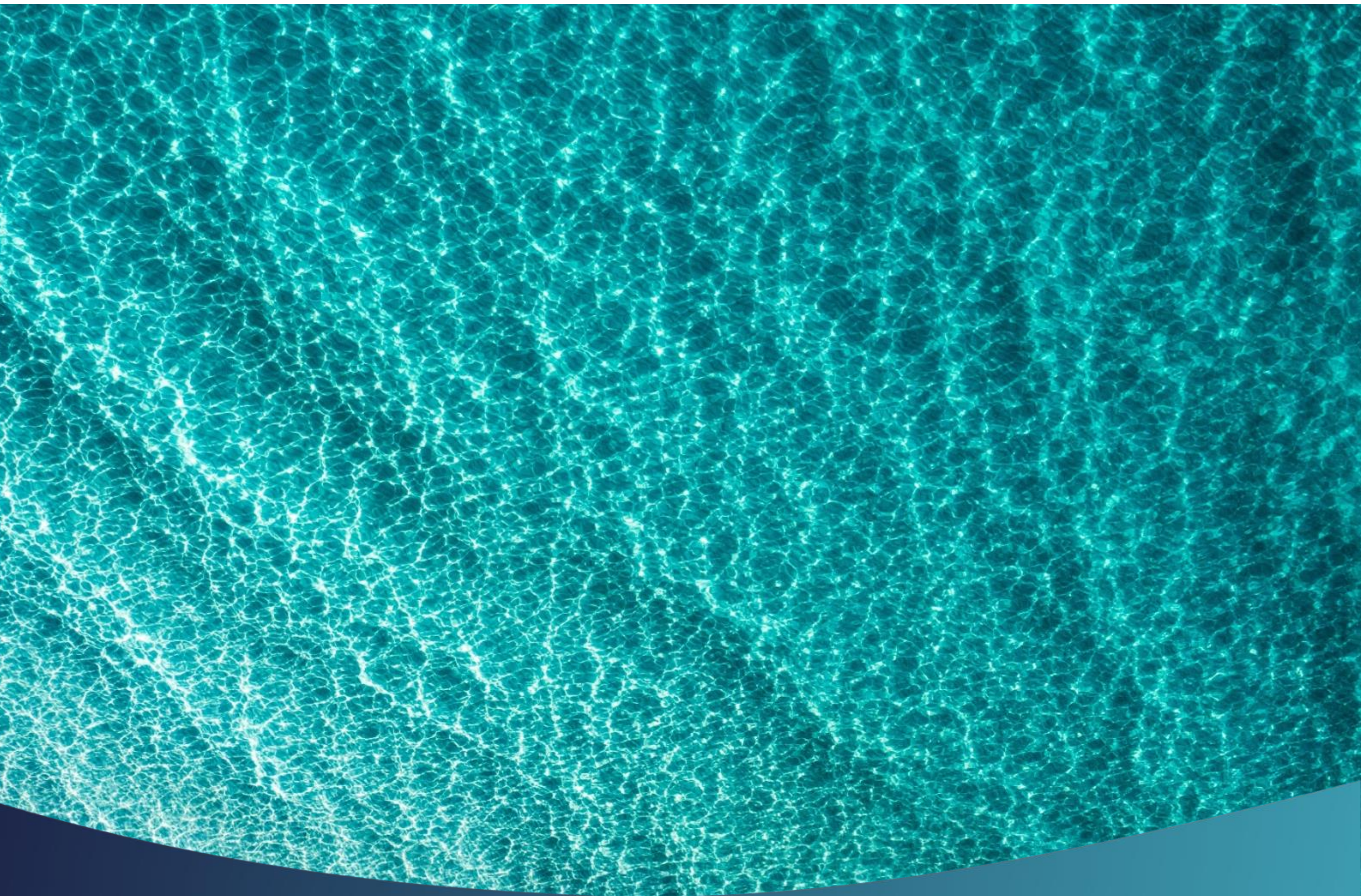
Bitterns Dispersion Modelling

ESSP Scenario 7.2



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Version Register

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Changes from Previous Versions

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

Revision	Change
3	The Digital Elevation Model (DEM) was adjusted based on the high resolution local bathymetric dataset. Dilution requirements and resulting zones of impact were updated.

Acronyms, Abbreviations and Definitions

Acronyms & Abbreviations	**Definitions**
3D	Three-Dimensional
AHD	Australian Height Datum
BCH	Benthic Communities and Habitat
D	Dilution Factor
DEM	Digital Elevation Model
DHI	DHI Group
DWER	Department of Water and Environmental Regulation
EC/IC 10%	10^{th} percentile effect concentration
EC/IC 50%	50^{th} percentile effect concentration
EIA	Environmental Impact Assessment
EOS80	UNESCO 1981 International Equation of State for Seawater80
EPA	Environmental Protection Authority
ESD	Environmental Scoping Document
ESSP / the Project	Eramurra Solar Salt Project
EQO	Environmental Quality Objectives
FM	Flow Model
GA	Geosciences Australia
GG	Guardian Geomatics
GL/a	Gigalitres per annum
GL/m	Gigalitres per month
HD	Hydrodynamic
HEPA	High Ecological Protection Area
LEP	Level of Ecological Protection
LOEC	Lowest Observed Effect Concentration
Leichhardt	Leichhardt Salt Pty Ltd (the Client)
MEQMMP	Marine Environmental Quality Monitoring and Management Plan

MIKE	MIKE Software by DHI
MNG	McMullen Nolan Group Pty Ltd
MSL	Mean sea level
Mt	Million tonnes
Mtpa	Million tonnes per annum
NOEC	No-Observed Effect Concentration
O2M	O2 Marine
O2Me	O2 Metocean (an O2 Marine Company)
ppt	Parts per thousand
PSU	Practical Salinity Units
RANS	Reynolds Averaged Navier Stokes
SBES	Single Beam Echo Sounder
SPL	Species Protection Level
SSD	Species Sensitivity Distribution
TDS	Total dissolved solids
The Proposal	The ESSP (Project) at the proposal stage.
WET	Whole Effluent Toxicity
WL	Water level

Executive Summary

Leichhardt Salt Pty Ltd (Leichhardt) is seeking to develop the Eramurra Solar Salt Project (ESSP), a solar salt project east of Cape Preston, to extract an average of 5.2 Mtpa of concentrated salt product from seawater, using a series of concentration and crystalliser ponds and processing plant, transport corridor, stockpiling and export from the Cape Preston East Port (the Project). The concentration and crystalliser ponds will be located on Mining Leases. Disturbance of no more than 12,201 hectares (ha) within the 20,160 ha Ponds Development Envelope is proposed. It is estimated that up to 5.9 GL/a of bitterns will be discharged near the channel and berth pocket.

O2 Metocean (O2Me) was engaged by Leichhardt to develop a hydrodynamic modelling program to support the environmental impact assessment of the ESSP according to the Environmental Scoping Document (ESD, Preston Consulting 2022), including modelling of the bitterns discharge to identify potential impacts to Benthic Community Habitats (BCH) and inform the preparation of a marine monitoring plan. The purpose of this report is to present the bitterns dispersion modelling study which results will support the evaluation of the effects of Project attributable changes on the Key Environmental Factors 'Benthic Communities and Habitats' (BCH), 'Marine Environmental Quality' identified in the ESD as well as 'Marine Fauna'.

O2Me adopted a nested approach to hydrodynamic modelling where boundary conditions (fluxes and water levels) for the local three-dimensional (3D) bitterns dispersion model were extracted from a regional, also 3D, hydrodynamic model described in O2Me (2022a). Surface stress and barometric pressure fields were extracted from the European Centre for Medium-Range Weather Forecasts ERA5 model. A high-resolution Digital Elevation Model (DEM) was developed for this study from six (6) independent datasets, including high resolution bathymetry and LiDAR data gathered for the ESSP.

Far-field modelling was conducted using DHI Group MIKE Flow Model (FM) suite of models. The study first considered an ocean outfall refinement phase which investigated the following parameters:

- Discharge rates
- Salinity content of the bitterns
- Pre-dilution
- Location of the diffuser
- Diffuser length and nozzles
- Diffuser orientation
- Discharge regime

Through analysis of the far-field modelling results by a panel of specialists consisting of Environmental Engineers, Marine Scientists, Environmental Approval Specialists, Coastal Engineers, and Process Engineers, the preferred outfall design was identified and adopted for the production runs that would feed into the Environmental Impact Assessment (EIA) and cumulative loss assessment of the ESSP. Further improvements were made to the proposed ocean outfall, such as a reduction of the bitterns discharge flow rate relative to the originally planned design. Leichhardt's preferred ocean outfall configuration for EIA is summarised in Table 15. The number of bitterns dilutions that could be achieved with a range of outfall configurations in the near-field and prior to mixing being primarily driven by the natural processes of Regnard Bay, were estimated with a near-field model. CORMIX was the selected software for this application. Results from the near-field model informed the adjustment of the far-field model set up.

Two far-field production simulations were conducted, representing a summer/wet season and winter/dry season discharge scenarios (defined in Table 7) for Leichhardt's preferred ocean outfall configuration for EIA. All key input parameters for the two production runs are summarised in Table 15.

In the absence of a bitterns product, a surrogate was adopted from the solar salt processing facility at Onslow (O2M 2019). The dilution requirements for moderate and high level of ecological protection were set to 321- and 509-fold, respectively.

Dilution contours around the proposed outfall structure that meet the moderate and high Level of Ecological Protection (LEP) were obtained for typical wet/summer and dry/winter seasons.

The largest areal impact (66 ha) that would result in between 90% to 99% species protection level (SPL) occurs in the wet/summer season, and the largest areal impact (63 ha) that would result in <90% SPL also occurs in the wet/summer season. Both areas contain the small existing Low LEP area defined for Cape Preston East Iron-Ore Export Facilities (DWER 2019). The LEP boundaries derived from this study will be used to inform the EIA of the ESSP.

This study satisfies the requirements set out in the Environmental Scoping Document (ESD) items 9, 52 (Preston Consulting 2022).

A formal EIA was excluded from this report.

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1. Introduction

1.1. Project Overview

Leichhardt Salt Pty Ltd (Leichhardt) is seeking to develop the Eramurra Solar Salt Project (ESSP), a solar salt project east of Cape Preston, approximately 55 km west-southwest of Karratha in the Pilbara region of WA (Figure 1). The Proposal will be implemented (with necessary connecting infrastructure) within three Development Envelopes shown in Figure 2. The Proposal will utilise seawater and natural solar evaporation processes to produce a concentrated salt product. An average production rate of 5.2 Million tonnes per annum (Mtpa) is being targeted with up to 6.8 Million tonnes (Mt) of salt deposited in a low rainfall year. The following infrastructure will be developed:

- Seawater intake, pump station and pipeline
- Concentration ponds totalling approximately 10,060 hectares (ha)
- Crystallisers, totalling approximately 1,840 ha
- Drainage channels and bunds
- Process plant and product dewatering facilities
- Water supply (desalination plant)
- Bitterns disposal pipeline and outfall
- Power supply and power lines
- Pumps, pipelines, roads, and support buildings including offices and communications facilities
- Workshops and laydown areas
- Landfill, and
- Other associated infrastructure.

A short summary of the Proposal is provided in Table 1.

Table 1: Short Summary of the Proposal

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

The export of salt is proposed to be via a trestle jetty. The jetty and associated stockpiles will be located at the Cape Preston East Port approved by Ministerial Statement (MS) 949. Dredging will be undertaken as part of this Proposal to remove high points at the Cape Preston East Port. Dredged material will either be disposed of at an offshore disposal location, or onshore within the Ponds and Infrastructure Development Envelope. The Cape Preston East Port jetty and associated stockpiles are excluded from the ESSP. The ESSP will produce a salt concentrate according to the following processes:

- Seawater will be pumped into the first concentration pond and commence progressive concentration by solar evaporation as it flows through successive concentration ponds
- Salt is deposited onto a pre-formed base of salt in the crystallisers
- Salt will be removed from the drained crystallisers by mechanical harvesters and stockpiled adjacent to the processing facilities
- Salt will be trucked to the trestle jetty approved by MS 949 for export, and
- A maximum of 5.9 Gigalitres (GL) of bitterns (at 410 parts per thousand (ppt) salinity) will be generated in any given year and up to 0.65 GL (at 410 ppt salinity) in a peak summer month. The bitterns will be diluted 1:1 volume ratio with local seawater prior to discharge via an ocean outfall diffuser within the Marine Development Envelope.

The Proposal may be developed in its entirety, or the East concentration ponds may be developed at a later stage. Table 2 outlines the extent of the physical and operational elements of the ESSP.

Table 2: Location and proposed extent of physical and operational elements

Element	Location	Proposed Extent
Physical Elements		
Pond and Infrastructure Development Envelope – Concentration ponds and crystallisers. Process plant, desalination plant, administration, water supply, intake, associated works (access roads, laydown, water supply and other services).	Figure 2	Disturbance of no more than 12,201 ha within the 20,160 ha Ponds Development Envelope.
Marine Development Envelope – Seawater intake and pipeline, dredge channel, bitterns pipeline, outfall diffuser and mixing zone.	Figure 2	Disturbance of no more than 53 ha within the 703 ha Marine Development Envelope.
Dredge Spoil Disposal Development Envelope – Disposal location for dredge spoil.	Figure 2	Disturbance of no more than 100 ha within the 285 ha Dredge Spoil Disposal Development Envelope.
Operational Elements		
Bitterns discharge	Figure 2	Discharge of up to 5.9 Gigalitres per annum (GL/a) of bitterns within a dedicated offshore mixing zone within the Marine Development Envelope
Dredge Volume	Figure 2	Approximately 400,000 m^3

O2 Marine was engaged by the proponent to undertake marine environmental investigations to help identify environmental risks of the ESSP, establish baseline conditions, help facilitate the environmental approvals process, and guide appropriate monitoring and management to minimise potential impacts to the marine environment during construction and operations.

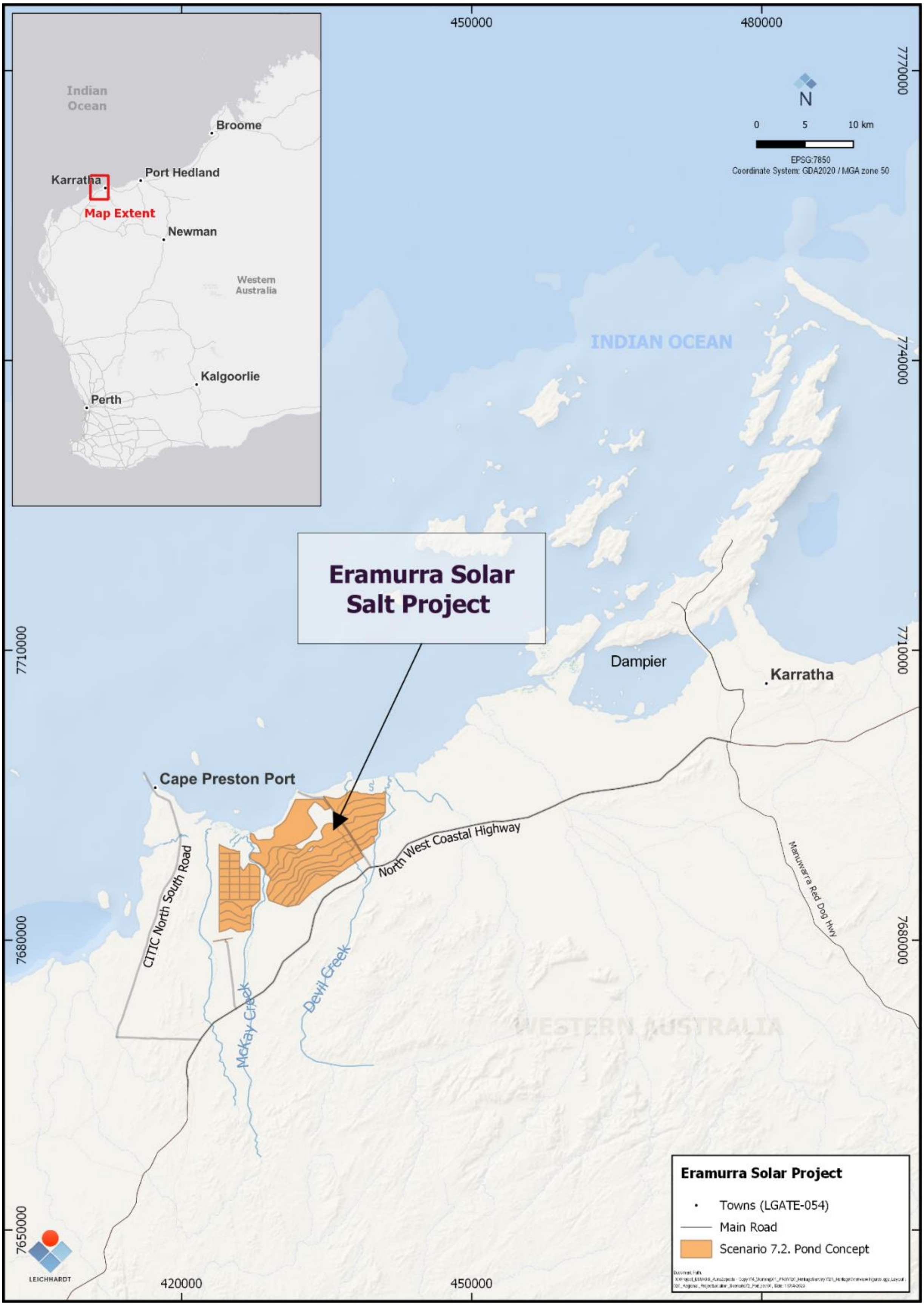

Figure 1: Regional location of the Proposal

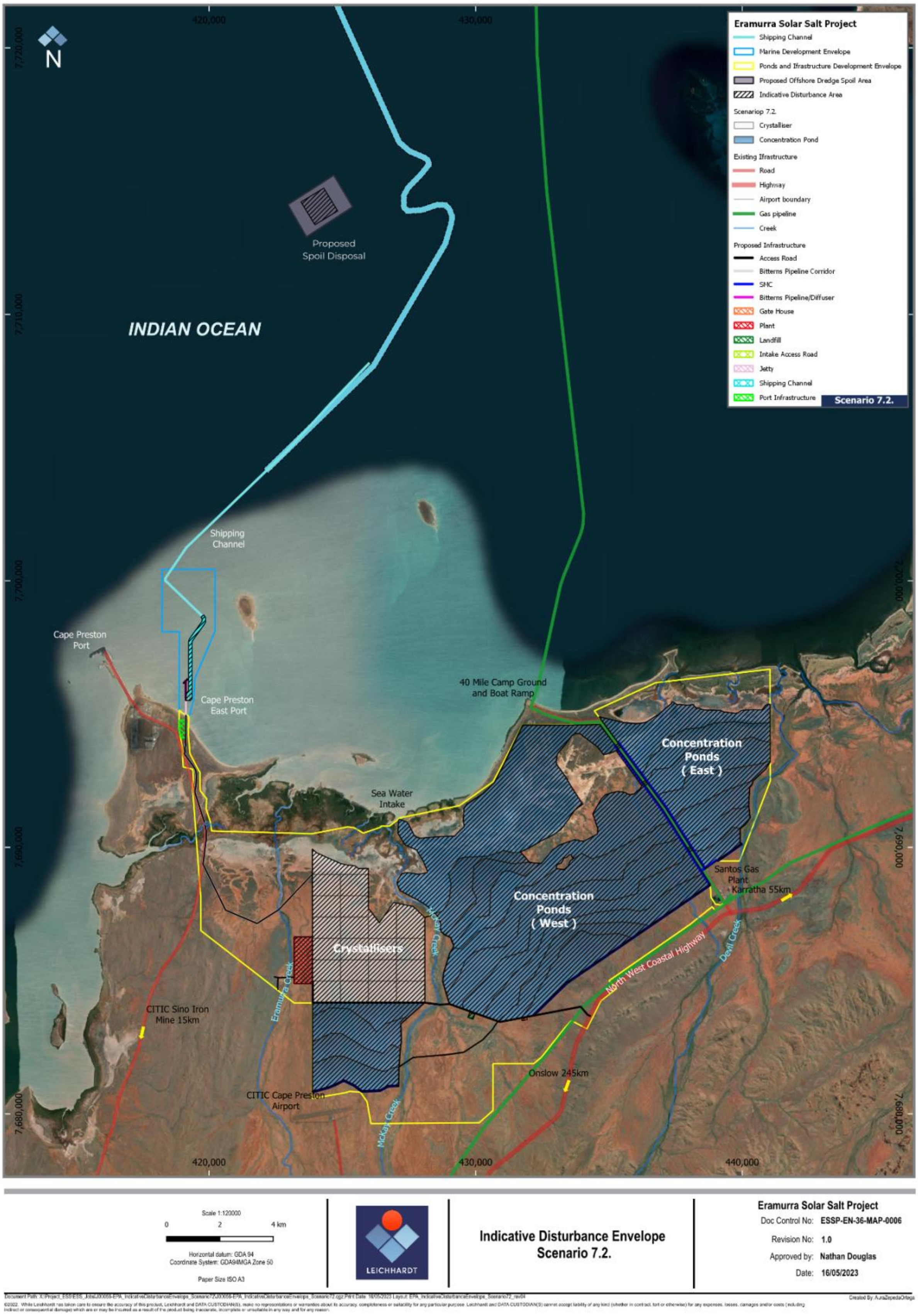

Figure 2: Development Envelopes

1.2. Purpose

The need for a bitterns outfall hydrodynamic modelling study is outlined in Items 9 and 52 of the Environmental Scoping Document (ESD) (Preston Consulting 2022) (Table 3).

Table 3: Work required for the assessment of the ESSP related to bitterns outfall discharge

ESD Item Number	Environmental Factor	ESD Scope Description
9	Benthic Community and Habitats (BCH)	Undertake a bitterns outfall modelling study, utilising local conditions (bathymetry and metocean conditions) together with published bitterns ecotoxicity concentrations to determine an appropriate discharge regime required to minimise detrimental effects to sensitive BCH;
52	Marine Environmental Quality	Undertake a bitterns outfall modelling study, utilising the hydrodynamic model together with published bitterns ecotoxicity concentrations to determine an appropriate discharge regime required to achieve the spatial levels of ecological protection defined in the proposed Marine Environmental Quality Monitoring and Management Plan (MEQMMP) described below. The modelling will utilise local conditions (bathymetry and tides) to determine: a. Dilution contours around the outfall, using several outfall designs if required b. Dilution that can be achieved by discharge velocity alone (no underlying currents) c. Predicted mixing zones required to meet the level of ecological protection of the waters surrounding the mixing zone.

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

1.3. Objective

The objectives of this report are to:

1. Address Item 9 of the ESD by identifying an appropriate discharge regime, outfall location, and outfall conceptual design that would minimise detrimental effects to sensitive BCH [i.e. an options assessment for the outfall]
2. Address Item 52a and 52c of the ESD by deriving dilution contours around the proposed outfall structure that meet the Level of Ecological Protection (LEP) of the waters surrounding the mixing zone to inform the EIA of the ESSP

3. Address Item 52b of the ESD by undertaking a near-field mixing study
4. Provide information to support the preparation of a Marine Environmental Quality Monitoring and Management Plan (MEQMMP) for the bitterns outfall.

An additional objective, not specifically listed in the ESD but requested by Leichhardt, was to evaluate the potential for recirculation between the bitterns outfall and intake for bitterns pre-discharge dilution, as excess contaminant in this intake stream may affect the required pre-discharge dilution.

1.4. Scope of Work

This report deals with the numerical assessment of the bitterns discharge. A bitterns dispersion modelling study based on the superseded ESSP pond layout scenario 6.2 and associated bitterns discharge regime was completed by O2Me on behalf of Leichhardt in February 2023. In response to Leichhardt's decision to revise the project layout to scenario 7.2, Leichhardt engaged O2Me to:

"Revise the bitterns dispersion modelling to account for changes arising from the new pond footprint and local bathymetry survey to meet the requirements relating to Benthic Communities and Habitats and

Marine Environment Quality in the Environmental Scoping Document (ESD) for the Eramurra Solar Salt

Project (ESSP)".

O2Me's approach to delivering the work was to:

- Define the dilution requirements to meet environmental quality objectives (EQO) as per EPA (2016a)
- Refine the validated hydrodynamic model of Regnard Bay (O2Me 2022a) for use in the assessment of far-field dilution of bitterns associated with the ESSP ocean outfall
- Conduct a 3D far-field numerical assessment of the bitterns discharge to:
  - Identify a suitable discharge configuration, site, and regime that would meet the LEP of the waters surrounding the mixing zone
  - Compare the modelling predictions against the guidance of EPA (2016b)
- Develop a near-field outfall mixing model to recommend the preliminary design of the outfall diffuser and evaluate the mixing associated with the outfall design.

1.5. Exclusions and Limitations

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

- Assessment of impacts to BCH
- Assessment of impacts to Marine Fauna
- Assessment of impacts to marine water quality
- Whole effluent toxicity (WET) testing.

1.6. Definitions and Conventions

'**Mixing**' is the physical process responsible for the scattering of particles or a cloud of diluted contaminants by the combined effect of shear and transverse diffusion, a process which causes one parcel of water to be mingled with or diluted by another.

‘**Mixing zone**’ is the area around the ocean outfall where a certain environmental quality criterion is exceeded.

‘**Near-field mixing**’ is a fluid dynamics concept used to describe the mixing that occurs due to the characteristics of the discharge, often based on the dominant mixing processes of a jet or plume.

A ‘**jet**’ is driven by the momentum of the discharge, whereas a ‘**plume**’ is driven by the potential energy of the discharge providing the fluid with a positive or negative buoyancy relative to its surroundings (Fischer et al. 1979).

The ‘**end of the near-field**’ is the point where mixing ceases to be dominated by differential momentum or buoyancy between the discharge and receiving environment and mixing by background turbulence begins to take over. There is no objective definition for the end of the near-field, and it cannot be resolved by a near-field only model. Numerical models that resolve jet and plume mixing dynamics are referred to as ‘**near-field models**’.

‘**Far-field mixing**’ is also a fluid dynamics concept that describes the mixing and transport of the discharge, away from the near-field, primarily due to natural processes (ambient hydrodynamics). Hydrodynamic models that solve the unsteady Reynolds-averaged Navier Stokes (RANS) equations of mass and momentum, incorporating non-hydrostatic and baroclinic pressure gradients, Coriolis effects, etc. are one type of ‘**far-field model**’.

‘**Dilution factor**’ (D) is the volumetric factor by which the volume of a sample (bitterns) is diluted (with seawater). As will be described in Section 4, the environmental protection of marine ecosystems is defined in terms of species protection levels (SPL) often linked to a particular target concentration of a constituent. For a conservative (non-reactive) tracer, the dilution factor *‘D’* can be calculated as follows:

Equation 1: $$D = \frac{C_{brine} - C_{target}}{C_{target} - C_{background}}$$

Here, C_{brine} is the content of a substance present in the brine, C_{target} is the target concentration of that substance to meet the required SPL, and $C_{background}$ is the concentration of that substance in the receiving environment. The dilution factor is often reported as “1:D”, meaning 1-part of sample to D-parts of dilutant.

Salinity is reported in either ppt when referring to bitterns absolute salinity, or in practical salinity units (PSU) when discussing the modelled behaviour of the bitterns upon discharge. PSU is a dimensionless quantity defined in terms of the electrical conductivity of seawater, which is a proxy for an absolute measure of the concentration of dissolved salts. The relationship between absolute and practical salinity is discussed in Section 5.3.3.

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

- usage in preceding Sections (e.g. Section 1.1, prior to introduction of this convention)
- when describing direction within a header
- when describing a proper noun (such as ‘Southwest Regnard Island’ or ‘Southwest Trade Winds’)
- when describing the direction that is not related to measured data or metocean parameters (such as describing a location for example ‘southern Australia’).

1.7. Reports of Relevance

Reports listed in Table 4 have been prepared to address specific items identified in the ESD by means of hydrodynamic modelling. A base hydrodynamic model (O2Me 2022a) capable of reproducing ambient waves, currents, and water levels E of Cape Preston was validated with locally acquired data (O2Me 2022b; 2022c). The base model was then adjusted to answer specific questions related to the EIA of the ESSP, namely:

- Dredge and dredge disposal plume dispersion modelling to assist with the assessment of impacts to BCH (O2Me 2023a)
- Bitterns discharge plume dispersion modelling to assist with the assessment of impacts to water quality (O2Me 2023b)
- Tidal inundation changes to assist with the assessment of impacts to inter-tidal habitats (O2Me 2023c)
- Coastal re-adjustments post ESSP development using the tidal inundation model to assist with the assessment of impacts to BCH (O2Me 2022d; 2023d).

Table 4: O2 Metocean (O2Me) reports of relevance.

Report number	Report title	Intext reference
R210323	ESSP: Base Hydrodynamic Model	O2Me 2022a
R200219	ESSP: Metocean Field Data Collection Programme: Data Report	O2Me 2022b
R210389	ESSP: Metocean Data Interpretation Report	O2Me 2022c
R210391	ESSP: Coastal Process Study to Support BCH Assessment: ESSP Scenario 6.2	O2Me 2022d
R210324	ESSP: Dredge Plume Modelling	O2Me 2023a
R210325[1]	ESSP: Bitterns Dispersion Modelling	O2Me 2023b
R210327	ESSP: Tidal Inundation Modelling	O2Me 2023c
R220181	ESSP: Coastal Processes Assessment: ESSP Scenario 7.2	O2Me 2023d

[1] This report

2. Background

2.1. Oceanographic Context

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

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

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

2.2. Ambient Currents

Leichhardt engaged O2Me to implement a metocean data collection programme to gather local oceanographic data (currents and waves) with the objectives of:

- Calibration of ambient wave and current modelling
- Validation of extreme events modelling (waves and current)
- Provision of support for operability studies
- Provision of support for coastal infrastructure design
- Provision of support for environmental approvals.

The locations of the six measurement sites are depicted in Figure 4. Site NCP05 was positioned near the proposed mooring berths and outfall structure. Data from NCP05 can therefore be used to characterise the ambient current conditions at the point of the bitterns discharge. The summary statistics for depth-averaged current speeds at NCP05 are presented in Table 5.

Table 5: Annual depth-averaged current speed at NCP05

Percentile	Depth Averaged Current Speed at NCP05
99th	0.35 m/s
95th	0.29 m/s
80th	0.21 m/s
50th	0.12 m/s
5th	0.02 m/s

Currents are primarily tidally driven (O2Me 2022c) and oriented NW-SE (and reversed) irrespective of the season (Figure 3).

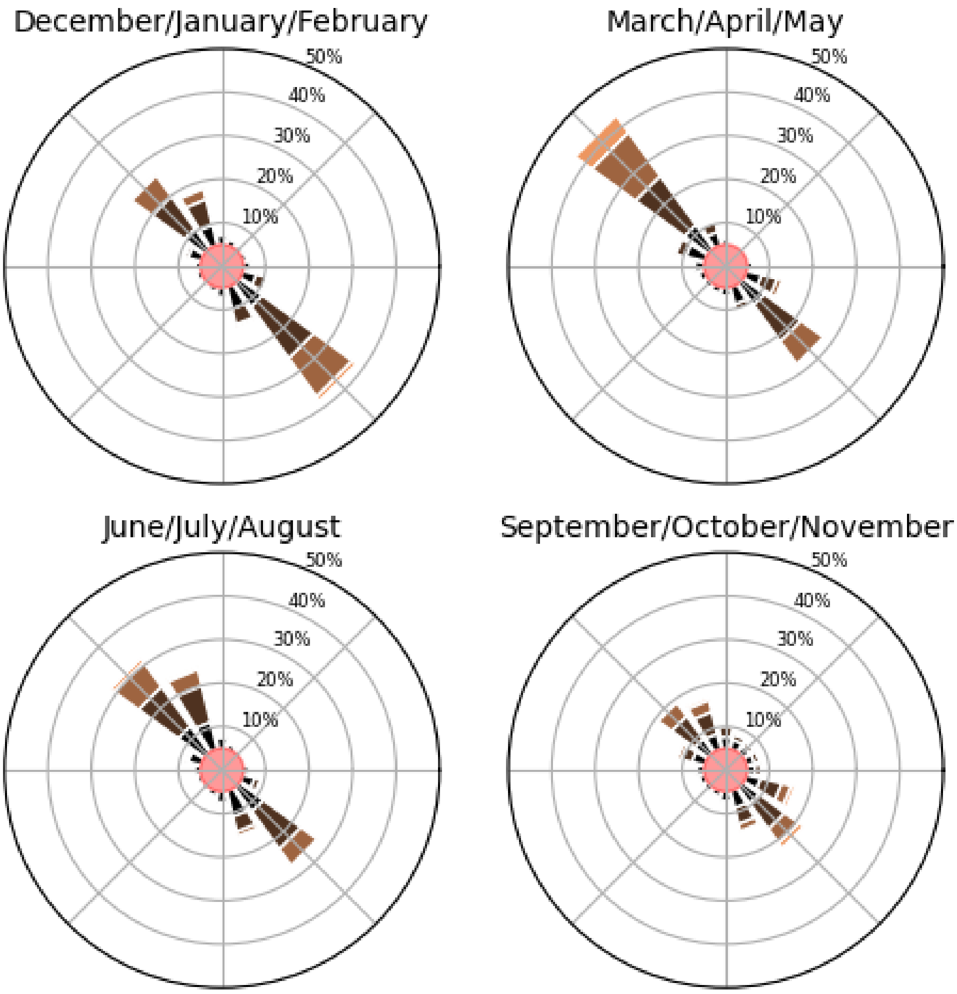

Figure 3: Seasonal current plots at NCP05 (source: Figure 13 in O2Me 2022c)

Figure 4: Oceanographic and creek measurement sites (source: Figure 10 in O2Me 2022b)

2.3. Ambient Temperature and Salinity

Approximately a year of temperature and salinity data were recorded at two locations in Regnard Bay (NCP05 and UNS05), with summary statistics for these locations presented in O2M (2022). Background temperature and salinity were taken as the median seasonal values for the location that was closest to the bitterns discharge location (NCP05). Table 6 indicates the seasonality of temperature and salinity adopted herein.

Table 6: Seasonality in ambient temperature and salinity.

Parameter	Units	Season	
		Summer / Wet	Winter / Dry
Temperature	°C	29.5	24.7
Salinity	PSU	35.1	35.4

3. Bitterns Discharge

3.1. Properties of the Bitterns

The characteristics of the undiluted bitterns projection are summarised in Table 7.

Table 7: Bitterns Generation Overview

Parameter	Units	Specification
Density	kg/m^3	1,290
Absolute Salinity (winter and summer)	ppt	410
Maximum annual discharge	GL/a	5.9
Peak **summer** discharge rate	GL/m	0.65
Peak **winter** discharge rate	GL/m	0.37
Summer discharge temperature	°C	30
Winter discharge temperature	°C	20

3.2. Diffuser Design Constraints

Preliminary analysis of the values in Table 7 (and its superseded versions) revealed a single-point discharge structure would not be a viable design to protect the marine environment: the salt content would be too high around the discharge point and over a large area. In consultation with O2Me, Leichhardt determined that the outfall structure would consist of a multi-port diffuser. Further, Leichhardt advised that the diffuser should preferably be placed North of the jetty structure, oriented S-N and contained within the ESSP's marine development envelope in its entirety.

For conceptual design purposes, O2Me and Leichhardt agreed to impose a maximum nozzle discharge velocity of 7 m/s to all nozzles (i.e. ports) in the diffuser. The maximum discharge velocity applies only to the relatively narrow nozzles at the point of discharge and not to the velocity in the main discharge pipeline which will be determined during detailed hydraulic design. Although chosen arbitrarily, exit velocities of 7 m/s usually result in adequate near-field mixing and are not expected to cause cavitation or create a nozzle scour risk (BMT WBM 2013; GHD 2013). As there is little information on the hydraulic design of the system (pumping station, pipeline type and diameter, etc.), attempts have been made to shorten the diffuser length to ≤ 200 m and minimise the number of nozzles since extraordinary long diffusers with many nozzles can lead to undesired head losses and consequently expensive pumping stations.

The remaining free design parameters were:

a. Location of the diffuser relative to the ESSP marine envelope

b. Orientation of the diffuser relative to the predominant current directions

c. Port discharge height above the seabed

d. Angle of the discharge relative to the horizontal and vertical (azimuth) planes

e. Number of nozzles and nozzle spacing (indirectly resulting in total diffuser length)

f. Nozzle diameter.

Should the bitterns be diluted with ambient seawater prior to discharge, the seawater would be extracted from an intake structure mounted on the proposed jetty. The intake structure should minimise any potential outfall-to-intake short-circuiting.

4. Dilution Requirements for Ecological Protection

4.1. EPA guidance

The EPA (2016b) provides a framework for protecting the quality of Western Australia's marine environment via processes to spatially define, assess, and manage potential impacts of proposals on marine environmental quality. One of the processes relevant to this report is the spatial designation of the area around the outfall into four LEPs:

1. Maximum
2. High
3. Moderate
4. Low.

The EQOs for the ESSP will be to maintain specific levels of ecological protection within defined zones close to the project infrastructure. These zones are currently being defined, though the EPA Technical Guidance Protecting the Quality of Western Australia's Marine Environment (EPA 2016b), provides the following guidance:

*A **moderate level** of ecological protection may be applied to relatively small areas within inner ports and adjacent to heavy industrial premises where waste discharges and contamination from current and/or historical activities may have compromised a high level of ecological protection. It may also be used to accommodate any accumulation of contaminants from anti-foulant paints, typically extending up to 250 m from ship turning basins and berths.*

And:

*A **low level** of ecological protection should only be considered around wastewater discharge where the need can be technically justified. They should be as small as possible and linked to the zone of initial dilution where reasonably practicable to do so, usually extending no more than 70 m from the diffuser. These areas should be located within moderate ecological protection areas where available.*

4.2. Existing Levels of Ecological Protection

Through the approval of the Cape Preston East Iron-Ore Export Facilities proposal, a small Low LEP area associated to the proposal's wastewater discharge was defined. This area is shown in Figure 5.

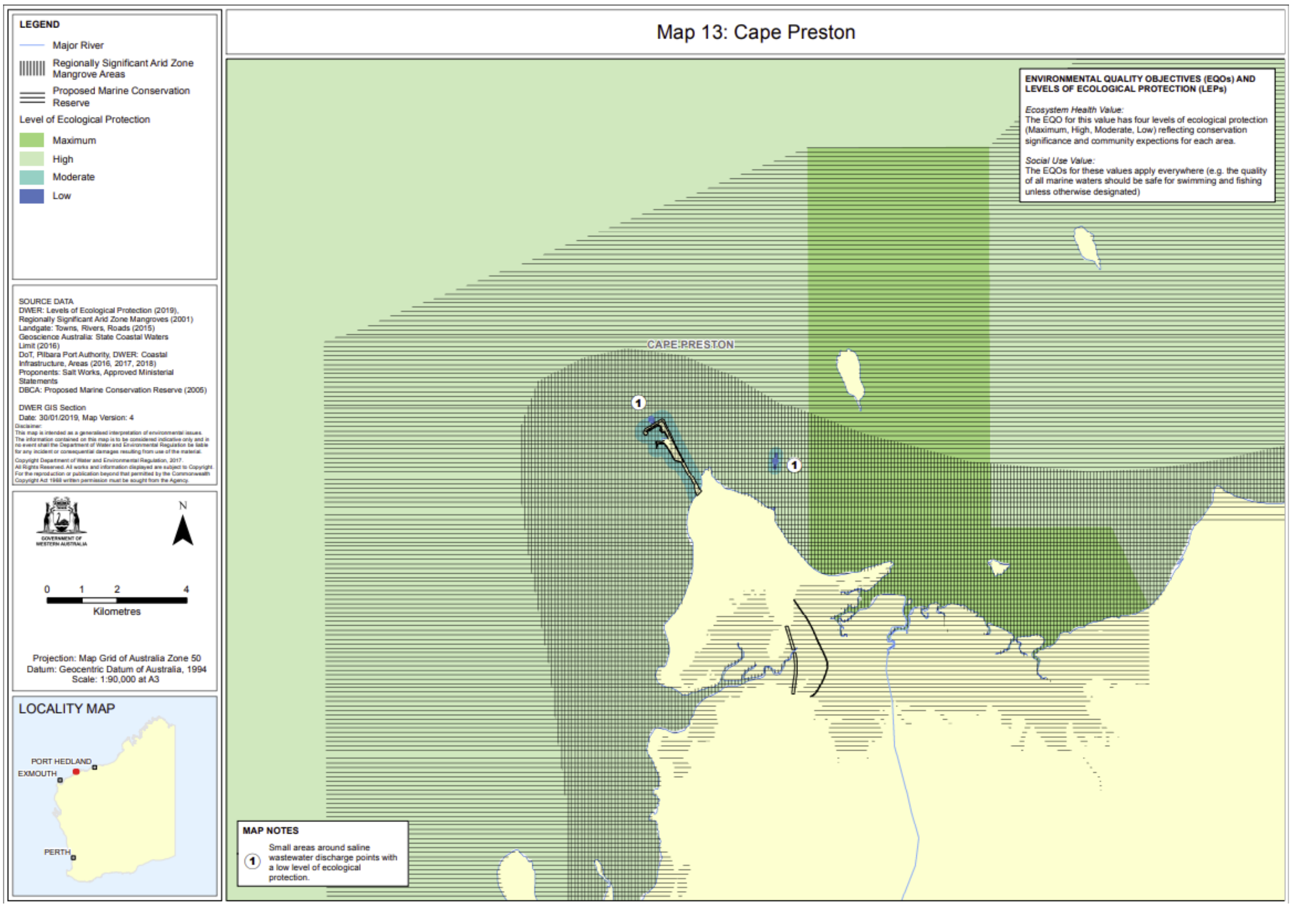

Figure 5: Department of Water and Environmental Regulation: Levels of Ecological Protection (Map13, Cape Preston) (Source: DWER 2019)

4.3. Dilution requirements

LEP are defined in terms of SPL with low, moderate, and high ecological protection defined as 80%, 90% and 99% levels of species protection, respectively. The Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG 2018) provide default guideline values for each SPL for numerous contaminants within a discharge. To use this approach requires modelling multiple constituents within the discharge to derive the number of dilutions required to meet the default guideline values for each contaminant, thus determining the spatial extent of the low, moderate and high levels of ecological protection.

An alternative approach commonly applied to an operational discharge is to derive SPLs relevant to the direct toxicity of the effluent being discharged, which is termed WET testing. This process examines the cumulative effect of the contaminants within the discharge on locally relevant species to provide a concentration that the effluent needs to be diluted to in order to meet SPLs. This approach requires modelling only a single output to measure the number of dilutions of the effluent to determine the spatial extent of the low, moderate and high levels of ecological protection. Methods for toxicity testing are provided in ANZG (2018).

In the absence of a bitterns product at the early EIA stage of a proposal, the toxicity of the proposed discharge bitterns must be estimated by conducting a WET test of a surrogate sample. WET testing was performed recently for approval of the Mardie Project, another solar salt proposal in the Pilbara approximately 40 km SW of the ESSP, using a surrogate bitterns collected from the solar salt processing facility at Onslow (O2M 2019). The surrogate sample provided to Ecotox Services Australia laboratory for analysis comprised a total dissolved solids (TDS) concentration of 420 g/L and a specific gravity of 1.25 at 25^{0}C, equivalent to an absolute salinity of 336 ppt. To estimate the ecotoxicity of the ESSP bitterns from the WET test results of the Onslow surrogate sample, it was assumed that toxicity scales linearly with TDS. Given that the TDS concentration expected in the ESSP bitterns is 529 g/L with a specific gravity of 1.29, yielding an absolute salinity of 410 ppt, a factor of 1.22 was applied to the dilution requirements derived for the surrogate sample.

A summary of the chronic tests undertaken on locally relevant species and toxicity results from the surrogate bitterns sample are presented in Table 8. The species sensitivity distribution (SSD) curve (±95% Confidence Intervals) developed using Burriloz 2.0 software from the chronic test results is shown in Figure 6. The SPLs derived using the species sensitivity distribution curve and the required dilutions to achieve moderate (90%) or high (99%) levels of ecological protection are presented in Table 8 (O2M 2019). Dilution requirements for the surrogate sample and those scaled by the 1.22 factor adopted for this study are tabulated in Table 9.

Table 8: WET assessment results for the proportion (%) of surrogate bitterns effluent resulting in the following observed effect concentrations: No-Observed Effect Concentration (NOEC), Lowest Observed Effect Concentration (LOEC), 50% (EC/IC 50%) and 10% (EC/IC 10%)

Test	Type	NOEC	LOEC	EC50/IC50	EC10/IC10
48-hr larval development test using the Milky oyster *Saccostrea echinata.*	Sub-chronic	0.31%	0.63%	0.70%	0.41%
8-day Sea anemone pedal lacerate development test using *Aiptasia pulchella*	Chronic	0.31%	0.63%	0.70%	0.43%
72-hr sea urchin larval development test using *Heliocidaris tuberculata*	Chronic	0.31%	0.63%	0.80%	0.55%
7-day fish imbalance toxicity test using barramundi *Lates calcarifer*	Chronic	1.25%	2.5%	1.81%	1.66%
7-day fish biomass toxicity test using barramundi *Lates calcarifer*	Chronic	0.63%	1.25%	1.70%	0.9%
72-hr marine algal growth test using *Nitzschia closterium*	Chronic	0.63%	1.25%	1.56%	0.73%

Table 9: Summary of dilution requirements adopted in this study

EQO: Level of ecological protection	SPL (%)	Estimated dilution (based on surrogate sample)	Dilution factor adopted for this study (1.22 x surrogate sample)
Moderate	90	263	321
High	99	417	509

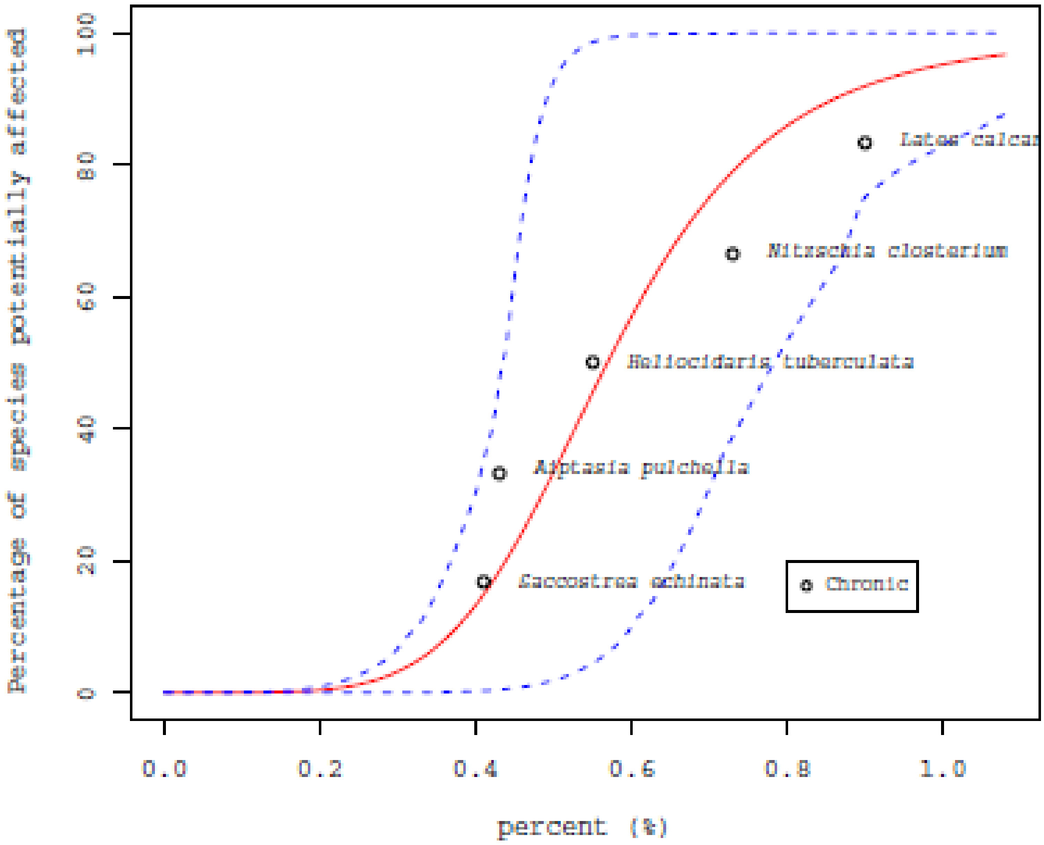

Figure 6: Burrlioz 2.0 Species Sensitivity Distribution (SSD) based on the chronic test results from the analysed bitterns effluent and the 95% Confidence Interval

5. Bitterns Dispersion Modelling

5.1. Overview

This section outlines the modelling approach that was adopted to simulate the dispersion of bitterns discharged in Regnard Bay.

Bitterns discharge modelling was undertaken using a combination of near-field and far-field commercial hydrodynamic numerical models. First, a near-field model was used to estimate the number of bitterns dilutions and the distance from the proposed outfall structure where the near-field dispersion process transitions into far-field mixing. Both the dilution and distance to far-field mixing processes were used to inform the vertical and horizontal discretisation of the far-field numerical mesh. An iterative process was adopted where results from the near-field model informed far-field model set up, and results from preliminary simulations of the latter were used to adjust the near-field model configuration.

The far-field model was established to refine the outfall configuration (site, orientation, length, depth), discharge regime (flow rate, pre-discharge dilutions, discharge patterns). A range of outfall configurations were proposed by a panel of multi-disciplinary specialists including Environmental Engineers, Marine Scientists, Environmental Approval Specialists, Coastal Engineers, and Process Engineers during regular workshops organised to discuss model test runs. O2Me adjusted the far-field model to represent these configurations, and results from each simulation informed subsequent far-field model runs until the preferred configuration was identified. The objective of this iterative process was to optimise the diffuser configuration and discharge regime such that areal footprint of the bitterns and its impact on corals and seagrass was minimised, where possible.

Two far-field 'production' simulations, one for the summer/wet and the other for winter/dry seasons, were run for the preferred outfall configuration and discharge regime to derive dilution contours around the proposed outfall structure that meet the LEP of the waters surrounding the mixing zone, in turn to inform the EIA of the ESSP.

5.2. Near-Field Model

Consistent with the conceptual phase of the ESSP, no specific outfall diffuser plans or specifications were provided (excluding those described in Section 3), particularly around hydraulics of the discharge. In the iterative approach implemented, the diffuser design was primarily driven by the environmental requirements addressed with the far-field modelling results, and no rigorous optimisation of the dilution potential of the selected diffuser was performed. The main purpose of the near-field assessment was to investigate the near-field mixing characteristics such that the outfall discharge could be appropriately parameterised in the far-field model.

The near-field assessment of the bitterns discharge was executed using the CORMIX model (Cornell Mixing Zone Model, Jones et al. 1996, Doneker and Jirka 2007). CORMIX is a rule-based analysis tool used for the prediction and design of outfall mixing zones that can result from the discharge of liquid pollutants into a water body. It is widely used for outfall design, with capacity to evaluate dilution and plume geometrical characteristics at different distances from the diffuser.

The CORMIX model consists of four different hydrodynamic models, namely:

- CORMIX1 for single port discharges

- CORMIX2 for multiport diffusers
- CORMIX3 for buoyant surface discharges
- DHYDRO for the analysis of dense and/or sediment discharges in coastal environments.

CORMIX2 was adopted for this study.

5.2.1. CORMIX Model Set Up

The bitterns will be denser than the receiving environment and will sink upon discharge. It is therefore favourable to point the discharge nozzles upward, at a vertical angle ranging from 50° to 70°, to extend the trajectory of the jet discharge prior to impacting the seabed, such that entrainment of ambient seawater into the discharge flow is maximised. Through the iterative processes adopted, it was determined that the 200 m long diffuser structure shall be placed perpendicular to the prevailing NW-SE tidal current direction with all nozzles pointing perpendicularly to the diffuser line (i.e. parallel to the prevailing currents). Though this arrangement may *a priori* seem unfavourable to maximise near-field mixing, it is the spreading of the proposed 21 ports over 200 m across the tidal current that makes the arrangement suitable to enhance mixing in the near-field.

The parameters used to define model cases in CORMIX include diffuser configuration, bitterns properties, and the characteristics of the ambient receiving environment, as outlined in Table 10.

Table 10: CORMIX model set up features. Bullet points are used to denote more than one value adopted for a particular parameter

Parameters / Features	Description
Effluent type	CORMIX parameterisation: Brine Discharge – Conservative Pollutant
Flow rate	• 0.65 GL/m (0.251 m^3/s) – peak summer month • 0.37 GL/m (0.143 m^3/s) – peak winter month
Discharge concentration (excess)	Difference between outfall salinity (Table 7) and background salinity (Table 6)
Pre-dilution	• No pre-dilution • Pre-dilution of 1:1 (volume : volume)
Discharge depth	-7.5 m MSL
Ambient velocity	Based on the range of modelled current speeds that the discharge will be in operation (Table 5). Whilst different percentiles of current speed were used in this investigation, the 50th percentile current condition (0.12 m/s) is most appropriate for 'predominant' conditions.
Darcy-Weisbach Friction Factor	0.02
Geometry	Multiport diffuser with alternating nozzles
Diffuser length	• 200 m • 50 m
Diffuser distance from nearest bank to diffuser mid-point	1,200 m (approximate distance to centre point)
Diffuser port height	1 m

Parameters / Features	Description
Total number of ports	• 21 for a 200 m long diffuser • 10 out of 21 ports open in a 200 m long diffuser • 6 for a 50 m long diffuser
Diffuser port diameter	• 0.050 m - diameter that achieves a max. exit velocity of ~7 m/s during peak summer month discharged without any pre-dilution, for 21 ports (see Section 3.2) • 0.075 m - diameter that achieves a max. exit velocity of ~7 m/s during peak winter month discharge diluted 1:1 by volume, for 21 ports • 0.087 m
Discharge velocity	Ranging from 3.5 to 7 m/s depending on flow rate and nozzle size
Diffuser port orientation	• Single port per riser • Alternating ports, perpendicular to diffuser structure • 50°, 60°, 70° Vertical angle of discharge

The diffuser geometry adopted in CORMIX for the 200 m long diffuser with 21-ports is shown in Figure 7. A close up image of the 1 m risers and ports is provided in Figure 8.

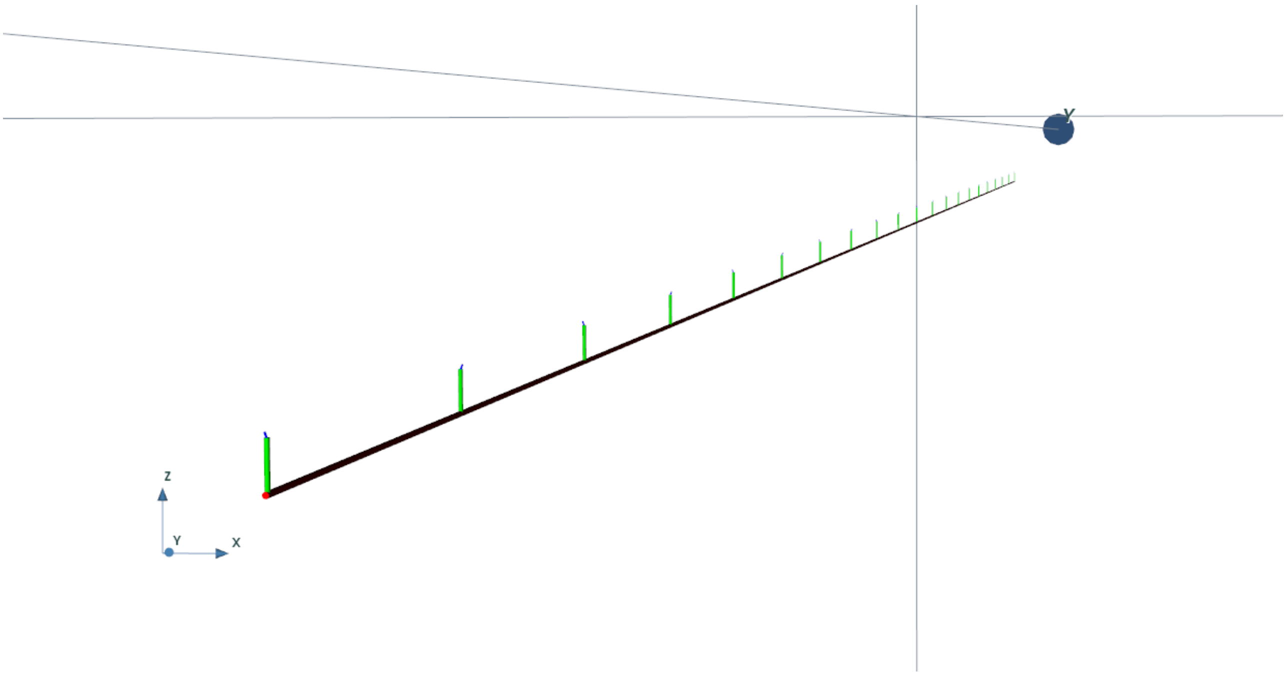

Figure 7: 200 m long diffuser geometry used in CORMIX

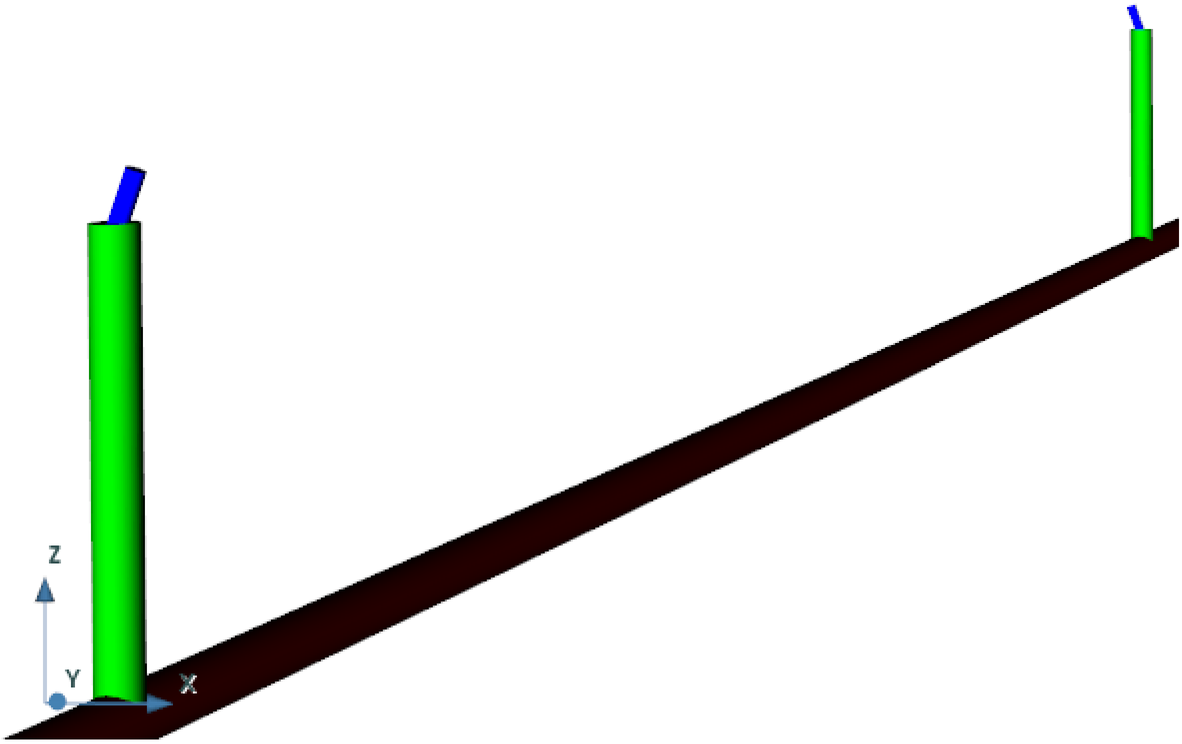

Figure 8: Close up of two adjacent risers and nozzles distanced 10 m along the diffuser, as used in CORMIX

5.2.2. CORMIX Model Results

The behaviour of the peak summer and peak winter bitterns discharge cases under the 50th, and 99th percentile current conditions and for the range of parameters presented in Table 10 are summarised in Table 11, as modelled by CORMIX. The maximum jet height reported by CORMIX was 2 m from the tip of the discharge point (not shown). After reaching its maximum height the jet commenced its descent due to it being heavier than the surrounding water, entraining ambient water in its descent until collapsing onto the seabed within < 10 m from the point of discharge, independently of the background currents or discharge flow considered. A typical bitterns discharge trajectory is shown in Figure 9 for case NF08 (Table 11). The dilution factor versus horizontal distance from the point of discharge for the same example is reproduced in Figure 10.

The bitterns dilution factor exceeded 26-fold at the edge of the near-field for all cases which considered a 5 cm nozzle diameter and no predilution. When a 1:1 pre-dilution by volume was accounted for (Cases NF08a to NF14a), both the 7.5 and 8.7 cm nozzle diameters achieved similar dilutions in the near field (>10-fold) during relatively calm conditions (0.12 m/s background currents), and >35-fold in ~0.35 m/s currents. Selection of the preferred nozzle diameter (i.e. ~8.7 or ~7.5 cm) shall consider factors not accounted for in this assessment such as the potential for erosion of the nozzles and precipitation of substances carried in the bitterns within the diffuser structure.

These CORMIX results suggest that:

- Near-field mixing is considerably suppressed beyond ~7 m from the point of discharge, hence:
- The length scale of the smallest far-field model grid size around the diffuser should be ~10 m, and
- In the far-field modelling set up, the bitterns discharge should be distributed over the bottom 2 horizontal layers (approximately the bottom 2 m).

Table 11: Configurations adopted for near-field modelling

Case	Diffuser Length & (Number of ports)	Season	Pre-dilution (vol.:vol.)	Port diameter cm	Port Discharge Velocity m/s	Port vertical angle °	Ambient current m/s	CORMIX distance from discharge to contact with seabed m	CORMIX dilution at point of contact with seabed fold	CORMIX dilution at end of near-field fold
NF01	200 (21)	Peak summer	No-predil.	5.0	6.08	50	0.12	< 3	18	26
NF02	200 (21)	Peak summer	No-predil.	7.5	2.70	50	0.12	< 3	9	12
NF03	200 (21)	Peak summer	No-predil.	5.0	6.08	60	0.12	< 3	18	26
NF04	200 (21)	Peak summer	No-predil.	5.0	6.08	70	0.12	< 3	19	28
NF05	200 (21)	Peak summer	No-predil.	5.0	6.08	70	0.35	5	54	77
NF06	200 (21)	Peak winter	No-predil.	5.0	3.46	70	0.35	< 3	47	66
NF07	50 (6)	Peak summer	No-predil.	8.7	7.00	70	0.35	4	28	40
NF08a	200 (21)	Peak summer	1:1	7.5	5.41	70	0.35	6	50	71
NF09a	200 (21)	Peak summer	1:1	8.7	4.02	70	0.12	< 3	13	19
NF10a	200 (21)	Peak summer	1:1	7.5	5.41	70	0.12	< 3	10	13
NF11a	200 (21)	Peak winter	1:1	7.5	3.08	70	0.35	4	38	54
NF12a	200 (10) (*)	Peak winter	1:1	7.5	6.46	70	0.35	7	54	77
NF13a	200 (21)	Peak winter	1:1	7.5	3.05	70	0.12	< 3	13	19
NF14a	200 (21)	Peak winter	1:1	8.7	2.29	70	0.12	< 3	10	15

(*) Case NF12a assumes 11 of the 21 nozzles can be closed during operations.

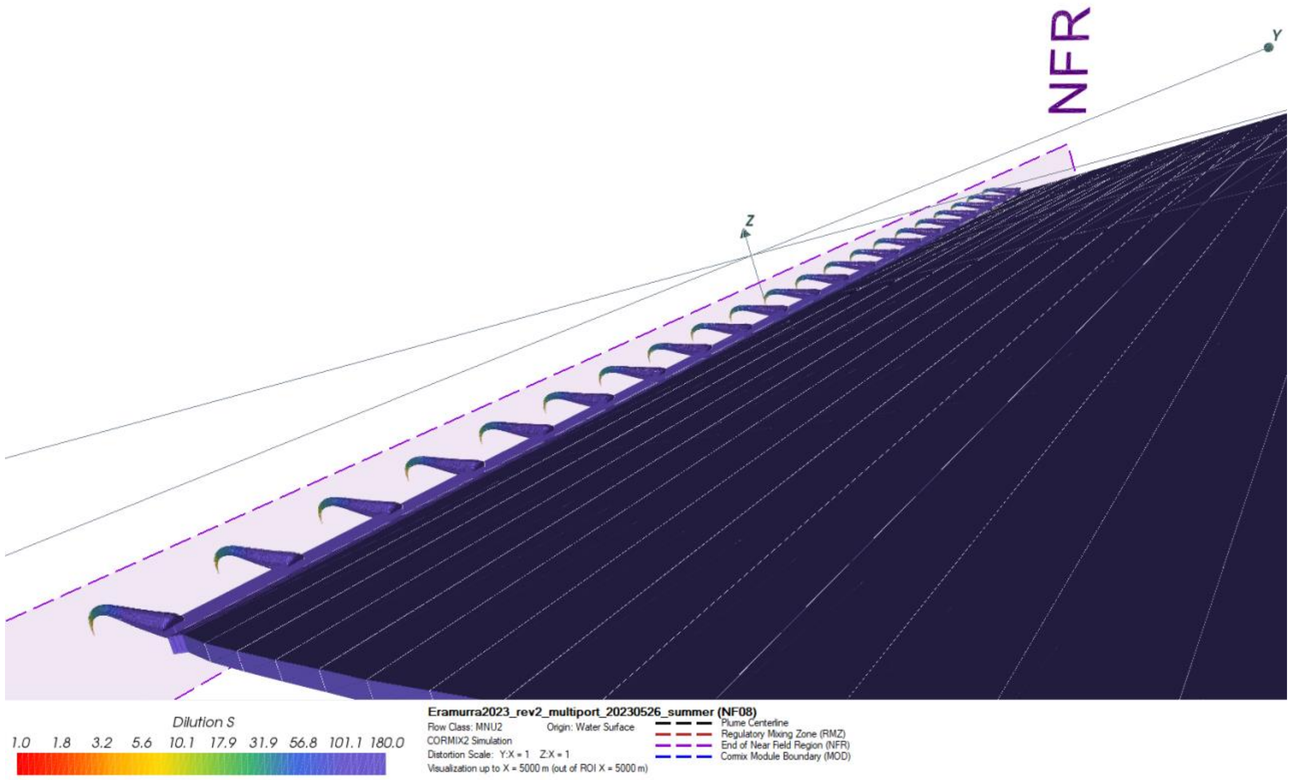

Figure 9: CORMIX predicted bitterns dilution and discharge trajectory for case NF08a (Table 11)

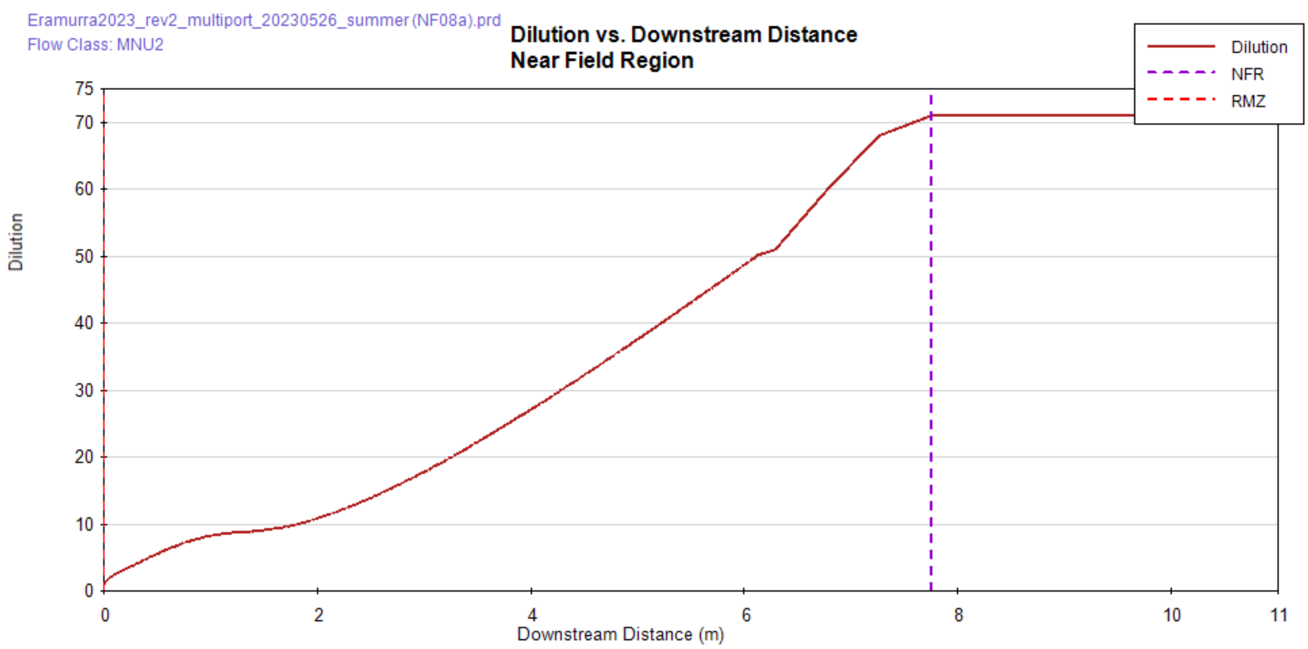

Figure 10: Bitterns discharge dilution versus downstream distance for case NF08a (Table 11)

5.3. Far-Field Model

O2Me adopted a nested approach to far-field hydrodynamic modelling, where boundary conditions to a local 3D bitterns transport model were extracted from a regional hydrodynamic model. Modelling was conducted using the DHI Group MIKE 3D FM/HD suite of models. The DHI MIKE FM hydrodynamic (HD) module 3D with 5 sigma layers was selected for this application (DHI 2023). Sigma layers were not evenly distributed, with higher resolution at the seabed being preferred (bottom two layers each occupying just 10 % of the water column).

5.3.1. Regional model

Boundary conditions for the 'local' numerical mesh used in the bitterns discharge dispersion model were extracted from O2Me's Adapted Pilbara model (Figure 11) – also referred to as 'Regional model', described fully in O2Me (2022a). For details on the underlying equations and assumptions, model set up, and hydrodynamic model validation, the reader is referred to O2Me (2022a).

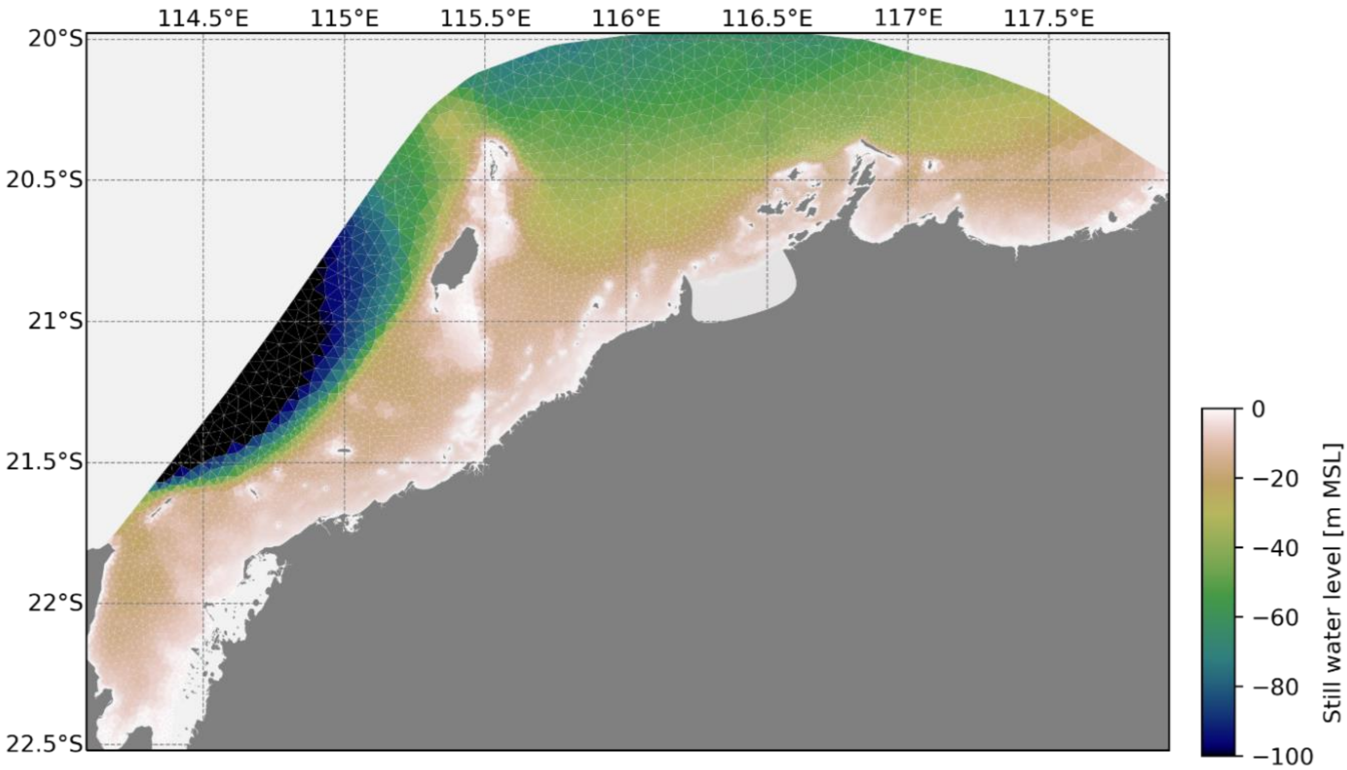

Figure 11: Numerical mesh of the Pilbara tidal model (O2Me 2022a) used to derive boundary conditions for the local bitterns dispersion model shown in Figure 13 and Figure 14

5.3.2. Local Regnard Bay model

Six (6) bathymetric and topographic datasets were considered during the development of the Digital Elevation Model (DEM) applied to the local hydrodynamic model, namely:

1. Geosciences Australia (GA) high-resolution gridded bathymetry and topography product (publicly available 2)
2. Guardian Geomatics (GG) bathymetry gathered for the ESSP, provided by Leichhardt
3. LiDAR topographic survey covering the landside (proposed ponds) and the intertidal zone undertaken by the McMullen Nolan Group Pty Ltd (MNG) for the ESSP, provided by Leichhardt
4. A bathymetry dataset compiled by EGS, provided by Leichhardt
5. A reconnaissance Single Beam Echo Sounder (SBES) bathymetry of the probable ESSP navigational channel gathered during the pre-feasibility phase of the Project, provided by Leichhardt
6. A reconnaissance SBES bathymetry of MacKay Ck and Straight Ck collected to support the site selection studies of the pump intake structure, gathered for the ESSP and provided by Leichhardt.

Overlapping datasets (e.g. EGS and GA, or GA and GG, etc.) were compared to identify vertical datum offsets and mean deviations between datasets which could lead to interpolation anomalies if simultaneously used without any manipulation.

Merging the least number of datasets was preferred to avoid introducing artificial edge effects ([3]), provided key features were retained. Such was the case for the DEM in the vicinity of the discharge site where two high-resolution bathymetric datasets existed: one localised (GG dataset) and the other extending beyond the local hydrodynamic model domain (GA dataset) as presented in Figure 12. Quantitatively, the difference between the two datasets rarely exceeded 1 m within the primary area of interest ([4]), with the median difference between the GA dataset and the GG dataset (within the bounds of the GG dataset) being 0.91m. Qualitatively, all key bathymetric features which influence bitterns transport are present in both bathymetric datasets (e.g. small sand ridge approximately 600 m N of the jetty, the trough at the diffuser site, the trough approximately 300 m S of the navigation channel bend, the mild-slope thalweg between the above-mentioned troughs, etc.).

Through a thorough assessment of the datasets available and data merging challenges, GA and LiDAR data were primarily used in the final DEM with other datasets used as quality controls.

For details on the bathymetric and topographic merge, refer to the tidal inundation model report (O2Me 2023c).

The DEM was further adjusted in two ways:

1. The DEM was lowered by 0.91 m, corresponding to the median offset observed between the GA bathymetry and the GG bathymetry.
2. To incorporate the proposed dredging depths of the navigational channel (-7.17 m AHD), turning basin, and berth pocket (-7.67 m AHD).

[2] https://ecat.ga.gov.au/geonetwork/srv/eng/catalog.search#/metadata/144600

[3] Anomalies have been inadvertently introduced in earlier DEMs for this bitterns dispersion model.

[4] Based on pilot bitterns dispersion modelling results

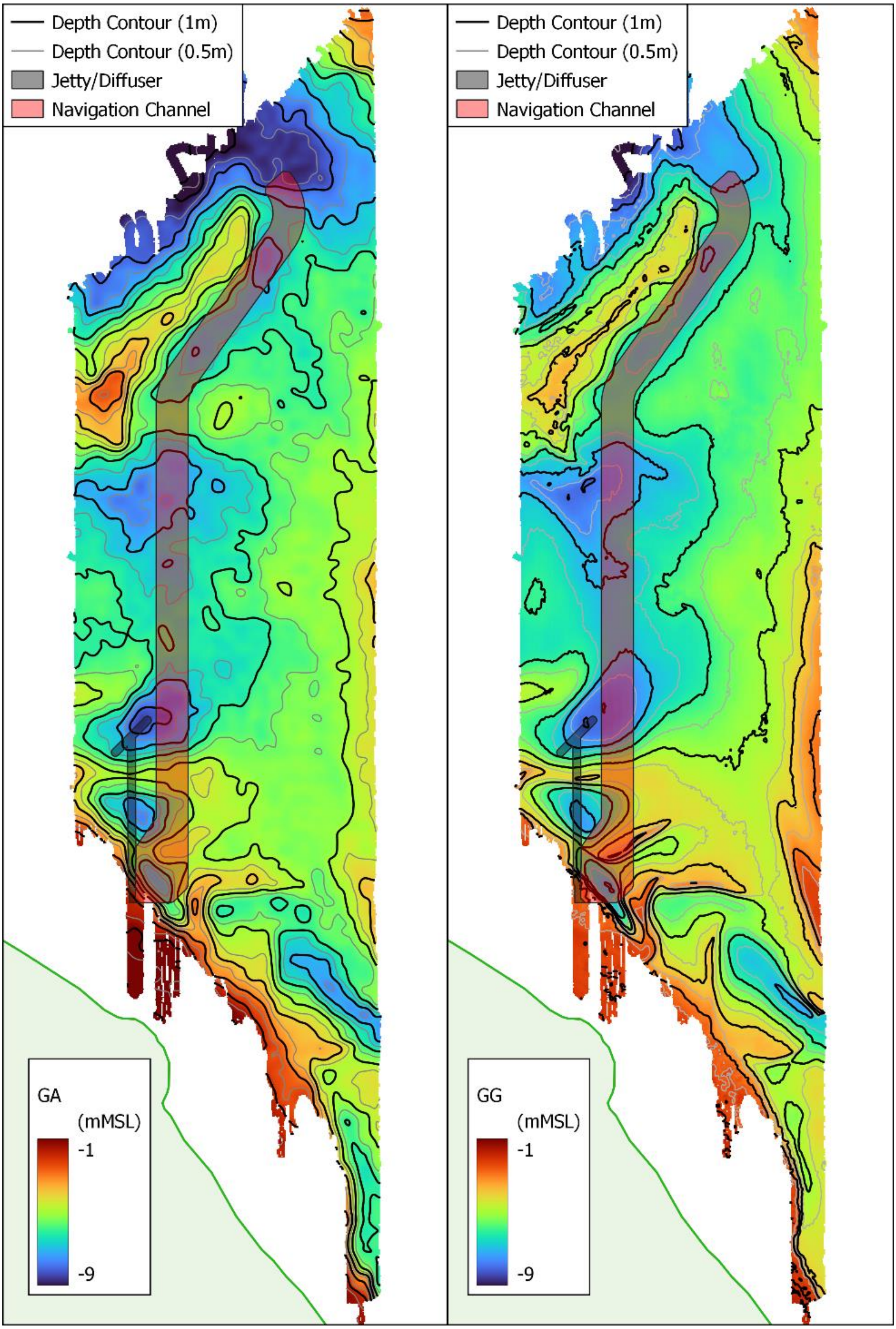

Figure 12: GA high-resolution dataset trimmed to the GG extent (left), GG dataset (centre), both referenced to MSL

The numerical mesh for the 3D ‘local’ model extends from the eastern boundary of 40-Mile Beach on the East, to 2 km West of Fortescue River mouth on the West, with an offshore boundary located approximately 15 km off the tip of Cape Preston (Figure 13), reaching depths of approximately -30 m Australian Height Datum (AHD). The suitability of the extent of the local model domain was confirmed via pilot depth-averaged model runs, ensuring no measurable salinity signature from the outfall was detected at the model boundaries after 2-months simulations.

Several numerical grids were established during the refinement of the preferred outfall configuration to accommodate different diffuser lengths, orientations, and locations. For simplicity, only the numerical grid adopted for the production runs is shown in this report. The domain was discretised with quadrangular elements around the diffuser and triangular elements elsewhere (Figure 13). The quadrangular region extended 260 m to the E, 260 m to the W, 200 m towards the coastline and 430 m towards offshore, measured from each extreme of the diffuser. In this quadrangular region, cell sizes ranged from 9-10 m (Figure 14) which is commensurate with the length scale of the near-field region (refer Section 5.2). Outside the quadrangular mesh, triangular elements gradually increased in size to a maximum nominal cell size of approximately 1 km at the open boundaries. 30 - 50 m (horizontal length scale) cells were used to represent the dredged channel.

The DEM bathymetry and the DEM bathymetry with the GG bathymetry prioritised over the GA bathymetry were both interpolated over the numerical grid and is presented in Figure 15. Bathymetry is presented between 6.5 AHD and 7.5 AHD to highlight the key bathymetric features surrounding the project infrastructure and proposed navigational channel.

Comparison of the two images concludes that use of the DEM bathymetry retains the key features that are observed when the GG bathymetry is merged into the DEM bathymetry when interpolated over the same numerical mesh. It also does so without causing any localised edge effects that the inclusion of the GG bathymetry creates. These key features are of high importance to a potentially bathymetric controlled bitterns discharge program and include:

- A deep pocket surrounding the diffuser which is at a deeper depth than the proposed dredge channel depth, potentially allowing for bitterns to funnel into the dredge channel; and
- A deep pocket approximately mid-way along the proposed dredge channel, which is deeper than the proposed dredge channel, potentially allowing for bitterns to escape the dredge channel prior to its most northern extent.

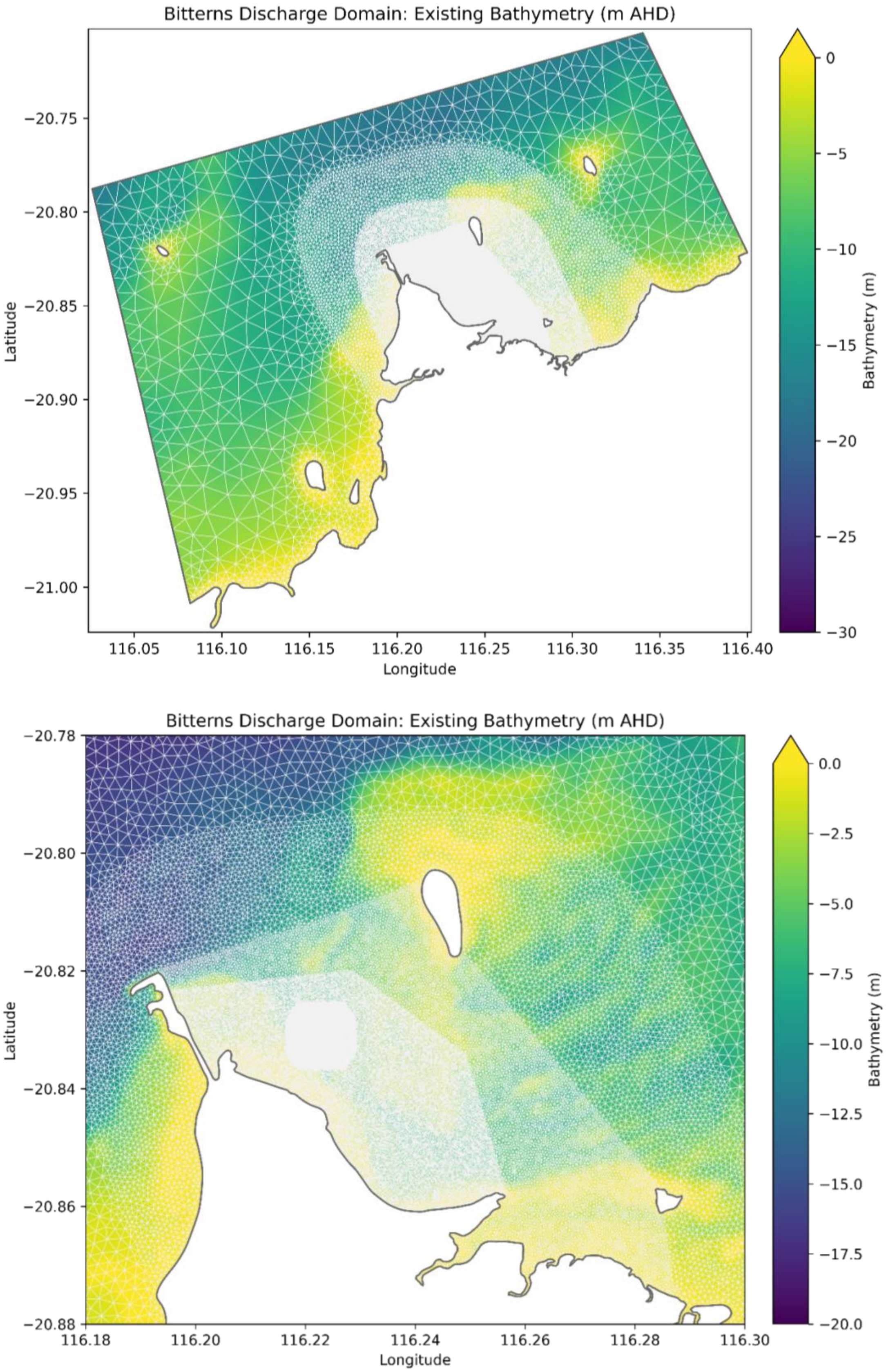

Figure 13: (Top) Numerical grid for the high-resolution bitterns discharge model overlaying bathymetry interpolated over the numerical grid. (Bottom) Zoomed in version of the top image with altered bathymetry limits

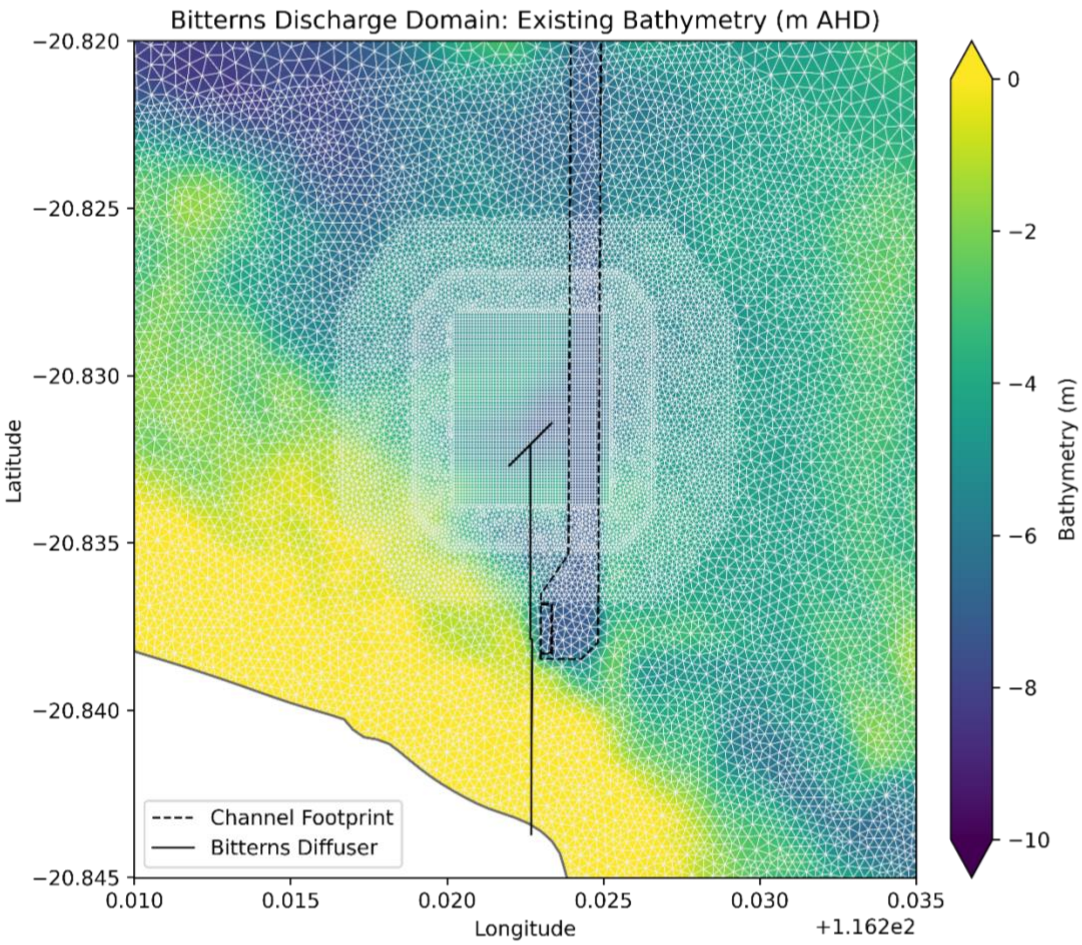

Figure 14: Zoomed view of the numerical grid showing the project infrastructure and modelled discharged locations

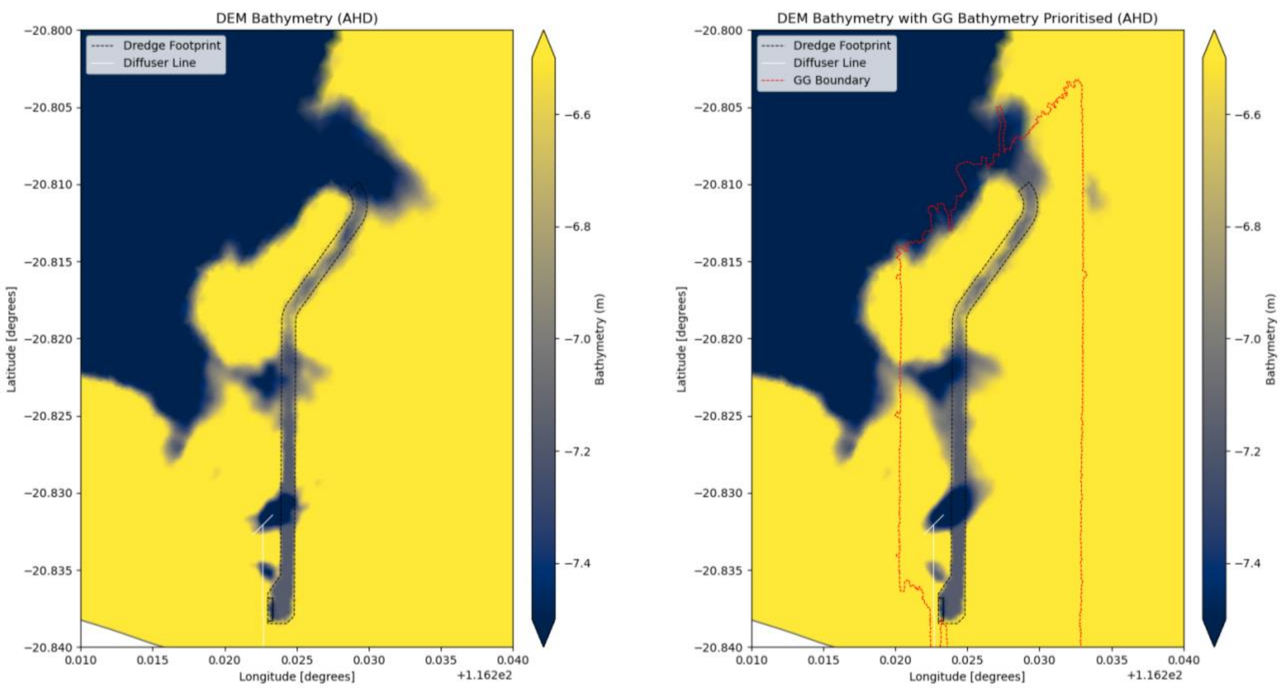

Figure 15 DEM bathymetry, without and with the GG bathymetry, interpolated over the numerical grid

Open boundaries of the local domain were forced with fluxes and water levels extracted from the Adapted Pilbara model (Figure 11; O2Me 2022a). Flather and Chapman boundary conditions were used for the open boundaries of the RANS equations. Winds from the Bureau of Meterology Karratha Airport weather station (ID 4083) were applied to the water surface, consistent with wind forcing application in O2Me (2022a). Constant and uniform background temperature and salinities representative of the ambient conditions were taken from Table 6.

The 3D far-field bitterns dispersion model solved the 3D incompressible RANS equations, and transport equations for temperature and salinity. The RANS equations are closed using a 2-equation (k-epsilon) closure scheme for the vertical fluxes, and a variable Smagorinsky scheme in the horizontal. Transport equations are closed by a scaled eddy diffusivity. The equations are discretised in space using a cell-centred finite volume approximation, with an unstructured grid in the horizontal, and a structured sigma scheme in the vertical, with 5-layers which are not spaced equidistantly (percentage of water column in each layer from the seabed to the surface being 10%/10%/25%/25%/30%).

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

Model results were saved at 30-minute intervals, including a timeseries of mass budget which allowed for the calculation of total weight of salt introduced in the model to confirm the expected net salt load (Table 7) had been met.

While the far-field modelling accounts for the proposed bathymetric modification along the navigational channel and berthing pocket, it does not account for hydrodynamic effects (mixing or lack thereof) induced by vessels, nor the relatively minor hydrodynamic effects around the berth and jetty infrastructure (such as dolphins and piles).

The model is capable of simulating the known dominant physical oceanographic processes in the region (R Steedman, 2022 – independent review of O2Me's modelling approach of the ESSP included as an Appendix to O2Me 2022a).

5.3.3. Outfall and Intake Representation

The bitterns discharge was represented as a 'standard source' (DHI 2023), where the source contribution to both the continuity and momentum equations was taken into account. Inputs for the standard source include a discharge rate (in m^3/s), salinity of discharged material (in PSU), temperature of discharged material (in °C) and the horizontal velocity components (easting and northing) of the discharged flow (in m/s).

Parameters adopted are listed next:

- discharge points (nozzles) were placed at 10 m intervals along the diffuser
- the temperature of the discharge was set as per Table 7
- the nozzle exit velocity was set to 7 m/s
- the discharge was perpendicular to the horizontal orientation of the diffuser, with neighbouring nozzles discharging in alternate directions (i.e. alternating the discharge to either side of the diffuser)
- the vertical angle of the discharge was indirectly accounted for by splitting the discharge among the bottom two model layers, based on the results of the near-field model (refer to Section 5.2.2).

Other parameters were simulation-specific and are discussed in Sections 5.3.4 and 5.3.5.

MIKE FM/HD suite of models calculate the water density as a function of practical salinity (PSU), water temperature (°C) and pressure (dbar) through the International Equation of State for Seawater (EOS80) (UNESCO 1981a, 1981b). Temperature and practical salinity are calculated at every model cell, at every time step. Leichhardt's ESSP crystallisation mass balance model, on the other hand, yields the temperature and absolute salinity of the bitterns defined as the mass of salt per unit mass (g/kg, or ppt). To O2Me's knowledge, no standard method of deriving practical salinity from absolute salinity exists, yet it is required for modelling of the bitterns discharge. For most practical oceanographic purposes and up to absolute salinities of ~100 ppt, the two can be considered equivalent with an error of the order of 10^{-3} ppt (Deltares 2023). A common industry practice extends this approximation to dispersion studies of high salt content discharges (e.g. Baird 2021), raising two important questions:

1. Is the total mass of dissolved solids carried by the EOS80 model representative of the total mass of dissolved solids projected to be discharged?
2. Is the density of the discharged bitterns correctly modelled?

To address the first question, let the PSU ≈ ppt approximation be applied to ESSP's bitterns discharge salinity concentration of 410 ppt (Table 7) in the EOS80 equation, which yields a density of 1,350 kg/m^3. For the peak summer discharge of 0.65 GL/m (Table 7), this density would results in a total mass of 0.88 Mt of salt discharged into the marine environment which is only 5% higher than the total mass of 0.84 Mt derived by Leichhardt from ESSP's mass balance of the crystallisation process (using the calculated density of 1,290 kg/m^3). Here, the 5% error is deemed relatively small and conservative, supporting the use of PSU ≈ ppt assumption for ESSP's high total dissolved solids content.

Since applying EOS80 equation of state to absolute salinities of up to ~100 ppt yields an acceptable level of precision, a pragmatic approach was proposed to justify that errors introduced by the EOS80 in > 100 ppt salinity cases may be neglected. First, the bitterns discharge will entrain ambient seawater and reach ~30 - 100 ppt salinity concentration within ~10 m from the discharge point, approximately the length scale of the smallest model cells. Changes to the characteristics of the bitterns that occur within a far-field model cell cannot be tracked. Second, the bulk of the denser-than-ambient seawater bitterns will propagate along the seabed upon discharge (Section 5.3.3): any heavier discharge would not change this condition; neither will a slightly lighter discharge. Hence, adoption of the PSU ≈ ppt assumption for ESSP's high total dissolved solids content is merited.

Water for pre-dilution of the discharge was extracted from mid-water depth at an intake site W of the jetty as shown in Figure 16.

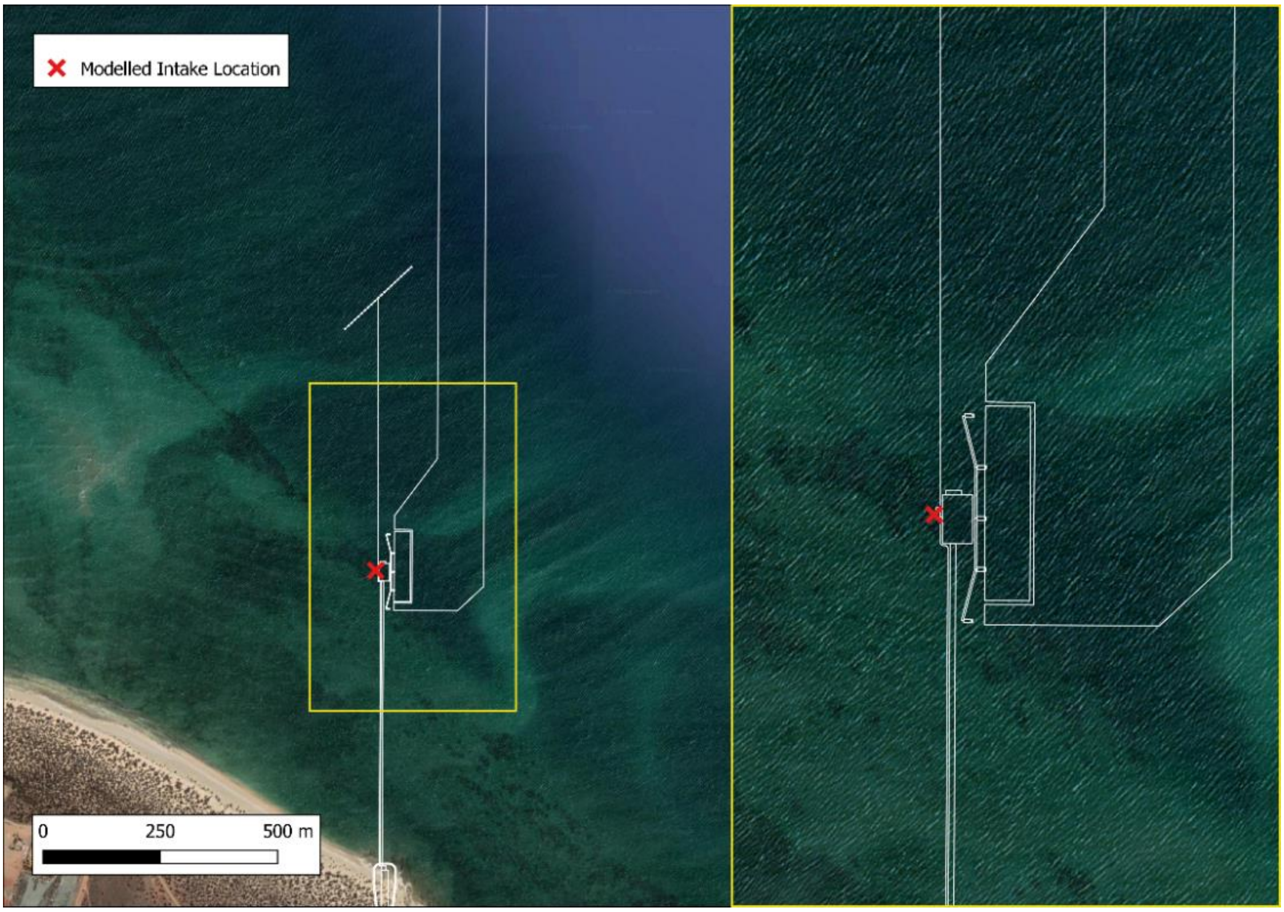

Figure 16: Proposed (preliminary) intake structure site.

5.3.4. Ocean Outfall Refinement (Far-field modelling)

The ocean outfall refinement phase consisted of eight simulations, each designed to answer a number of key questions that could help optimise the final production runs. The eight simulations are hereafter referred to as 'tests'. This section highlights the purpose, setup, and conclusions drawn from each test. Results associated with the eight tests that inform the conclusions described in this section can be found in Appendix A. Parameters investigated during the ocean outfall refinement phase consisted of:

- Discharge rates (1,390,000; 1,000,000; and 700,000 m^3/month)
- Salinity content of the bitterns (300, and 370 PSU) ([5])
- Pre-dilution (1:0, 1:1, 1:5)
- Location (from the tip of the jetty extending N, and N of a bathymetric feature approximately 600 m N of the jetty)
- Diffuser length and nozzles (50 m long with 5 nozzles, and 200 m long with 21 nozzles)
- Diffuser orientation (N-S aligning with the jetty alignment, and NE-SW perpendicular to main tidal currents – see Section 2.2)
- Discharge regime (continuous and uniform discharge, intermittent during ebb tides only, and intermittent when the water level exceeded a particular threshold).

[5] Range of salinities investigated consistent with earlier Project scenarios.

5.3.4.1. Test simulations A to D

The main purpose of the first four tests was to assess different diffuser arrangements and locations, whilst also learning how different discharge rates and pre-dilution may influence the results.

Table 12 summarises the first four test simulations, outlining the key differences between each simulation. Note that these simulations featured a constant discharge regime and were run over the same period. In short:

- Tests A and B differed in terms of the pre-dilution regime but featured the same salt content; and
- The salt content was altered for tests C and D along with the level of pre-dilution, the diffuser arrangement and the diffuser location.

Table 12: Key input parameters for test simulations A to D.

Parameter	Test A	Test B	Test C	Test D
Period	2-Month	2-Month	2-Month	2-Month
Location	Tip of the jetty	Tip of the jetty	Tip of the jetty	~600 m N of the jetty
Orientation	N-S	N-S	N-S	NE-SW
Length of diffuser (m)	50	50	200	200
Number of nozzles	5	5	21	21
Diffuser depth (m below MSL)	4-5	4-5	4-5	6-8
Discharge regime	Continuous	Continuous	Continuous	Continuous
Bitterns discharge volume – undiluted (m^3/month)	1,390,000	1,390,000	1,000,000	1,000,000
Bitterns discharge salinity – undiluted (PSU)	300	300	300	300
Pre-dilution (with 35.1 PSU)	1:0	1:5	1:1	1:1
Resultant outfall discharge (m^3/month)	1,390,000	8,340,000	2,000,000	2,000,000
Require flow rate from the diffuser (m^3/s)	0.536	3.217	0.772	0.772

Observations drawn from the first four test simulations include:

- The diffuser location and orientation proposed in Test D appeared to perform better than a diffuser located near the tip of the jetty, independently of its length (Test A to C). In Tests A to C the diffuser is conveniently located near the jetty but S of a shallow ridge in the bathymetry which appears to obstruct the bitterns and force it into the shallows. With limited seawater to dilute the bitterns, it spreads across the shoreline with minimal mixing and thus high concentrations of salt can be seen over large areas. However, by locating the diffuser N and beyond the shallow ridge in the bathymetry, the discharge occurs in deeper waters before being steered into the dredge footprint by the currents interacting with the bathymetry. Once in the dredge channel, the bitterns propagates N before turning NW through a natural deepening of the bathymetry. The plume appears to follow the typical ebb and flood tide currents thereafter

- A diffuser length of 50 m appears too short to achieve the required initial mixing with un-perturbed seawater. Though arbitrarily selected, a 200 m diffuser with 21 nozzles returns better results. A longer diffuser would potentially lead to complex engineering solutions and was therefore discarded
- Pre-diluting the bitterns with 5 parts of seawater resulted in larger areas of low and moderate LEP compared to tests considering smaller volumes of seawater for pre-dilution (e.g., 1:1 and 1:0 pre-dilutions). The areal extent of the LEP areas resulting from the 1:1 (C and D) and 1:0 (B) pre-dilution tests were similar. Pre-diluting the effluent with more than its equivalent part of seawater appears to have no added benefit and, in fact, may have a detrimental effect on the environment as relatively high salt areas extend over large areas
- As expected, the lower the discharged salt content, the smaller the mixing zone.

Findings from Tests A to D support Test D as the most promising configuration to reduce the extent of the LEP areas. Though the comparison of the 1:1 Tests (C and D) to the 1:0 Test (B) is inconclusive, preliminary near-field simulations run in parallel to these tests supported the concept of discharging bitterns pre-diluted 1:1 with seawater.

5.3.4.2. Test simulations D1 to D4

An additional four tests were conducted using the Test D diffuser location and arrangement, to further optimise the ocean outfall before carrying out the production runs. These tests were run over shorter periods, yet long enough to inform the assessment.

The properties of the brine (salt content and flow rate), diffuser location, diffuser orientation and simulation run time, remained unchanged during tests D1 and D4 to allow for a quantitative comparison between these tests.

Tests D1 to D4 are summarised in Table 13.

Table 13: Key input parameters for test simulations D1 to D4

Parameter	Test D1	Test D2	Test D3	Test D4
Period	7-Days	7-Days	7-Days	7-Days
Location	~600 m N of the jetty	~600 m N of the jetty	~600 m N of the jetty	~600 m N of the jetty
Orientation	NE-SW	NE-SW	NE-SW	NE-SW
Length of diffuser (m)	200	200	200	200
Number of nozzles	21	21	21	21
Diffuser depth (m below MSL)	6-8	6-8	6-8	6-8
Discharge regime	Discharge when water level (WL) is greater than mean sea level (MSL)	Discharge during ebb tide only	Discharge during ebb tide only	Continuous
Bitterns discharge volume – undiluted (m^3/month)	700,000	700,000	700,000	700,000
Bitterns discharge salinity – undiluted (PSU)	370	370	370	370
Pre-dilution (with 35.1 PSU)	1:1	1:1	1:0	1:1
Resultant outfall discharge (m^3/month)	1,400,000	1,400,000	700,000	1,400,000
Required flow rate from the diffuser (m^3/s) when discharging	1.080	1.080	0.540	0.540

Conclusions drawn from these four test simulations include:

- pre-diluting the bitterns discharge with one-part of seawater (1:1) decreases the concentration of salt at the point of discharge and, therefore, it is beneficial to the environment within the immediate vicinity of the diffuser. However, negligible reduction of the areal extent of the LEP zones is noted, compared to the 'no-pre-dilution' (1:0) Test D3
- a continuous discharge regime provides the smallest EPA zones compared to an intermittent discharge regime such as discharging when WL>MSL or discharging during ebb tides only.

5.3.5. Production runs (Far-field modelling)

The preferred diffuser site, diffuser length, diffuser orientation, bitterns pre-dilution and discharge regime were selected during the ocean outfall refinement phase. Further reduction of any negative environmental impact from the bitterns discharge was pursued by optimising the bitterns NaCl recovery rates, resulting in a lower load of salt discharged into the marine environment than previously modelled in the test runs.

Bitterns pre-dilution will be achieved by injecting seawater into the diffuser, extracted from an intake structure mounted on the jetty (Figure 16). Some recirculation from the outfall to the intake is expected, but timeseries of salinity extracted from the intake site for both production runs demonstrated it will be minimal (< 0.6 PSU, Appendix B) and, hence, the 1:1 pre-dilution assumption holds.

The basic model set up parameters were identical for both simulations, only the simulation periods (Table 14) differed to accommodate for wet/summer and dry/winter drift currents and ambient mixing.

Key parameters adopted in the production runs are listed in Table 15.

Table 14 Production run simulated periods

Name	Simulated period	Season represented
Production run 1	01/12/2020 – 01/02/2021	Wet/Summer season
Production run 2	01/06/2021 – 02/08/2021	Dry/Winter season

Table 15: Key input parameters for production runs 1 and 2

Parameter / Feature	Value	Description
Period	2-month (62 days)	Period for each production run defined in Table 14
Diffuser location	~600 m N of the jetty	Outcome of test simulations
Orientation	NE to SW	Outcome of test simulations
Length of diffuser (m)	200	Outcome of test simulations
Number of nozzles	21	Outcome of test simulations.
Diffuser depth (m below MSL)	6-8	Outcome of test simulations.
Discharge regime	Constant discharge	Outcome of test simulations.
Bitterns discharge volume – undiluted (m^3/month)	Summer: 650,000 Winter: 370,000	Production run discharge volume provided by the Leichhardt (Section 3.1) – peak month during each season
Bitterns discharge salinity – undiluted (ppt)	410	Section 3.1
Pre-dilution (volume : volume)	1:1	Outcome of test simulations and past experience.
Pre-dilution intake location	Longitude: 116.222618 E Latitude: 20.837647 S	Intake location provided by the Leichhardt.

5.3.5.1. General Behaviour of the Bitterns Dispersion

For both scenarios, the general behaviour of the bitterns plume was dictated by tidal flow and the bathymetry surrounding the diffuser location. Tidal flows are the main driver of movement of the plume, with forcing causing the discharged material to move S during flood periods and NW during ebb periods. However, due to the increased density, the bitterns plume sits low in the water column after being discharged and thus it was heavily influenced by nearby bathymetry changes (such as changes where the dredged channel is located), causing the plume to direct away from the NW-SE tidal plane.

To demonstrate this behaviour, salinity during a large spring tide period for each production run (Figure 17 and Figure 18) was plotted spatially over 12-hours (hourly spaced) as shown in Figure 19 and Figure 20.

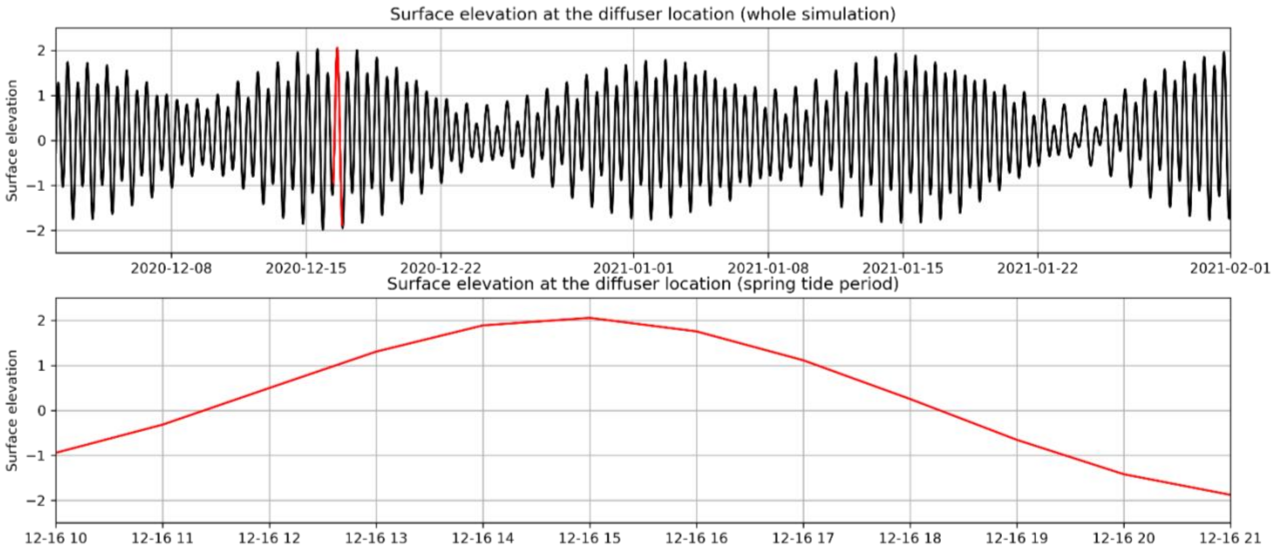

Figure 17: Production run 1: Surface elevation at the midpoint of the diffuser

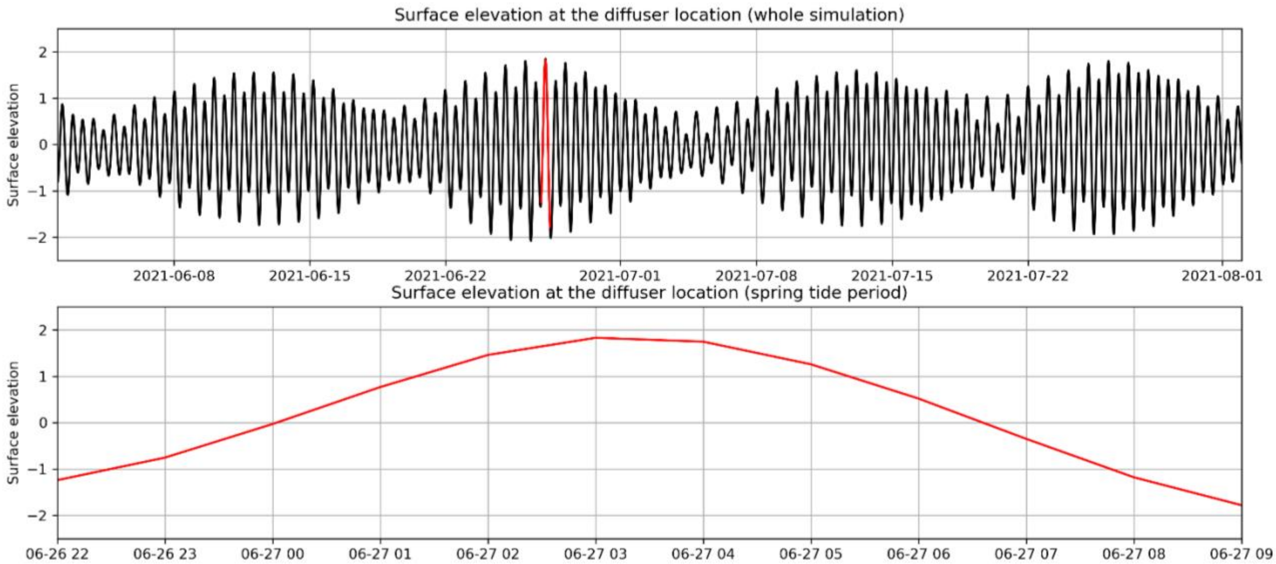

Figure 18: Production run 2: Surface elevation at the midpoint of the diffuser

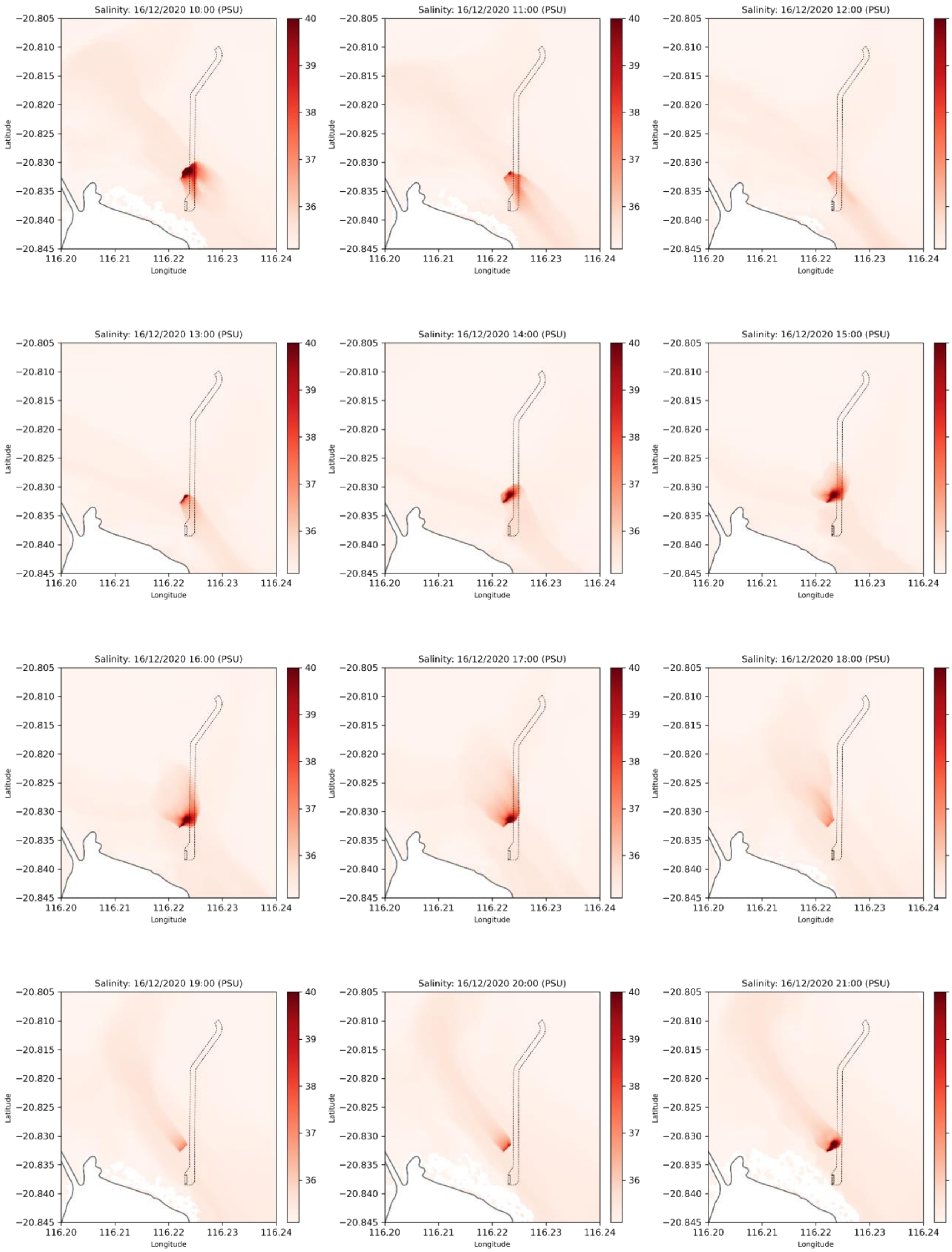

Figure 19: Production run 1: Salinity during a 12-hour period covering a large spring tide

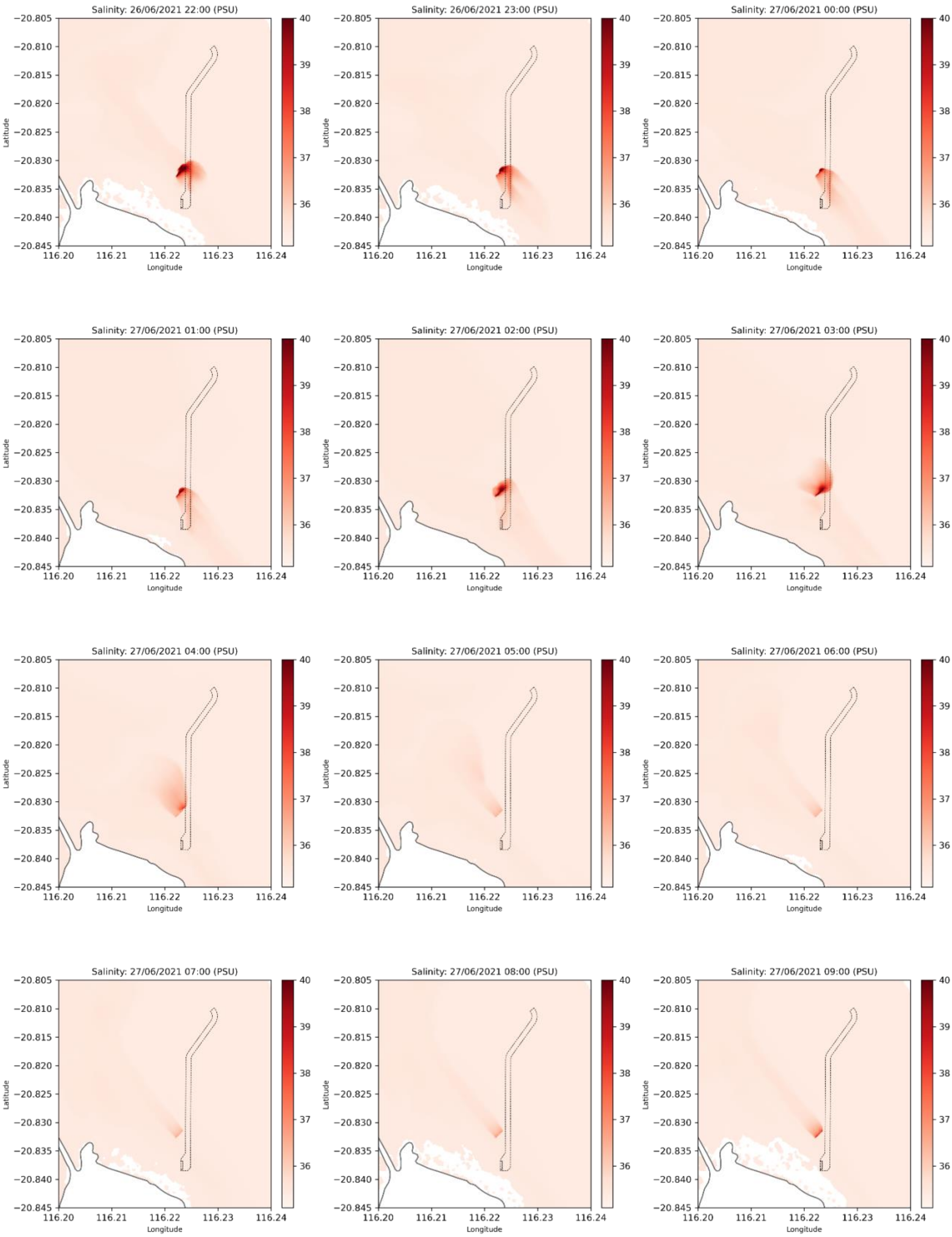

Figure 20: Production run 2: Salinity during a 12-hour period covering a large spring tide

5.3.6. Potential environmental impact

The areal extent of the mixing zones associated with the target dilutions presented in Table 9 were derived as follows:

1. The maximum salinity through the water column was identified at each timestep
2. The percentage of time the target dilutions were exceeded was identified
3. The mixing zone boundaries were drawn where results from point 2 were exceeded 5% of the time during the simulation.

As a result, the boundaries shown in this section enclose the area where a target SPL is not met or, in other words, the SPL are met outside the boundaries.

Figure 21 and Figure 22 present the 90% and 99% SPL boundaries for production run 1 and production run 2 superimposed over the subtidal BCH (O2M 2023a) respectively. The areas of each BCH type that lay within the 90% and 99% SPL boundaries (and hence do not achieve the target levels of SPL) are discussed elsewhere (i.e. the cumulative impact report). However, total areal extents enclosed by the 90% and 99% SPL boundaries are shown in Table 16.

Note that the area presented for exceeding the Moderate LEP dilution requirements has been calculated as the area within the 90% SPL boundary, whilst the area exceeding the High LEP dilution requirements has been calculated as the area between the 90% and 99% SPL boundaries.

Table 16 Areal extent of zones exceeding the dilution required to achieve the EQO

Season	Area exceeding dilution required for Moderate LEP (ha) (inside the 90% SPL boundary)	Additional area exceeding dilution required for High LEP (ha) (between the 90^{th} and 99^{th} SPL boundaries)	Total area exceeding dilution required for High LEP (ha) (total area contained by the 99% SPL boundary)
Wet/Summer	63	66	129
Dry/Winter	33	45	78

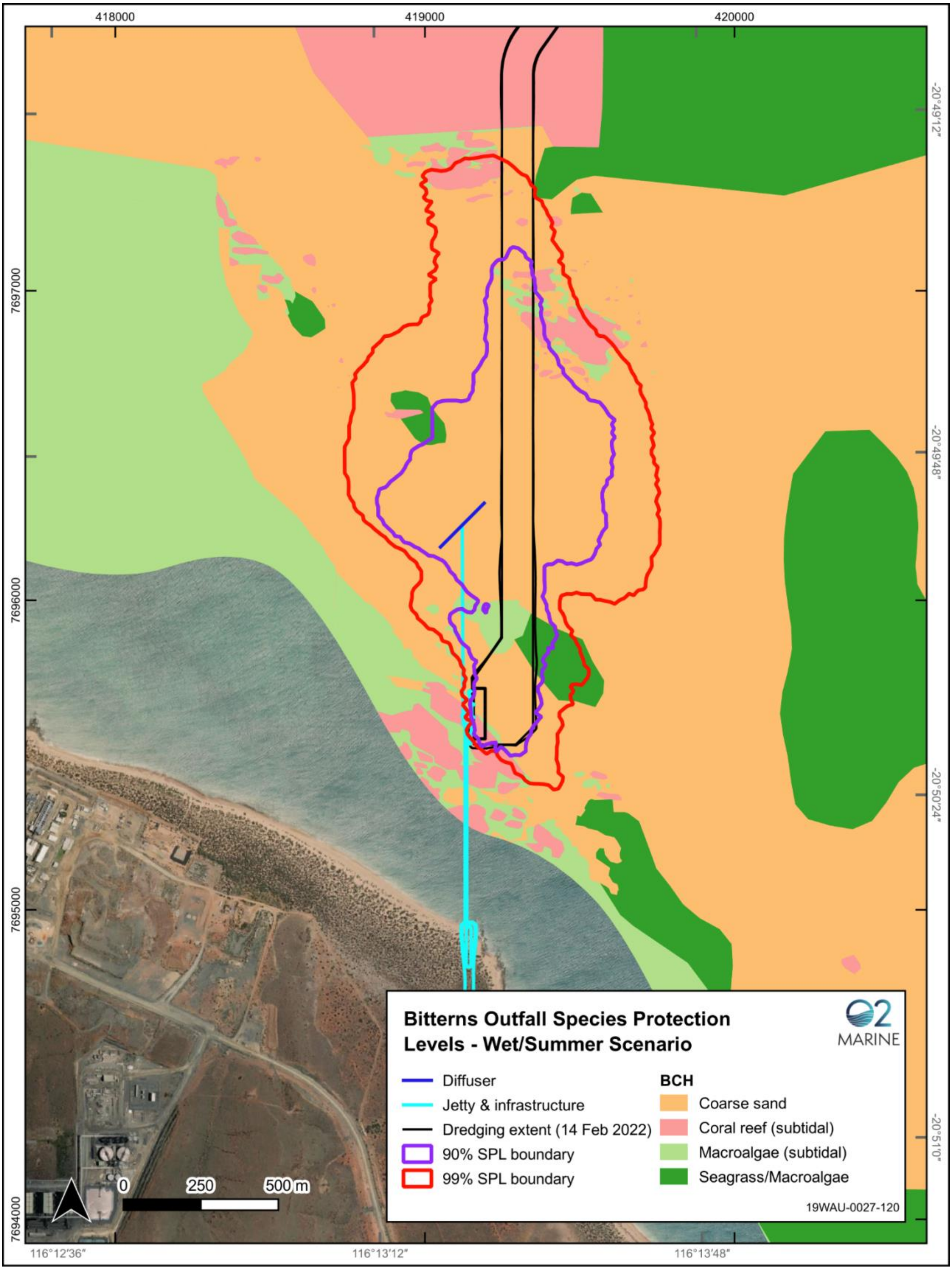

Figure 21: Production run 1: 90% and 99% SPL boundaries intersection with subtidal BCH

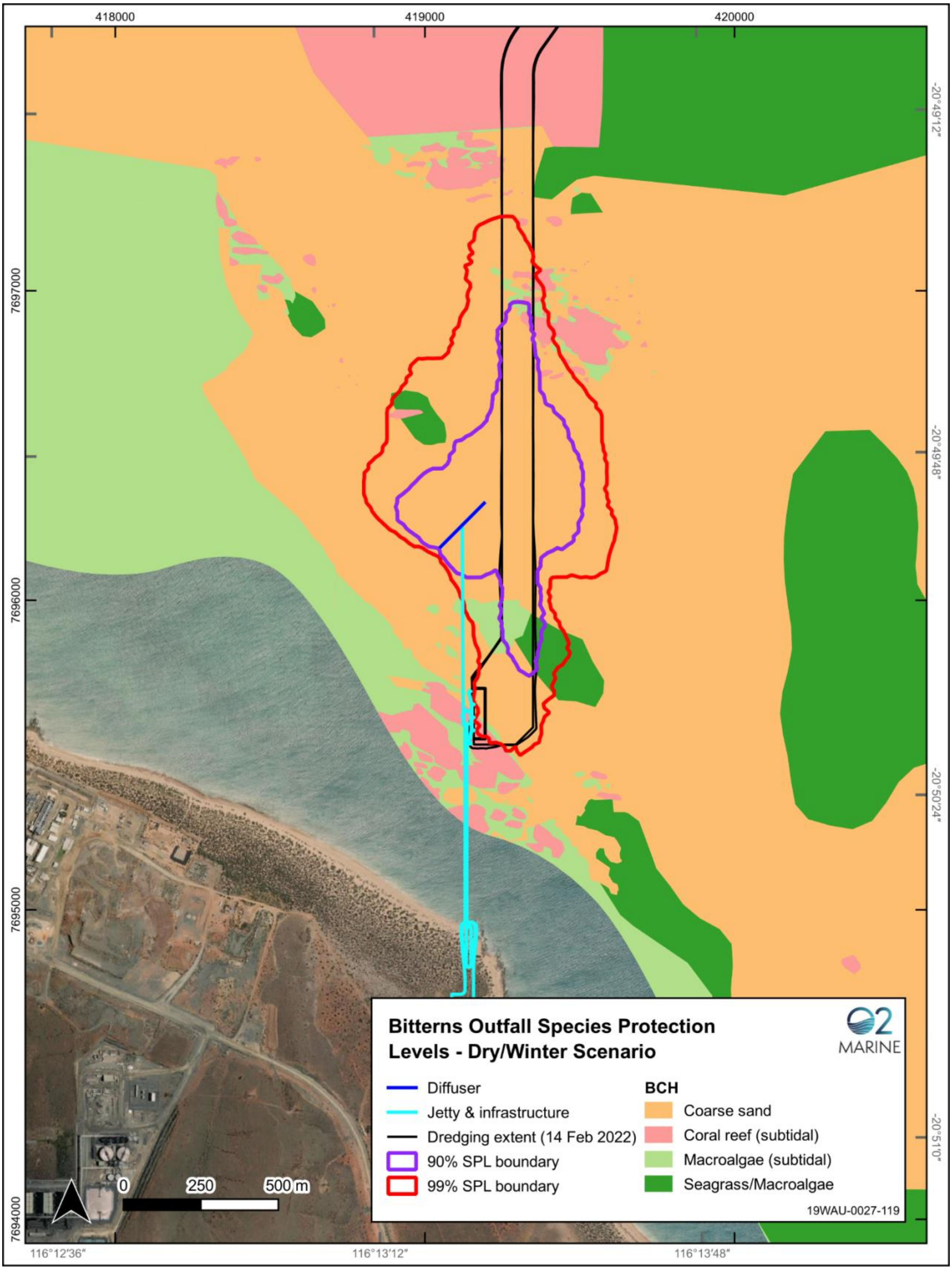

Figure 22: Production run 2: 90% and 99% SPL boundaries intersection with subtidal BCH

6. Summary and Conclusions

Through an analysis of the far-field modelling results by a panel of specialists consisting of Environmental Engineers, Marine Scientists, Environmental Approval Specialists, Coastal Engineers, and Process Engineers, the preferred outfall design was identified and adopted for the production runs that would feed into the EIA and cumulative loss assessment of the ESSP.

The number of bitterns dilutions that could be achieved with Leichhardt's preferred outfall configuration in the near-field and prior to mixing being primarily driven by the natural processes of Regnard Bay, was estimated with a near-field model. CORMIX was the selected software for this application.

Informed by the near-field studies conclusions, two far-field production simulations were conducted, representing a summer/wet season and winter/dry season discharge scenarios (defined in Table 7) for Leichhardt's preferred ocean outfall configuration for EIA. All key input parameters for the two production runs are summarised in Table 15.

In the absence of a bitterns product, a suitable surrogate was adopted from the solar salt processing facility at Onslow (O2M 2019). The dilution requirements for moderate and high level of ecological protection were set to 321- and 509-fold, respectively.

Dilution contours around the proposed outfall structure that meet the moderate and high LEP were obtained for typical wet/summer and dry/winter seasons. The largest areal impact (66 ha) that would result in between 90% to 99% SPL occurs in the wet/summer season, and the largest areal impact (63 ha) that would result in <90% SPL also occurs in the wet/summer season. Both areas contain the small existing Low LEP area defined for Cape Preston East Iron-Ore Export Facilities (DWER 2019). The LEP boundaries derived from this study will be used to inform the EIA of the ESSP.

A formal EIA was excluded from this report.

7. References

ANZG (2018) Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Australian and New Zealand Governments and Australian state and territory governments, Canberra ACT, Australia. Available at www.waterquality.gov.au/anz-guidelines

BMT WBM (2013) Port Pirie Marine Modelling Assessment of Cooling Water Discharges to the Marine Environment. Report R.B20232.001.01 (rev1), prepared for Nyrstar Port Pirie Pty Ltd.

Baird (2021) Mardie Project: Bitterns Outfall Modelling Report, prepared for BCI Minerals, 12979.401.R3.RevA

Deltares (2023) Delft3D-Flow: User Manual, version https://content.oss.deltares.nl/delft3d4/Delft3D-FLOW_User_Manual.pdf

DHI (2023) Mike 3 Flow Model FM: Hydrodynamic Module, User Guide: https://manuals.mikepoweredbydhi.help/latest/Coast_and_Sea/MIKE_FM_HD_3D.pdf

Doneker RL and Jirka GH (2007) CORMIX User Manual: A hydrodynamic mixing zone model and decision support system for pollutant discharges into surface waters, US Environmental Protection Agency, EPA-283-K-07-001 (updated July 2021)

DWER (Department of Water and Environmental Regulation) (2019) Department of Water and Environmental Regulation: Levels of Ecological Protection (2019, Map13, Cape Preston), EPA, Western Australia.

EPA (Environmental Protection Authority) (2016a) Statement of Environmental Principles, Factors and Objectives, EPA, Western Australia.

EPA (2016b) Technical Guidance – Protecting the Quality of Western Australia's Marine Environment. EPA, Western Australia.

Fischer HB, List EJ, Koh RCY, Imberger J and Brooks NH (1979). Mixing in Inland and Coastal Waters. Academic Press.

GHD (2013) Cape Preston East Environmental Studies: Brine Dispersion Study. GHD Report 28777\WP\129052 prepared for Iron Ore Holdings Limited, January 2013.

Jirka GH, Doneker RL and Hinton SW (1996) User's Manual For Cormix: A Hydrodynamic Mixing Zone Model And Decision Support System For Pollutant Discharges Into Surface Waters. US-EPA.

Jones GR, Nash JD and Jirka GH (1996) CORMIX3: An Expert System of Mixing Zone Analysis and Prediction of Buoyant Surface Discharges. DeFrees Hydraulics Laboratory, Cornell University.

O2 Marine (O2M),2019, Mardie Project – Whole Effluent Toxicity Assessment, O2 Marine Report R190054, . Report prepared for Mardie Minerals Pty Ltd prepared by O2 Marine.

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

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

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

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

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

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

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

O2 Metocean (O2Me) (2023b) Eramurra Solar Salt Project: Bitterns Dispersion Modelling, O2Me Report R210325, Fremantle 6160, Western Australia. Report prepared for Leichhardt Salt Pty Ltd.

O2 Metocean (O2Me) (2023c) Eramurra Solar Salt Project: Tidal Inundation Modelling, O2Me Report R210327, Fremantle 6160, Western Australia. Report prepared for Leichhardt Salt Pty Ltd.

O2 Metocean (O2Me) (2023d) Eramurra Solar Salt Project: Coastal and Intertidal Processes Assessment: ESSP Scenario 7.2, O2Me Report R220181, Fremantle 6160, Western Australia. Report prepared for Leichhardt Salt Pty Ltd.

Preston Consulting (2022) Eramurra Solar Salt Project: Environmental Scoping Document. Document Number LEI-ERA-ESD-02.

UNESCO (United Nations Educational, Scientific and Cultural Organisation) (1981a). Background papers and supporting data on the international equation of state 1980. Tech. Rep. 38, UNESCO.

UNESCO (United Nations Educational, Scientific and Cultural Organisation) (1981b) The practical salinity scale 1978 and the international equation of state of seawater 1980. Tech. Rep. 36, UNESCO. Tenth report of the Joint Panel on Oceanographic Tables and Standards (1981), (JPOTS), Sidney, B.C., Canada.

Appendix A. Test simulation results

Section 5.2 introduced eight different test simulations that were conducted as part of the Eramurra bitterns far-field modelling study. These eight simulations were split into two sets of four tests runs, with conclusions being drawn from comparison of the four tests within each set.

These conclusions have already been discussed in sections 5.3.4.1 and 5.3.4.2 for tests A to D and D1 to D4 respectively. However, the results that were the basis for those conclusions are presented in Appendix A.1 and Appendix A.2 for tests A to D and D1 to D4 respectively.

Note that discussions regarding the test objectives, test simulation input parameters and conclusions related to these test simulations are not repeated in this appendix. Where relevant, references will be made to where these discussions can be found in the main report.

Appendix A.1. Model results for test simulations A to D

Test runs A to D differed in terms of model inputs parameters including the mass of salt introduced into the model (see Table 12 for input summary). Therefore, the same fold dilutions should not be compared against one another with details (as they represent different concentrations). As the purpose of these tests was to understand the general plume behaviour under different diffuser arrangements, pre-dilution regimes and locations, only a qualitative comparison of several different dilution targets were made, primarily based around the behaviour of the plumes.

Qualitative comparison of test results

Figure 23 to Figure 26 presents the 5th percentile salinity exceedance for eleven different dilutions for test runs A to D respectively. Note that the calculation of these boundaries for each dilution target is consistent with the methodology used for calculation of the moderate and high LEP boundaries defined in Section 5.3.6.

This qualitative review led to the conclusions noted in Section 5.3.4.1 and fed into the design of the test runs A to D.

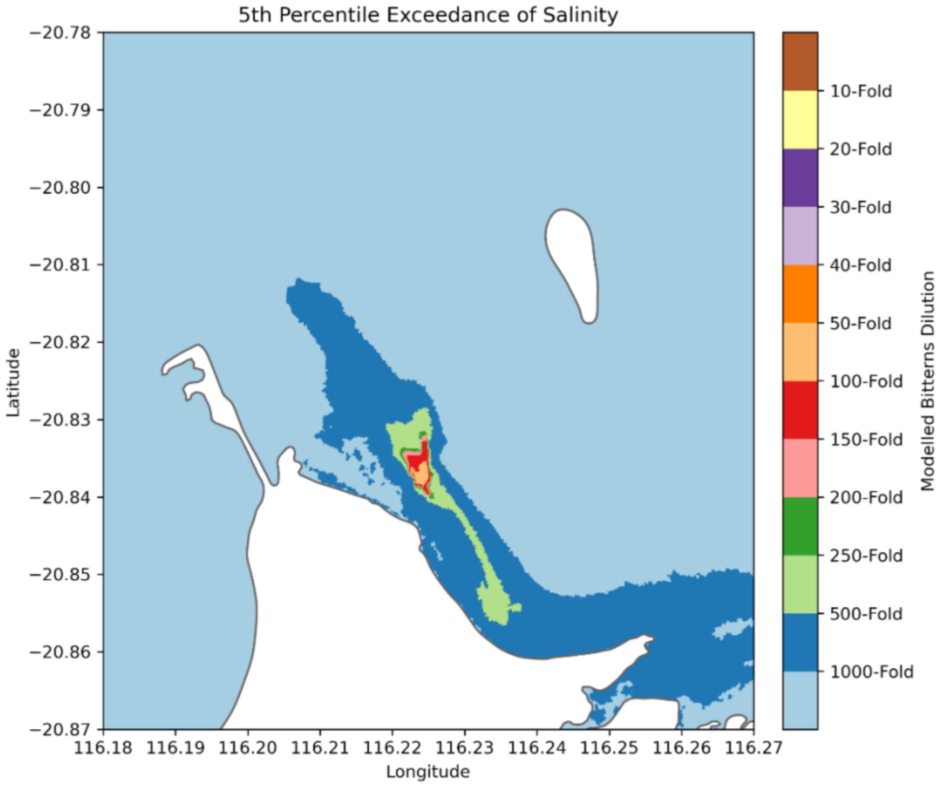

Figure 23: Test run A: 5th percentile salinity exceedance for different fold dilutions

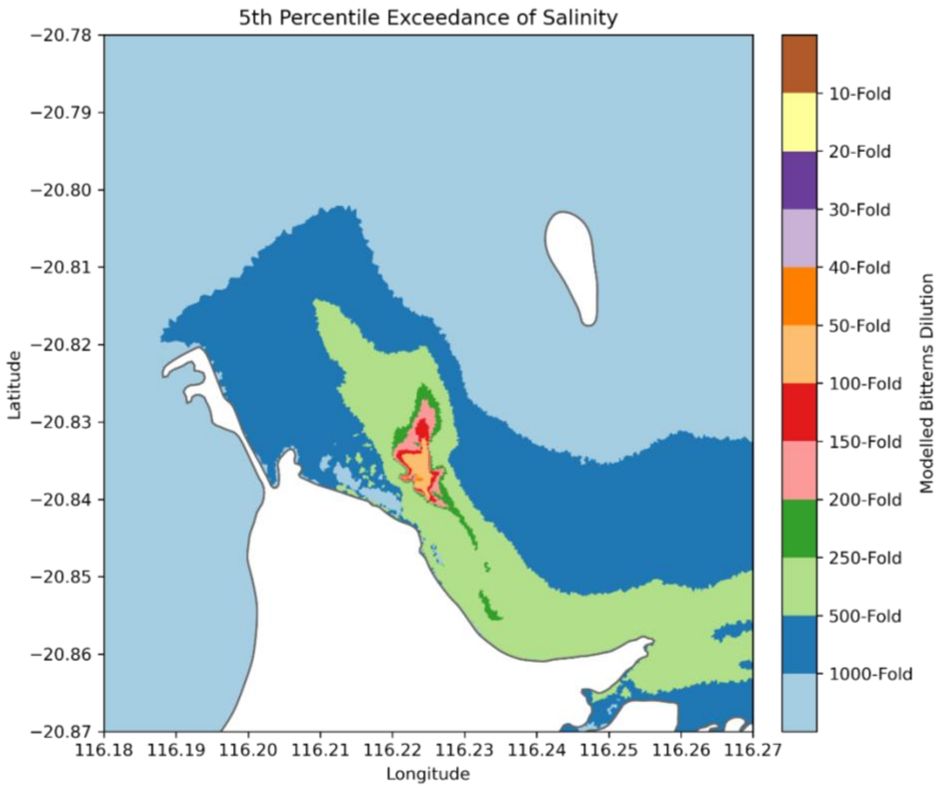

Figure 24: Test run B: 5th percentile salinity exceedance for different fold dilutions

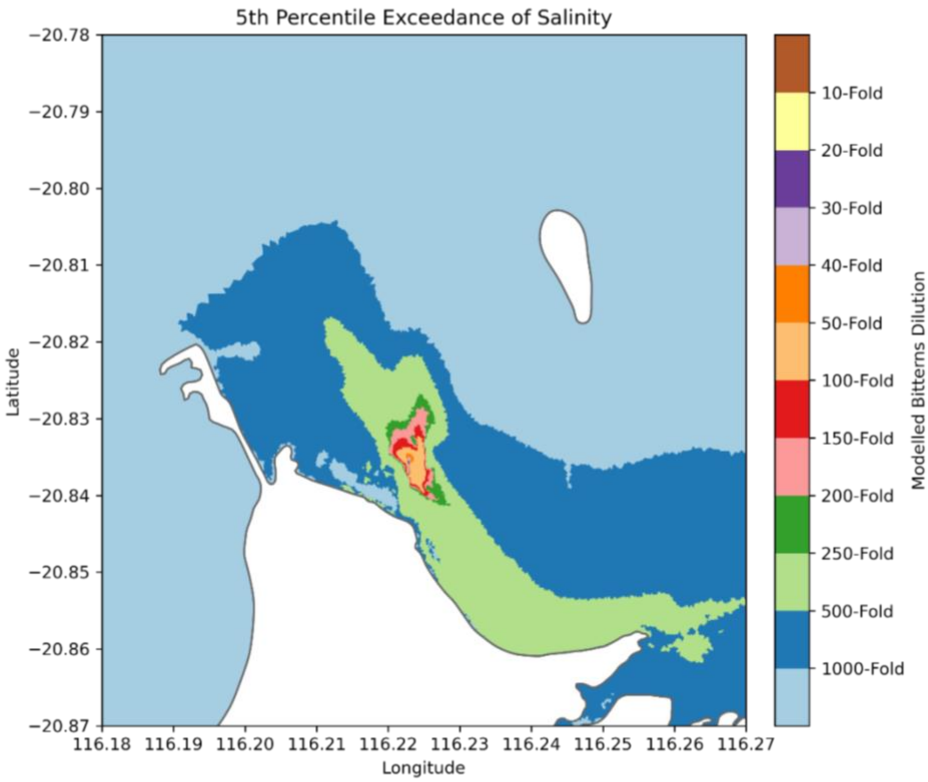

Figure 25: Test run C: 5th percentile salinity exceedance for different fold dilutions

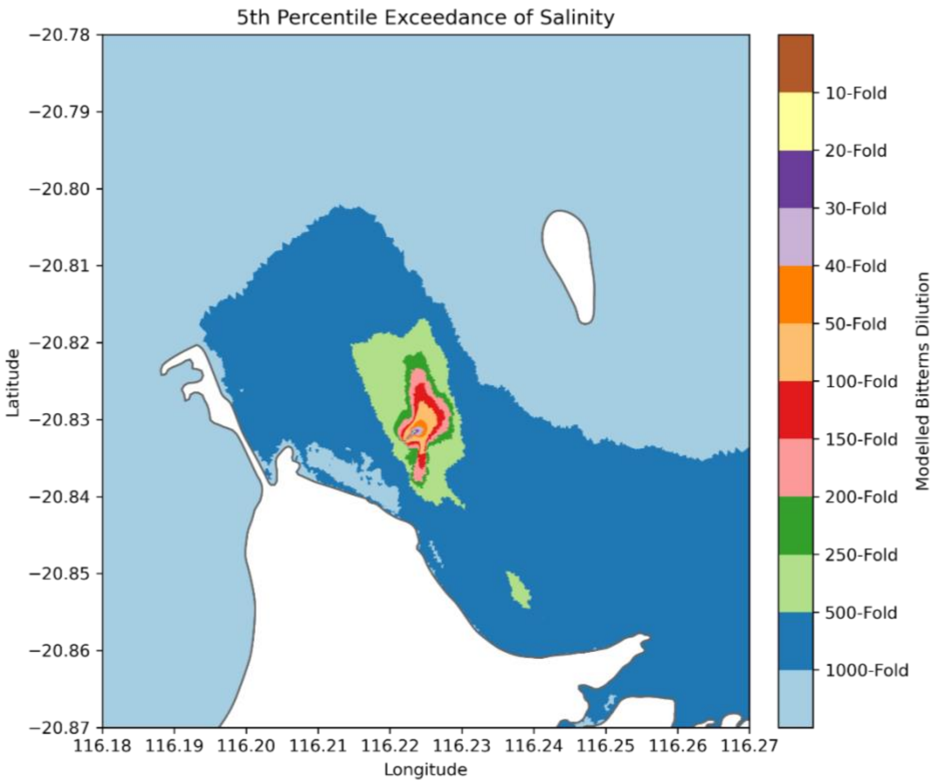

Figure 26: Test run D: 5th percentile salinity exceedance for different fold dilutions

Appendix A.2. Model results for test simulations D1 to D4

Unlike the previous test runs, test runs D1 to D4 all utilised the same diffuser arrangement, location, and mass of salt in the bitterns discharge, thus providing comparable results (see Table 13 for input summary). The shorter (7-day) test runs were designed to quantitatively confirm what discharge regime and extent of pre-dilution should be used in the production runs.

Salt Mass Balance

A salt mass balance between these four simulations was performed to confirm that these simulations were indeed quantitatively comparable. Note however, that these tests did not utilise a connected inlet source for the pre-dilution material. Instead, pre-dilution and bitterns were effectively combined prior to model entry and discharged together, therefore introducing more salt than that of the proposed bitterns discharge (Table 17). This pre-dilution method reduced the number of model sources required for the test runs and was used to simplify the test runs but was handled differently for the production runs. To account for extra salt, the mass of salt within the pre-dilution material has been removed from the salt mass balance output for each test run (Table 18). The mass of salt within the pre-dilution material has been quantified as the mass difference between test D2 and D3 (Ebb discharge regime with and without pre-dilution respectively).

Table 17: Test run D1 to D4 proposed bitterns discharge regime: mass of salt calculation.

Parameter	Proposed bitterns discharge
Bitterns density	1.29 t/m^3
Bitterns discharge volume (per 30-days)	700,000 m^3
Bitterns salinity	370 ppt
Mass of salt in bitterns discharge (per 30-days)	334,110 t
Mass of salt in bitterns discharge (over simulated period of 7 days)	77,959 t

Table 18: Salt mass introduced to the model for test runs D1 to D4.

Simulation	Mass of salt introduced	Percentage difference from mass presented in Table 17
Test run D1	79,014 t	-1.35 %
Test run D2	78,887 t	-1.19 %
Test run D3	78,887 t	-1.19 %
Test run D4	77,235 t	0.93 %

General behaviour of different discharge regimes

A twelve panel plot of maximum salinity in the water column is presented for test runs D1 to D4 in Figure 27 to Figure 30 respectively, during the selected spring tide period (presented in the production run results in Figure 17). These figures highlight the difference between the discharge regimes, with test runs D1, D2 and D3 only discharging at certain periods of time within the 12-hour period.

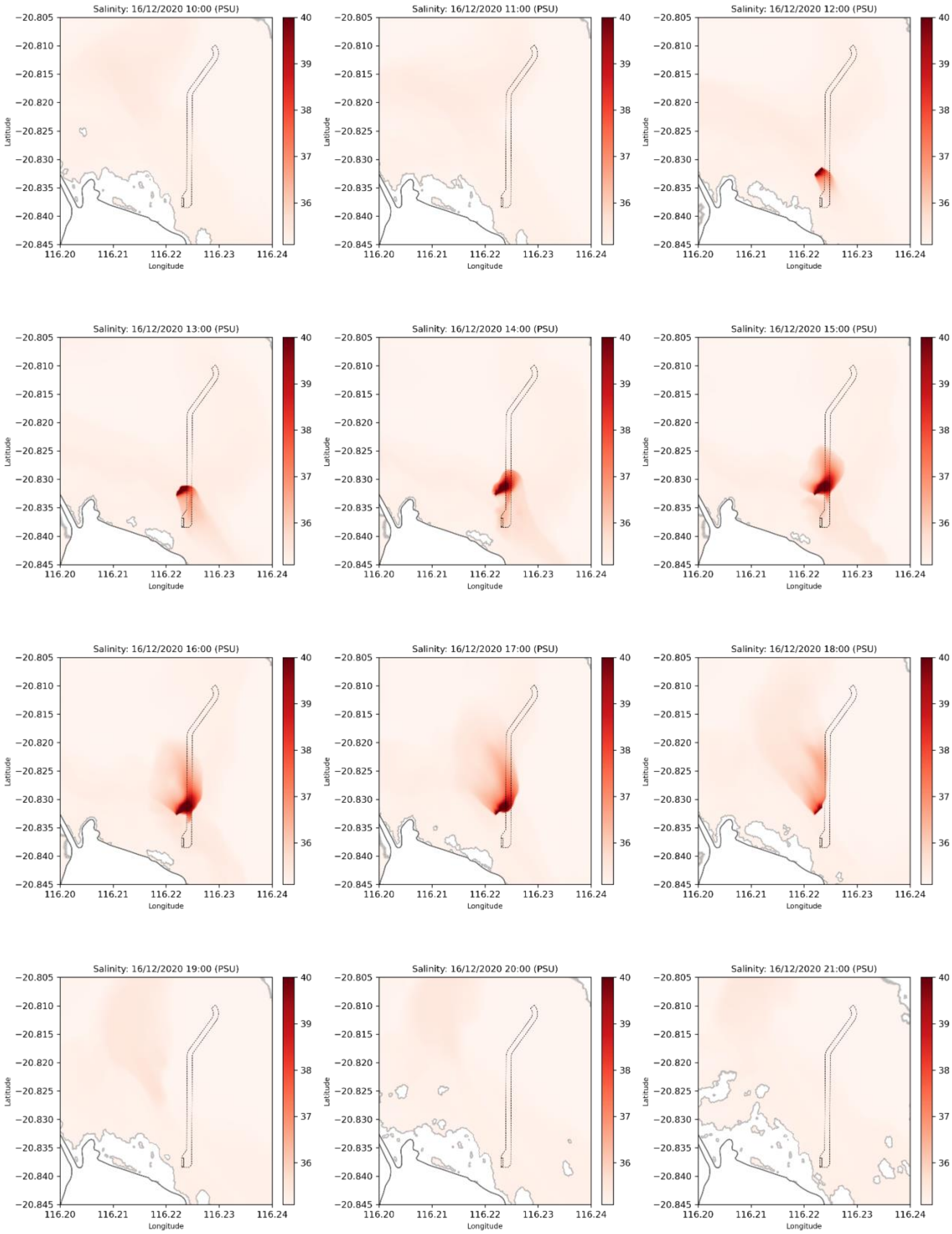

Figure 27: Test run D1: Salinity during a 12-hour period covering a large spring tide

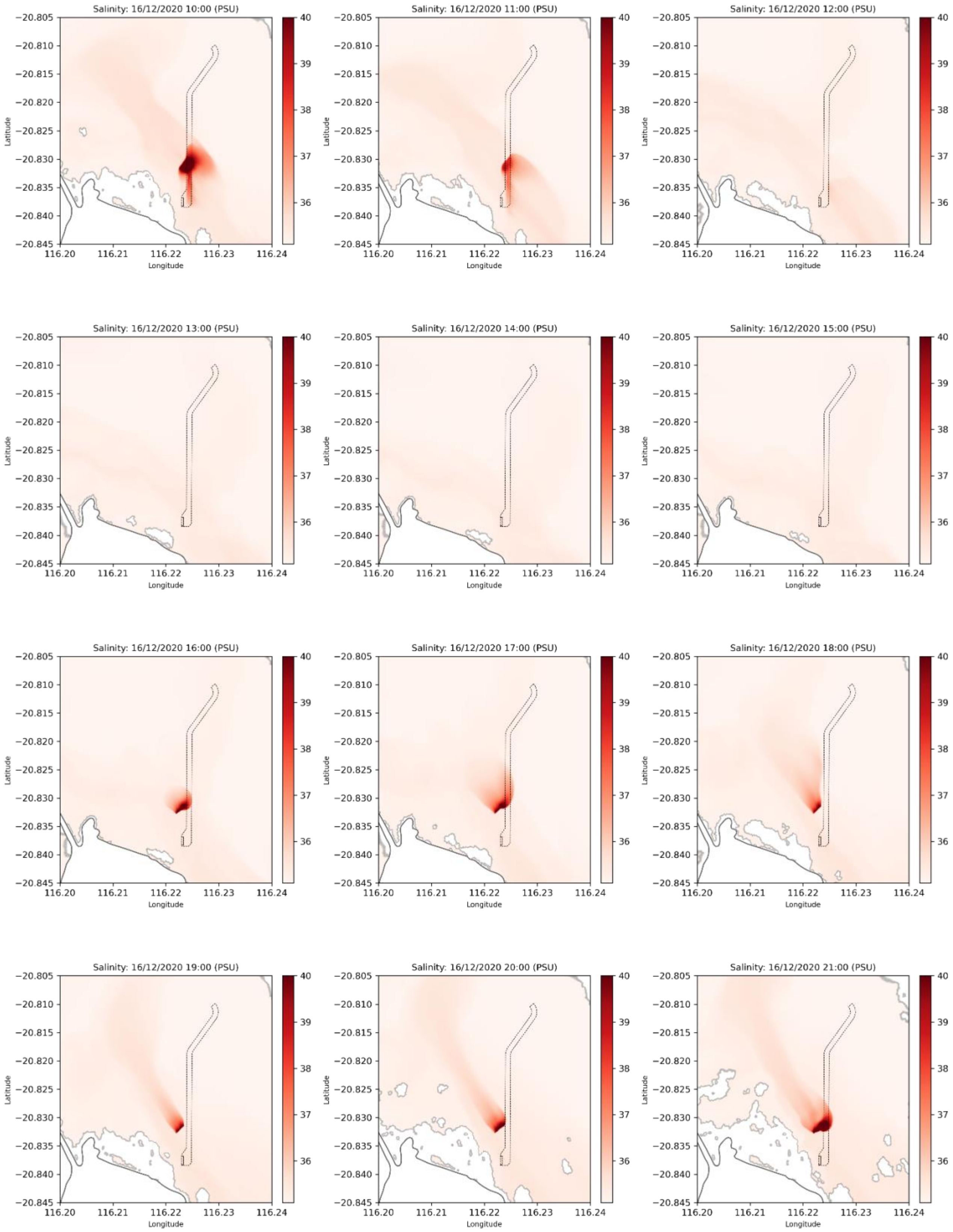

Figure 28: Test run D2: Salinity during a 12-hour period covering a large spring tide

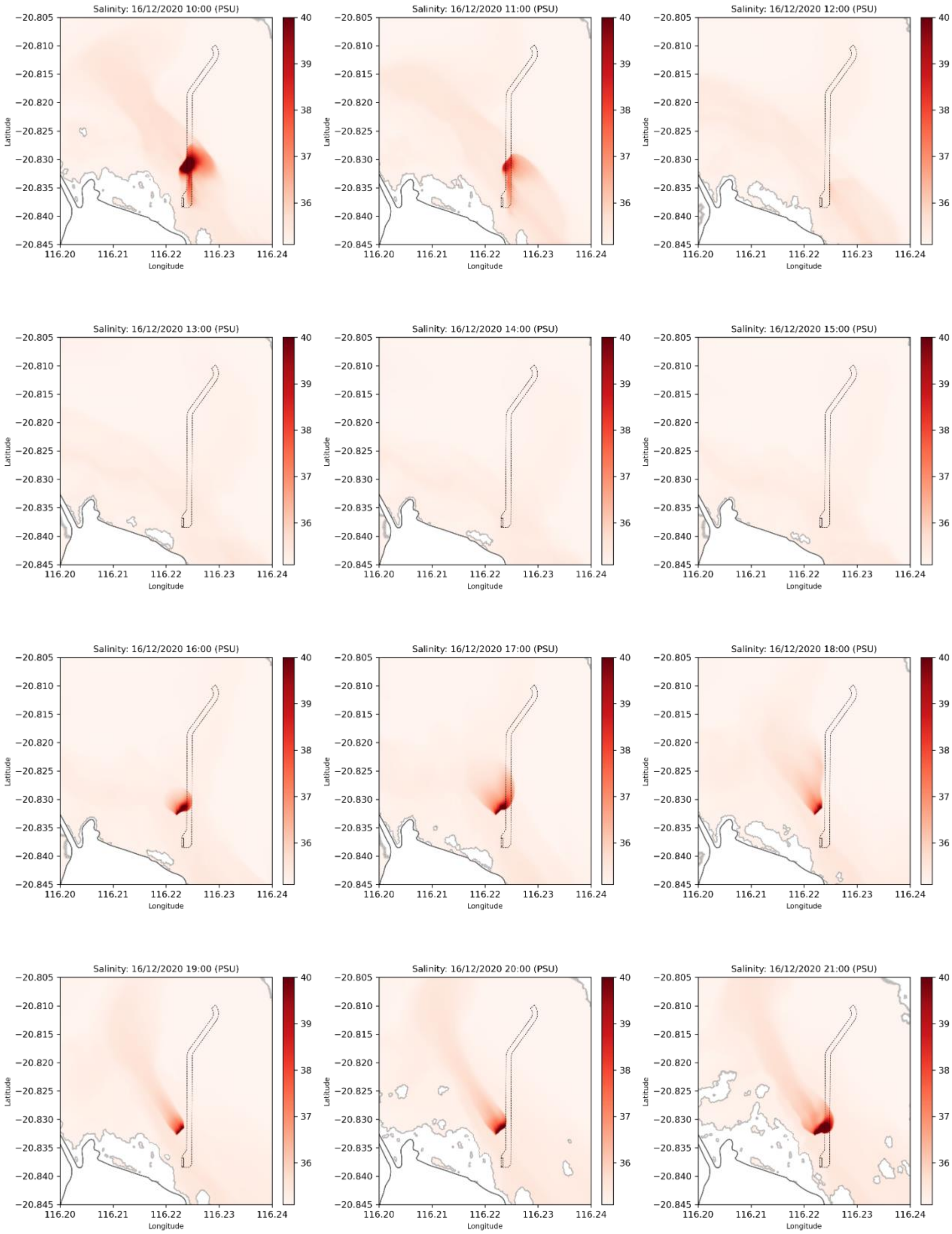

Figure 29: Test run D3: Salinity during a 12-hour period covering a large spring tide

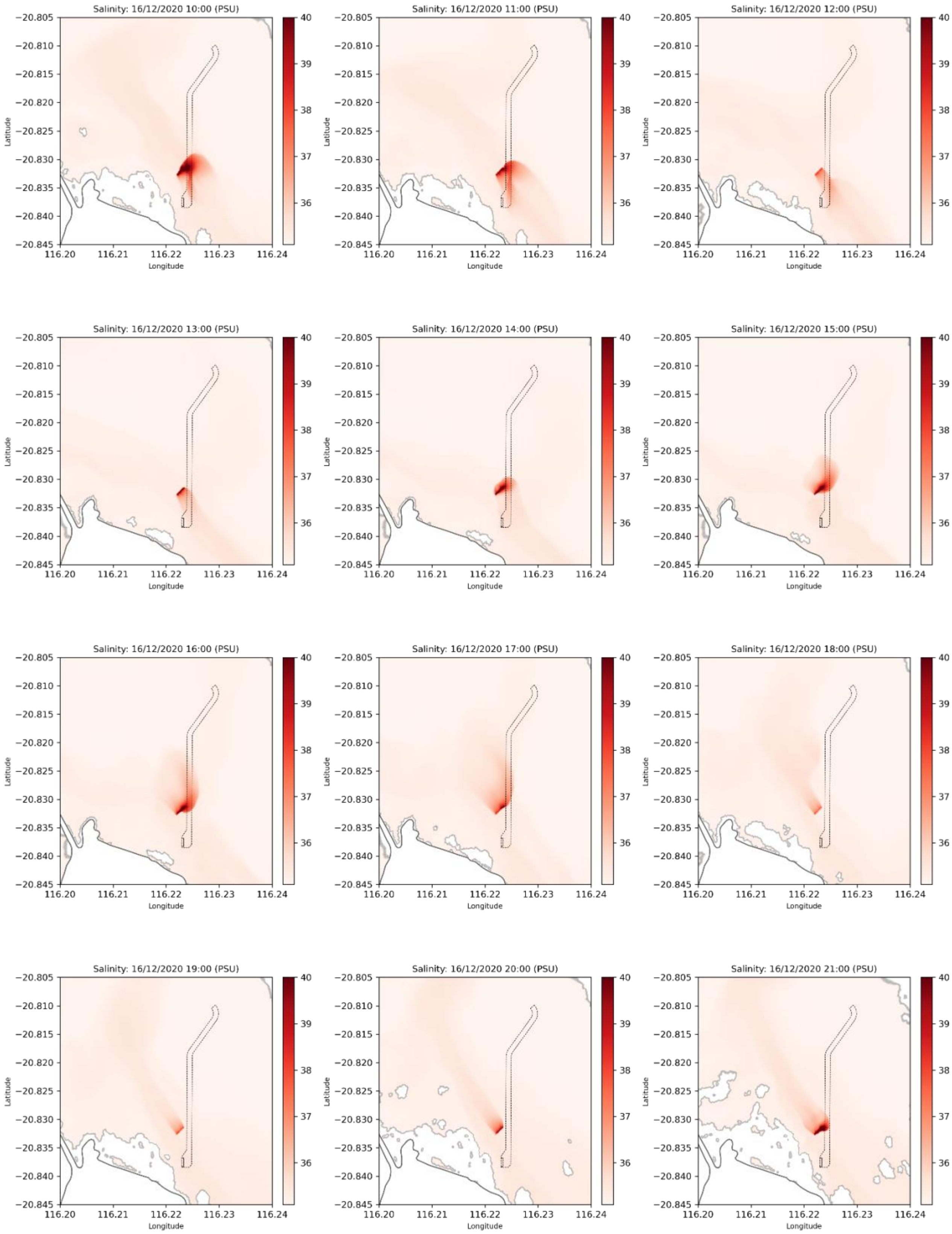

Figure 30: Test run D4: Salinity during a 12-hour period covering a large spring tide

Quantitative comparison of test results

As the test runs D1 to D4 introduce the same mass of salt in the bitterns discharge into the model, comparison of the dilution requirements from (Table 9) can be made between each test run. A quantitative comparison was conducted through the calculation of ecological impact zones for these dilution requirements and by plotting these comparable areas for each test on the same figure.

Note that whilst the same dilution requirements used for the production runs have been imposed on test runs D1 to D4, the results are not representative (not suitable) for impact assessment or comparison against the production run results (due to the shorter simulation period, where a steady state is not achieved). Rather, the results of each test run are suitable for comparison against each other (D1 to D4) alone. However, given the shorter simulation period and results from other preliminary test runs (not shown), the 1st percentile salinity exceedance may provide for a better representation of a 5th percentile salinity exceedance during a two-month simulation (where a steady state is achieved. Figure 31 and Figure 32 therefore presents a comparison of the 1st percentile salinity exceedance for the 270-fold and 420-fold dilutions (equivalent of the moderate and high ecological impact zones) respectively for test runs D1 to D4. Note that the calculation of these boundaries for each dilution target is consistent with the methodology used for calculation of the moderate and high ecological impact zones defined in Section 5.3.6.

This quantitative review led to the conclusions noted in Section 5.3.4.2 and fed into the design of the test runs D1 to D4.

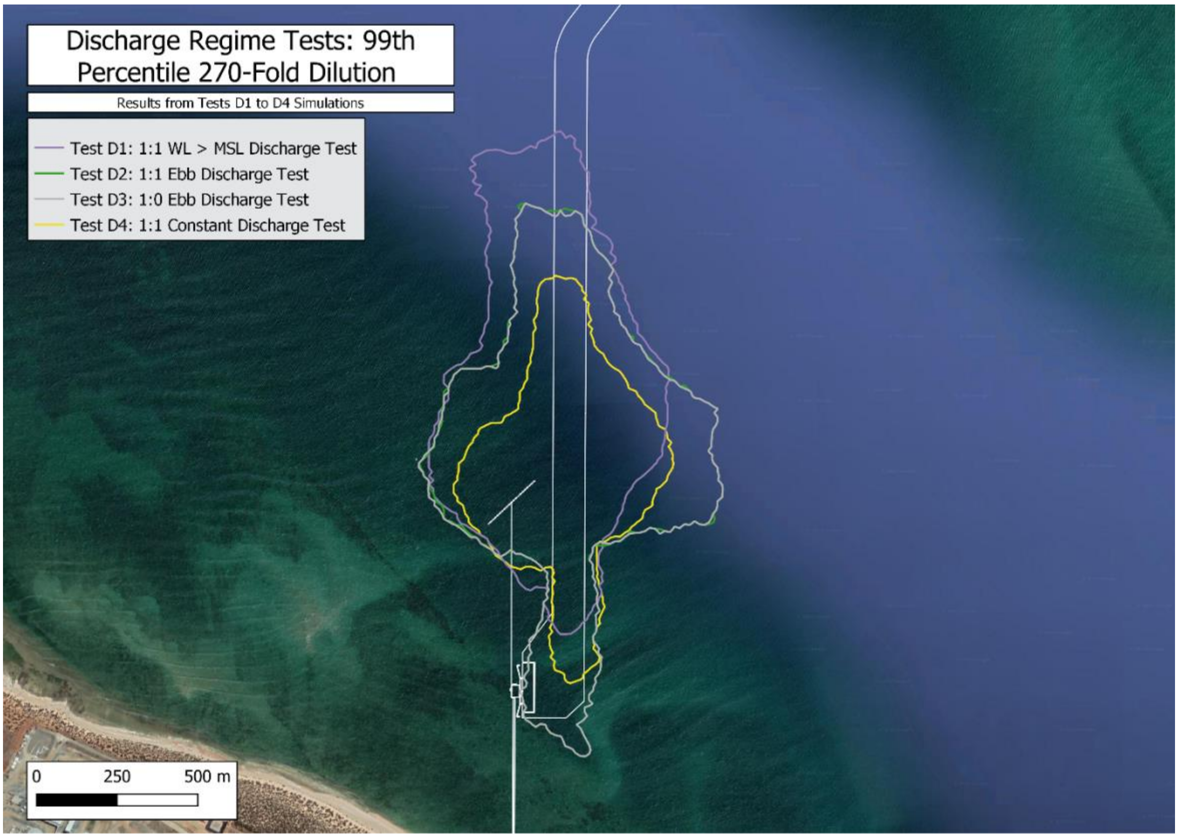

Figure 31: Test runs D1 to D4: percentile exceedance of salinity corresponding to a 270-fold dilution

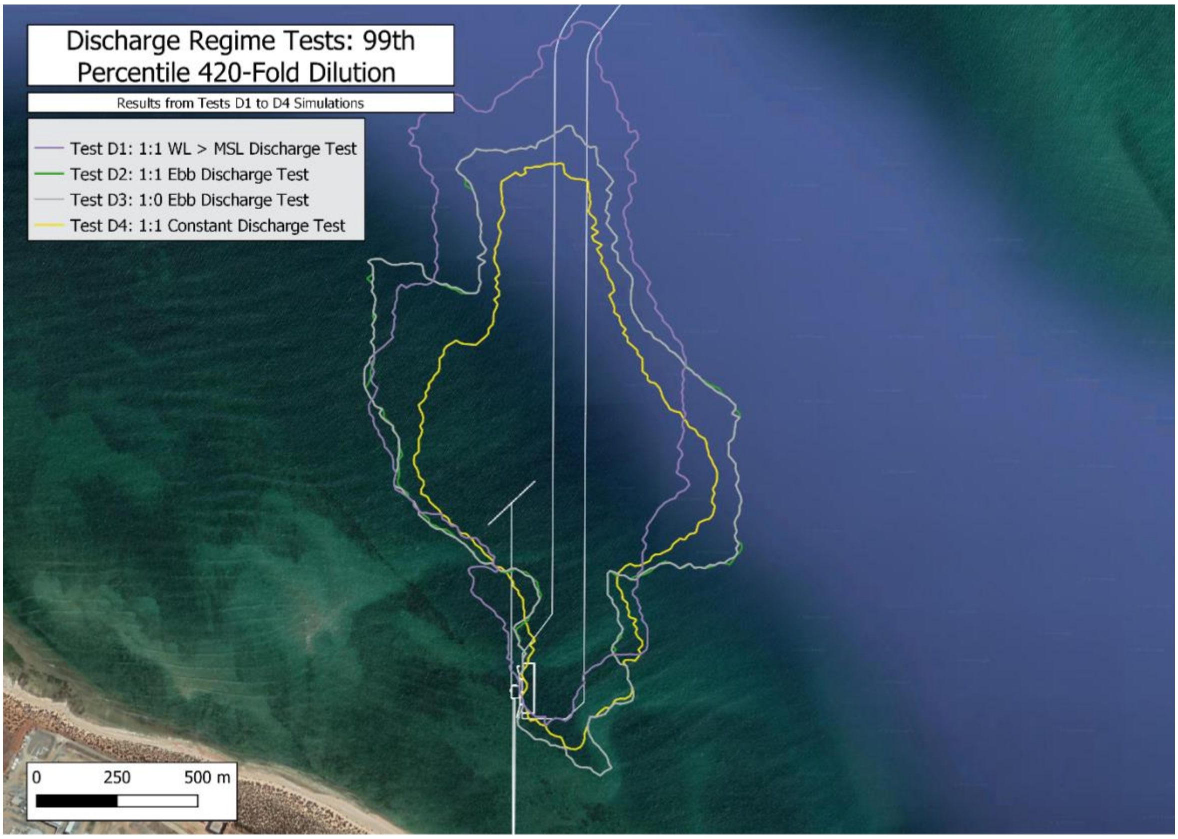

Figure 32: Test runs D1 to D4: percentile exceedance of salinity corresponding to a 420-fold dilution

Appendix B. Short-circuiting from outfall to intake

Time series of salinity at the intake site were extracted for both production runs (Figure 33 and Figure 34) for production runs 1, and 2, respectively). Extracted time series show a slight short-circuiting of bitterns salt from the diffuser to the intake, with up to 0.6 PSU above ambient salinity over the simulated periods. Strictly speaking, bitterns pre-dilution with seawater is slightly lower than 1:1.

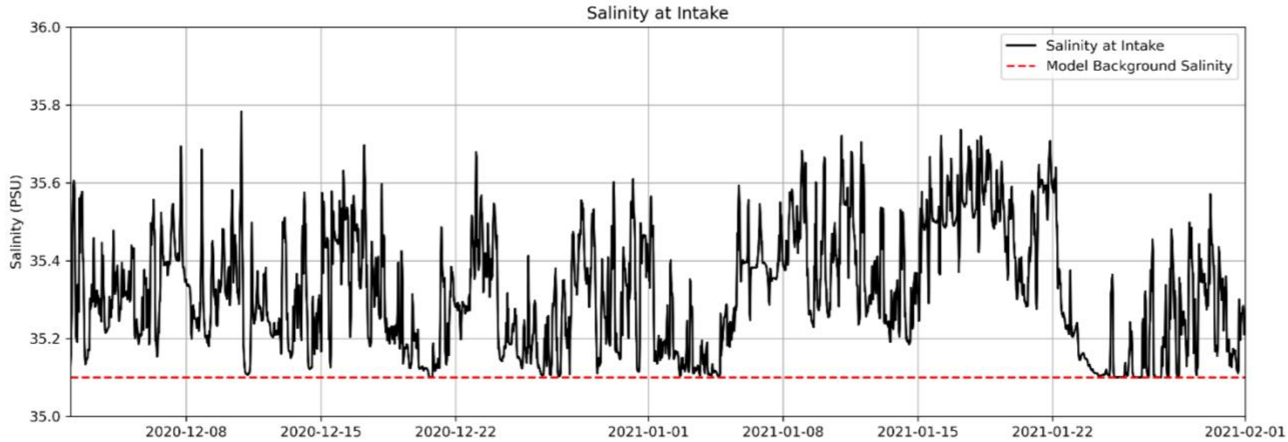

Figure 33: Production run 1: Salinity timeseries for pre-dilution material (extracted from the intake location)

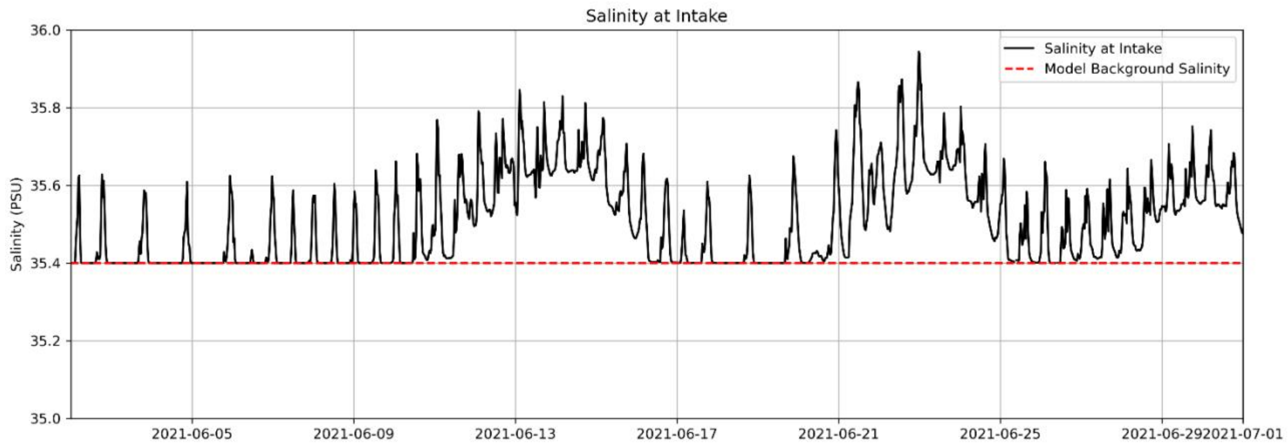

Figure 34: Production run 2: Salinity timeseries for pre-dilution material (extracted from the intake location)

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