by the client. Typical sediment SPD values used for calculations and consequently, NATA endorsement does not apply to hydrometer. Median Particle Size is not covered under the current scope of ALS's NATA accreditation.

Sample Comments: AS1289.3.6.3 states that hydrometer analysis is not applicable for samples containing <10% fines (<75µm). Results should be assessed accordingly

Loss on Pretreatment NA

Sample Description: Sand, shells

Test Method: AS1289.3.6.2/AS1289.3.6.3

Soil Particle Density (<2.36mm)

NATA Accreditation: 825 Site: Newcastle
 This document is issued in accordance with NATA's accreditation requirements. Accredited for compliance with ISO/IEC 17025. This document shall not be reproduced, except in full.



Analysed: 7-Apr-20

Limit of Reporting: 1%

Dispersion Method Shaker

Aleksandar Vujkovic
 Laboratory Supervisor
Authorised Signatory

Certificate of Analysis

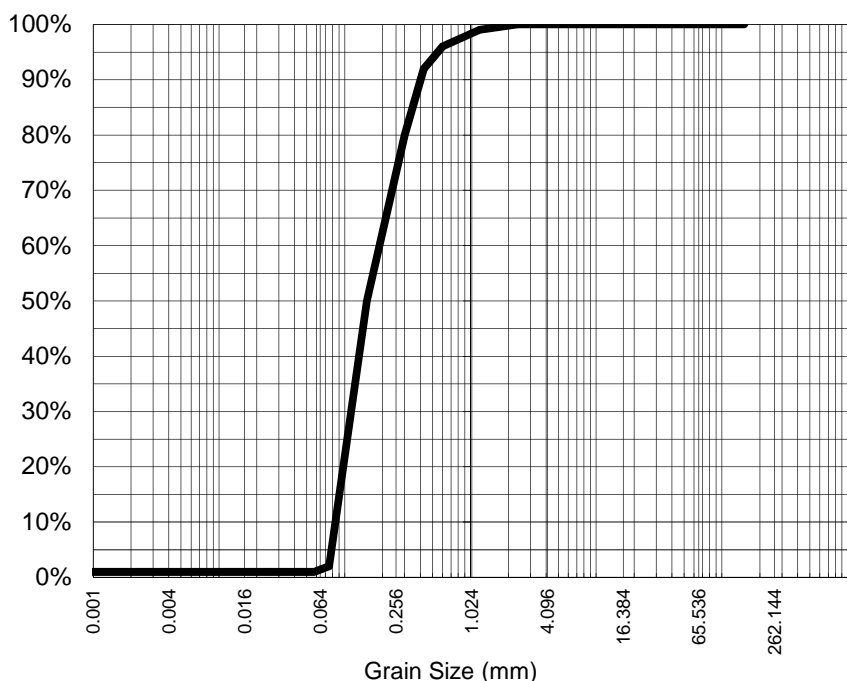
ALS Laboratory Group Pty Ltd
5/585 Maitland Road
Mayfield West, NSW 2304
pH 02 4014 2500
fax 02 4968 0349
samples.newcastle@alsenviro.com

ALS Environmental
Newcastle, NSW



CLIENT: DANIEL STRICKLAND **DATE REPORTED:** 9-Apr-2020
COMPANY: CARDNO (WA) PTY LTD **DATE RECEIVED:** 3-Apr-2020
ADDRESS: 222 Planet Street **REPORT NO:** ES2011348-008 / PSD
 Welshpool
 WA, Australia
PROJECT: Mandorah Marine Facilities **SAMPLE ID:** MS1

Particle Size Distribution



Particle Size (mm)	% Passing
2.36	100%
1.18	99%
0.600	96%
0.425	92%
0.300	80%
0.150	50%
0.075	2%
Particle Size (microns)	
57	1%
40	1%
28	1%
20	1%
15	1%
10	1%
7	1%
5	1%
1	1%

Median Particle Size (mm)*	0.150
----------------------------	-------

Analysis Notes

Samples analysed as received.

* Soil Particle Density required for Hydrometer analysis according to AS 1289.3.5.1—2006 was unable to be performed as insufficient sample was supplied by the client. Typical sediment SPD values used for calculations and consequently NATA endorsement does not apply to hydrometer. Median Particle Size is not covered under the current scope of ALS's NATA accreditation.

Sample Comments: AS1289.3.6.3 states that hydrometer analysis is not applicable for samples containing <10% fines (<75µm). Results should be assessed accordingly

Loss on Pretreatment NA

Sample Description: Sand

Test Method: AS1289.3.6.2/AS1289.3.6.3

Soil Particle Density (<2.36mm)

NATA Accreditation: 825 Site: Newcastle
 This document is issued in accordance with NATA's accreditation requirements. Accredited for compliance with ISO/IEC 17025. This document shall not be reproduced, except in full.

Analysed: 7-Apr-20

Limit of Reporting: 1%

Dispersion Method Shaker



Aleksandar Vujkovic
 Laboratory Supervisor
Authorised Signatory

Certificate of Analysis

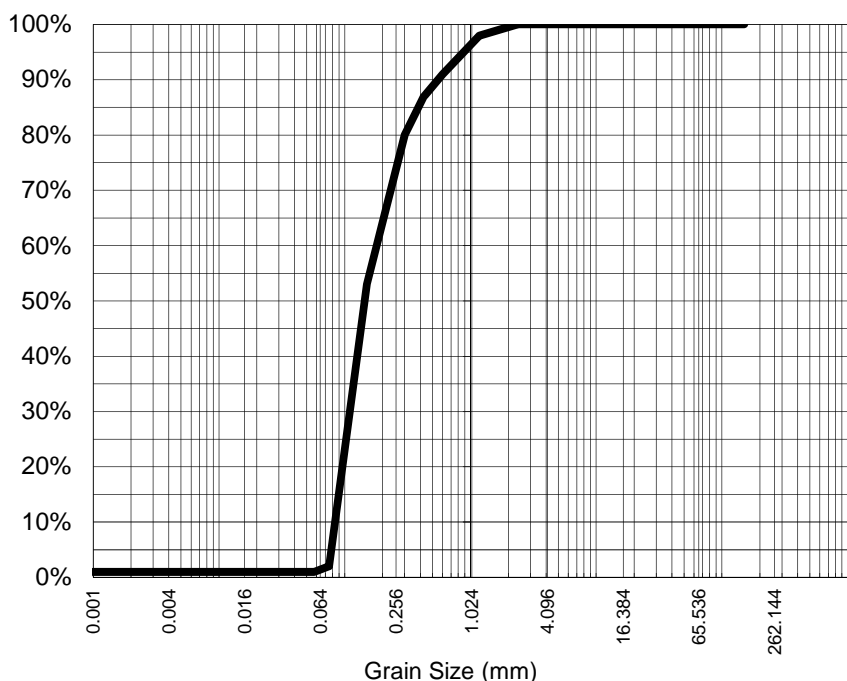
ALS Laboratory Group Pty Ltd
5/585 Maitland Road
Mayfield West, NSW 2304
pH 02 4014 2500
fax 02 4968 0349
samples.newcastle@alsenviro.com

ALS Environmental
Newcastle, NSW



CLIENT: DANIEL STRICKLAND **DATE REPORTED:** 9-Apr-2020
COMPANY: CARDNO (WA) PTY LTD **DATE RECEIVED:** 3-Apr-2020
ADDRESS: 222 Planet Street **REPORT NO:** ES2011348-009 / PSD
 Welshpool
 WA, Australia
PROJECT: Mandorah Marine Facilities **SAMPLE ID:** MS2

Particle Size Distribution



Particle Size (mm)	% Passing
2.36	100%
1.18	98%
0.600	91%
0.425	87%
0.300	80%
0.150	53%
0.075	2%
Particle Size (microns)	
57	1%
40	1%
28	1%
20	1%
15	1%
10	1%
7	1%
5	1%
1	1%

Median Particle Size (mm)*	0.146
----------------------------	-------

Analysis Notes

Samples analysed as received.

* Soil Particle Density required for Hydrometer analysis according to AS 1289.3.5.1—2006 was unable to be performed as insufficient sample was supplied by the client. Typical sediment SPD values used for calculations and consequently NATA endorsement does not apply to hydrometer. Median Particle Size is not covered under the current scope of ALS's NATA accreditation.

Sample Comments: AS1289.3.6.3 states that hydrometer analysis is not applicable for samples containing <10% fines (<75µm). Results should be assessed accordingly

Loss on Pretreatment NA

Sample Description: Sand

Test Method: AS1289.3.6.2/AS1289.3.6.3

Soil Particle Density (<2.36mm)

NATA Accreditation: 825 Site: Newcastle
 This document is issued in accordance with NATA's accreditation requirements. Accredited for compliance with ISO/IEC 17025. This document shall not be reproduced, except in full.

Analysed: 7-Apr-20

Limit of Reporting: 1%

Dispersion Method Shaker



Aleksandar Vujkovic
 Laboratory Supervisor
Authorised Signatory

Certificate of Analysis

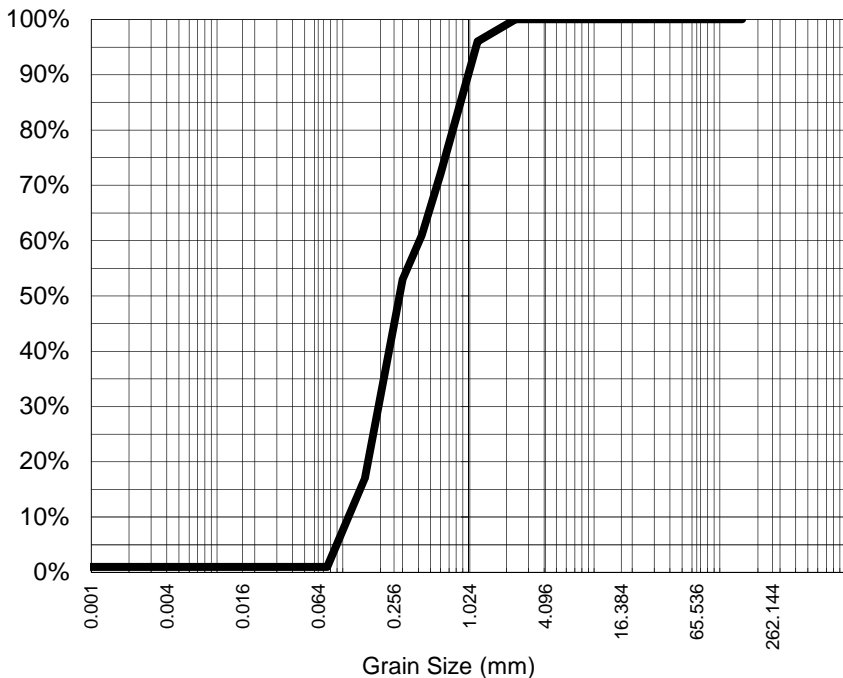
ALS Laboratory Group Pty Ltd
 5/585 Maitland Road
 Mayfield West, NSW 2304
 pH 02 4014 2500
 fax 02 4968 0349
 samples.newcastle@alsenviro.com

ALS Environmental
 Newcastle, NSW



CLIENT: DANIEL STRICKLAND **DATE REPORTED:** 9-Apr-2020
COMPANY: CARDNO (WA) PTY LTD **DATE RECEIVED:** 3-Apr-2020
ADDRESS: 222 Planet Street **REPORT NO:** ES2011348-010 / PSD
 Welshpool
 WA, Australia
PROJECT: Mandorah Marine Facilities **SAMPLE ID:** MS3

Particle Size Distribution



Particle Size (mm)	% Passing
2.36	100%
1.18	96%
0.600	72%
0.425	61%
0.300	53%
0.150	17%
0.075	1%
Particle Size (microns)	
57	1%
40	1%
28	1%
20	1%
15	1%
10	1%
7	1%
5	1%
1	1%

Median Particle Size (mm)*	0.288
----------------------------	-------

Analysis Notes

Samples analysed as received.

* Soil Particle Density required for Hydrometer analysis according to AS 1289.3.5.1—2006 was unable to be performed as insufficient sample was supplied by the client. Typical sediment SPD values used for calculations and consequently NATA endorsement does not apply to hydrometer. Median Particle Size is not covered under the current scope of ALS's NATA accreditation.

Sample Comments: AS1289.3.6.3 states that hydrometer analysis is not applicable for samples containing <10% fines (<75µm). Results should be assessed accordingly

Loss on Pretreatment NA

Sample Description: Sand

Test Method: AS1289.3.6.2/AS1289.3.6.3

Soil Particle Density (<2.36mm)

NATA Accreditation: 825 Site: Newcastle
 This document is issued in accordance with NATA's accreditation requirements. Accredited for compliance with ISO/IEC 17025. This document shall not be reproduced, except in full.

Analysed: 7-Apr-20

Limit of Reporting: 1%

Dispersion Method Shaker



Aleksandar Vujkovic
 Laboratory Supervisor
Authorised Signatory

Certificate of Analysis

ALS Laboratory Group Pty Ltd
5/585 Maitland Road
Mayfield West, NSW 2304
pH 02 4014 2500
fax 02 4968 0349
samples.newcastle@alsenviro.com

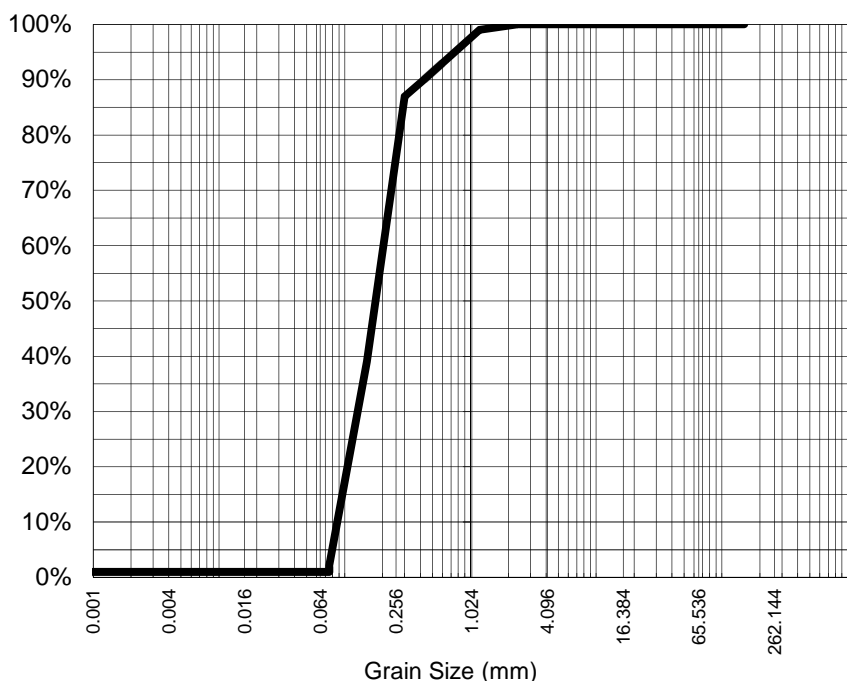
ALS Environmental

Newcastle, NSW



CLIENT: DANIEL STRICKLAND **DATE REPORTED:** 9-Apr-2020
COMPANY: CARDNO (WA) PTY LTD **DATE RECEIVED:** 3-Apr-2020
ADDRESS: 222 Planet Street **REPORT NO:** ES2011348-011 / PSD
Welshpool
WA, Australia
PROJECT: Mandorah Marine Facilities **SAMPLE ID:** MS4

Particle Size Distribution



Particle Size (mm)	% Passing
2.36	100%
1.18	99%
0.600	93%
0.425	90%
0.300	87%
0.150	39%
0.075	2%
Particle Size (microns)	
57	1%
40	1%
28	1%
20	1%
15	1%
10	1%
7	1%
5	1%
1	1%

Median Particle Size (mm)*	0.184
----------------------------	-------

Analysis Notes

Samples analysed as received.

* Soil Particle Density required for Hydrometer analysis according to AS 1289.3.5.1—2006 was unable to be performed as insufficient sample was supplied by the client. Typical sediment SPD values used for calculations and consequently NATA endorsement does not apply to hydrometer. Median Particle Size is not covered under the current scope of ALS's NATA accreditation.

Sample Comments: AS1289.3.6.3 states that hydrometer analysis is not applicable for samples containing <10% fines (<75µm). Results should be assessed accordingly

Loss on Pretreatment NA

Sample Description: Sand

Test Method: AS1289.3.6.2/AS1289.3.6.3

Soil Particle Density (<2.36mm)

NATA Accreditation: 825 Site: Newcastle
This document is issued in accordance with NATA's accreditation requirements. Accredited for compliance with ISO/IEC 17025. This document shall not be reproduced, except in full.

Analysed: 7-Apr-20

Limit of Reporting: 1%

Dispersion Method Shaker



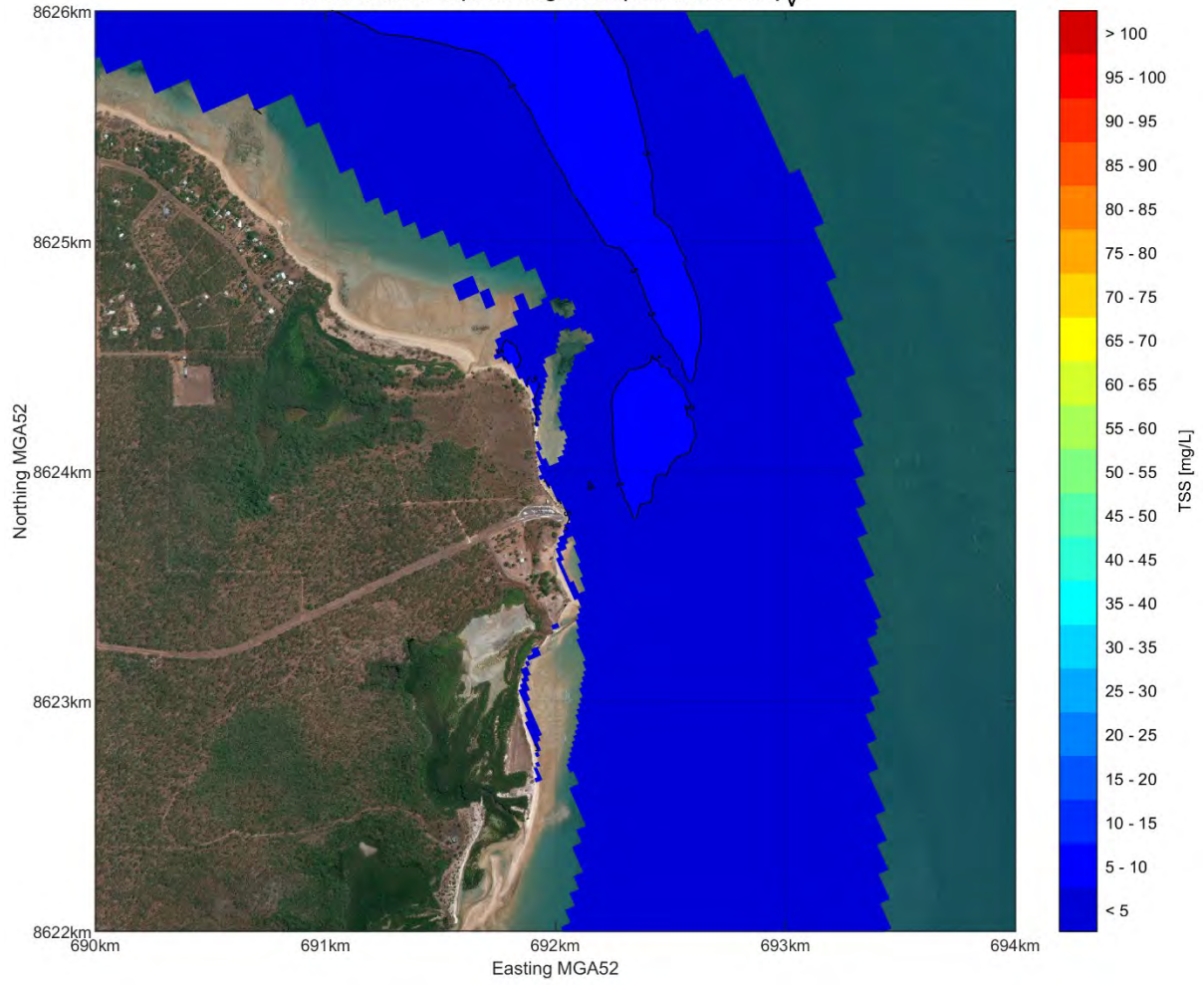
Aleksandar Vujkovic
Laboratory Supervisor
Authorised Signatory

APPENDIX

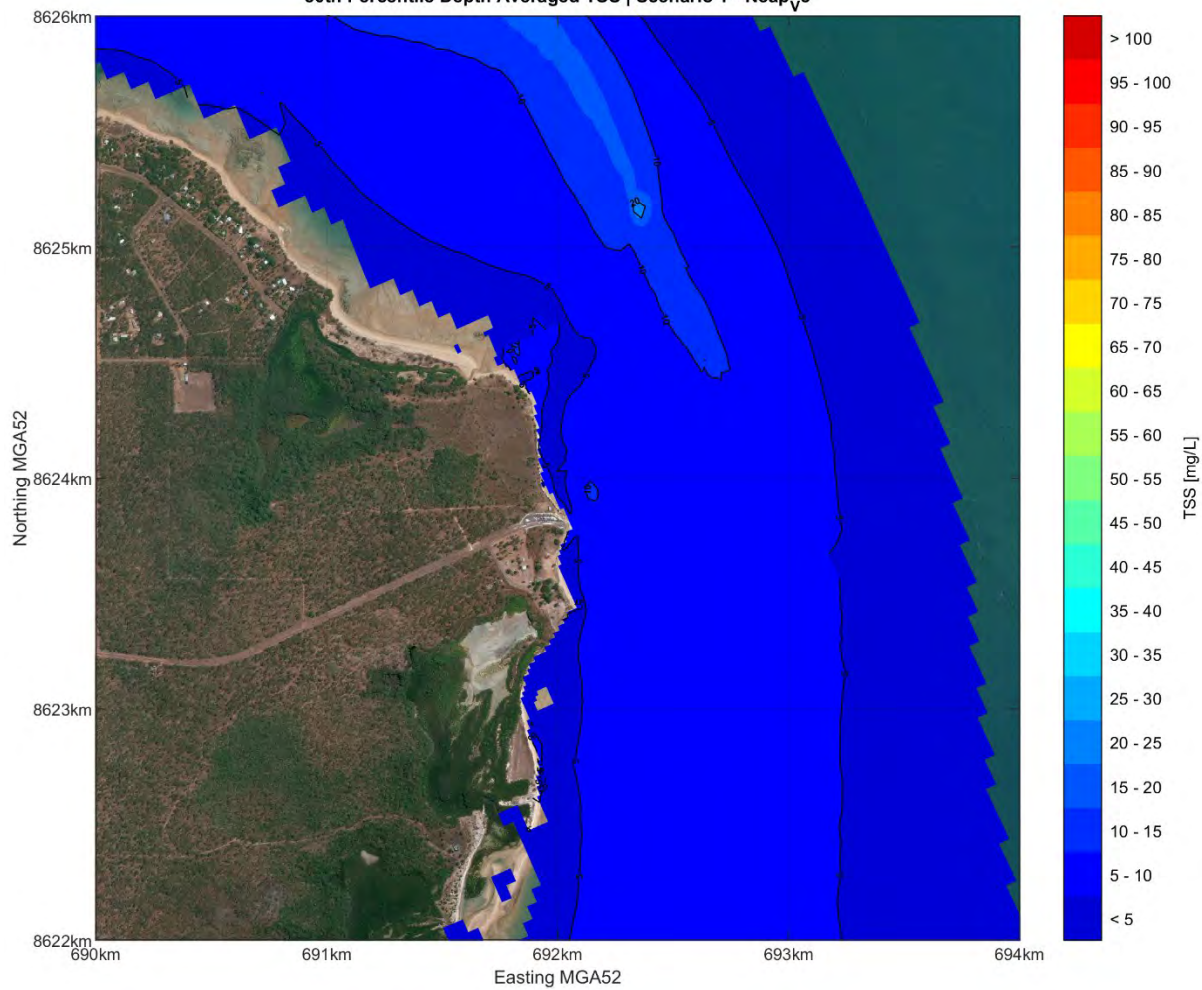
D

DREDGE PLUME DISPERSION
MODELLING RESULTS

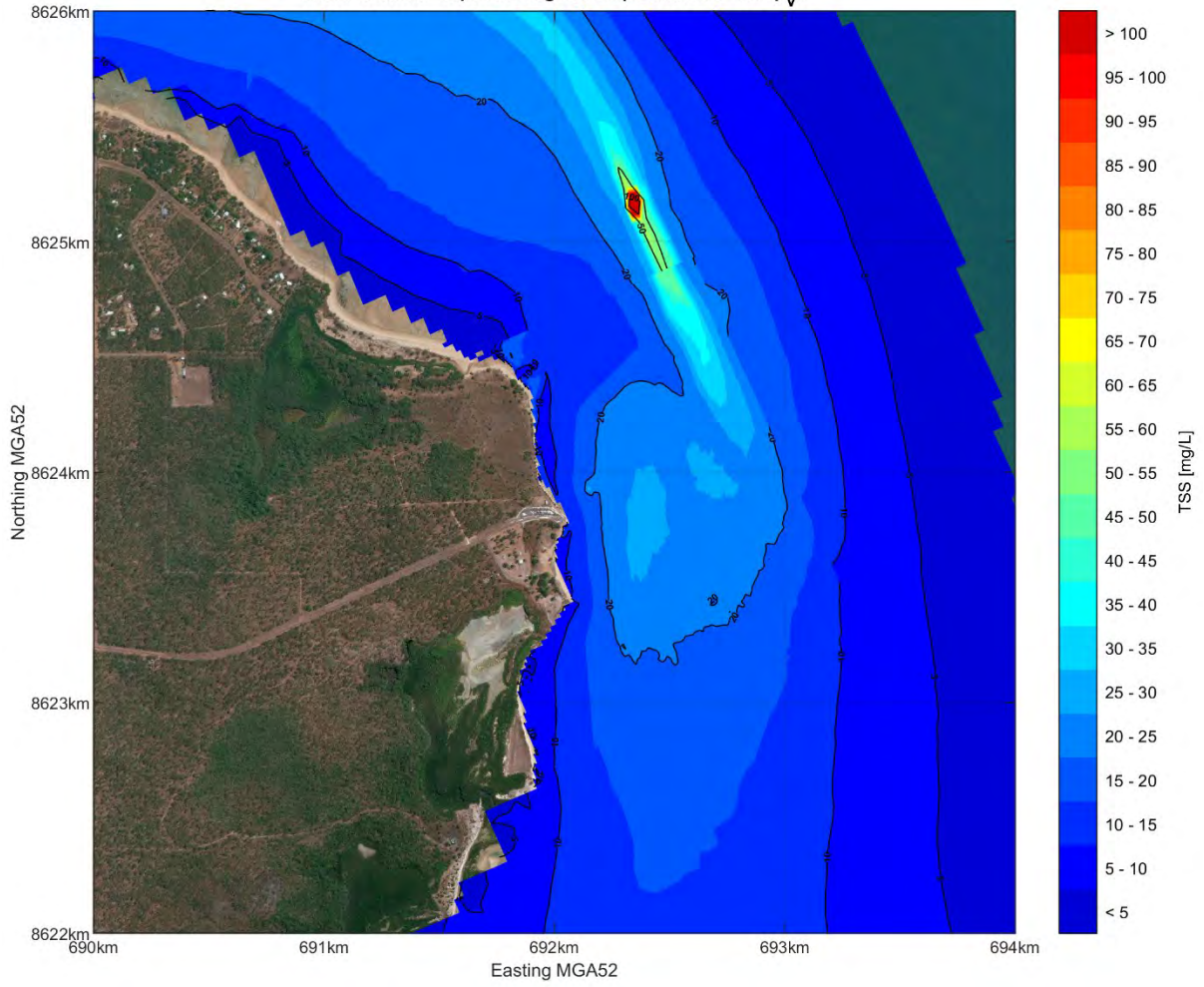
25th Percentile Depth Averaged TSS | Scenario 1 - Neap_v3



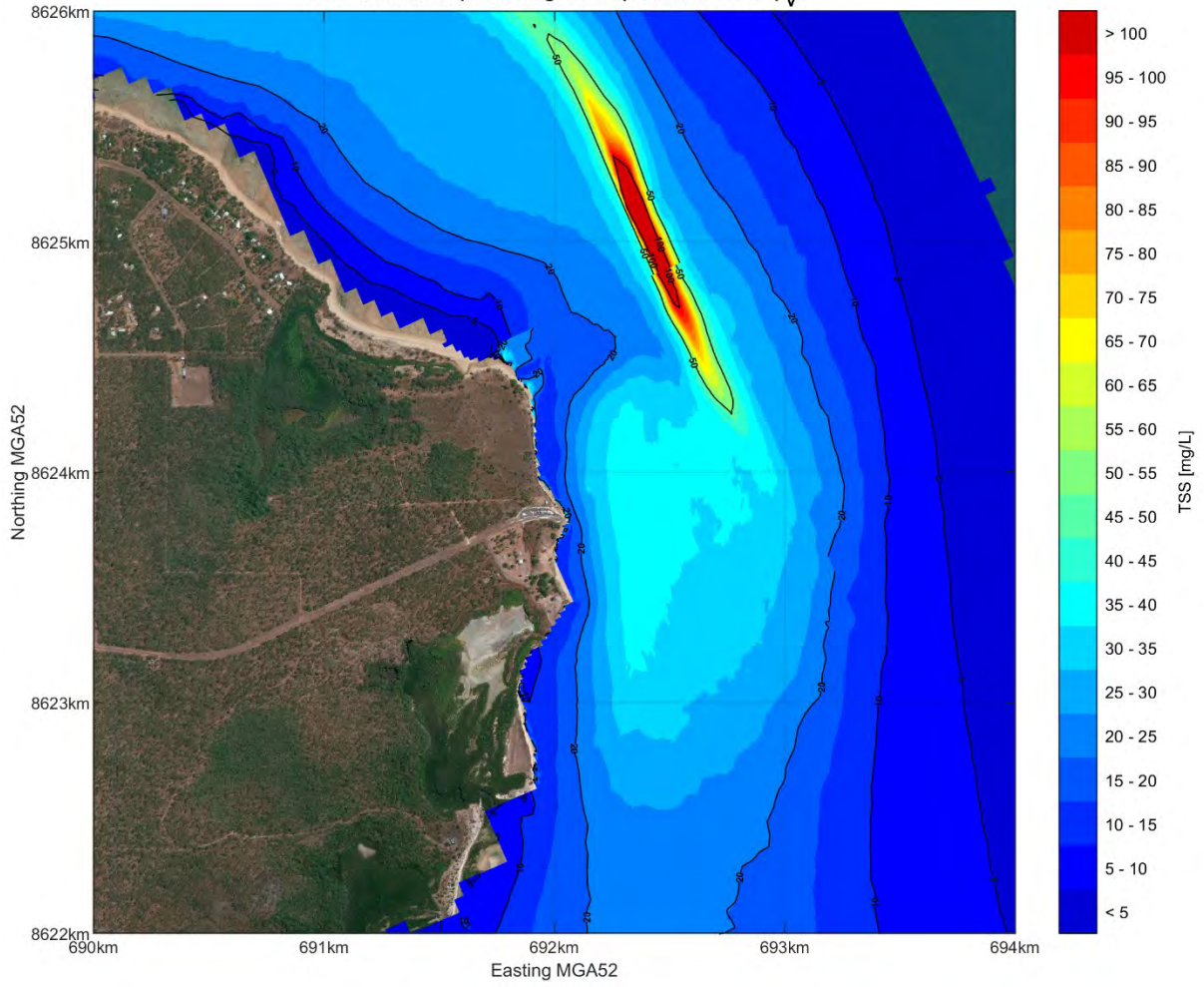
50th Percentile Depth Averaged TSS | Scenario 1 - Neap_v3



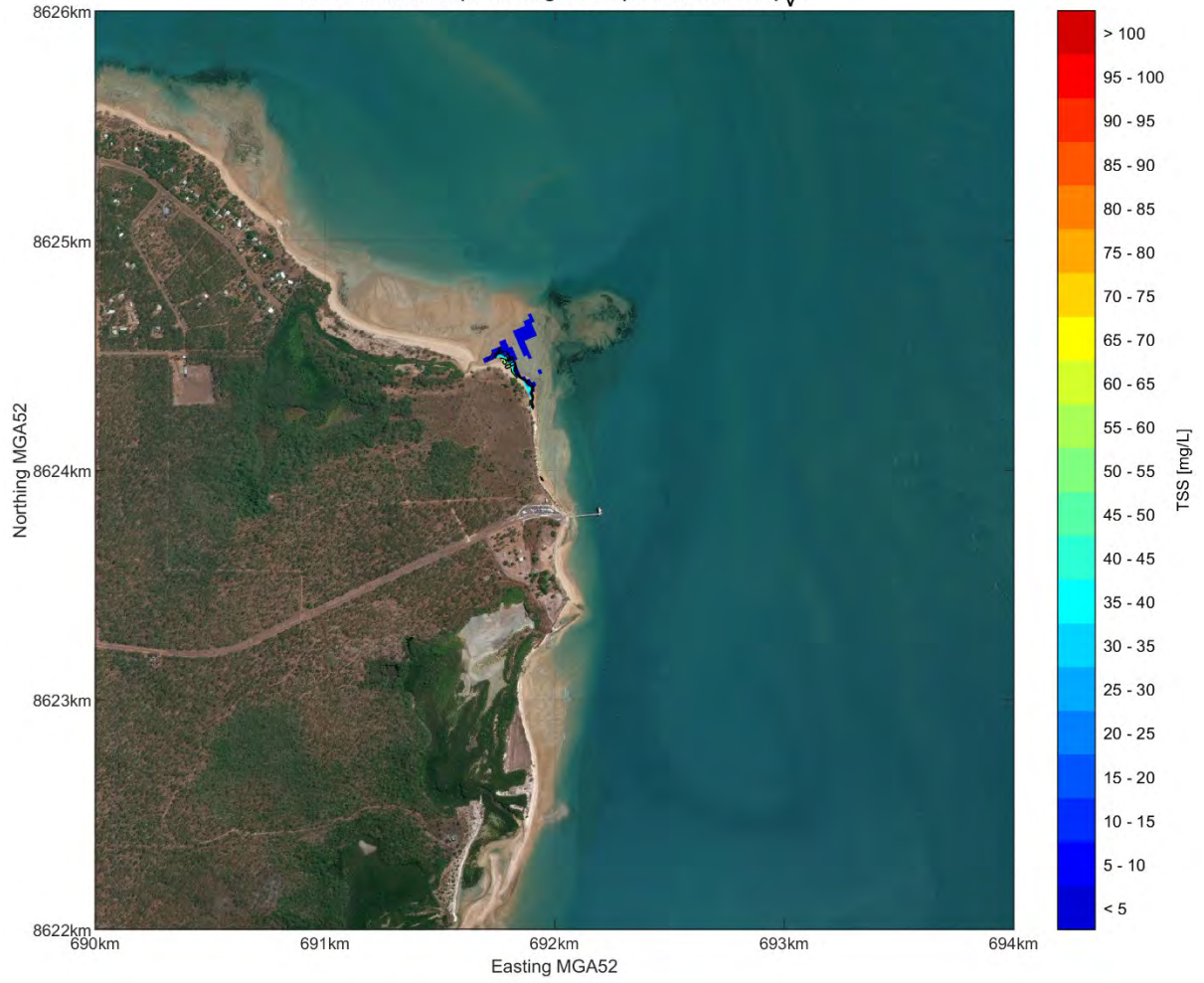
80th Percentile Depth Averaged TSS | Scenario 1 - Neap_v3



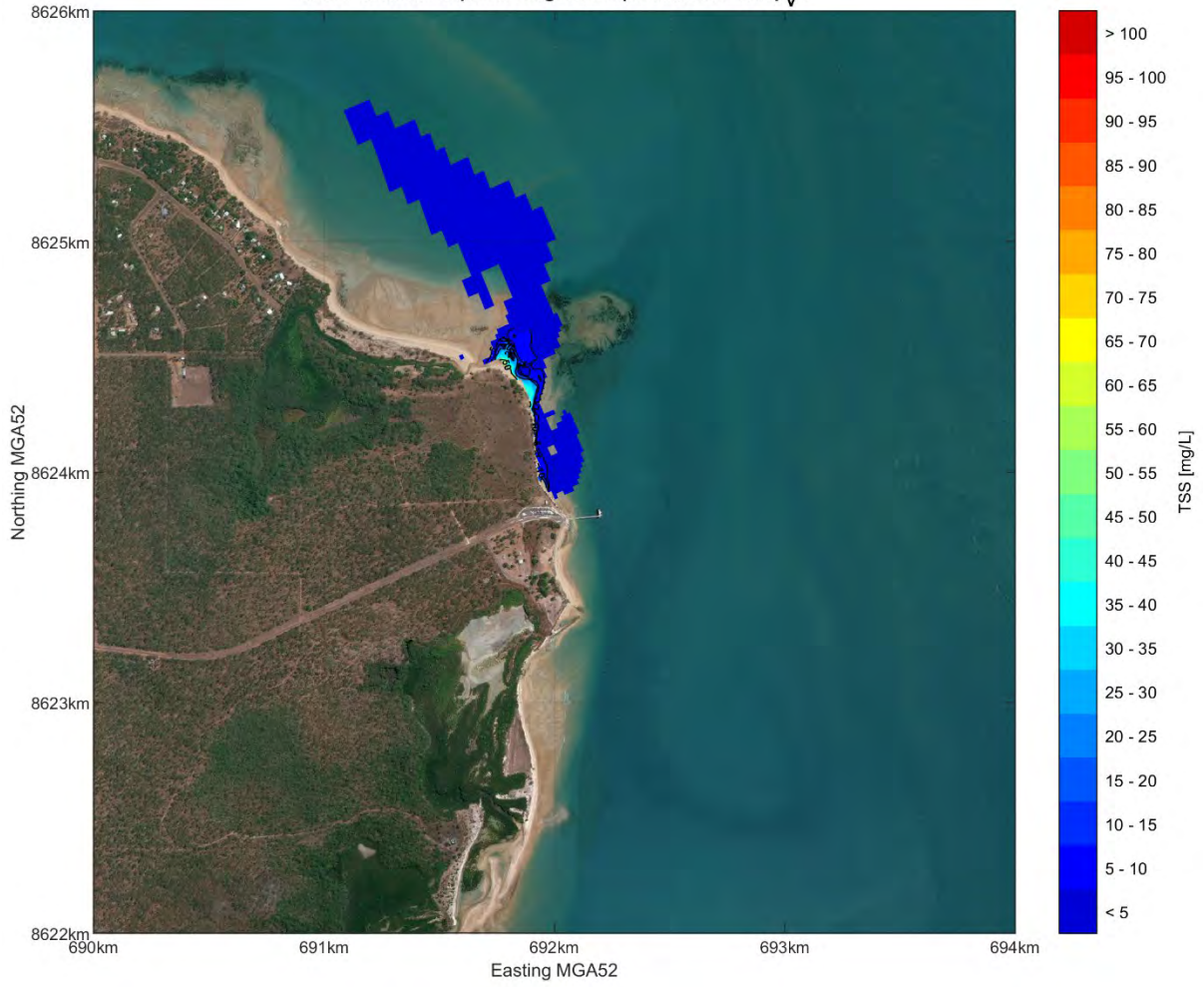
90th Percentile Depth Averaged TSS | Scenario 1 - Neap_v3



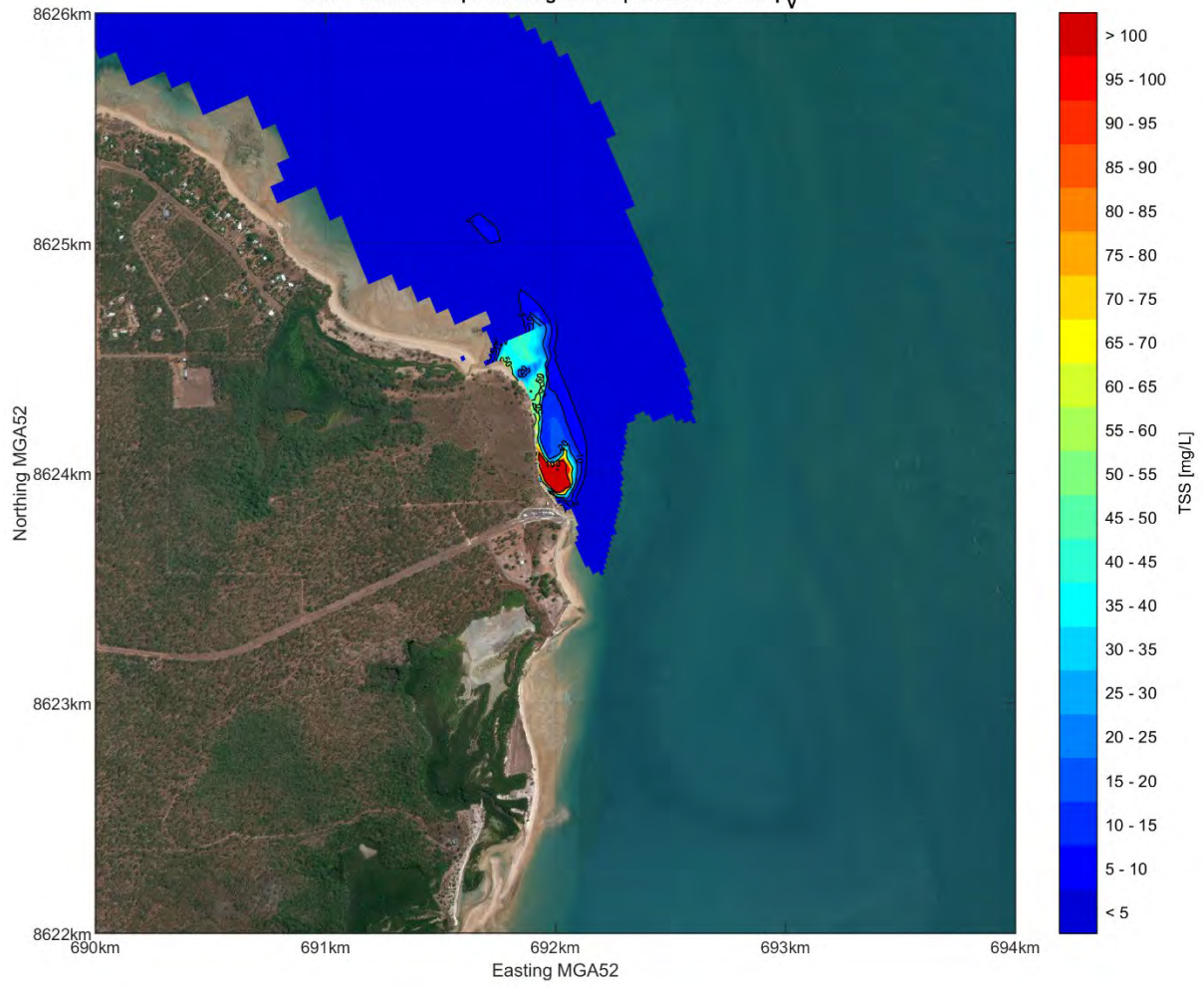
25th Percentile Depth Averaged TSS | Scenario 2 - Neap_v2



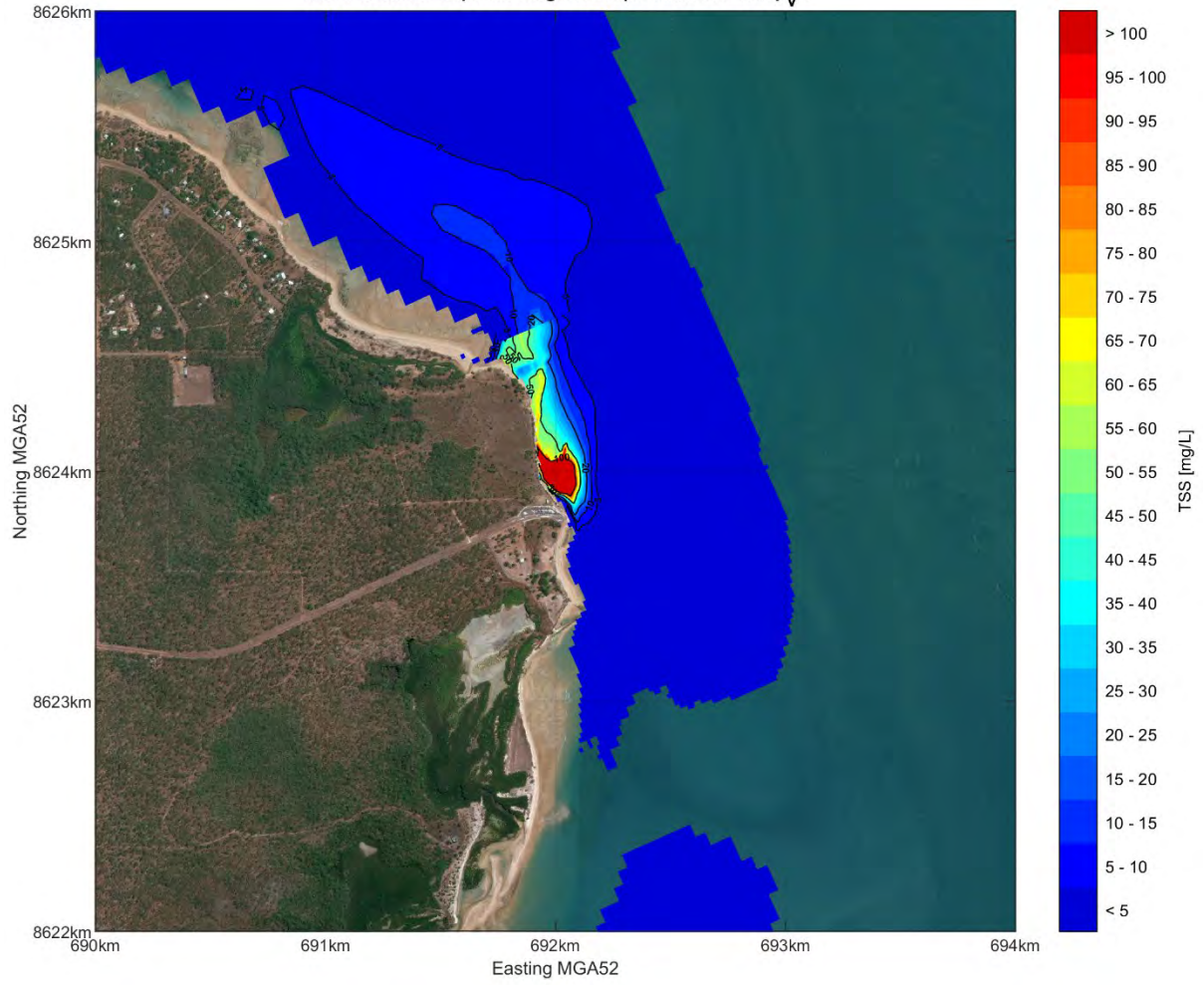
50th Percentile Depth Averaged TSS | Scenario 2 - Neap_v2



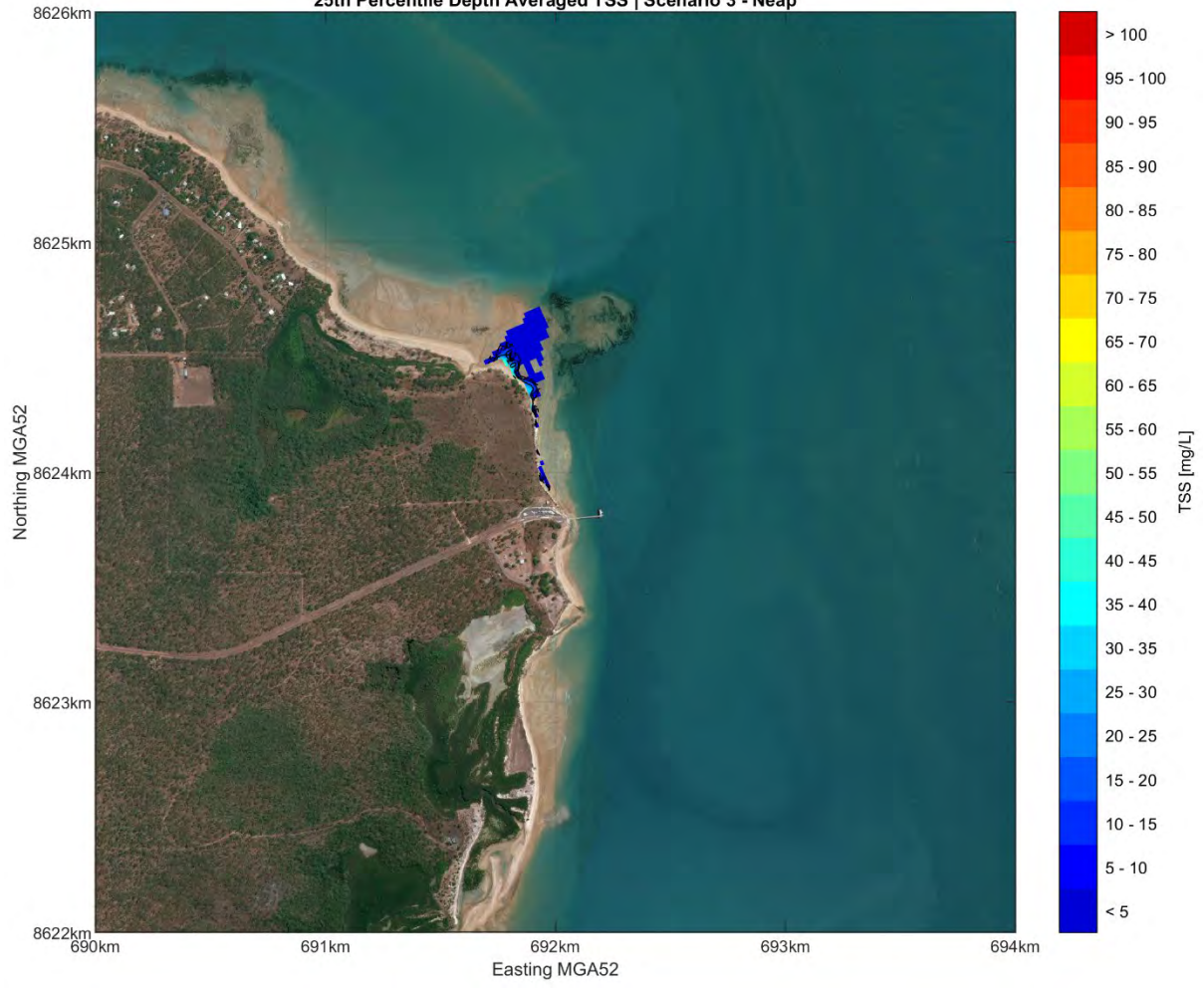
80th Percentile Depth Averaged TSS | Scenario 2 - Neap_v2



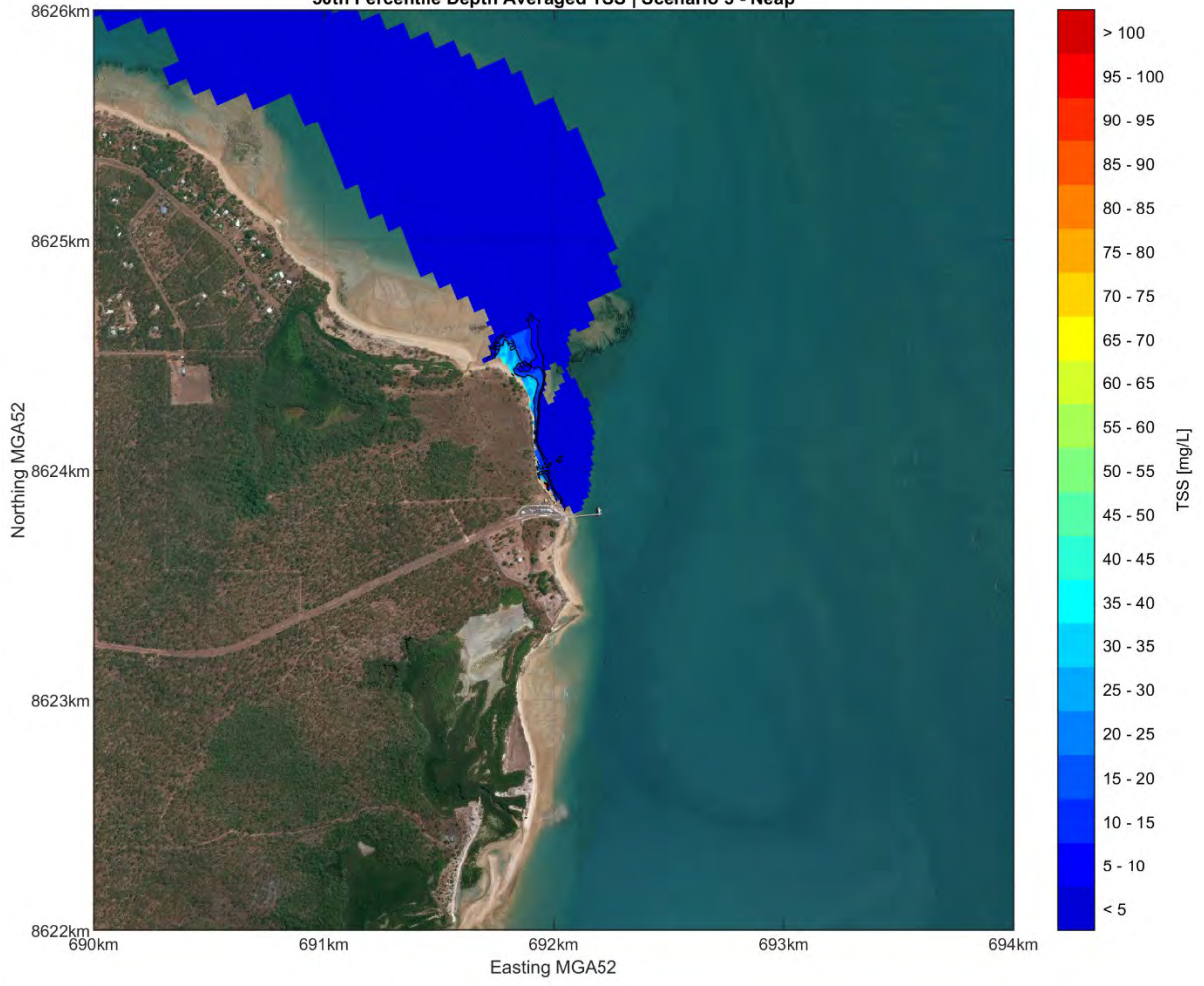
90th Percentile Depth Averaged TSS | Scenario 2 - Neap_v2



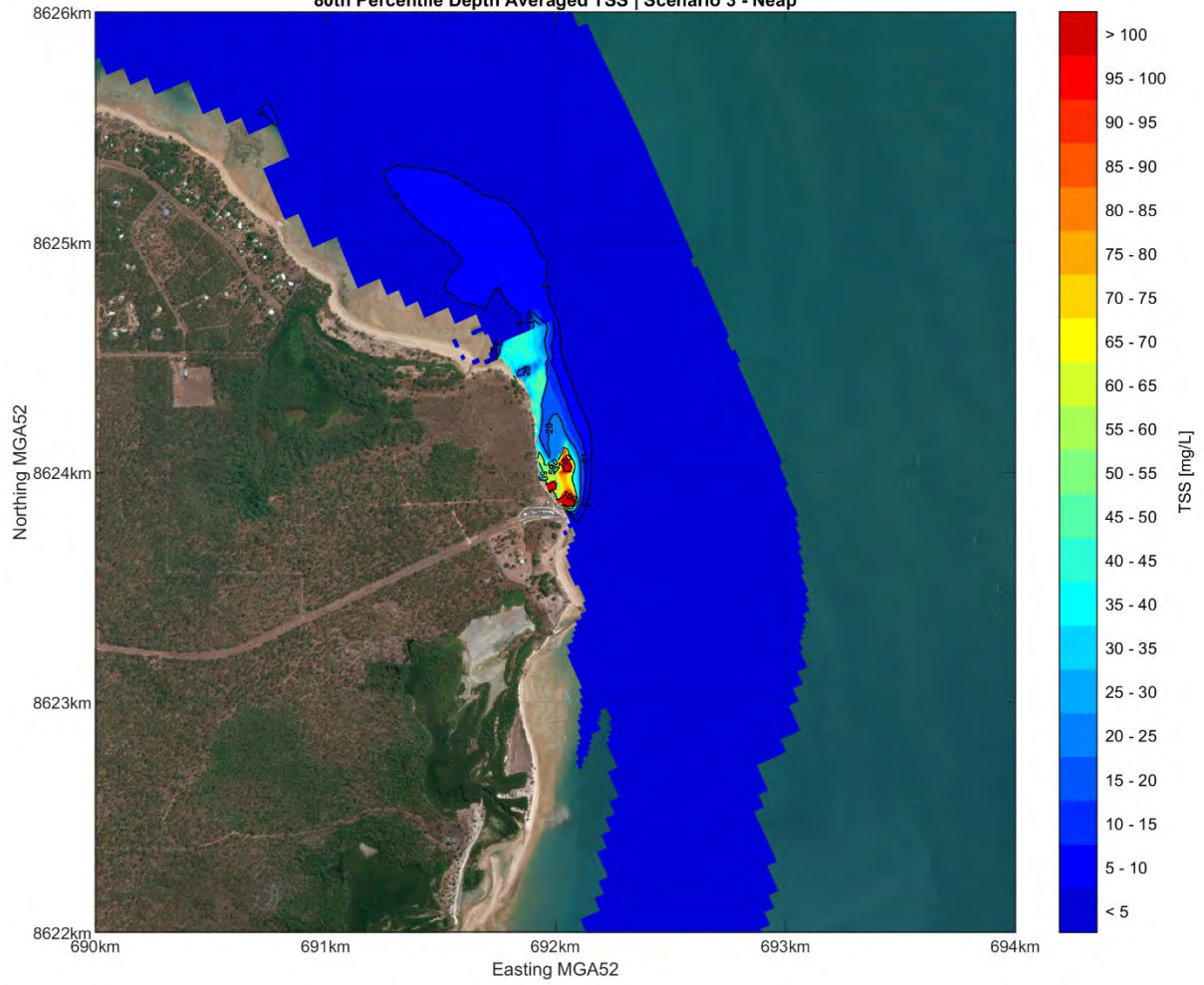
25th Percentile Depth Averaged TSS | Scenario 3 - Neap



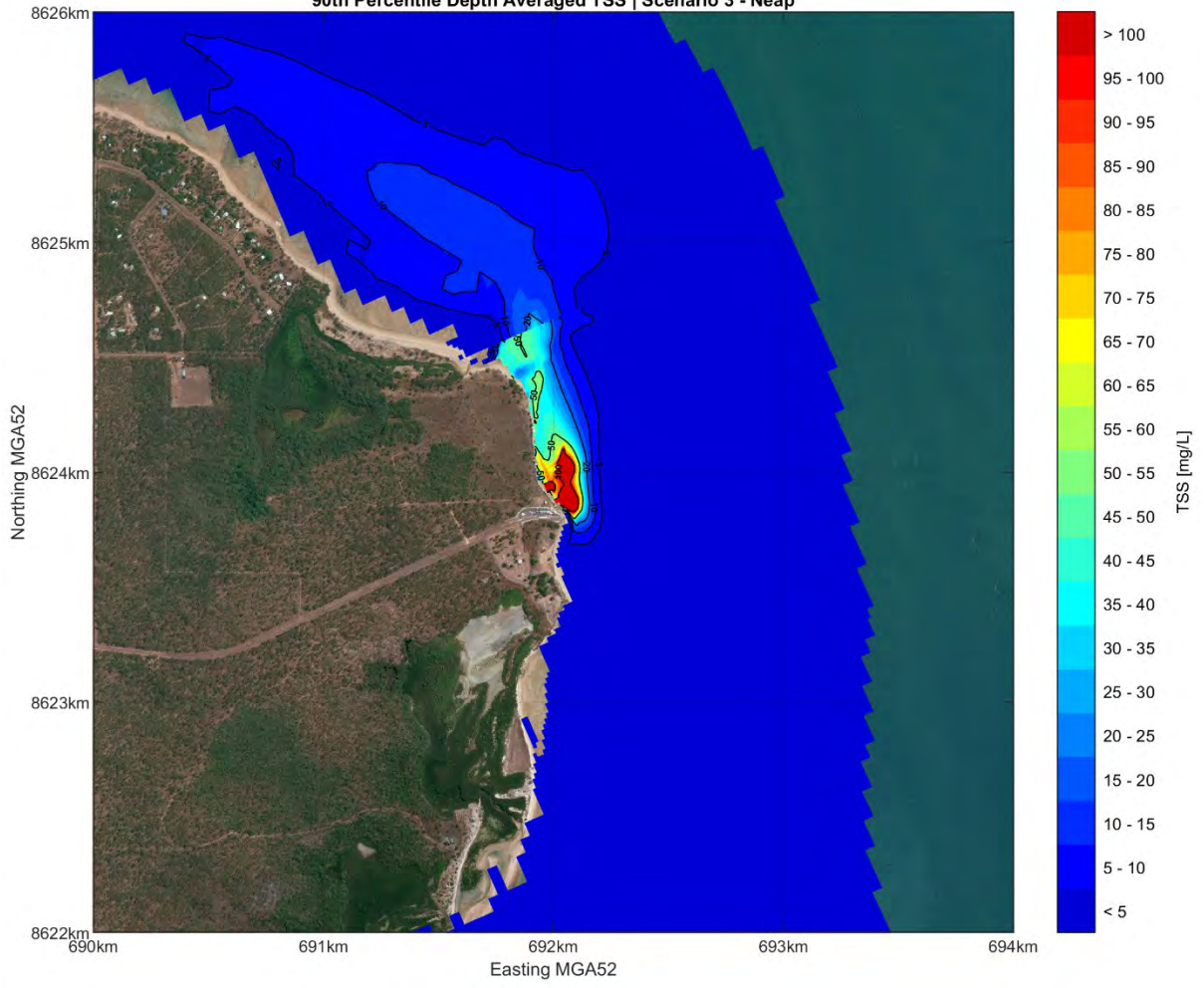
50th Percentile Depth Averaged TSS | Scenario 3 - Neap



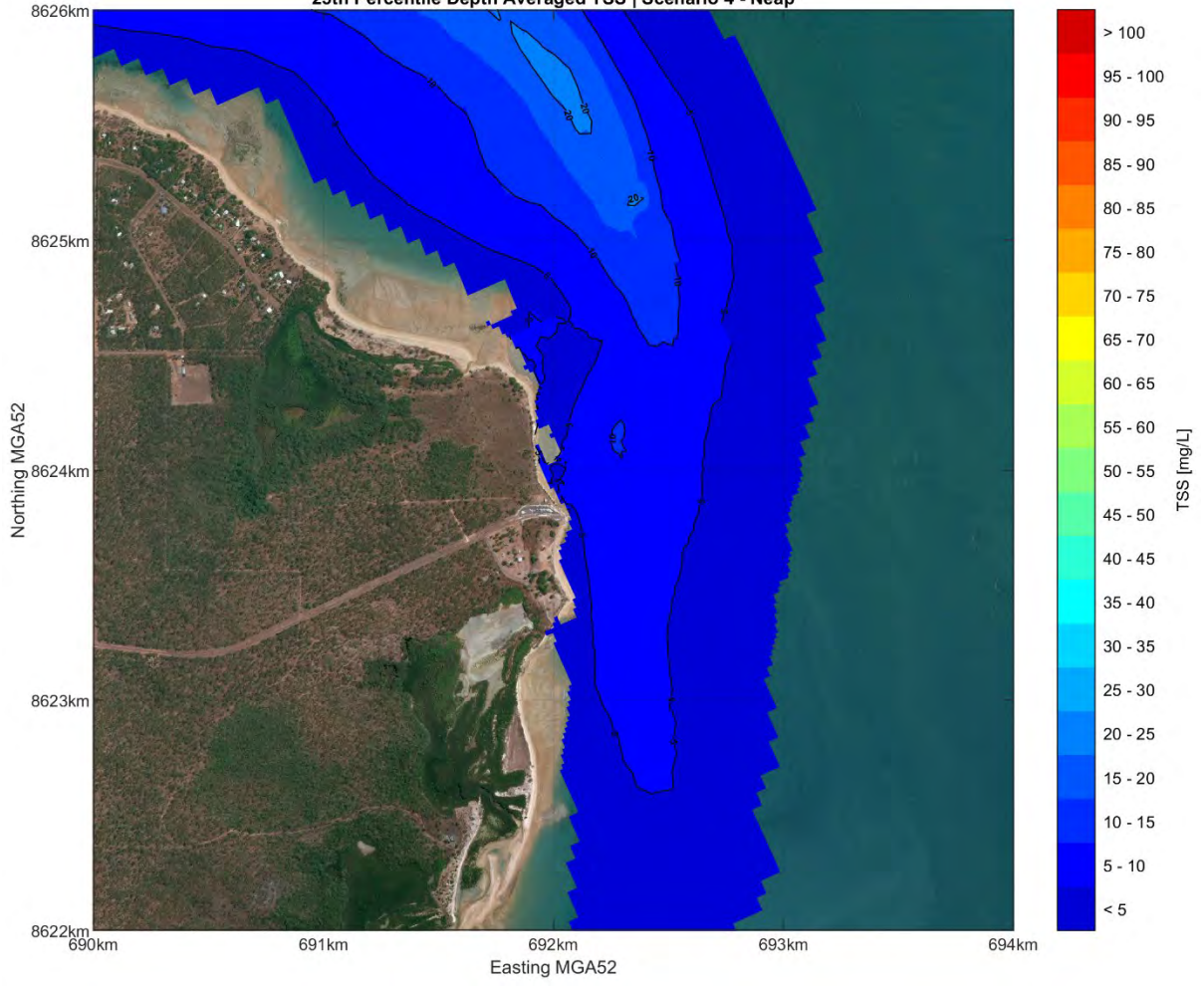
80th Percentile Depth Averaged TSS | Scenario 3 - Neap



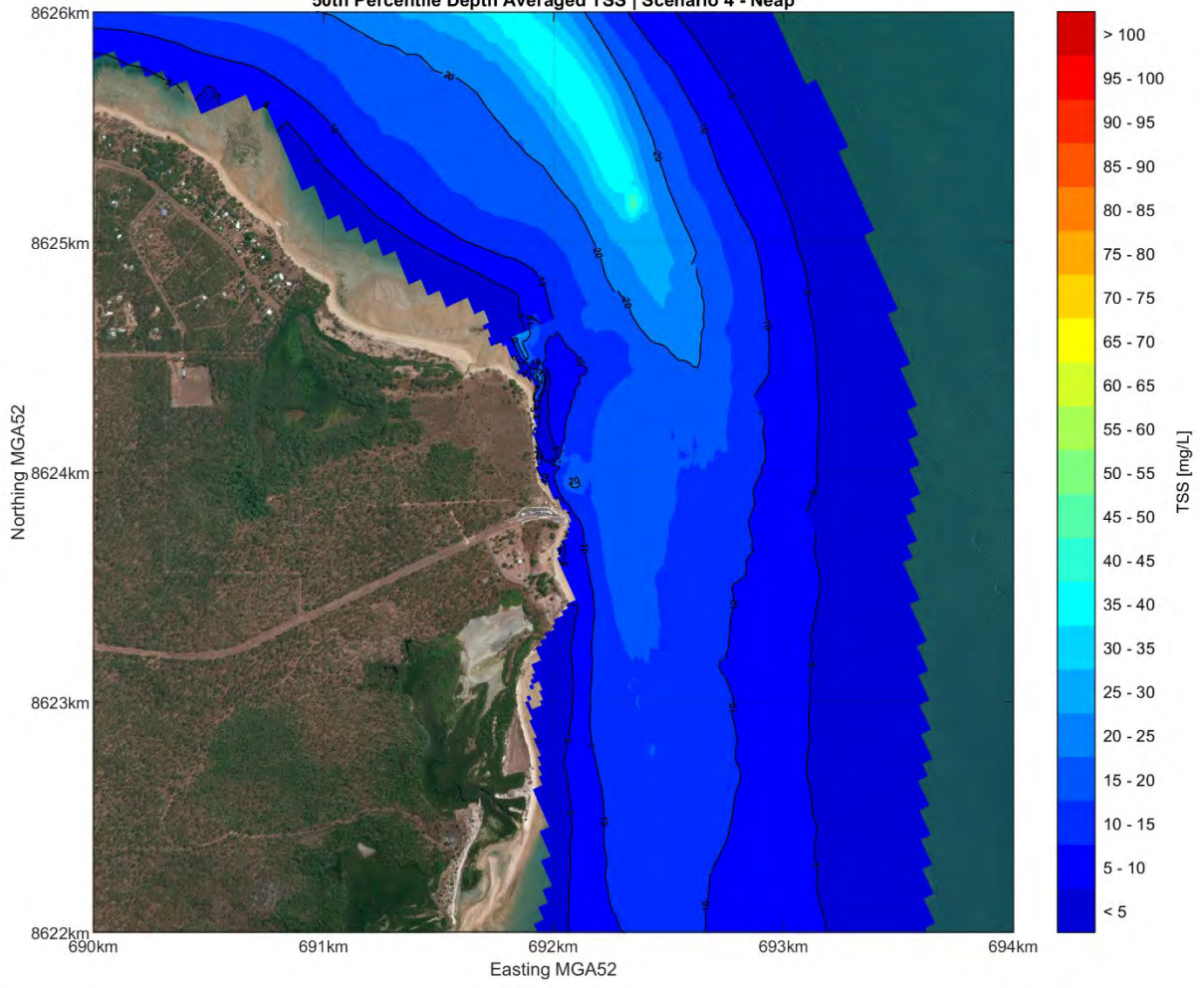
90th Percentile Depth Averaged TSS | Scenario 3 - Neap



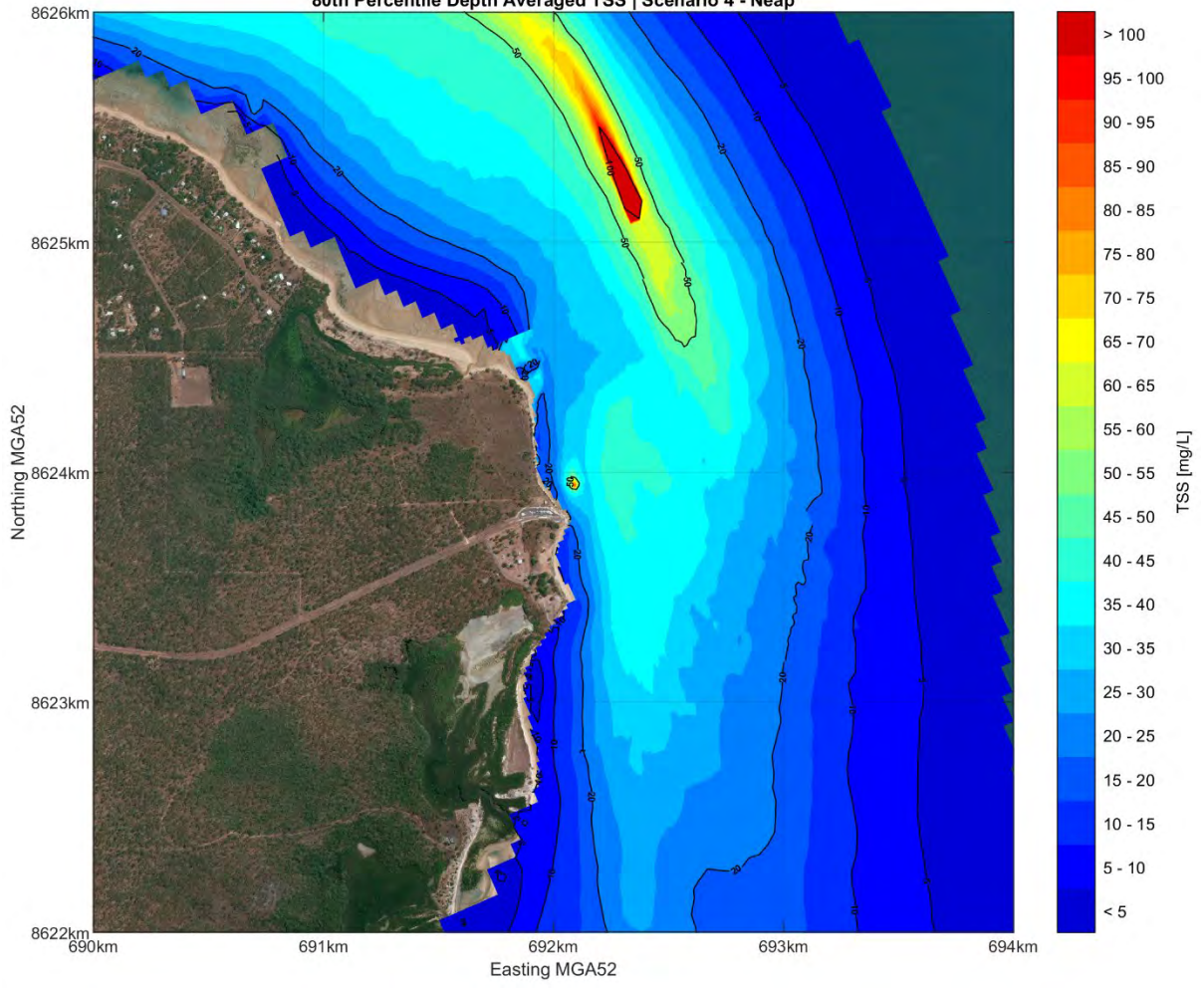
25th Percentile Depth Averaged TSS | Scenario 4 - Neap



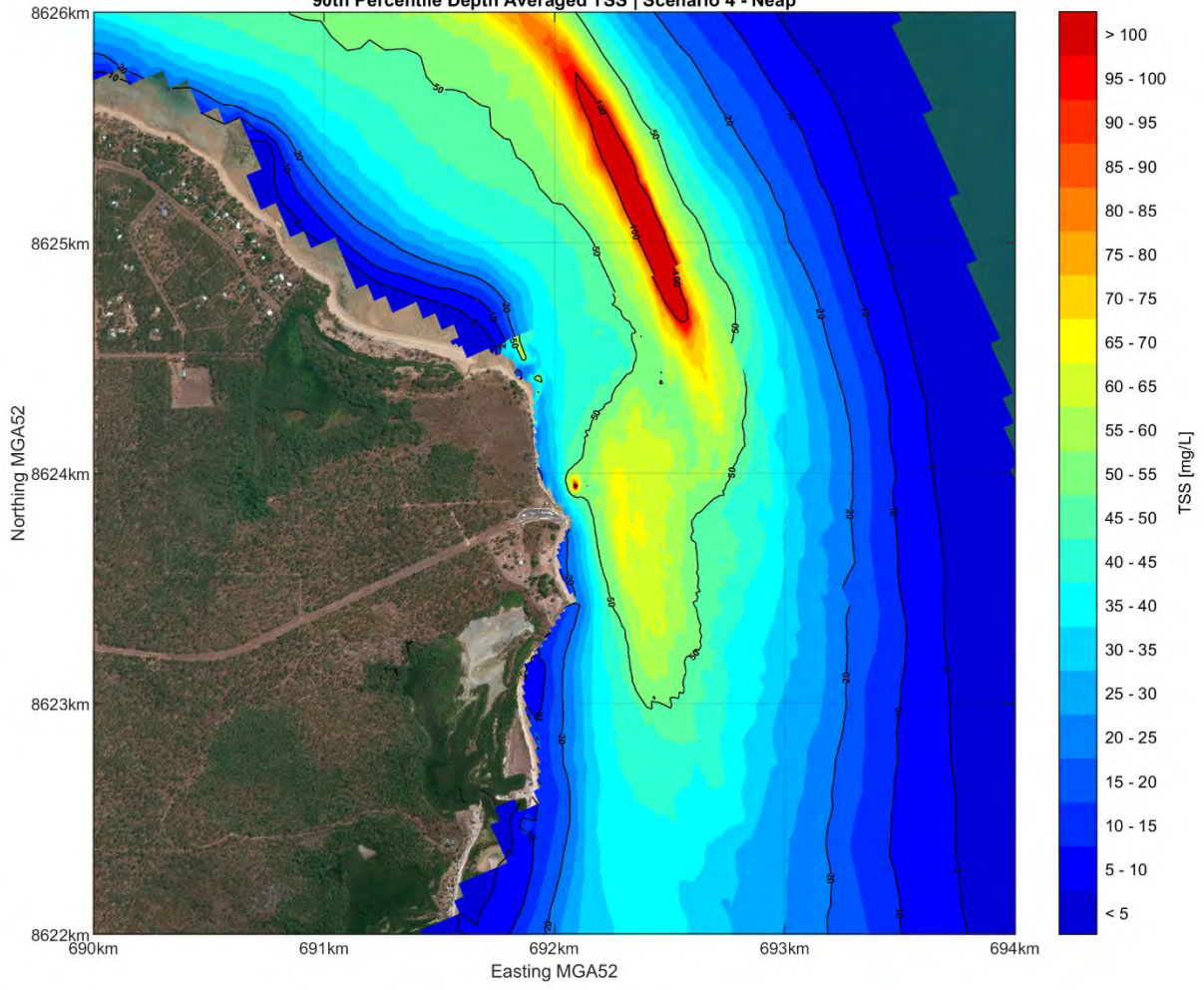
50th Percentile Depth Averaged TSS | Scenario 4 - Neap



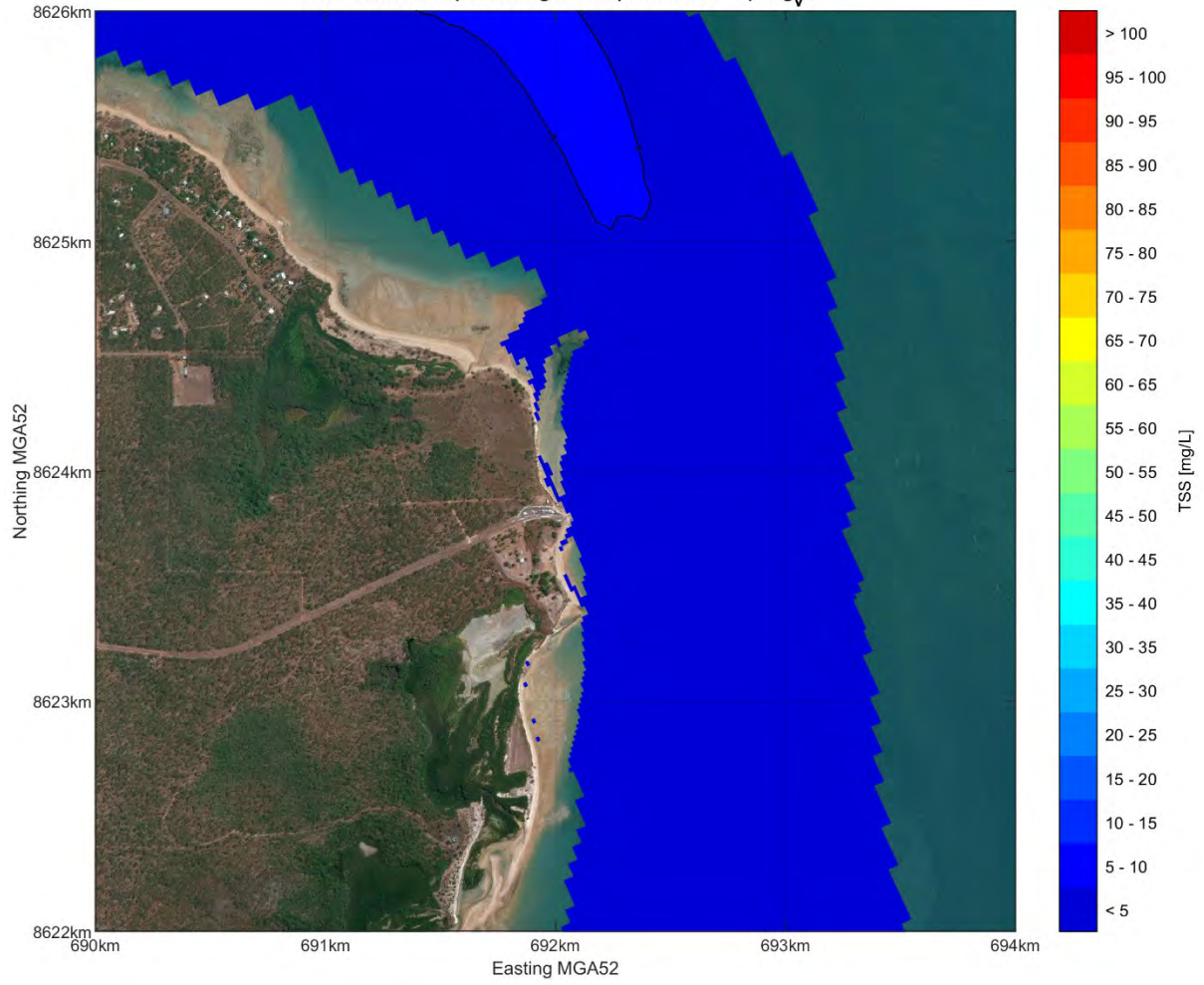
80th Percentile Depth Averaged TSS | Scenario 4 - Neap



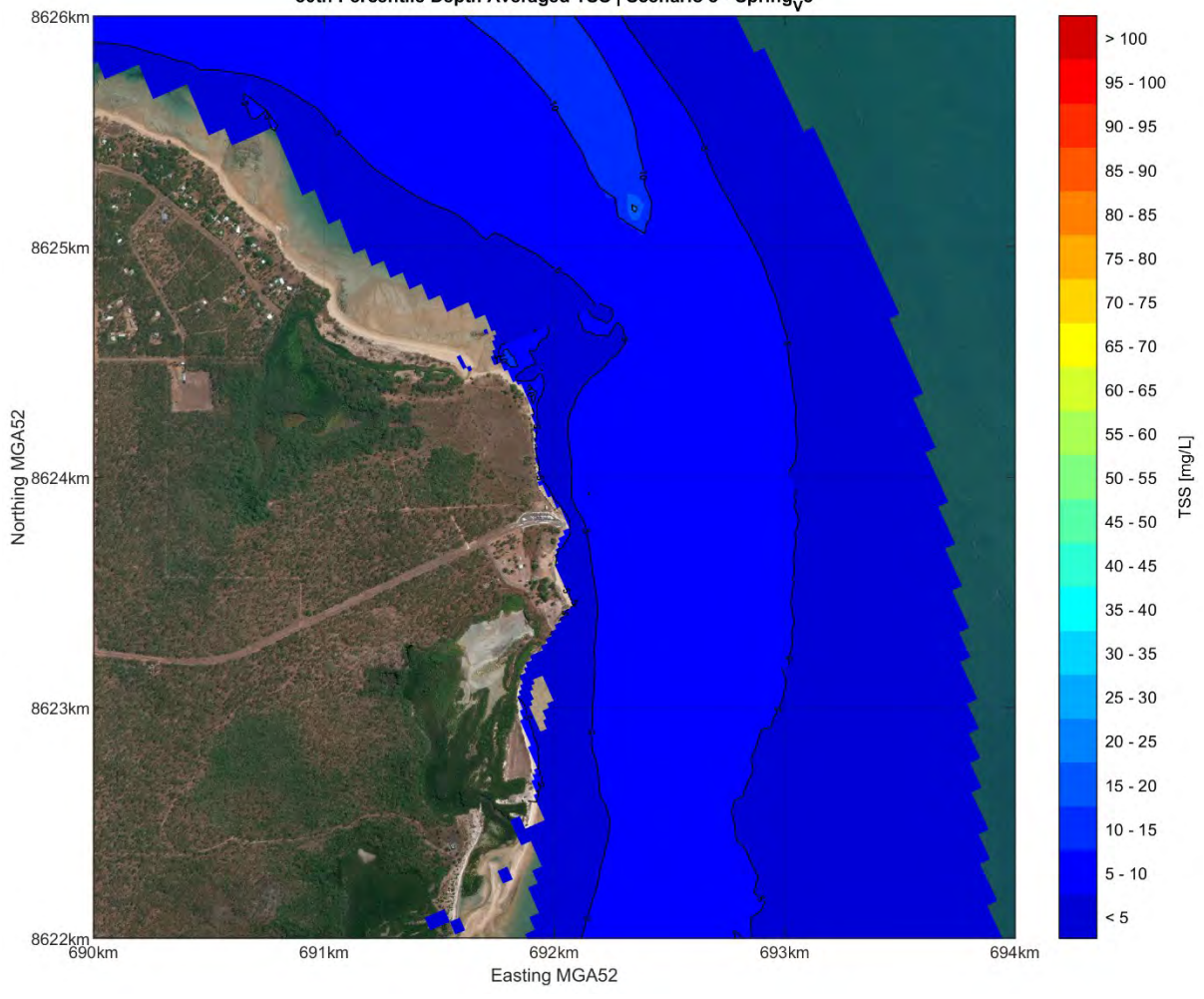
90th Percentile Depth Averaged TSS | Scenario 4 - Neap



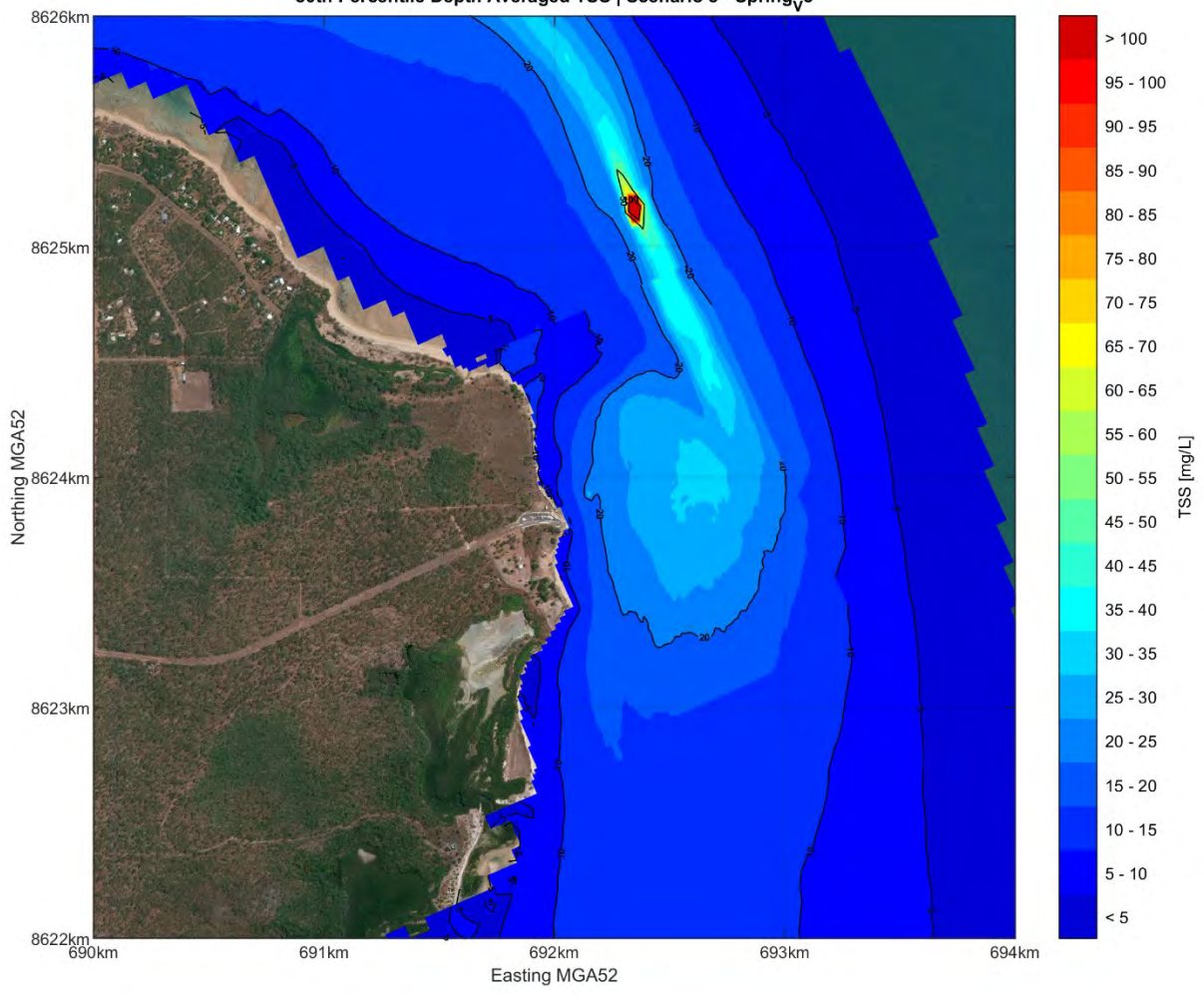
25th Percentile Depth Averaged TSS | Scenario 5 - Spring_v3



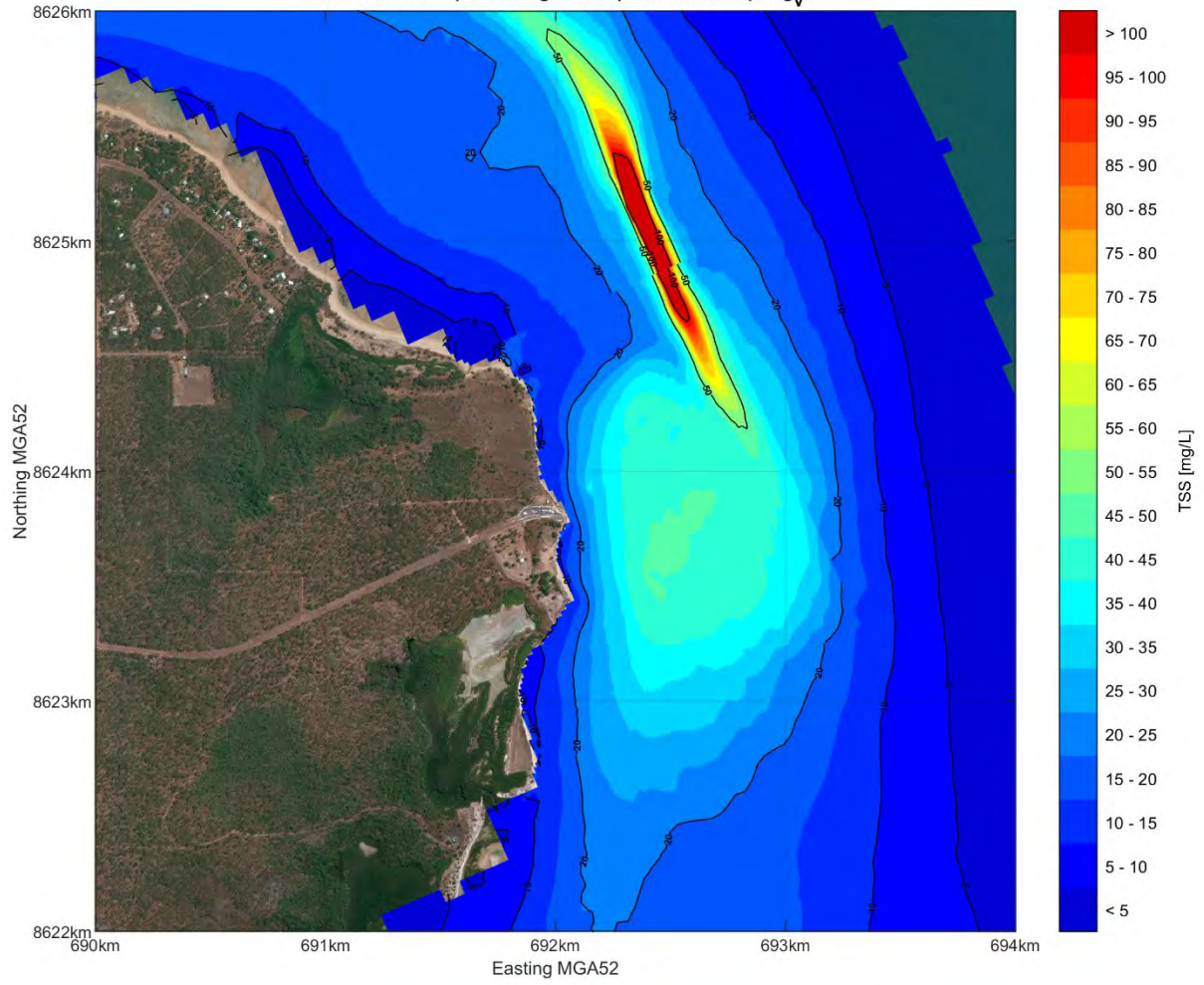
50th Percentile Depth Averaged TSS | Scenario 5 - Spring_v3



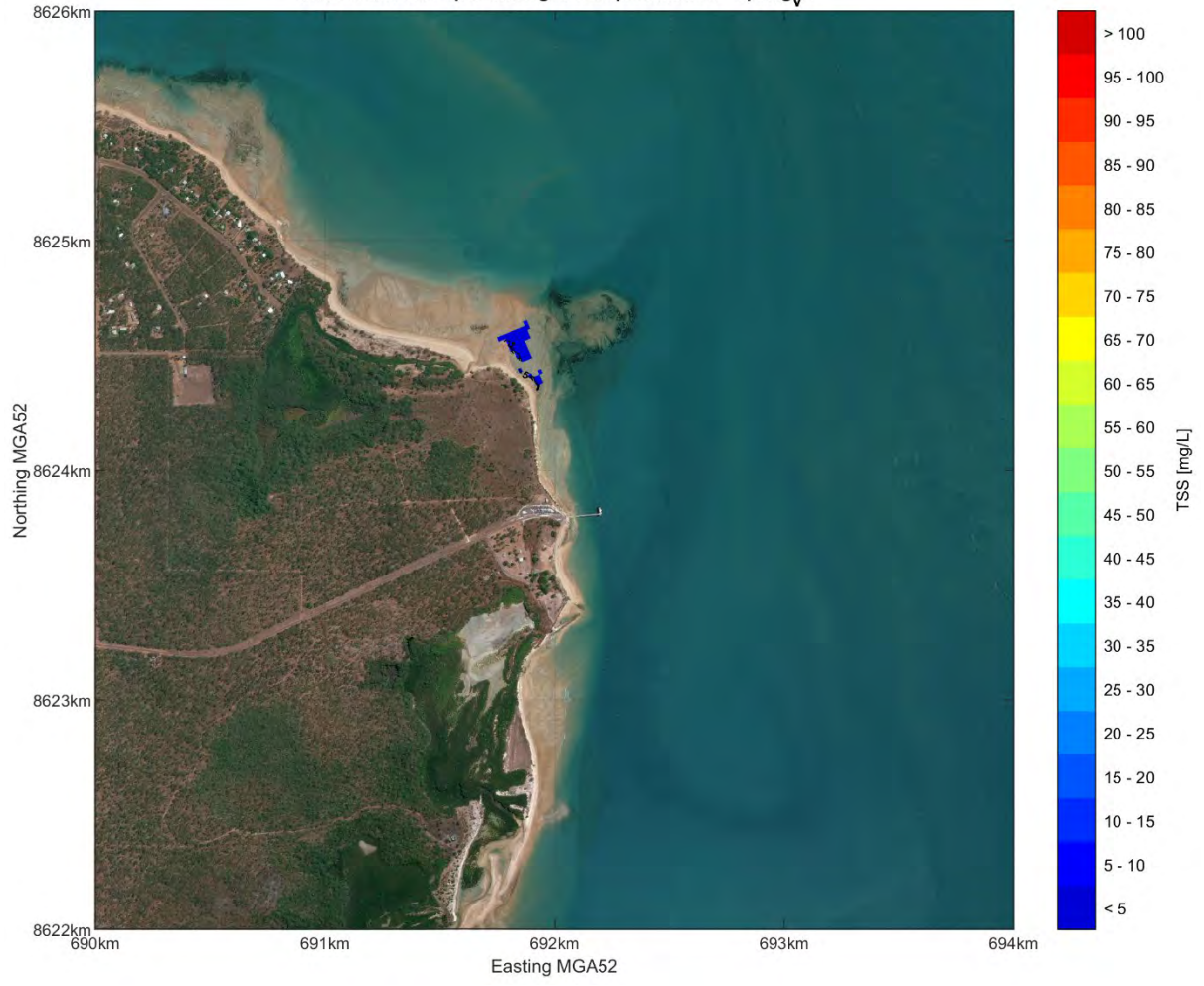
80th Percentile Depth Averaged TSS | Scenario 5 - Spring_v3



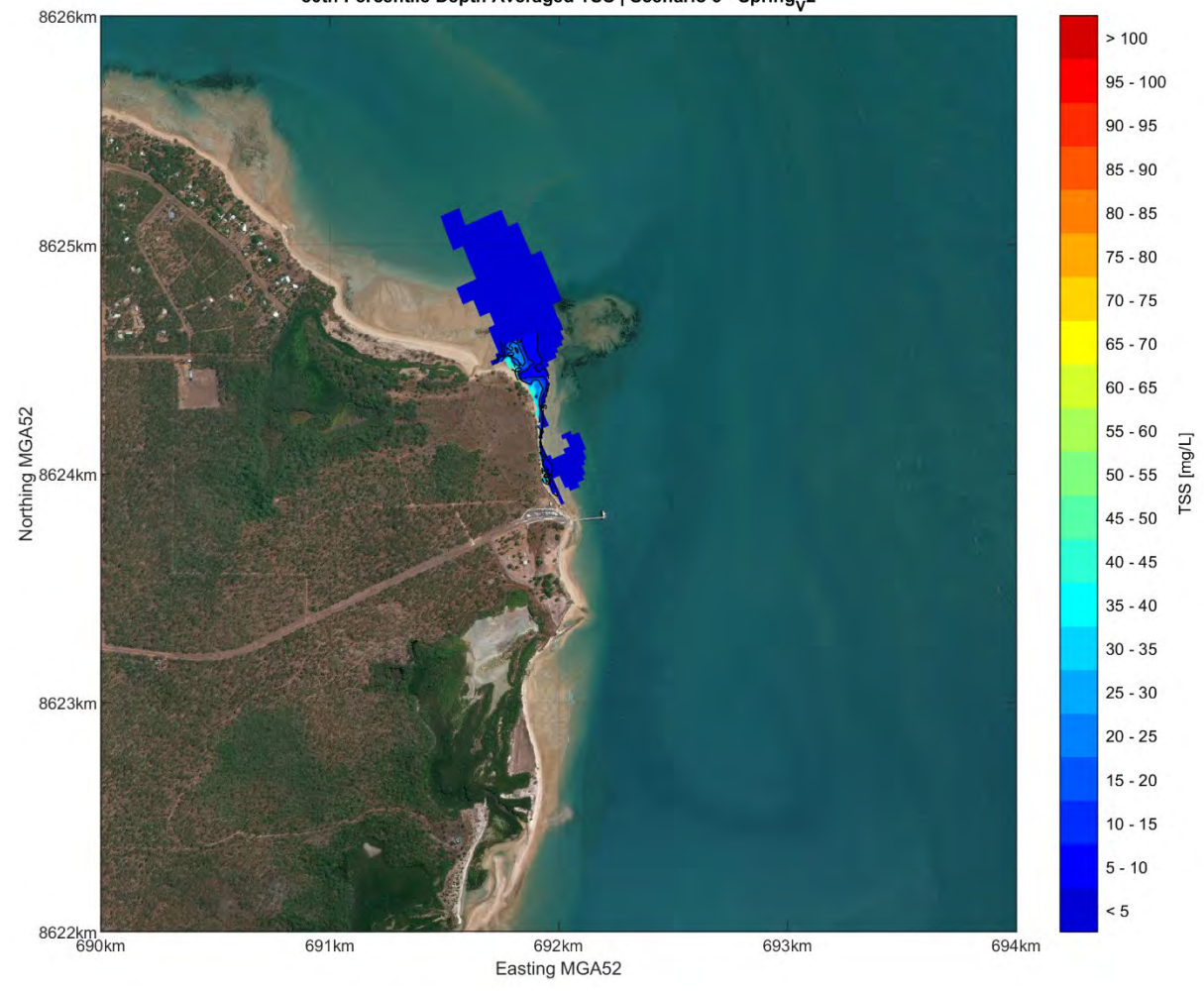
90th Percentile Depth Averaged TSS | Scenario 5 - Spring_v3



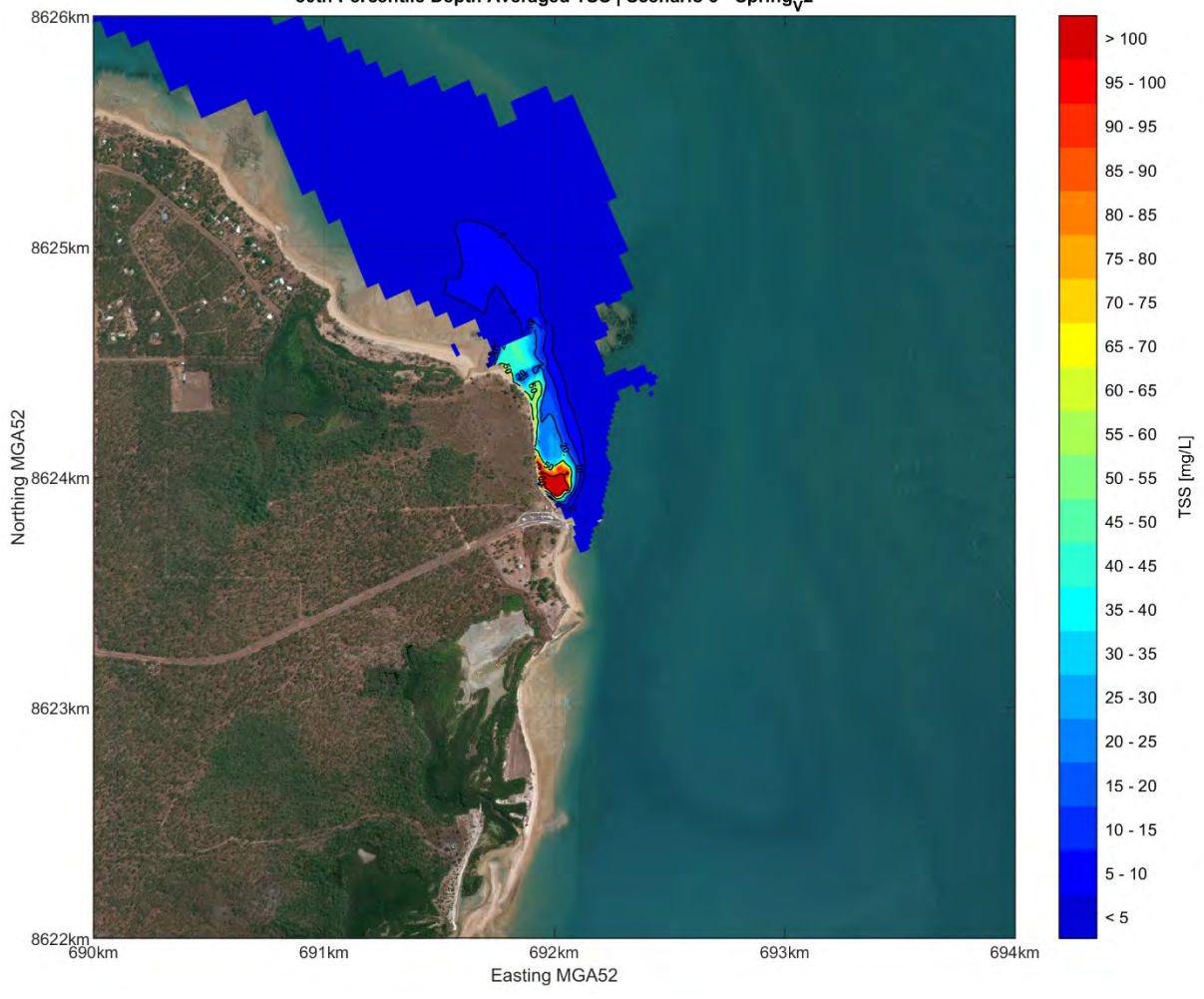
25th Percentile Depth Averaged TSS | Scenario 6 - Spring_v2



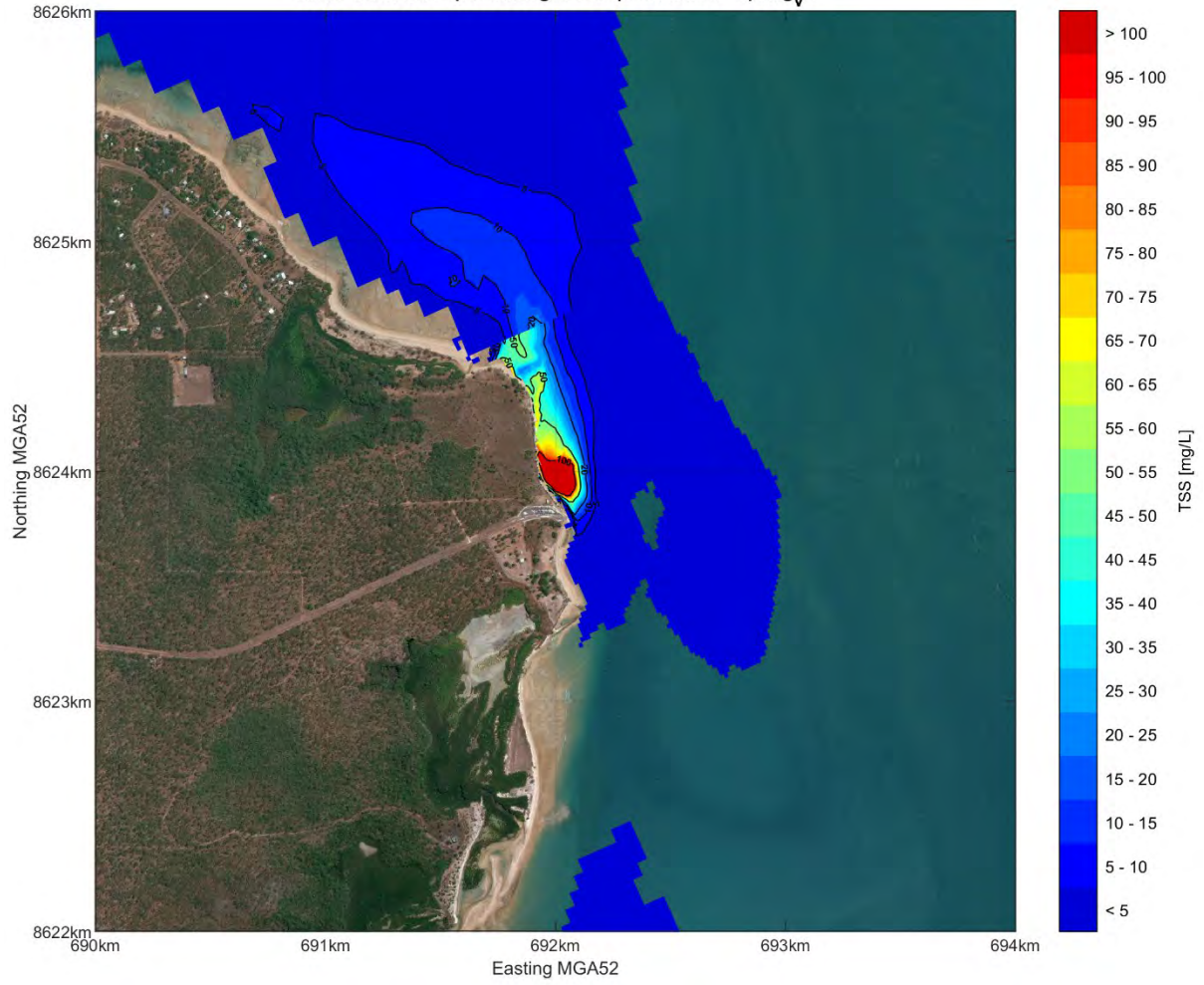
50th Percentile Depth Averaged TSS | Scenario 6 - Spring_v2



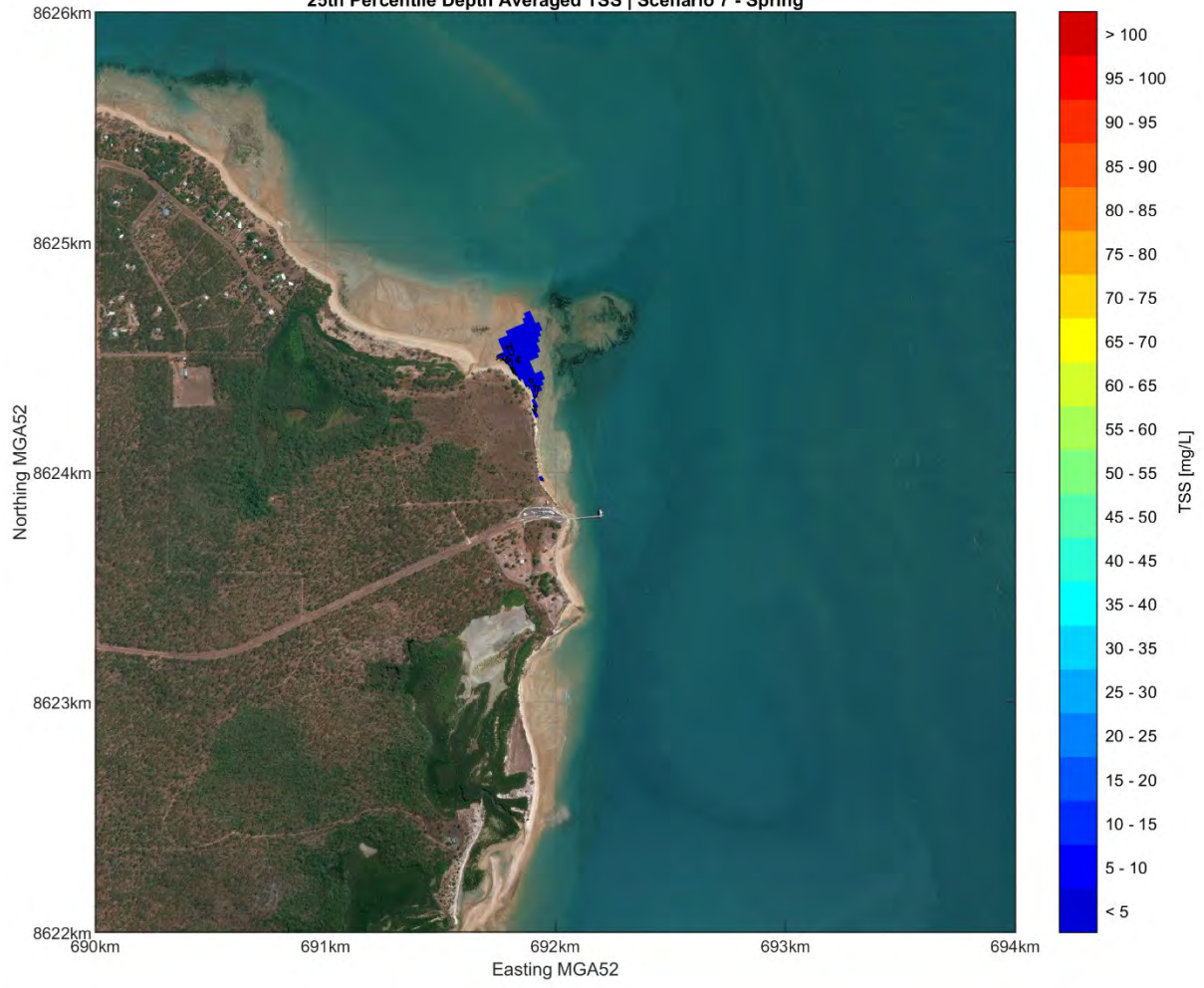
80th Percentile Depth Averaged TSS | Scenario 6 - Spring_v2



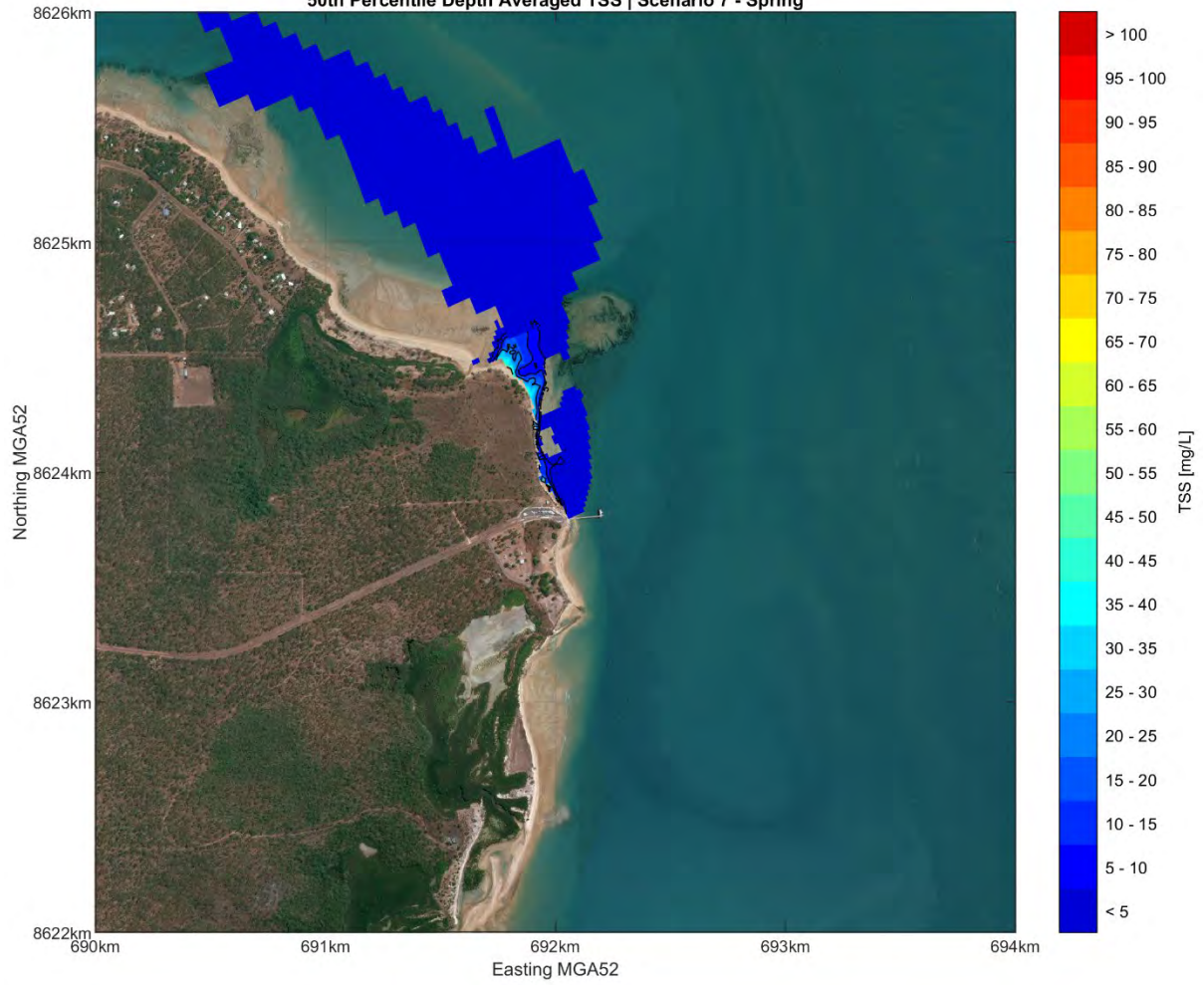
90th Percentile Depth Averaged TSS | Scenario 6 - Spring_v2



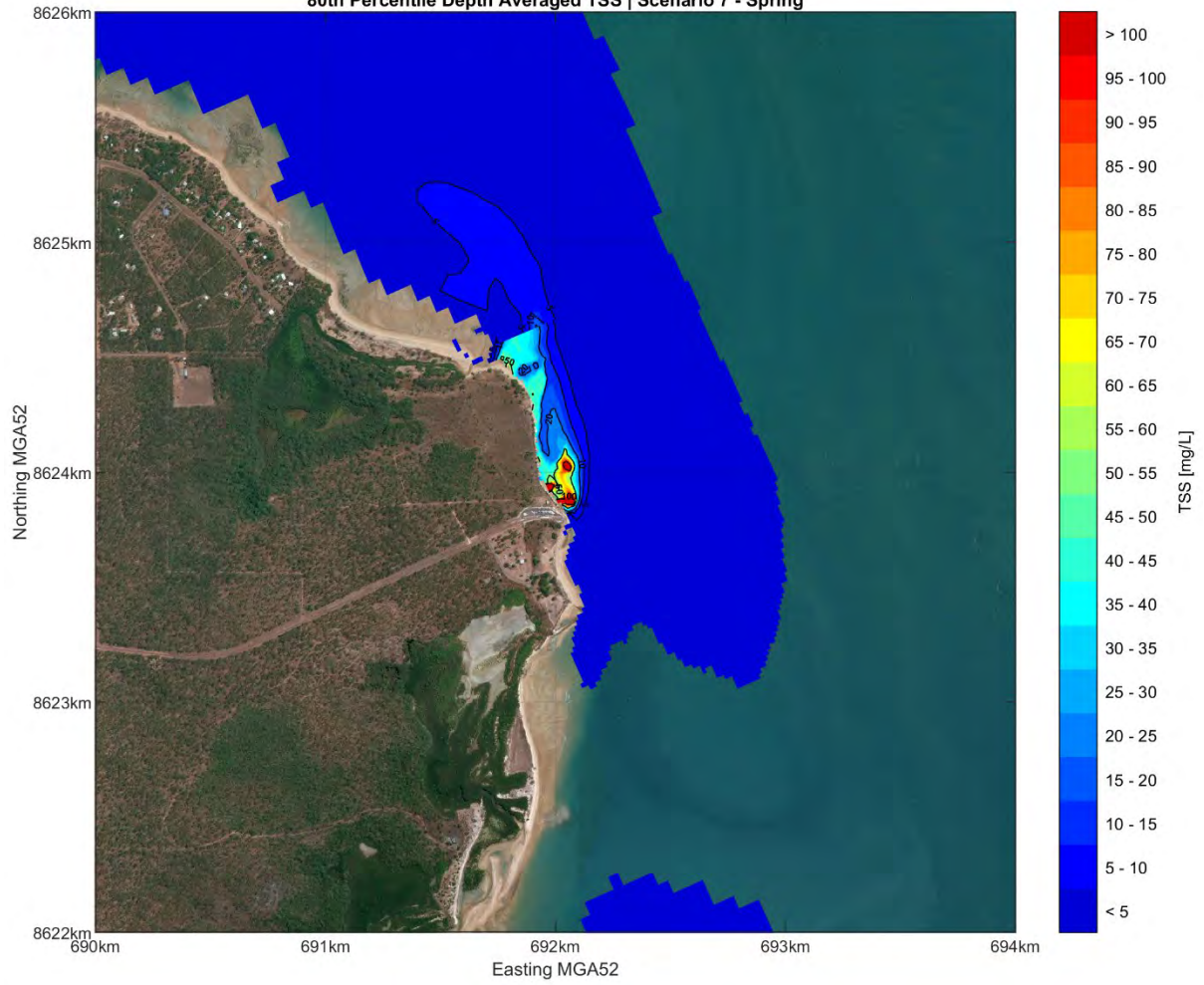
25th Percentile Depth Averaged TSS | Scenario 7 - Spring



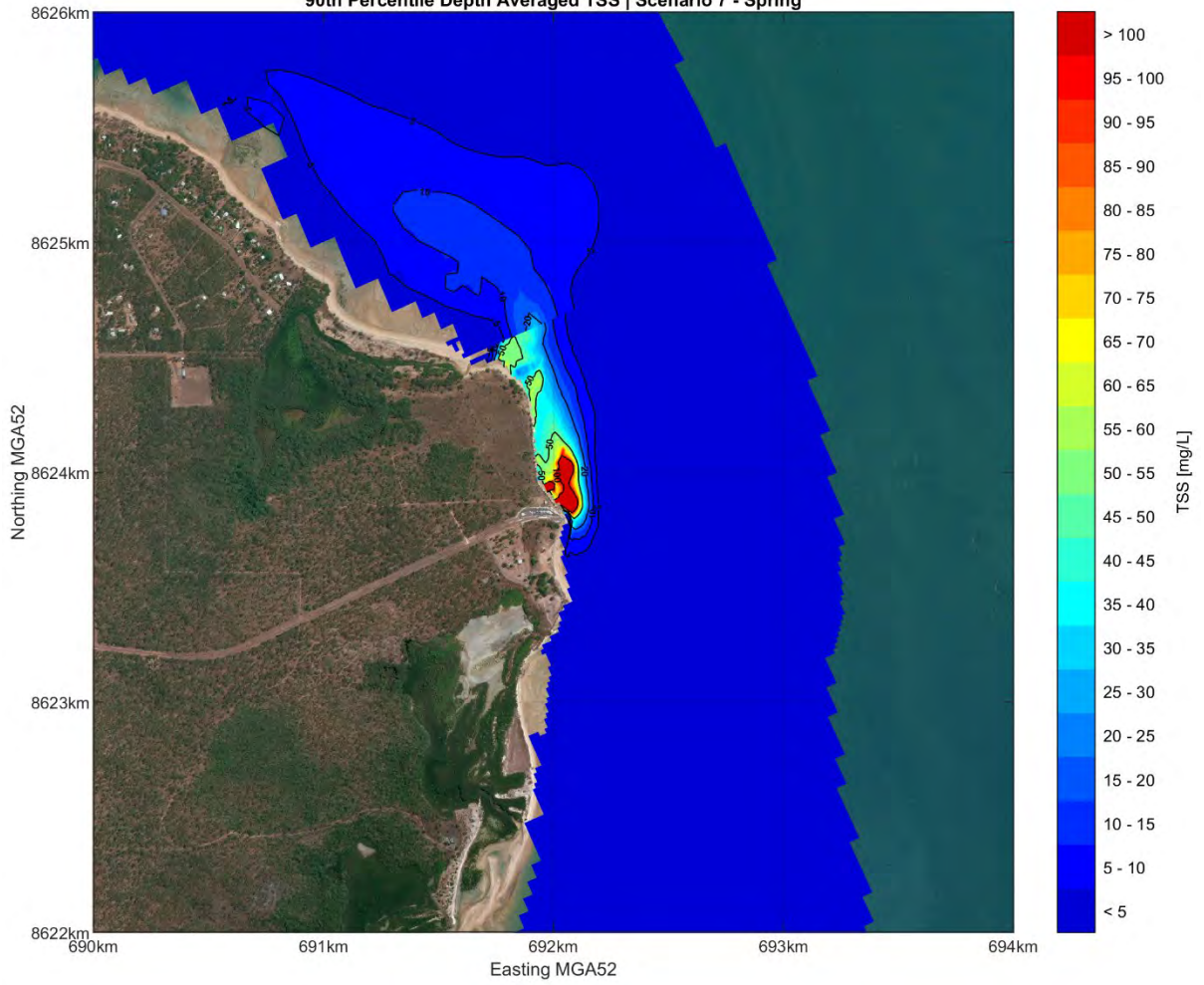
50th Percentile Depth Averaged TSS | Scenario 7 - Spring



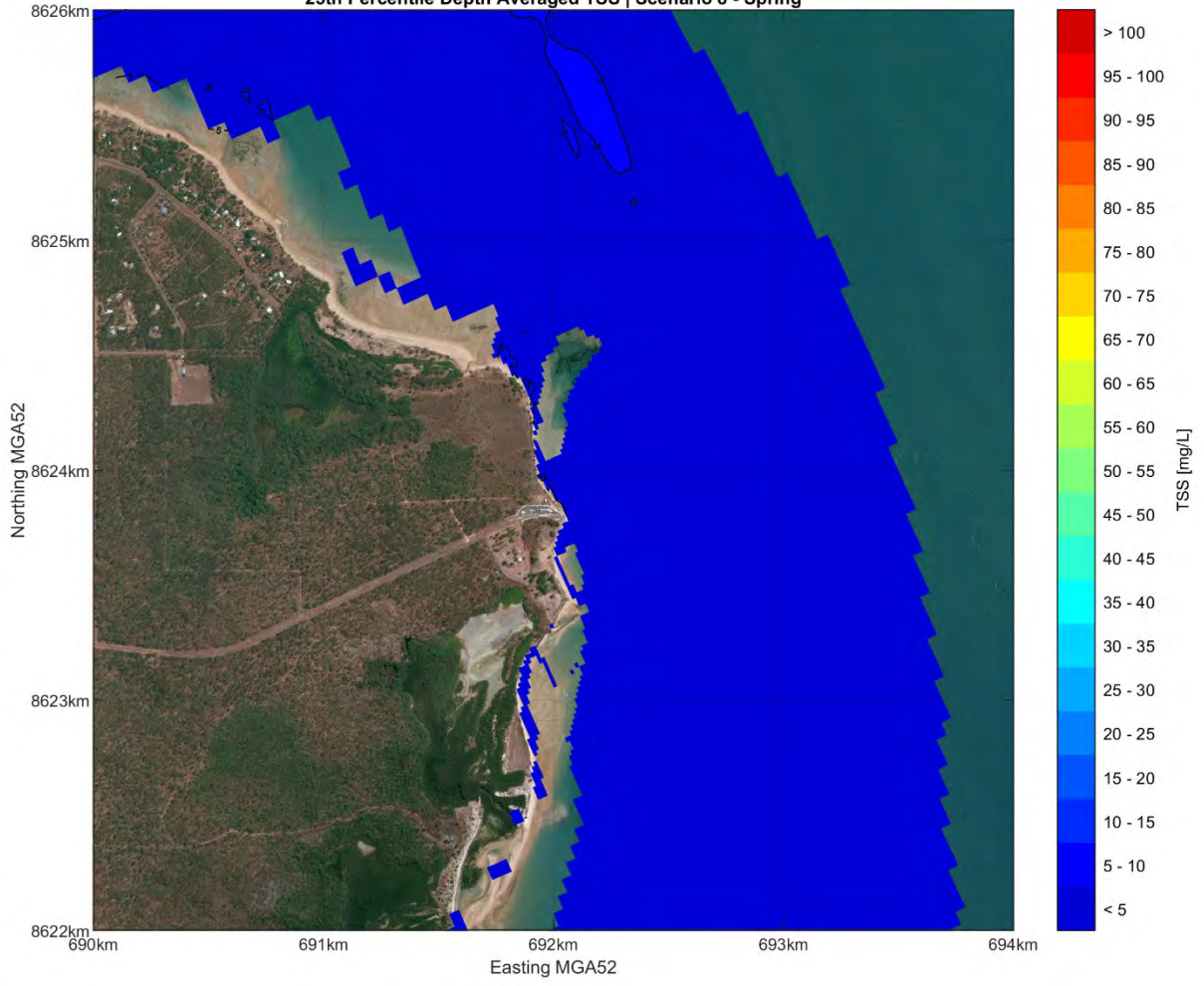
80th Percentile Depth Averaged TSS | Scenario 7 - Spring



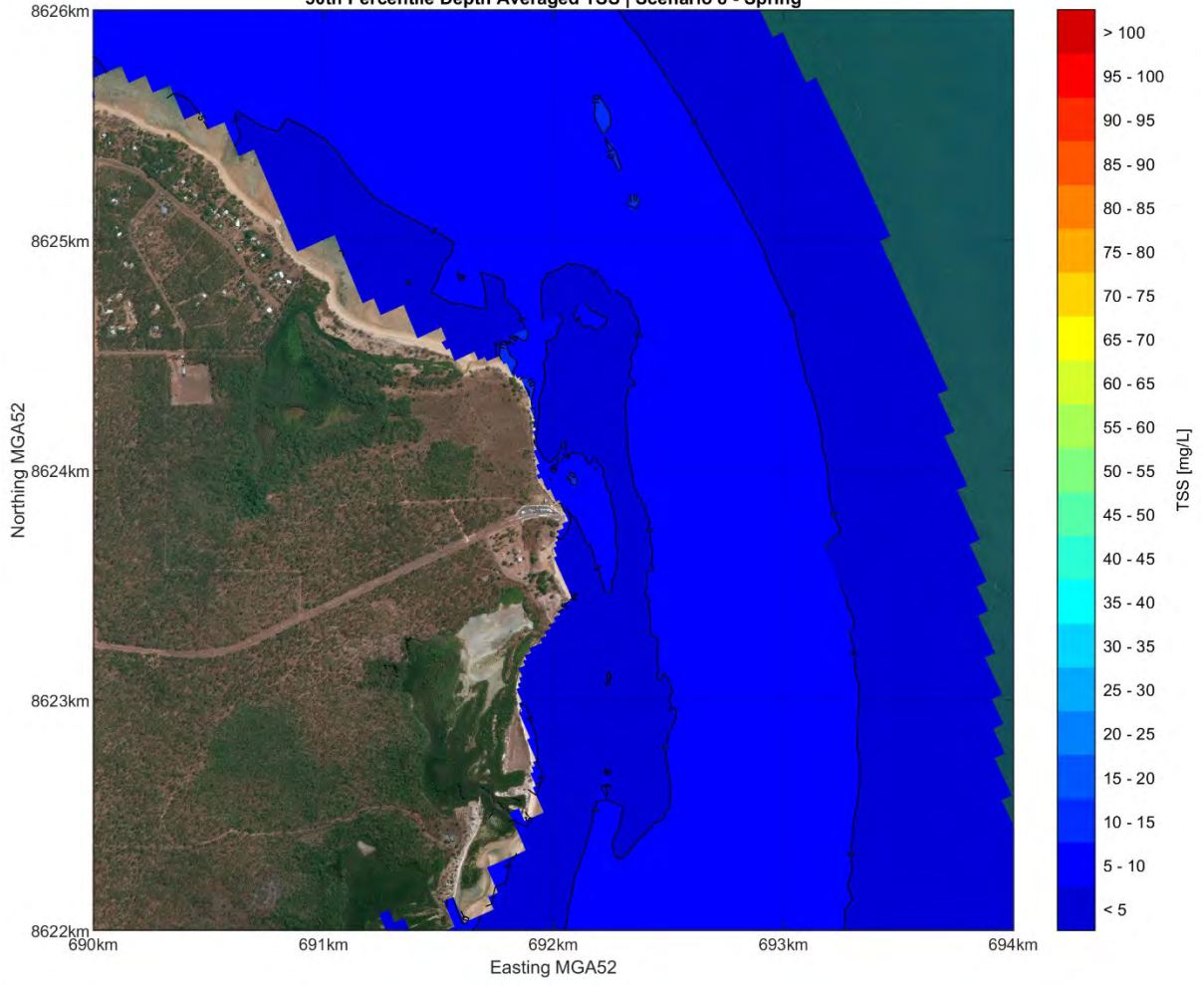
90th Percentile Depth Averaged TSS | Scenario 7 - Spring



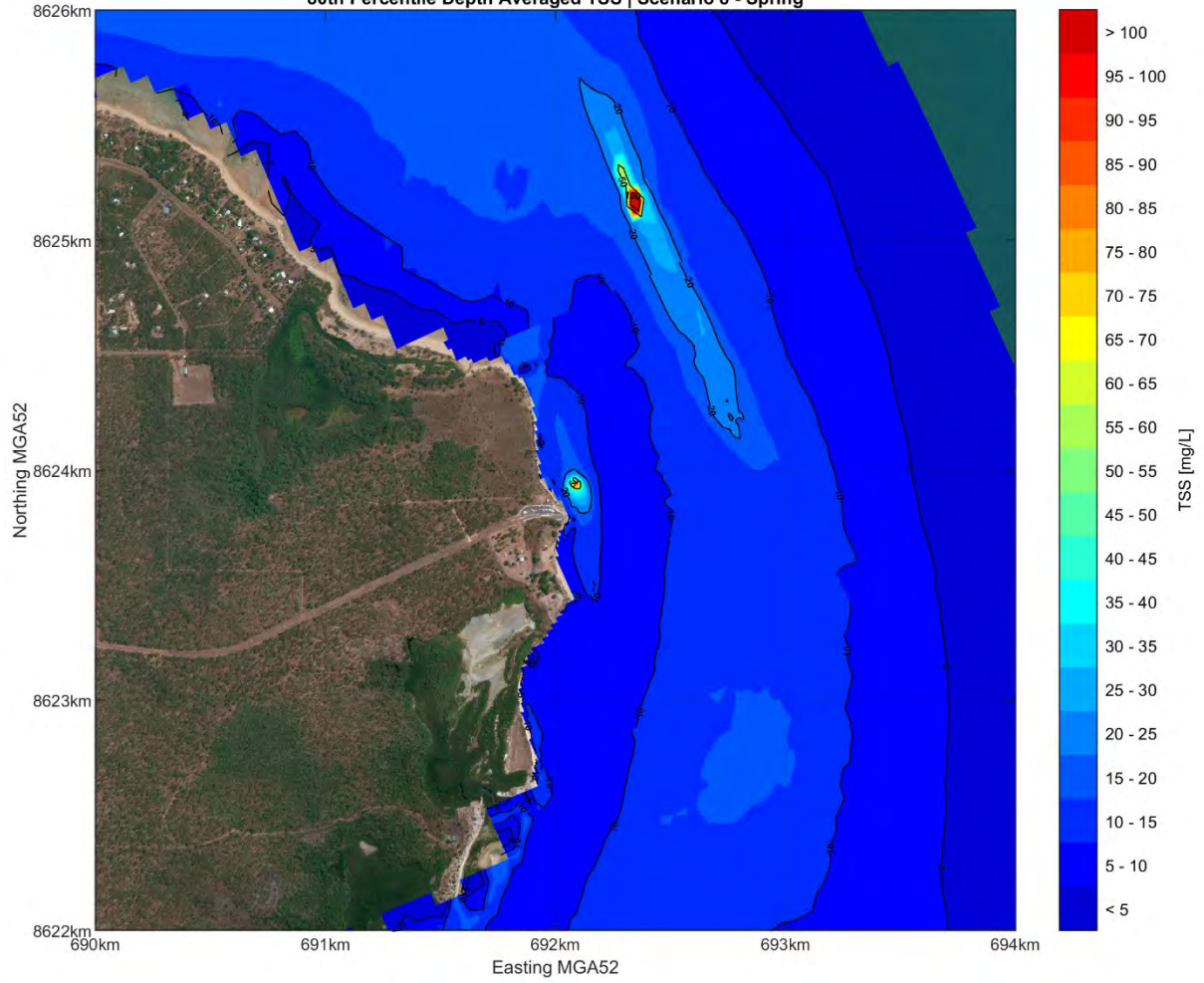
25th Percentile Depth Averaged TSS | Scenario 8 - Spring



50th Percentile Depth Averaged TSS | Scenario 8 - Spring



80th Percentile Depth Averaged TSS | Scenario 8 - Spring



90th Percentile Depth Averaged TSS | Scenario 8 - Spring

