Tidal Inundation Modelling

ESSP Scenario 7.2

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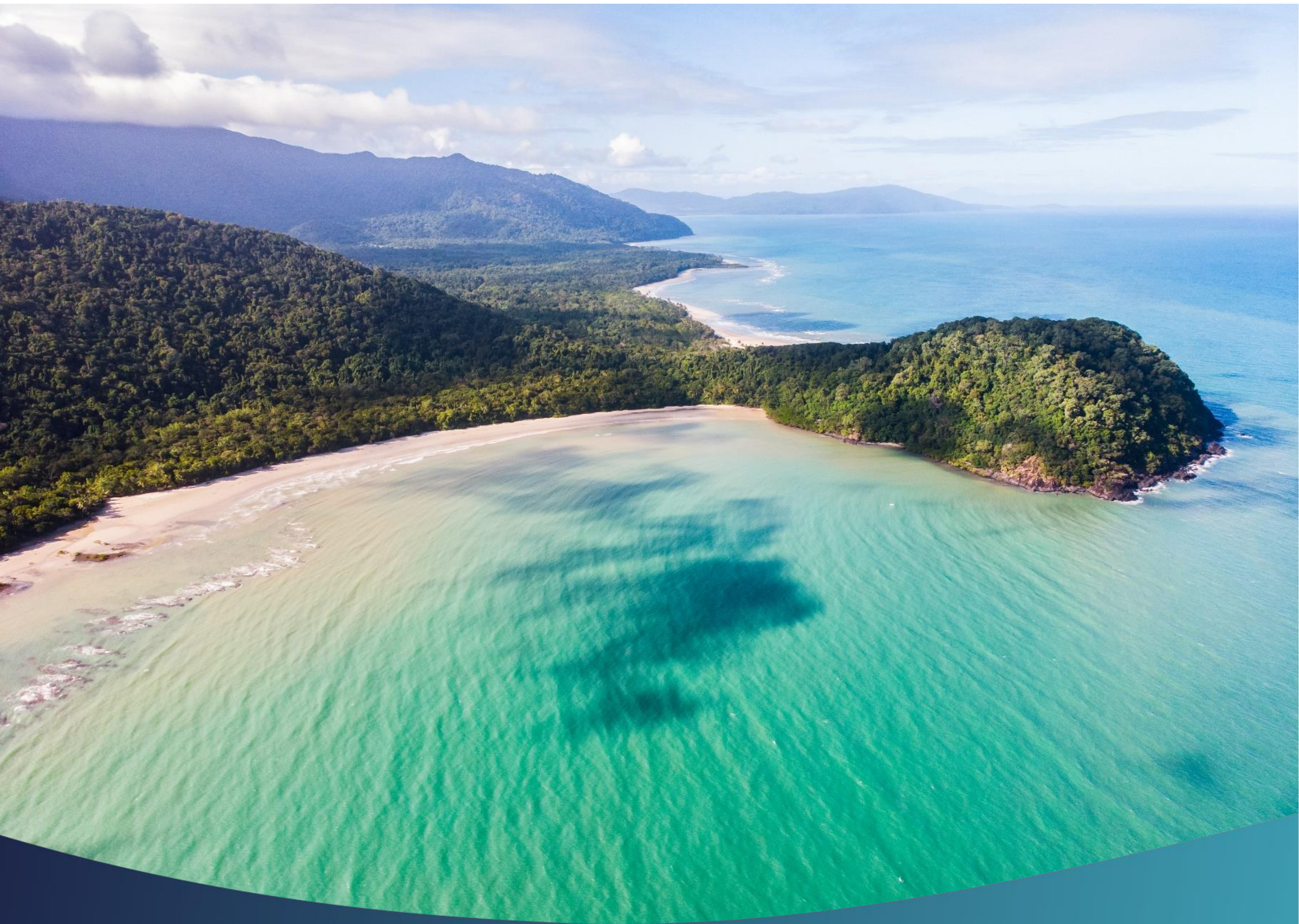

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Version Register

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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.

Section	Change
Whole Report	New merged Digital Elevation Model (DEM) Revised pond layout Report adjusted to accommodate for outcomes from new DEM and pond layout

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Acronyms, Abbreviations and Definitions

Acronyms & Abbreviations	Definitions
AHD	Australian Height Datum
BCH	Benthic Communities and Habitats
Ck	Creek
DEM	Digital Elevation Model
DHI MIKE FM	Danish Hydraulic Institute MIKE Flexible Mesh hydraulic model
EIA	Environmental Impact Assessment
ERA5	European Centre for Medium-Range Weather Forecasts 0.25 degree hourly hindcast
ESD	Environmental Scoping Document
ESSP	Eramurra Solar Salt Project
GA	Geoscience Australia
GG	Guardian Geomatics
GL	Gigalitres
ha	Hectare
HAT	Highest Astronomical Tide
IOA	Index of Agreement
Km	kilometres
LAT	Lowest Astronomical Tide
Leichhardt	Leichhardt Salt Pty Ltd (the Client)
LiDAR	Light detection and ranging
m	Metres
m^3	Metres cubed
MBES	Multibeam Echosounder
MHWS	Mean High-water springs
MNG	McMullen Nolan Group Pty Ltd
MSL	Mean Sea Level
MS	Ministerial Statement
Mtpa	Million tonnes per annum

Acronyms & Abbreviations	Definitions
O2M	O2 Marine Pty Ltd
O2Me	O2 Metocean Pty Ltd
ppt	Parts per thousand
RSME	Root mean squared error
SBES	Single Beam Echo Sounder
SME	Subject Matter Expert
SRTM	Shuttle Radar Topography Mission
TPXO	Oregon State University TOPEX/Poseidon Global Inverse Solution tidal model
WA	Western Australia
WST	Western Standard Time

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 Million tonnes per annum (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.

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 tidal inundation flows. The purpose of this report is to present the tidal inundation 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) and 'Inland Waters', and on the Other Environmental Factor 'Coastal Processes' discussed in O2Me (2023d).

O2Me adopted a nested approach to hydrodynamic modelling where boundary conditions (fluxes and water levels) for the local tidal inundation model were extracted from either a regional, 3D hydrodynamic model or a spatial and time varying TPXO (global tidal model) dataset as described in O2Me (2022a). Surface stress and barometric pressure fields were extracted from the European Centre for Medium-Range Weather Forecasts Forecasts 0.25 degree hourly hindcast (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. The tidal model was validated against water level measurements at MacKay Creek (Ck) and at three stations within Regnard Bay. The validation period was a 14-day period that contained large amplitude spring tides, as required by the ESD. The post-development DEM was derived from the DEM of the validated tidal model for Leichhardt's Pond Scenario 7.2.

Water level (inundation) results between the pre-development and post-development simulations over the selected representative spring tide period were compared to derive an understanding of changes in inundation behaviour between the two scenarios to investigate the potential changes in local hydrodynamic processes associated with the construction of the salt ponds. Two types of comparison plots were used: percentage time 'wet' and 'change in total water depth'. The plots highlighted the importance of the system of interconnected creeks within the intertidal region and the areas that would be affected by the emplacement of the ponds and intake pumping station. The creeks which will be mostly affected by pond emplacement are MacKay Ck, Straight Ck, and Barnard Ck. Though the percentage of time 'wet' before and after development differed little north of the crystallisers, changes in the total water depth of the order of 10 cm will be experienced at some locations during (possibly) every spring tide. Most notable changes are predicted north of the crystallisers, around the proposed intake structure, and behind 40 Mile Beach near the Barnard Ck mouth.

Maps of percentage of time 'wet' and 'change in total water depth' were prepared for comparison to Benthic Communities and Habitats (BCH) maps, to facilitate assessment of the environmental impact on BCH within the affected area.

The validated tidal model is deemed suitable to inform the Coastal and Intertidal Processes Assessment (O2Me 2023d).

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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-south-west 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 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.

The short summary of the Proposal is given 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
- 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.

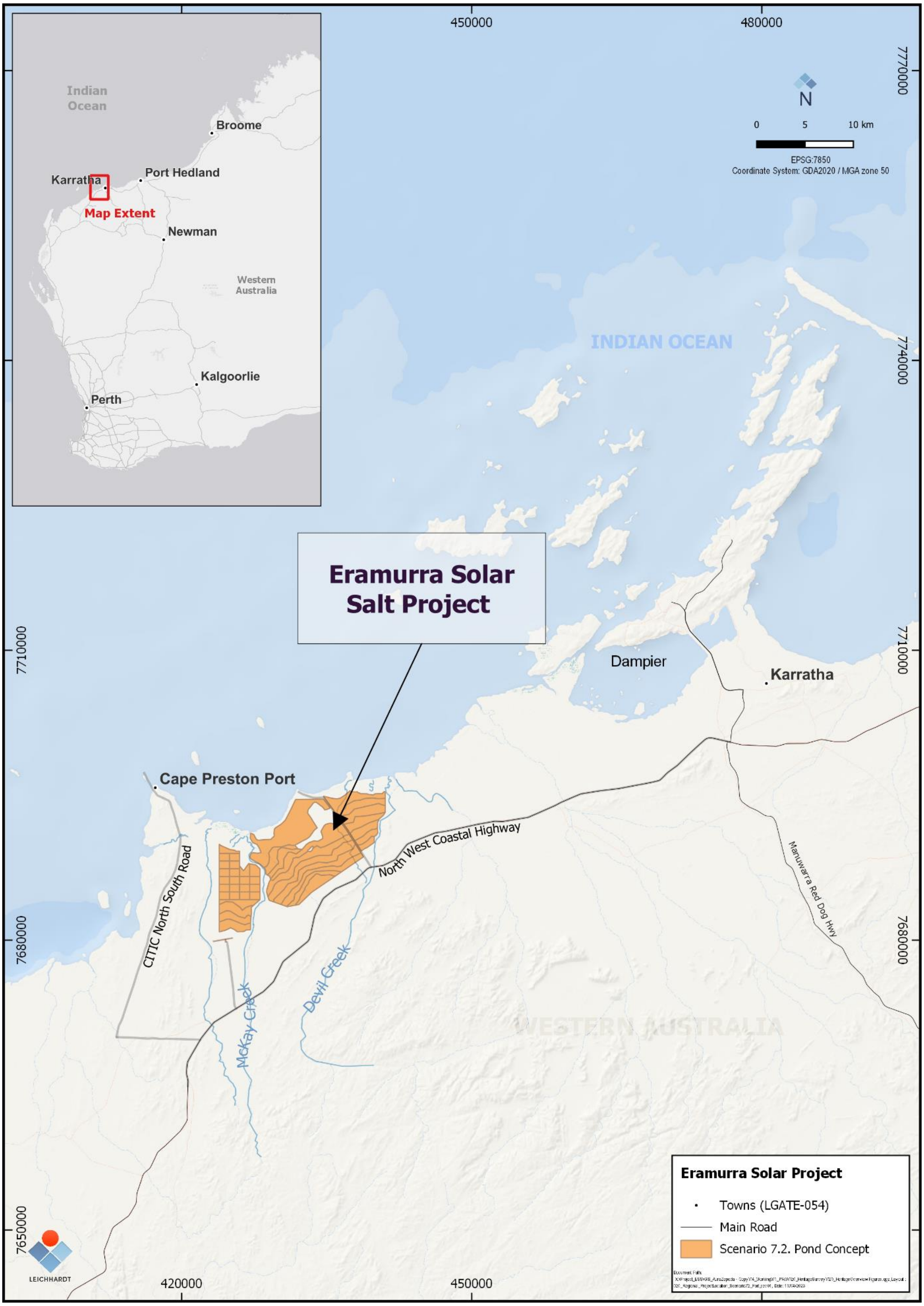

Figure 1: Regional location of the Proposal

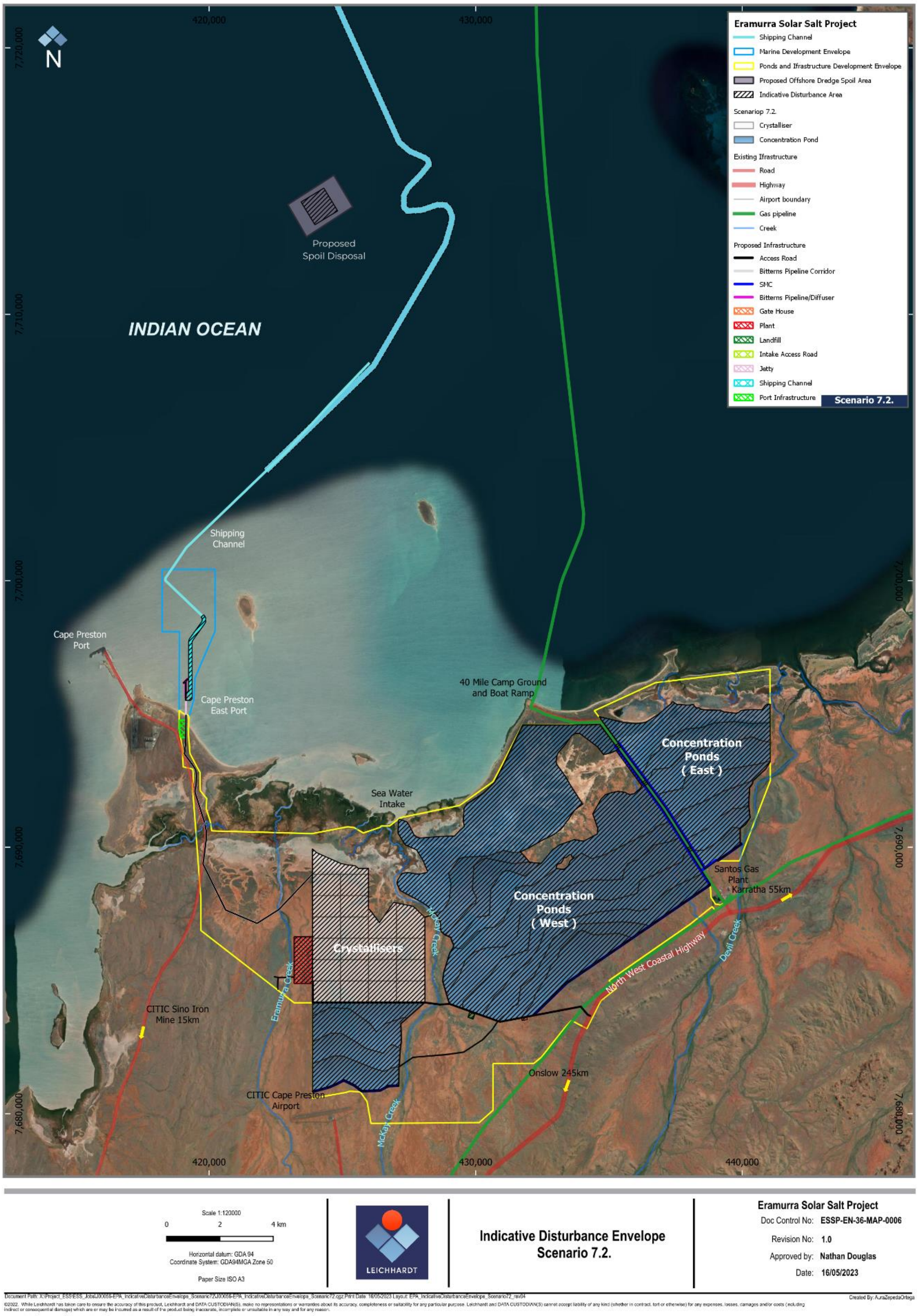

Figure 2: Development Envelopes

1.2. Purpose of this report

The need for a tidal inundation modelling study is outlined in Items 20b, 22 and 132b of the Environmental Scoping Document (ESD) (Preston Consulting 2022) as reproduced in Table 3.

Table 3: Work required for the assessment of the ESSP related to coastal processes changes attributable to the ESSP which require a tidal inundation modelling study (ESD, Preston Consulting 2022)

ESD Item Number	Environmental Factor	Work required
20.b	BCH	Undertake a […] inundation study to produce a series of flood and storm surge maps for different event scenarios, with and without the Proposal (using confirmed Proposal general arrangement drawings and levels). It will incorporate weather data, accurate contour data and tidal information. The study will include the following: Modelling and assessment of tidal flows before and after the development of the Proposal, using several scenarios (i.e. spring high tide through to storm surge events). This will determine which areas will remain inundated under a range of scenarios after these events and for how long (pre- and post-development)
22	BCH	Undertake modelling and assess the impacts of climate change on intertidal BCH based on sea level rise predictions for the next 100 years;
132.b	Inland Waters	Undertake a [..] inundation study to produce a series of flood, tidal inundation and storm surge maps for different event scenarios, with and without the Proposal (using confirmed Proposal general arrangement drawings and levels). It will incorporate weather data, accurate contour data and tidal information. The study will include the following: Modelling and assessment of tidal flows before and after the development of the Proposal, using several scenarios (i.e. spring high tide through to storm surge events). This will determine which areas will remain inundated under a range of scenarios after these events and for how long (pre- and post-development)

The purpose of this report is to present the tidal inundation modelling study undertaken by O2 Metocean (O2Me) on behalf of Leichhardt to support the evaluation of the effects of Project attributable changes on the Key Environmental Factors 'Benthic Communities and Habitats' (BCH) and 'Inland Waters', and on the Other Environmental Factor 'Coastal Processes', required to inform the assessment of environmental impacts from the ESSP as specified in the ESD (Preston Consulting 2022). This report is thus not strictly designed to address ESD items 20b, 22 and 132b, rather it presents the tidal inundation model that informs their evaluation. ESD items 20b, 22 and 132b are discussed in O2Me (2022d; 2023d).

1.3. Objective

The objective of this study was to develop a tidal inundation model including the ESSP footprint and creeks (where changes to the tidal inundation regime due to the placement of ESSP pond walls may be experienced) to inform the Coastal Process study (2023d) for the purpose of the environmental impact assessment (EIA).

The ESSP footprint adopted in this study is based on ESSP's scenario 7.2. The model is based on the existing hydrodynamic model of Cape Preston (O2Me 2022a)

1.4. Scope of work

A tidal inundation study based on the superseded ESSP pond layout scenario 6.2 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 tidal inundation modelling for a new pond footprint to meet the requirements relating to Benthic Communities and Habitats and Inland Waters in the ESD for the ESSP, being ESD items #20 and #132 (excluding surface water flows)".

Eight (8) tidal inundation model scenarios were agreed between Leichhardt and O2Me (Table 4).

Table 4: Tidal inundation model simulations for interpretative coastal processes study

Simulation	Description	Simulation period	Presentation of results & discussion
01	**Pre**-ESSP development ERA5 wind and no waves (i.e. calm, **current** conditions)	14-days of 'close to Lowest Astronomical Tide (LAT) and Highest Astronomical Tide (HAT)' **spring** tidal period, identified by Subject Matter Expert (SME) ([1])	This report
02	**Post**-ESSP Scenario 7.2, No wind or waves (i.e. calm, **future** conditions)	14-days of 'close to LAT and HAT' **spring** tidal period, identified by SME	This report
03	**Pre**-ESSP development, ERA5 wind and no waves, Accounting for **0.9 m** mean sea level rise	14-days of 'close to LAT and HAT' **spring** tidal period, identified by SME	O2Me 2023d
04	**Post**-ESSP Scenario 7.2, No wind or waves, Accounting for **0.9 m** mean sea level rise	14-days of 'close to LAT and HAT' **spring** tidal period, identified by SME	O2Me 2023d
05	**Post**-ESSP Scenario 7.2, Constant 12.86 m/s (i.e. 25 knots) **SW'ly** winds, +2 m **surge**	4-days centred at peak of large spring tidal cycle	O2Me 2023d
06	**Post**-ESSP Scenario 7.2, Constant 12.86 m/s **W'ly** winds, +2 m **surge**	4-days centred at peak of large spring tidal cycle	O2Me 2023d

[1] Dr Piers Larcombe

Simulation	Description	Simulation period	Presentation of results & discussion
07	Post-ESSP Scenario 7.2, Constant 12.86 m/s E'ly winds, +2 m surge	4-days centred at peak of large spring tidal cycle	O2Me 2023d
08	Post-ESSP Scenario 7.2, constant 12.86 m/s SE'ly winds, +2 m surge	4-days centred at peak of large spring tidal cycle	O2Me 2023d

O2Me's approach to delivering the work was to:

1. Merge publicly available bathymetric datasets with inter-tidal bathymetry and supra-tidal topography LiDAR data gathered for the ESSP
2. Identify a 15-day spring-neap tidal cycle with water levels ranging from close to LAT to close to HAT for assessment of inundation areas under ambient conditions
3. Expand the validated hydrodynamic model of Regnard Bay (O2Me 2022a) using an optimised domain size and numerical mesh in the vicinity of the ESSP (hereafter the 'tidal inundation model')
4. Run simulation 01 (Table 4) – current conditions – to validate the tidal inundation model with water levels gathered for the ESSP at the oceanographic sites NCP05, UNS05, and ERA05, and the creek site SIC02 (refer to O2Me 2022b)
5. Run the tidal inundation model with an altered bathymetry representative of the post project development state over the validation period (simulation 02, Table 4). This is referred to as the 'post-development' scenario
6. Compare inundation results between the existing and post ESSP development simulations to derive an understanding of potential changes in tidal inundation patterns in the vicinity of the ESSP, due to the development of the ESSP
7. Offer the tidal model to the Coastal Processes Study to run simulations 03 to 08 (Table 4) and use the results to investigate the potential changes in local hydrodynamic processes with the ponds emplaced.

1.5. Exclusions and limitations

Surface water flows due to storm runoff were excluded from this study.

1.6. Definitions and conventions

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

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

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

1.7. Reports of relevance

Reports listed in Table 5 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 5: O2 Metocean (O2Me) reports of relevance

Report number	Report title	Intext reference	In-text abbreviation
R210323	ESSP: Base Hydrodynamic Model	O2Me 2022a	BHM
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	CP1
R210324	ESSP: Dredge Plume Modelling	O2Me 2023a	DPM
R210325	ESSP: Bitterns Dispersion Modelling	O2Me 2023b	BDM
R210327	ESSP: Tidal Inundation Modelling	O2Me 2023c	-
R220181[2]	ESSP: Coastal and Intertidal Processes Assessment: ESSP Scenario 7.2	O2Me 2023d	CP2

[2] This report

2. Background

2.1. Oceanographic context

The proposed ESSP is located South 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, referred to as the dry season, winds are predominantly easterly to southerly, coincident with the trade winds. During the NW monsoon, referred to as the wet season, winds are predominantly west to south-west. 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 most-cyclone prone section of the Australian coast, 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 modelling report (O2Me 2022a).

3. Numerical model

Modelling was conducted using the DHI MIKE FM suite of models. Details can be found in O2Me (2022a).

3.1. Bathymetry

A detailed and accurate bathymetry is paramount to the tidal inundation modelling study. A digital elevation model (DEM) was compiled for this study to:

a) increase the model resolution around the intake pump site (creeks) and near the pond walls, and
b) remove anomalies that had been inadvertently introduced in earlier bathymetry merge attempts (see modelling of ESSP scenario 6.2).

Bathymetric and topographic datasets considered in this merge included:

1. Geosciences Australia (GA) gridded bathymetry and topography product (publicly available)
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

3.1.1. Datasets

GA Bathymetry Dataset

The 30 m, high-resolution digital elevation model (DEM) of the Northwest Shelf (Figure 3) referenced to mean sea level (MSL) was downloaded from GA's web portal[3]. This DEM consists of:

- Publicly available multibeam echosounder (MBES) datasets
- Satellite derived bathymetry produced using 1000+ images acquired between January 2017 and December 2019 (Lebrec et al 2021)
- Seismic derived bathymetry extracted from 100+ surveys acquired between 1981 and 2015.
- Shuttle Radar Topography Mission (SRTM) topography, reprocessed by Galant et al (Geoscience Australia 2011)
- 2009 Australian Bathymetry and Topography grid (Geoscience Australia 2009)

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

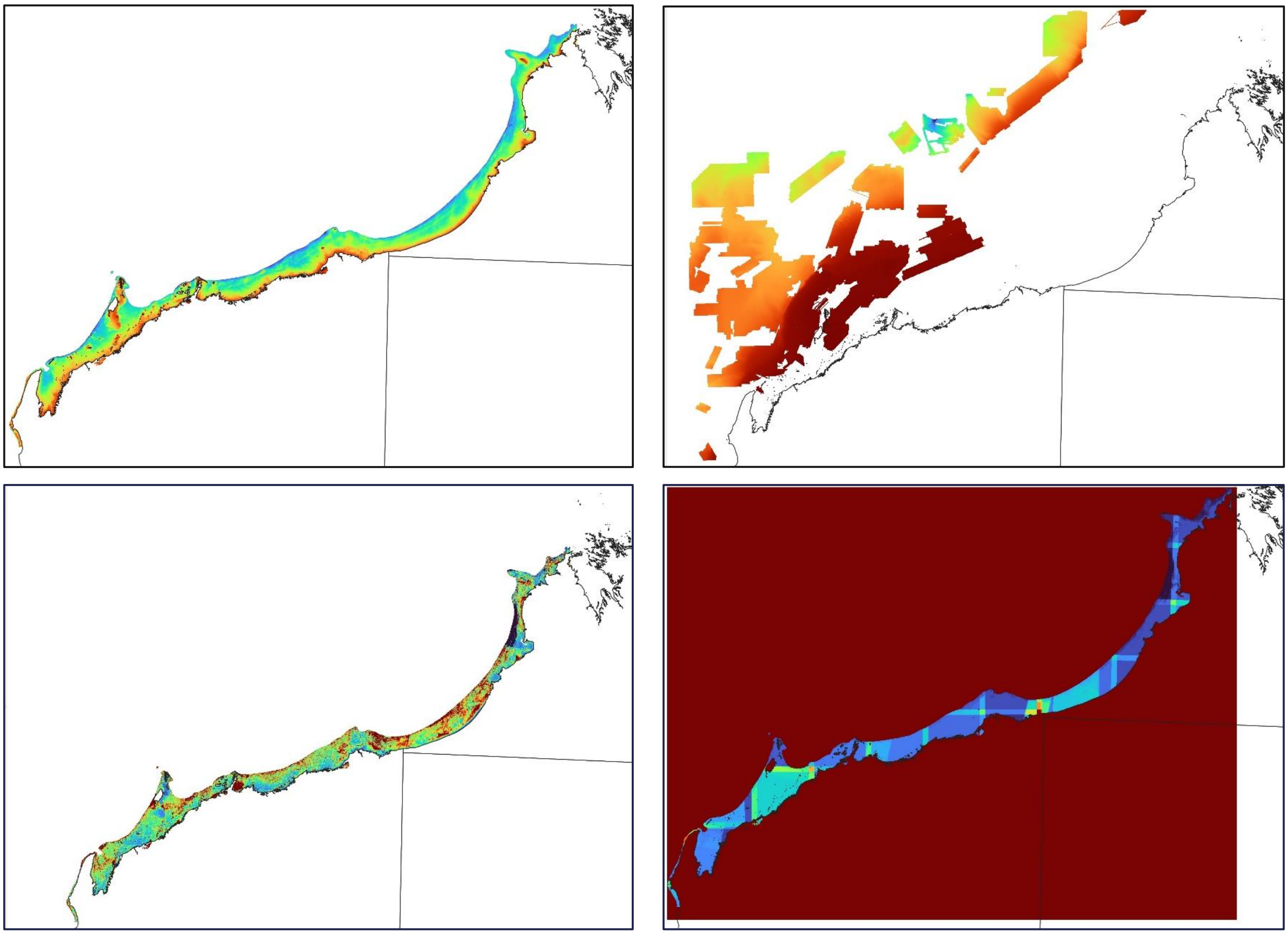

Figure 3: Overview of GA Satellite and Seismic Derived bathymetries (Top left: Satellite Derived DEM; Top right: Seismic Derived DEM; Bottom left: Satellite Derived standard deviation; Bottom right: Satellite Image Count)

GG Bathymetry Dataset

The GG's dataset provided by Leichhardt (Figure 4) referenced to LAT consisted of:

- 5 m horizontal resolution of the offshore sections including tentative dredge spoil grounds
- 1 m horizontal resolution of a nearshore area covering the proposed project footprint, and nearshore navigational channel.

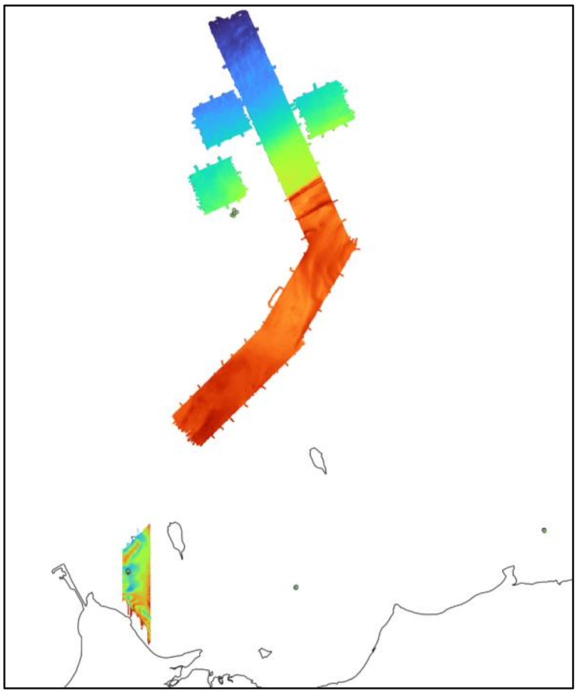

Figure 4: GG bathymetry coverage (source: Leichhardt)

LiDAR topographic survey

The LiDAR dataset was acquired by MNG in 2022 at Leichhardt's request (Figure 5). Data was referenced to Australian Height Datum (AHD). The LiDAR was flown at low tide across the coastal region and between 7 am and 4 pm for the onshore portion ensuring a sun angle within 30° from vertical. The data was calibrated to 17 ground control sites across the survey area. With rigorous acquisition parameters and a robust processing workflow, the final point cloud allowed for the generation of a high quality 0.50 m resolution grid, however given the foreseeable minimum tidal model numerical grid size, a 5 m resolution was utilized for this merge project. The LiDAR was viewed as the most accurate and trusted dataset over the inter-tidal and supra-tidal project area and was used to help calibrate the other datasets in the project.

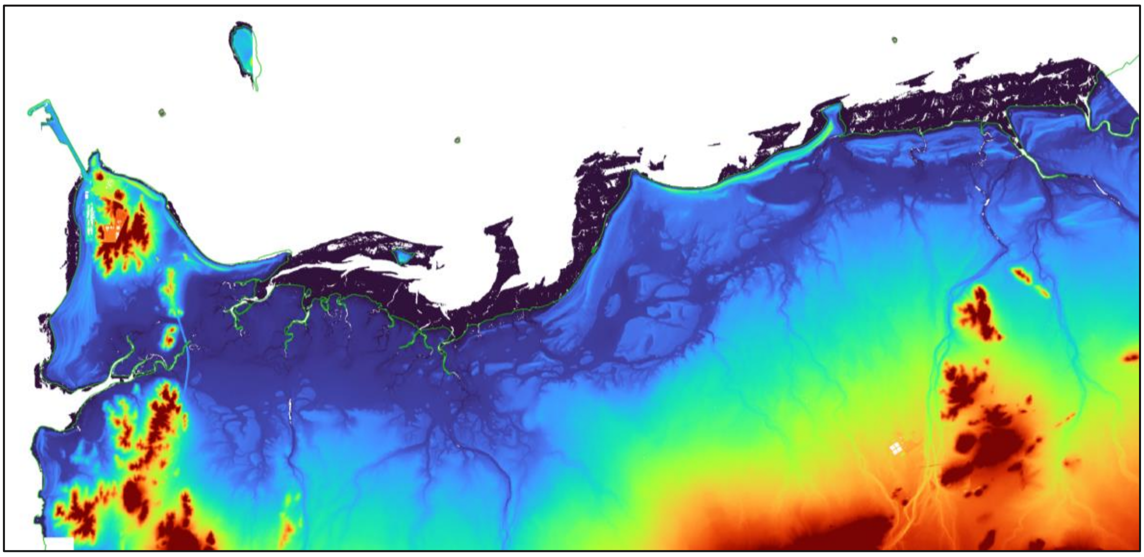

Figure 5: LiDAR topographic survey (source: Leichhardt)

EGS Bathymetry

The EGS data (Figure 6) were provided relative to LAT and in xyz format as pseudo xyz grid cell size Dx=3.71 m, Dy= 3.672 m. Conversion to las format was done using lastools, loaded into QGIS. The resulting DEM adopted a horizontal grid cell size of 3.7 m.

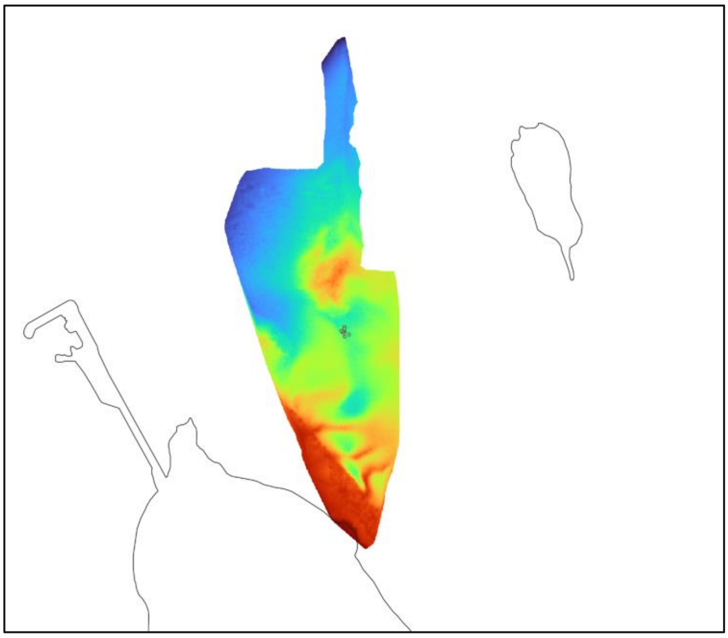

Figure 6: EGS bathymetry coverage (source: Leichhardt)

Reconnaissance SBES bathymetry of nearshore navigational channel

The SBES data (Figure 7) were provided relative to LAT and in xyz format as pseudo xyz grid cell size Dx=7.3355 m and Dy=2.4 m. Conversion to las format was done using lastools, loaded into QGIS. The resulting DEM adopted a horizontal grid cell size of 2.4 m.

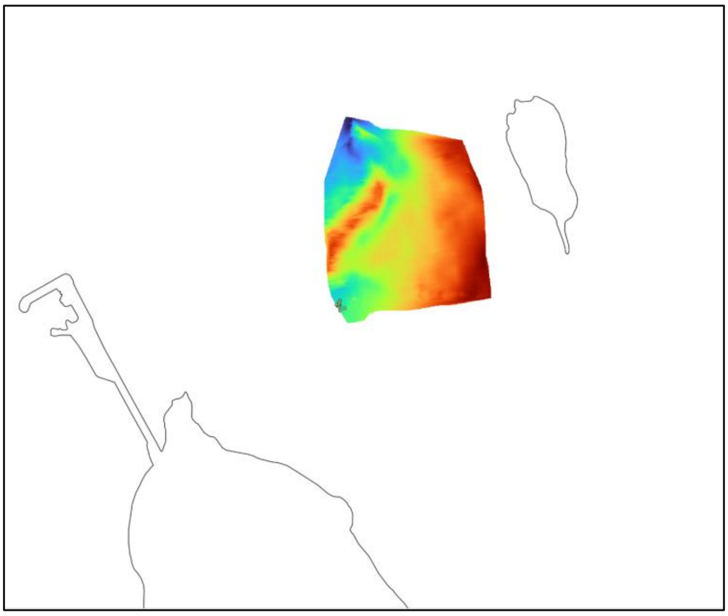

Figure 7: Reconnaissance SBES bathymetry (source: Leichhardt)

Reconnaissance SBES bathymetry of MacKay and Straight Ck

Data were provided relative to LAT in xyz format (O2Me 2020). This dataset was utilized to support infill values in the creek where there are gaps in the LiDAR dataset due to high water depth (Figure 8).

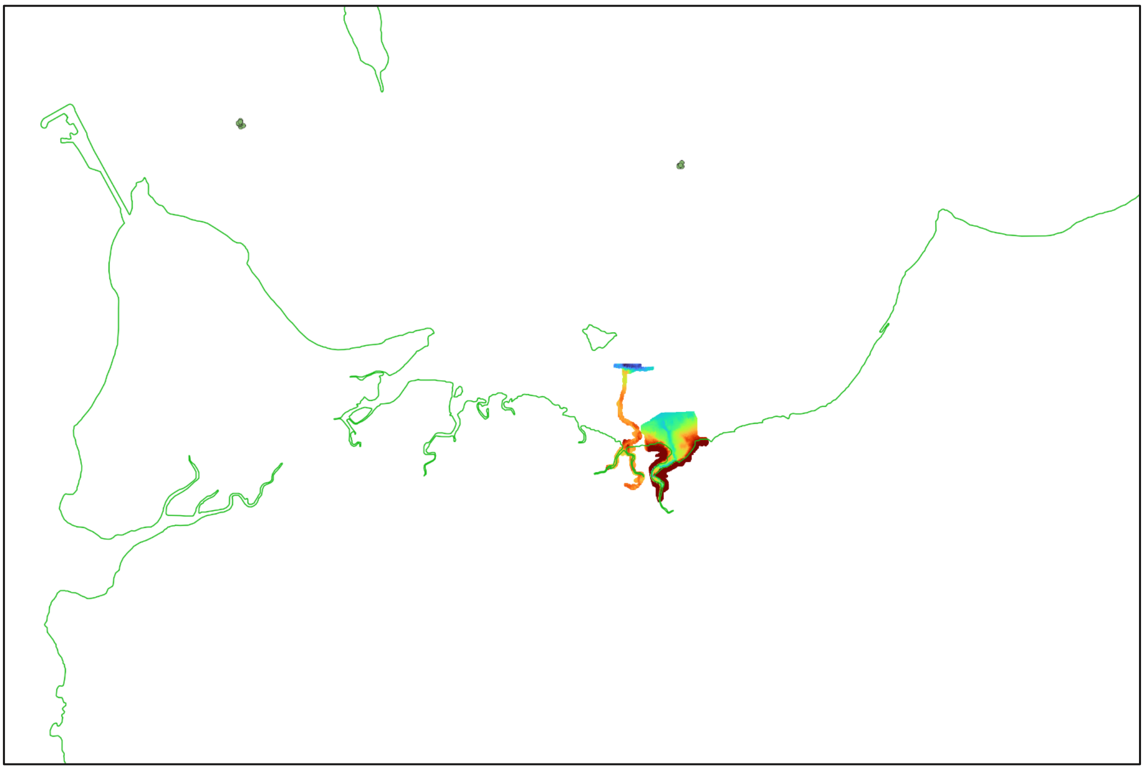

Figure 8: Reconnaissance SBES bathymetry of MacKay and Straight Ck (source: Leichhardt)

3.1.2. Merge

Overlapping datasets (for example EGS and GA, or GA and GG, etc.) were compared to identify offsets and mean deviations between datasets which could lead to interpolation anomalies, if simultaneously used without any manipulation. From this analysis it was concluded that:

- Offshore, the GA dataset is of poor quality and presents some anomalies due to variations of image count. However, it is the only bathymetric dataset that covers most of the oceanographic area, which is considered essential in the merge. Oceanographers' experience suggest that the dataset is of sufficient quality for the study, and that it is unlikely to substantially impact nearshore hydrodynamics.
- Overland, the GA dataset is poor quality and unreliable compared to the LiDAR dataset.
- Local features captured by the GG dataset are also observed in the GA dataset ([4]).
- Errors of between -2 and +2 m are observed between the GA and GG datasets, particularly near the boundaries of the GG dataset, which would introduce significant edge effects should an attempt to embed the GG dataset into the GA dataset be attempted. Manipulation of both datasets around the GG dataset boundary would be significant and the process likely exceed the time available for this study, without any quantifiable benefit to the hydrodynamic processes investigated herein.

[4] For details regarding the GA to GG comparison, refer to the bitterns discharge modelling report (O2Me 2022e)

- The GA dataset present a marked and exaggerated edge effect at the water-land transition isobath, requiring intensive care, blending, and smoothing to ensure a smooth edge.
- The LiDAR data are of higher resolution than the GA data, thus care must be exercised when they are merged.
- Given each dataset coverage and based on experience with other projects which suggest that, where possible, merging the least number of datasets should be attempted to reduce edge effects, the GA and LiDAR data were primarily used in the bathymetry merge with other datasets used as quality controls.

Based on this review, merging of the datasets consisted of:

- Resample GA data to 5 m resolution using Cubic Spline Resampling to ensure no plateauing of the GA dataset and cropping the datasets to the area of interest.
- The GA dataset that overlapped with the LiDAR data (primarily overland) was cropped out to allow the merged bathymetric grid to match the reliable LiDAR as a primary dataset. A small overlap area was retained to ensure the feathering blend algorithm had the best chance to minimise edge effects. This step was iterated after manually reviewing the output DEM until a satisfactory result was obtained. The cropping polygon can be seen in Figure 9.
- Sharp bathymetric changes between two datasets were further smoothed by applying manually defined nulling polygons. Bathymetry in these polygons was interpolated from the nearby datasets laying immediately outside the polygons. The nulling polygons can be seen in Figure 10.
- Using aerial imagery, reconnaissance bathymetries, field observations and hydrodynamic modeller experience, depths were manually and arbitrarily assigned to creek ponds and channels where no bathymetry data was available (for example where LiDAR instruments could not penetrate). Some arbitrary points were placed beyond the blanking polygons to assist with the feather merge (Figure 11).
- Interpolating the gaps. Interpolation was done using the QGIS “Fill nodata” tool which effectively grids the data over the gaps utilizing values on the edge of the gaps. A 20 m maximum distance with one smoothing iteration was found to give optimal results.
- Spikes arising from the manual control points were removed manually (de-spiking step) to ensure a smooth grid result.

While it is acknowledged that the resulting DEM incorporates some inaccuracies, it is seamless (without merging effects) and captures the creeks and intertidal channels near the proposed ESSP pond walls as practicably as possible. It is for these reasons, that the resulting DEM is superior to the formerly adopted DEM (refer to scenario 6.2) and is suitable for use in hydrodynamic modelling studies of the tidal inundation regimes in the vicinity of the ESSP.

The resulting DEM is shown in Figure 12.

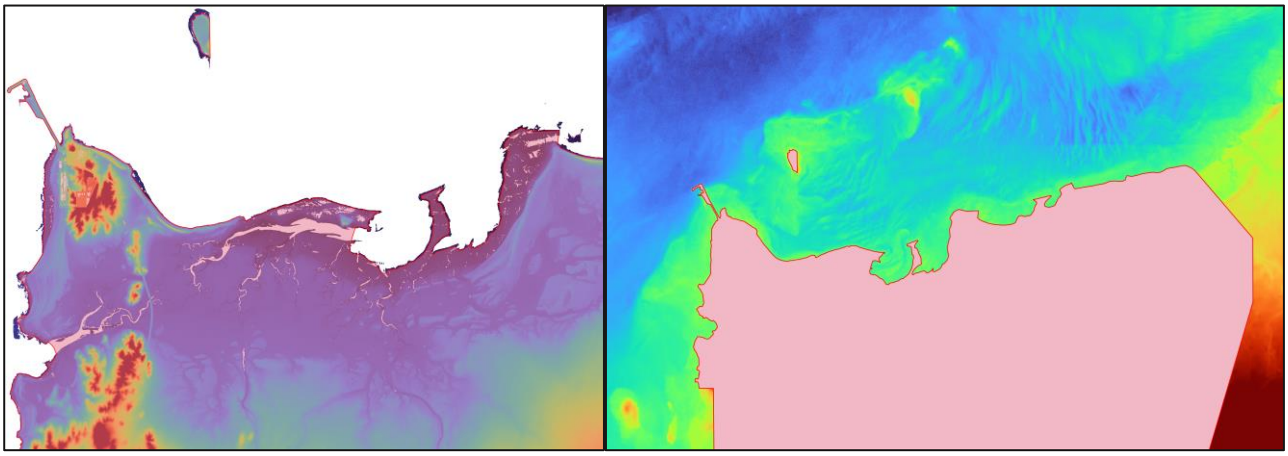

Figure 9: LiDAR topographic data with blanked GA data (left) and GA data with blanked topographic data (right)

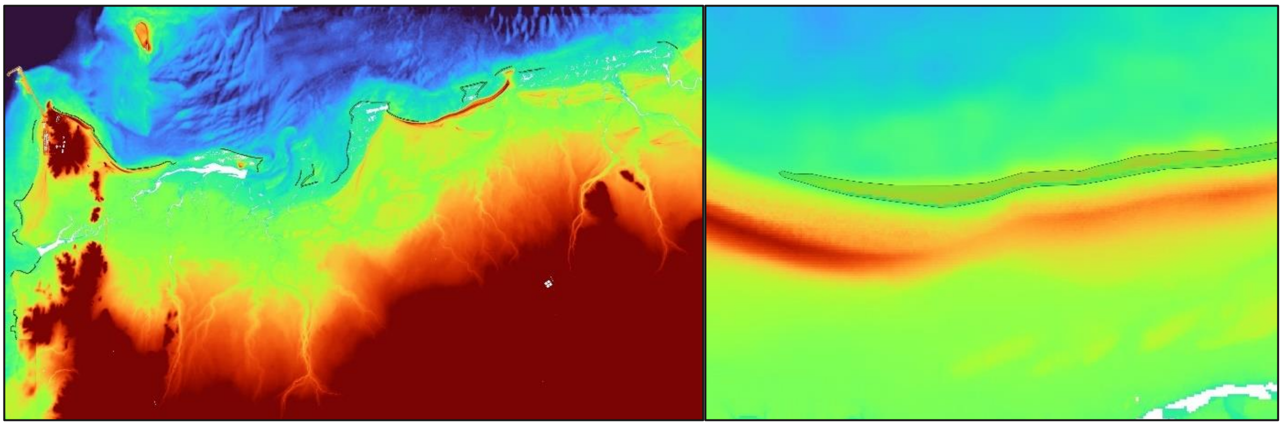

Figure 10: Locations of manually added blanking polygons (left) and typical blanking polygon (right)

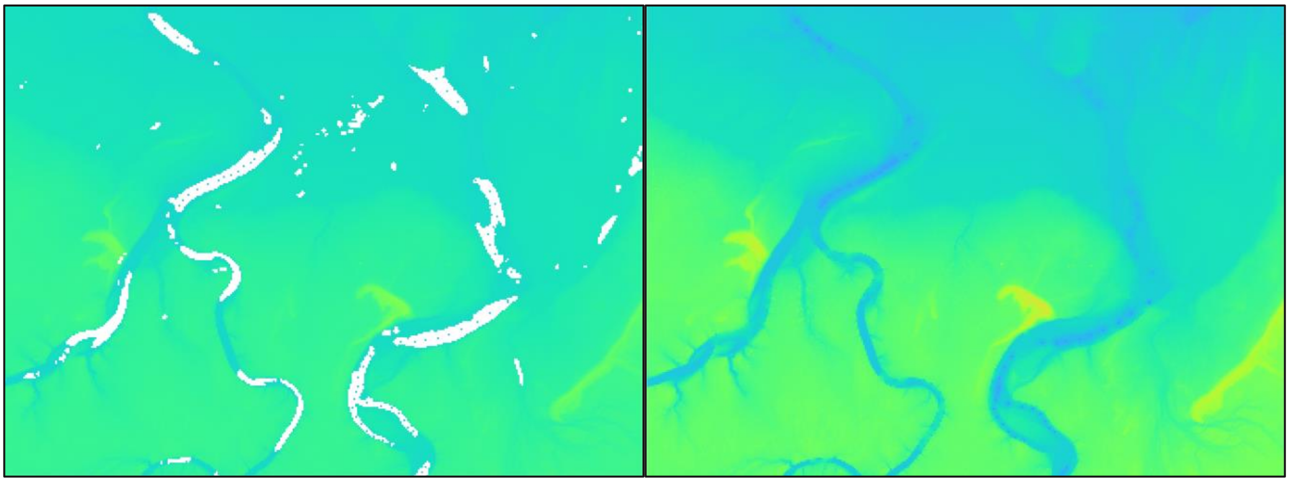

Figure 11: Manual addition of data points where LiDAR sensor was unable to penetrate using reconnaissance bathymetry data where possible (left) and interpolated example (right)

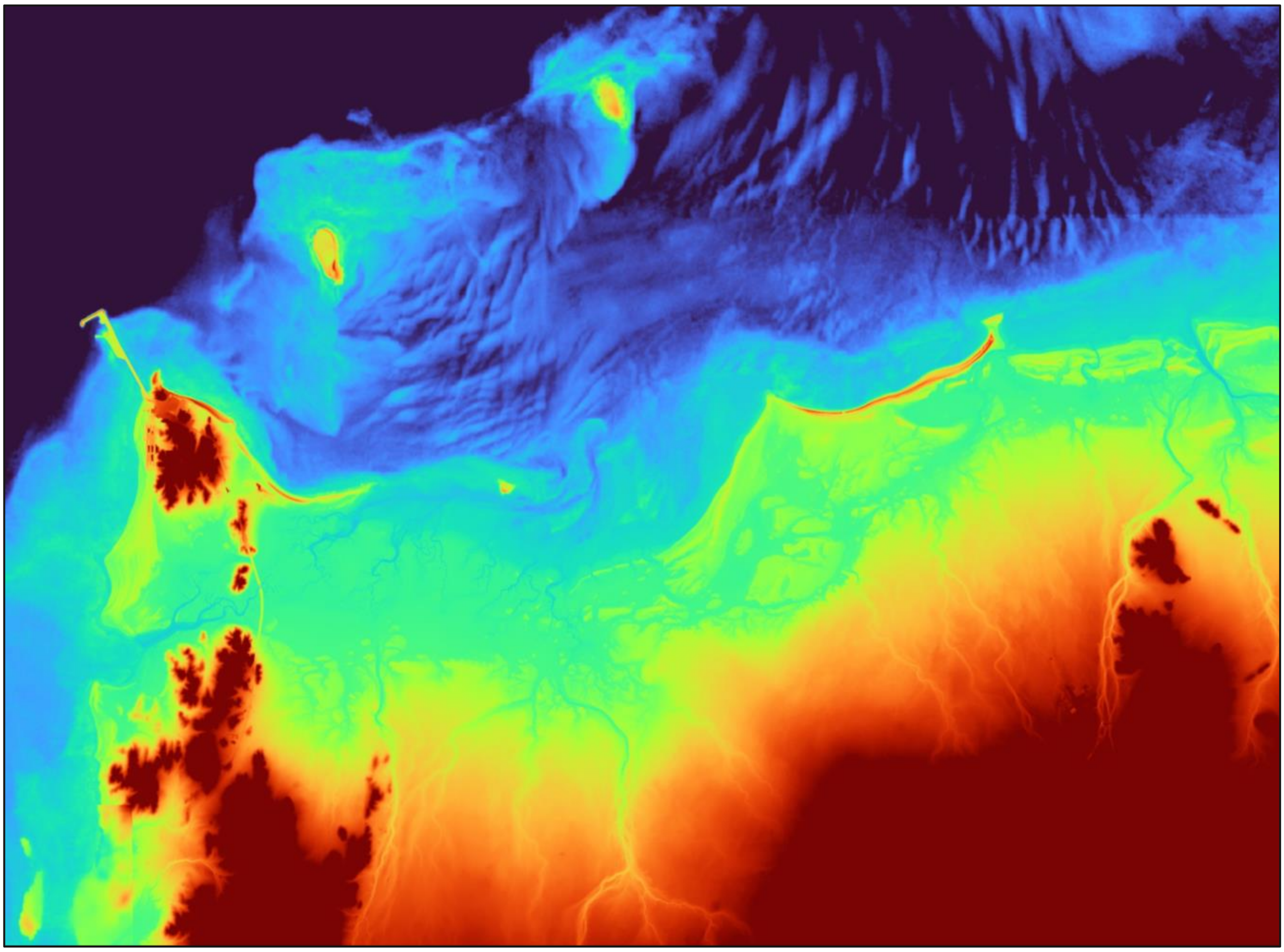

Figure 12: DEM of merged bathymetry and topography used in the construction of the numerical model grid

3.2. Tidal inundation model

The tidal inundation model domain extends from the western side of Cape Preston to West Intercourse Island, covering approximately 50 km of coastline centred at Regnard Bay (blue polygon in Figure 13). Depths range from approximately -25 m AHD near the offshore boundary through to heights of approximately 10–15 m AHD south of the ESSP ponds, allowing for full coverage of the inter-tidal regions of interest.

The domain was discretised with triangular elements ranging from 300 – 500 m in some offshore regions through to approximately 10 m across the main intertidal region and 5 m cells along the narrow creeks. This 5 m high-resolution grid was the result of an iterative process of interpolating the merged bathymetry (see Section 3.1.2) into a tentative grid, running the preliminary tidal model over peak tides, and comparing modelled water levels in MacKay Ck and Straight Ck with measured surface elevations until satisfactory results were obtained. The optimised model grid is shown in Figure 14 to Figure 18 for the polygons shown in Figure 13.

The bed friction parameterisation and its coefficients were taken as calibration tools. Perfect slip boundary condition (no bed shear stress), no-slip boundary condition (zero velocity at the seabed), and Manning's parameterisation of bed friction for Manning's coefficients ranging from 20 to 32 $m^{1/3}/s$ were tested. Best agreement between measured and modelled water levels were obtained with a Manning's coefficient of 25 m$^{1/3}$/s. Currents measured at SIC02 are representative of highly localised (order of meters), time varying conditions (e.g. along-creek bed sediment displacement) which cannot be reproduced by the tidal inundation DEM or scaled by the digital model grid, hence were deemed unsuitable for assessment of model performance.

To assist with the analysis of changes between pre and post ESSP development, a second model bathymetry that incorporates the proposed ponds was developed by altering the existing bathymetry within the ponds footprint. For this post ESSP bathymetry, the seabed elevation at every model cell within the pond wall arrangement was elevated to 6 m AHD. Data points higher than 6 m AHD were not modified.

The unstructured mesh arrangement for both the pre-project development model and the post-project development model are identical, allowing for cell-to-cell comparison of the modelled results.

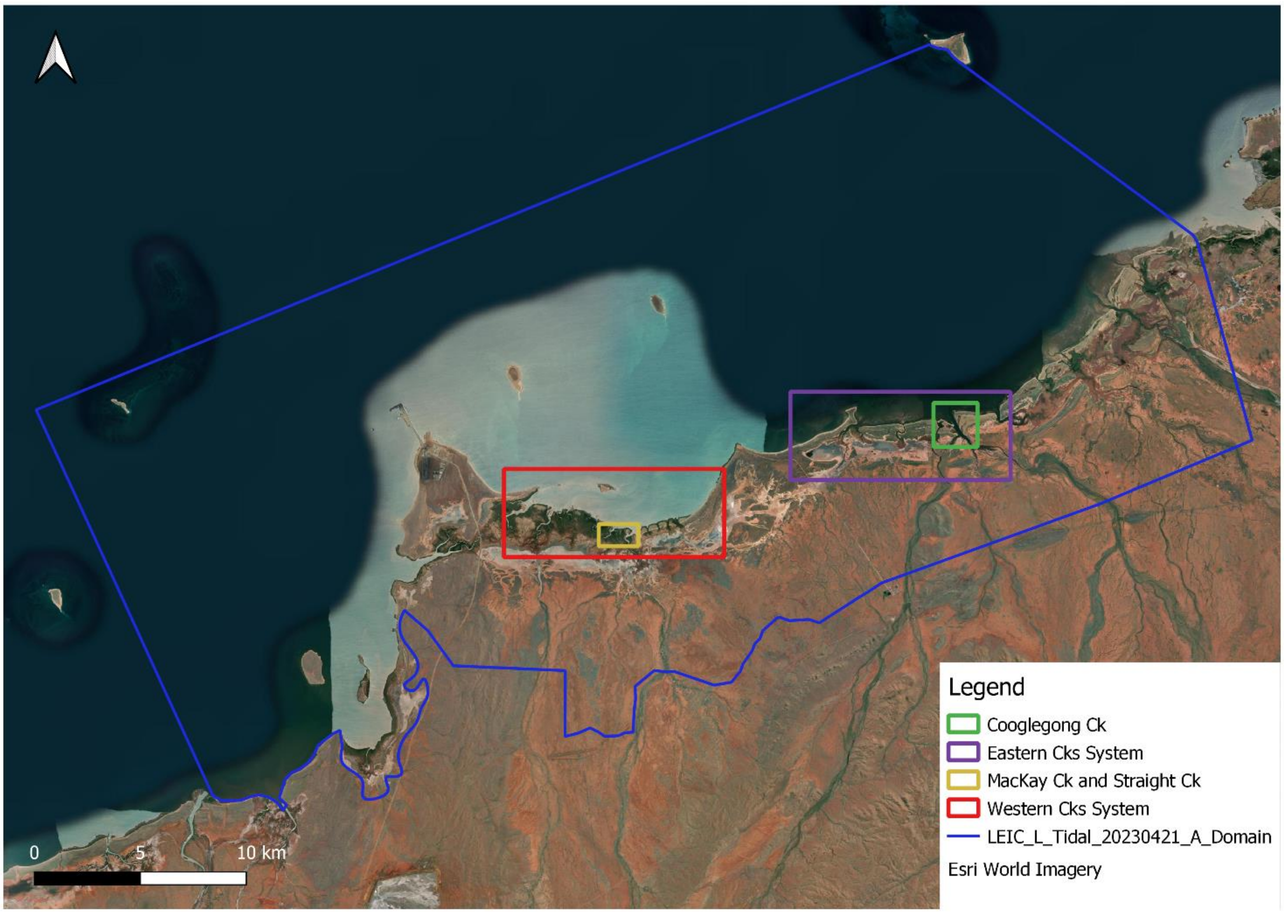

Figure 13: Extent of model domain (blue polygon). Red, yellow, green, and purple polygons show extent of detailed bathymetry Figure 15 to Figure 18

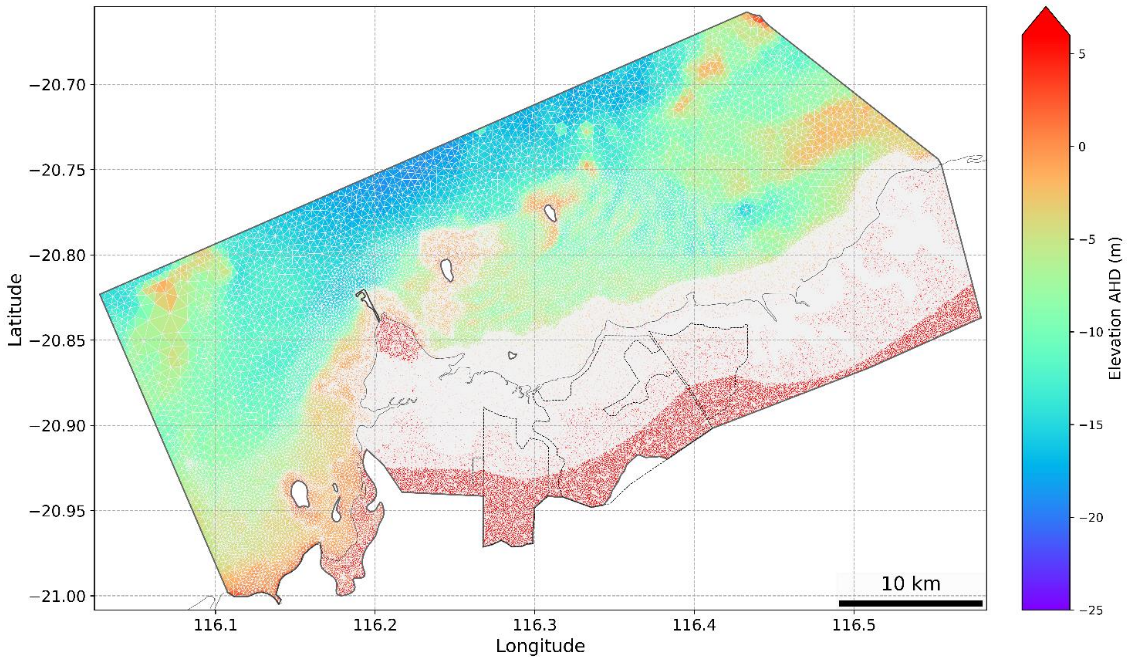

Figure 14: Optimised modelled grid (white triangles), bathymetry/topography (colour map), and project footprint (black polygons). Details masked by the model grid are show in Figure 15 to Figure 18

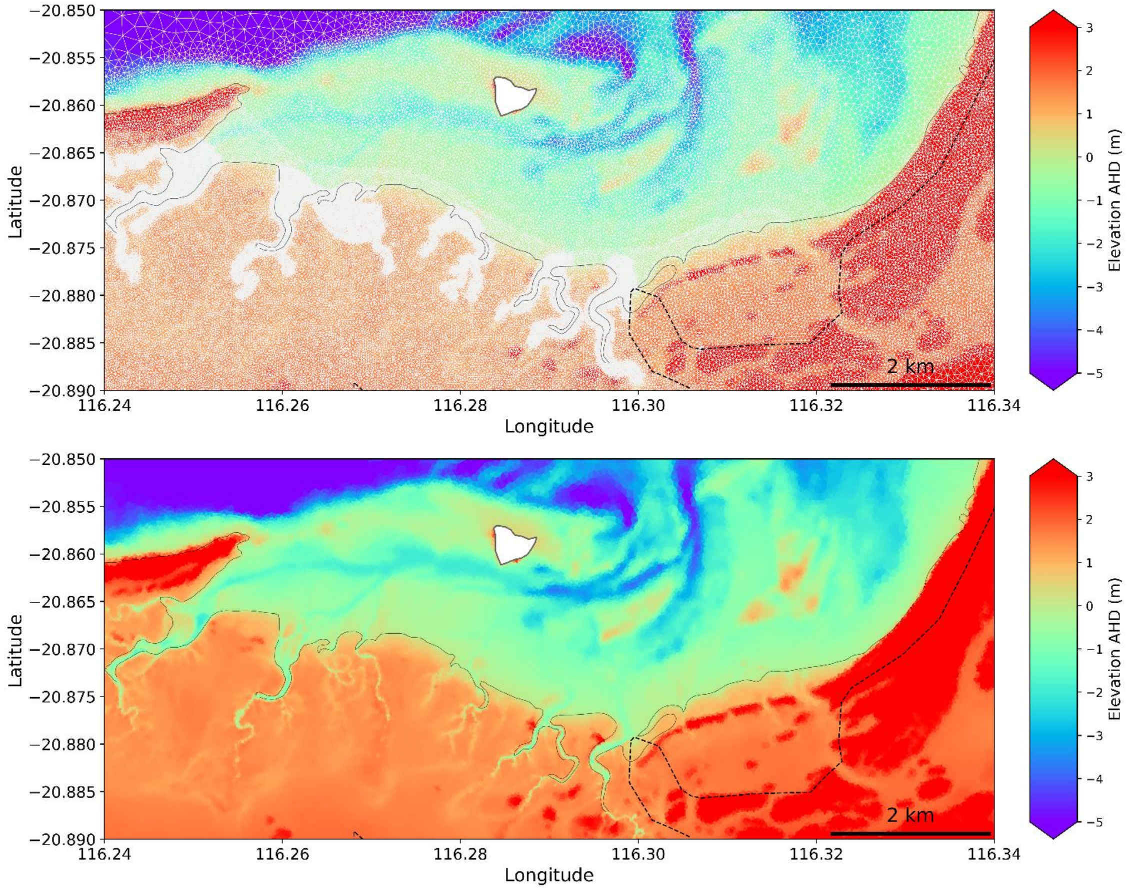

Figure 15: Detailed numerical grid (white triangles) and interpolated bathymetry (colour map) of area marked with a red polygon in Figure 14. Note 5 m cell size in creeks

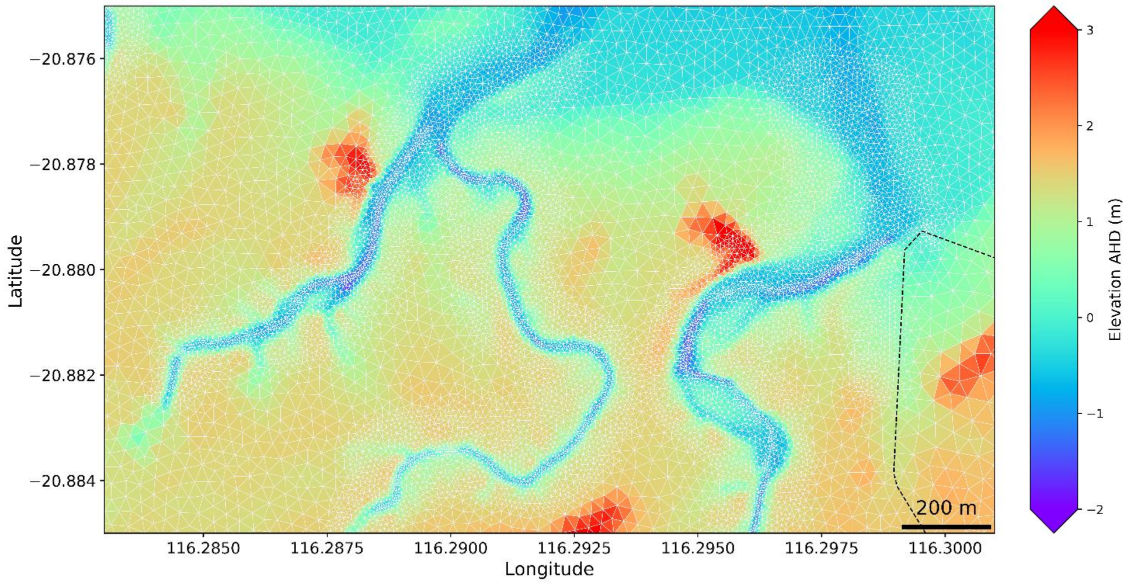

Figure 16: As per Figure 15 for yellow polygon in in Figure 14. Note 5 m cell size in creeks

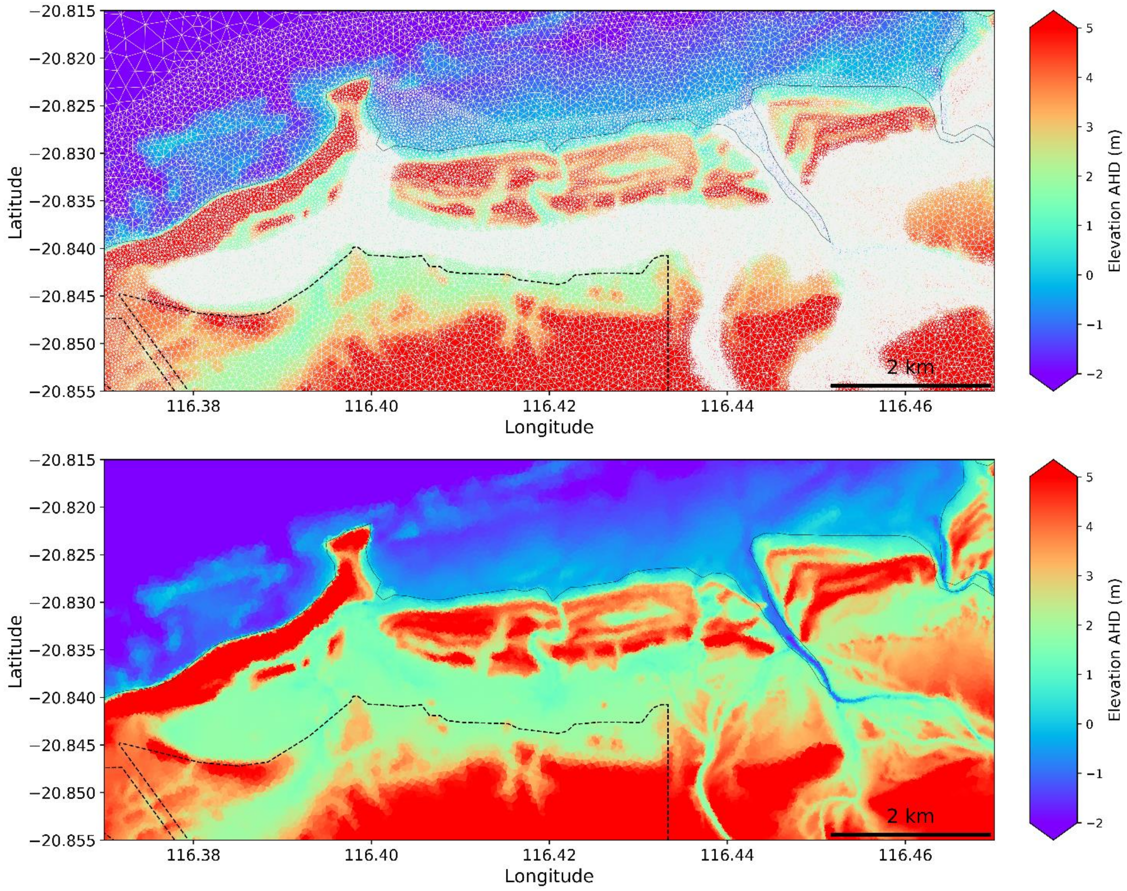

Figure 17: As per Figure 15 for purple polygon in in Figure 14. Note 5 m cell size in creeks

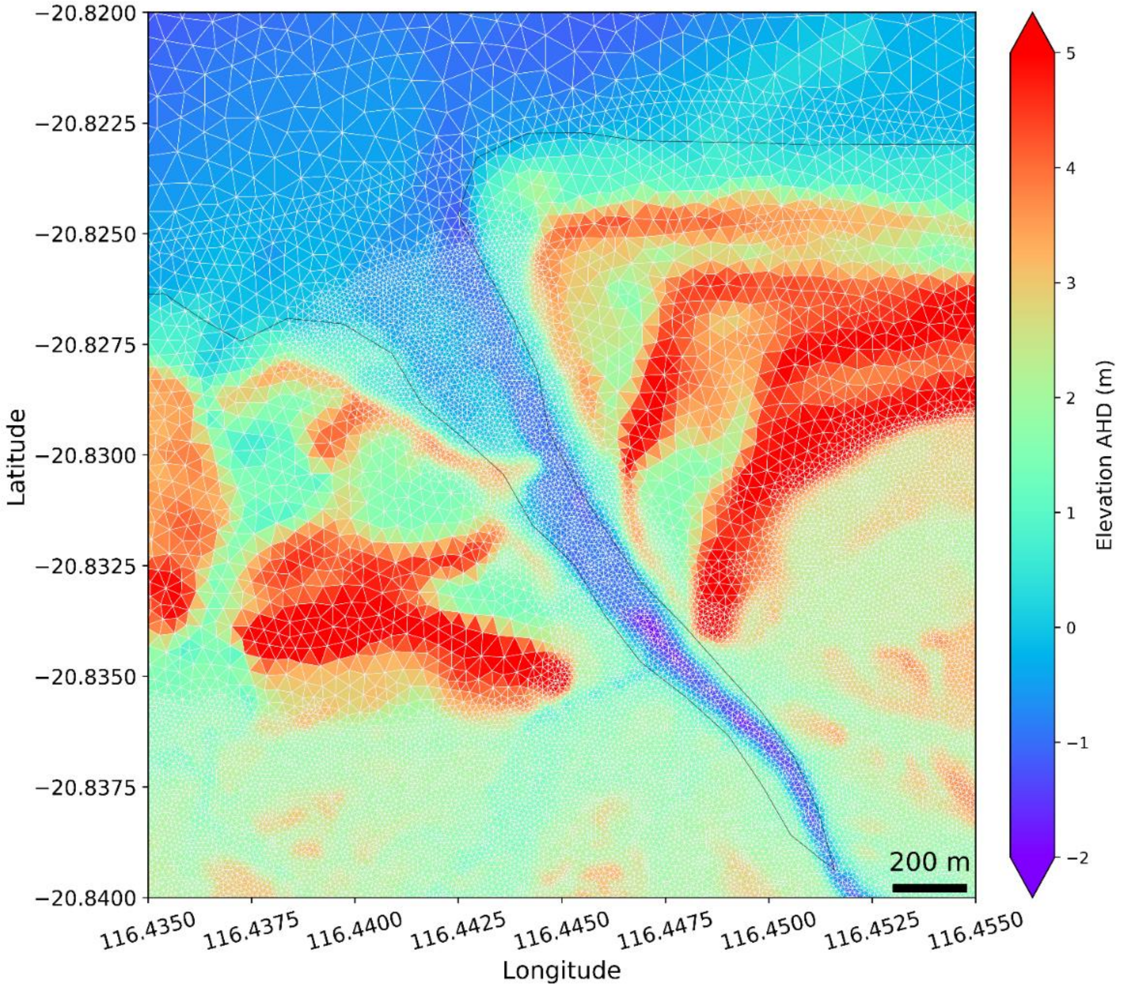

Figure 18: As per Figure 15 for green polygon in in Figure 14. Note 5 m cell size in creeks

3.3. Simulation period

A single simulation period was used in this report. Additional, idealised scenarios which did not require validation are listed in Table 4 and described in O2Me (2023d). Two scenarios were considered: pre-development and post development (simulation 01 and 02, Table 4, respectively).

The simulation period (24th March 2021 to 08th April 2021) encompassed some of the largest tidal ranges in the measured data and allowed for the comparison of tidal inundation processes over the tidal range experienced around the ESSP. The period was selected by O2Me's Coastal Processes SME on the basis of meeting the ESD requirement of modelling scenarios 'from spring high tide through to storm surge events', the availability of high quality validation data concurrently gathered at oceanographic data collection sites (UNS05, NCP05 and ERA05) and creeks (STR02 and SIC02) (Figure 19).

The model was allowed to spin up for 1 day before results were analysed, thus only results from 25th March 2021 onward are shown.

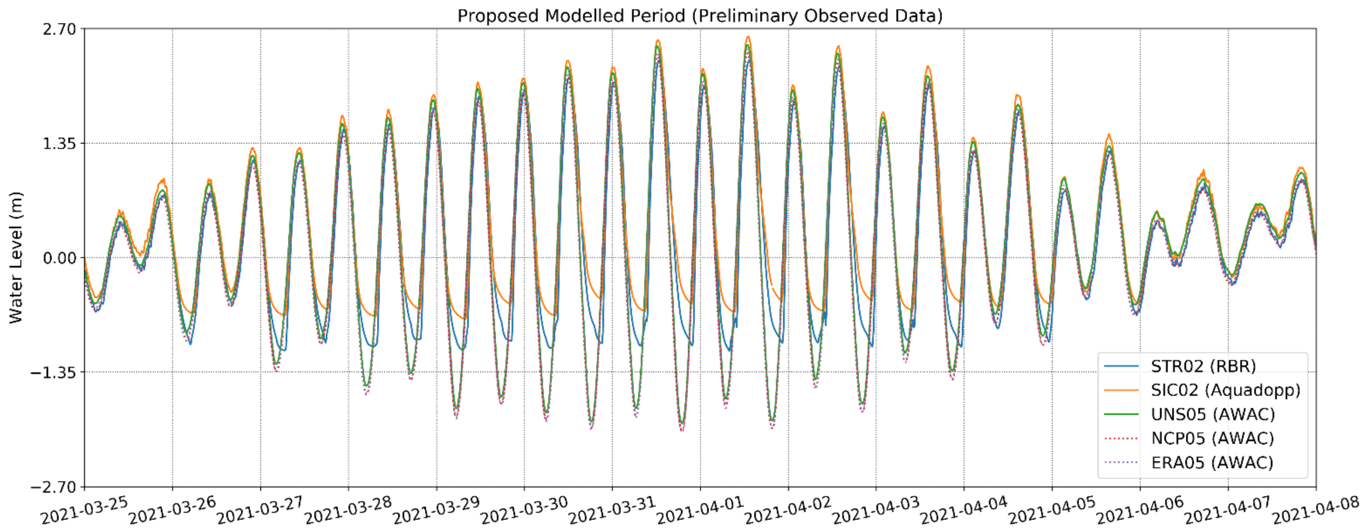

Figure 19: Water levels measured at metocean measuring sites during the validation period

3.4. Forcing

Water levels at the open boundary were forced with spatial and time varying Oregon State University TOPEX/Poseidon Global Inverse Solution tidal model (TPXO) (global tidal model) data. Wind forcing was sourced from the ERA5 model (spatial and time varying). Further details on model forcing can be found in O2Me (2022a).

3.5. Validation

Validation of modelled water levels over the simulated period was conducted for sites NCP05, ERA05, UNS05 (nearest metocean data site to the ESSP, within Regnard Bay) and SIC02 (in-creek station) (Figure 20).

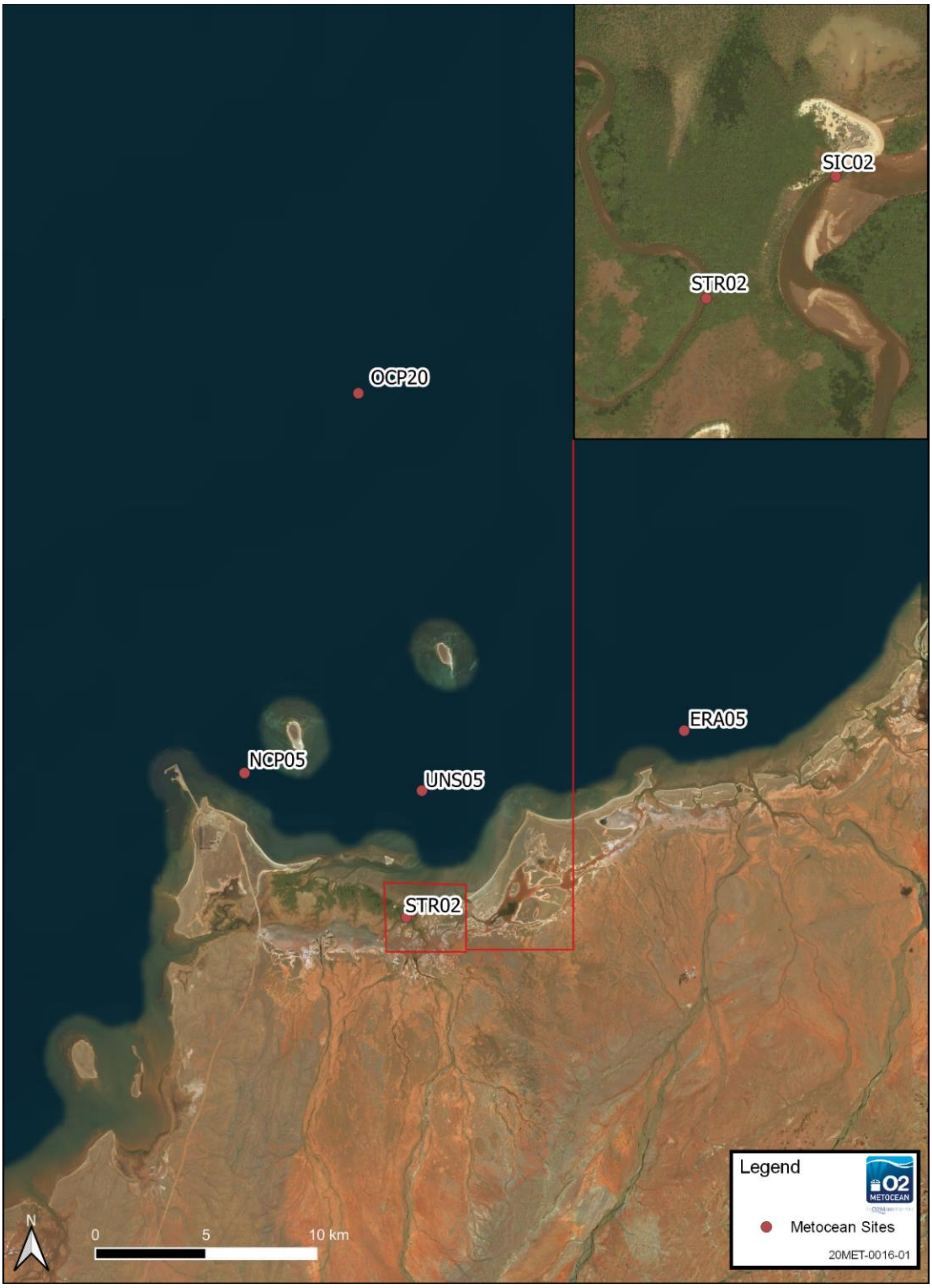

Figure 20: Metocean data collection locations (source: Metocean Data Collection Programme (O2Me 2022b))

3.5.1. Quantification of model skill

Model validation of water levels was quantified using the same methodology applied in the base hydrodynamic model (O2Me 2022a). This incorporates the calculation of the model bias, root mean squared error (RMSE), Murphy (1988) *skill score* and the Willmott (1981) Index of Agreement (IOA) (equations 1, 2, 3 and 4 respectively).

$$Bias = \frac{1}{n}\sum_{i=1}^{n}[M_i - O_i], \tag{1}$$

$$RMSE = \left[\frac{1}{n}\sum_{i=1}^{n}[M_i - O_i]^2\right]^{\frac{1}{2}}, \tag{2}$$

$$SS^M = 1 - \frac{\sum_{i=1}^{n}[M_i - O_i]^2}{\sum_{i=1}^{n}[O_i - \bar{O}]^2}, \tag{3}$$

$$IOA^W = 1 - \frac{\sum_{i=1}^{n}[M_i - O_i]^2}{\sum_{i=1}^{n}\left[[M_i - \bar{O}] + [O_i - \bar{O}]\right]^2} \tag{4}$$

In these formulae 'n' is the number of observations, M and O represent modelled and observed values, respectively, the subscript i indicates the i^{th} point in the record, and the overbar denotes the arithmetic mean. As each of these equations require that Mi and Oi are contemporaneous, the observed data was transformed by means of linear interpolation in time.

3.5.2. Water-level timeseries validation

Water level validation plots are presented for sites NCP05, ERA05, UNS05 and SIC02 (Figure 21).

Modelled and observed water levels at the oceanographic sites NCP05, ERA05, and UNS05 is remarkably good, with Murphy skill score and Willmott IOAs exceeding 0.975 and 0.994, respectively. Model fit to observed water levels at the in-creek station SIC02 is also remarkably good, with bias of 0.06 m, Murphy skill score of 0.916, and Willmott IOAs of 0.977. The RMSE at SIC02 is 0.25 m. It is evident from Figure 21 that discrepancies mostly occur at low tides. At peak water levels, water levels are well matched. The phase of the water level is also well modelled at all sites.

The timeseries plot and model skill values derived from the model versus measured water level comparison demonstrate that the model captures the main inundation drivers and thus it is suitable to represent tidal levels across Regnard Bay and around the proposed intake structure at SIC02. By extension, it is inferred that the model is capable of reproducing tidal inundation levels along the proposed ESSP pond walls.

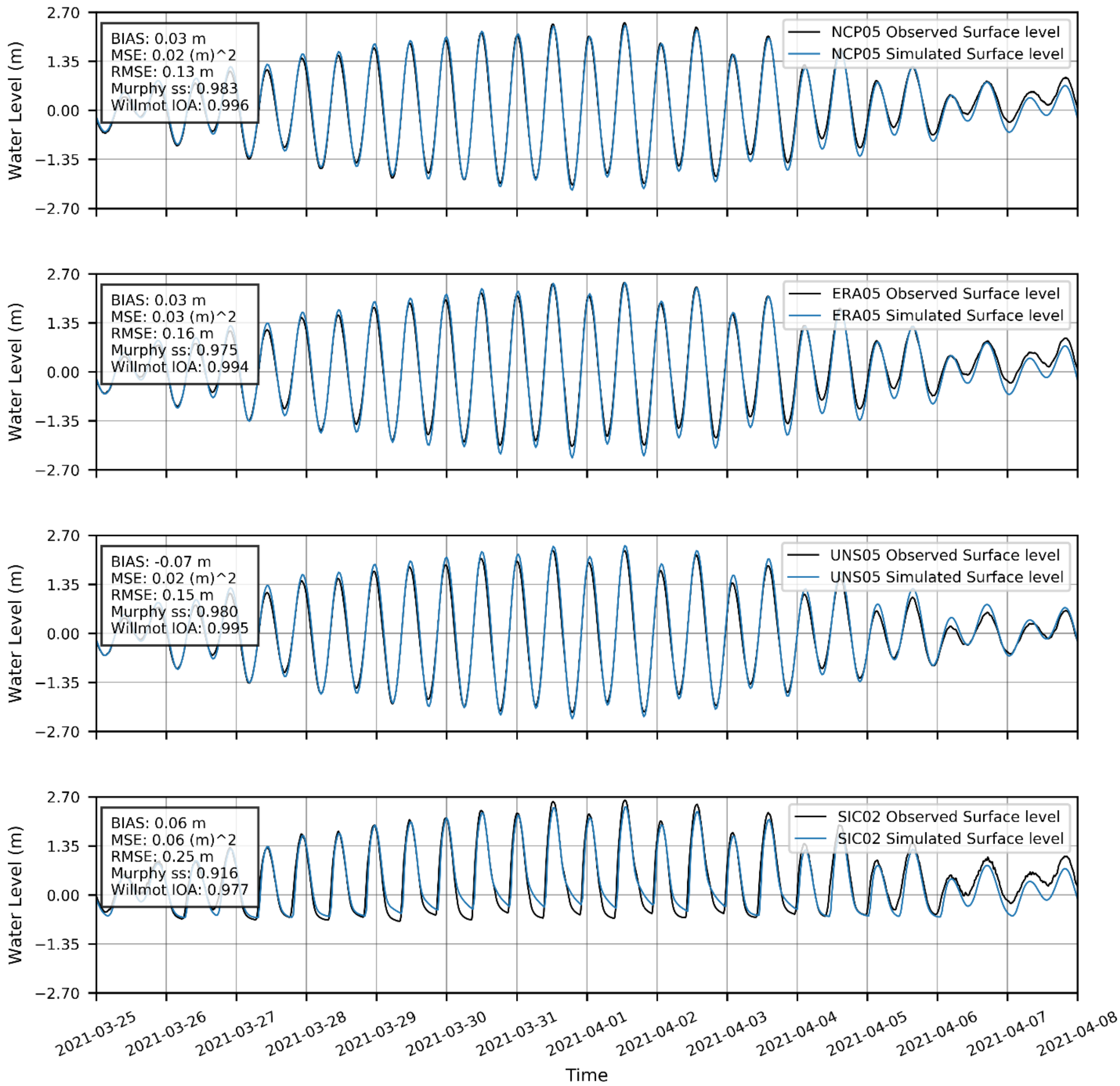

Figure 21: Observed vs modelled water levels at key sites during the simulated period of 25/03/2021 to 08/04/2021

4. Results and discussion

Key outputs required to meet ESD items 20b, 22, and Item 132b are:

1. Spatial map of the percentage of time wet, where the term 'wet' is defined as having a total water depth greater than 0 m at any location, before the establishment of the proposed development;
2. Spatial map of the percentage of time 'wet' for a post-ESSP development condition;
3. Spatial map of the relative change in percentage of time 'wet', that is the difference between what is observed now and what will be observed post-development; and
4. Spatial maps of the predicted change in total water depth between the current and post-development conditions across a semidiurnal spring tidal cycle.

These outputs were designed to identify locations that experience changes in both water supply and retention, whilst quantifying the change as a function of time.

4.1. Percentage of time 'wet'

4.1.1. No Sea-Level Rise

The spatial evaluation of the total water depth was analysed to determine the percentage of simulation time that each cell was 'wet' (total water depth greater than 0 m). By comparing this parameter between the pre-project and post-project development, the impact of the ESSP around its footprint can be quantified.

Figure 22 presents a map covering the intertidal region of interest, illustrating the percentage of time 'wet' pre-project development. The map shows the two main intertidal creek systems which flood under normal spring high tide conditions but remain isolated from each other. Not shown is the agreement between the <50% 'wet' regions during typical spring tides with the aerial coverage of the algal mats (O2M 2023). The same map was replicated with the results from the post-project development model run (Figure 23), which shows how the pond walls block some of the flow south of the main creeks particularly near the proposed seawater intake area at MacKay Ck. When compared to each other in Figure 24, minor-to-negligible changes in the tidal inundation regime outside the proposed pond walls footprint are seen. The percentage of time 'wet' in areas directly impacted by the ESSP development (for example inside the proposed pond walls) is not discussed herein.

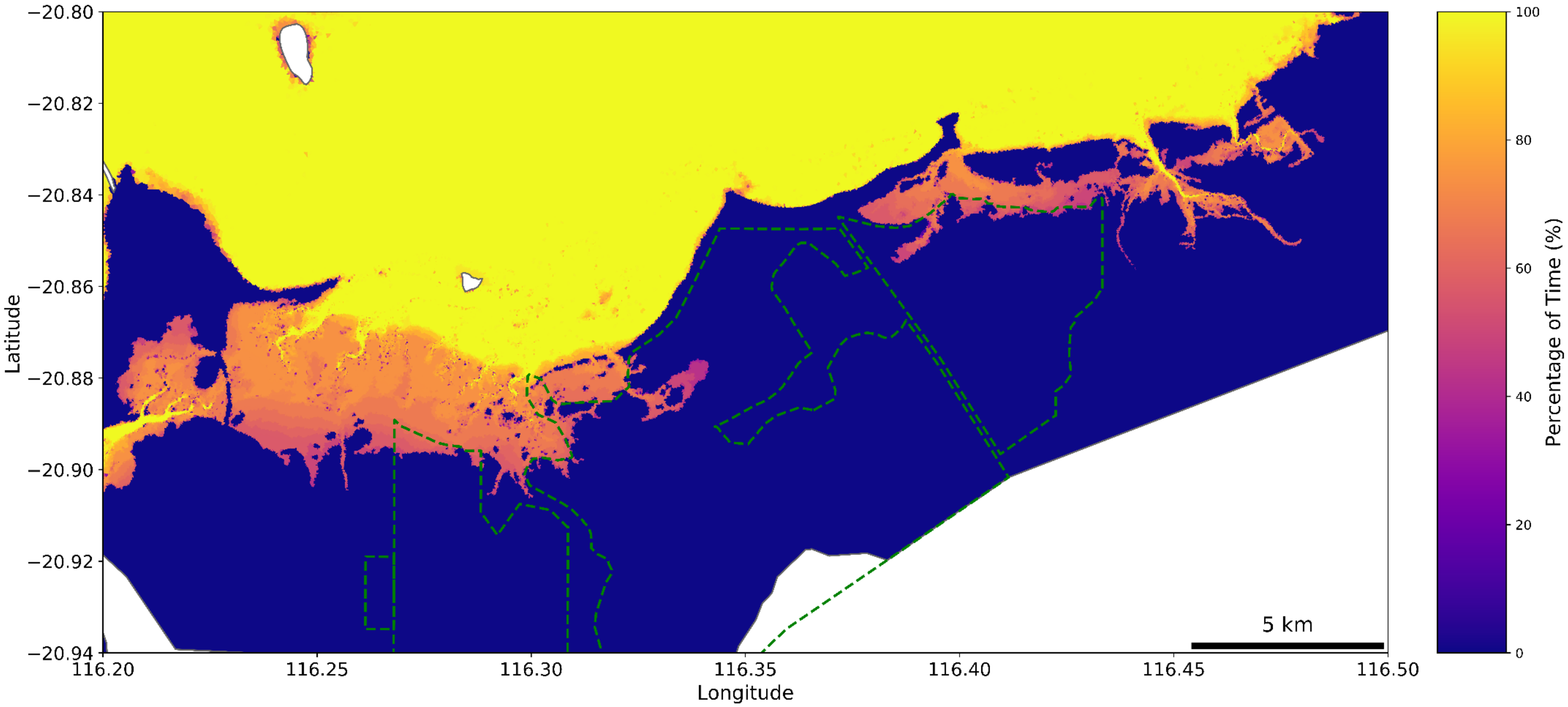

Figure 22: Percentage of time ‘wet’: Pre-project development (existing bathymetry model)

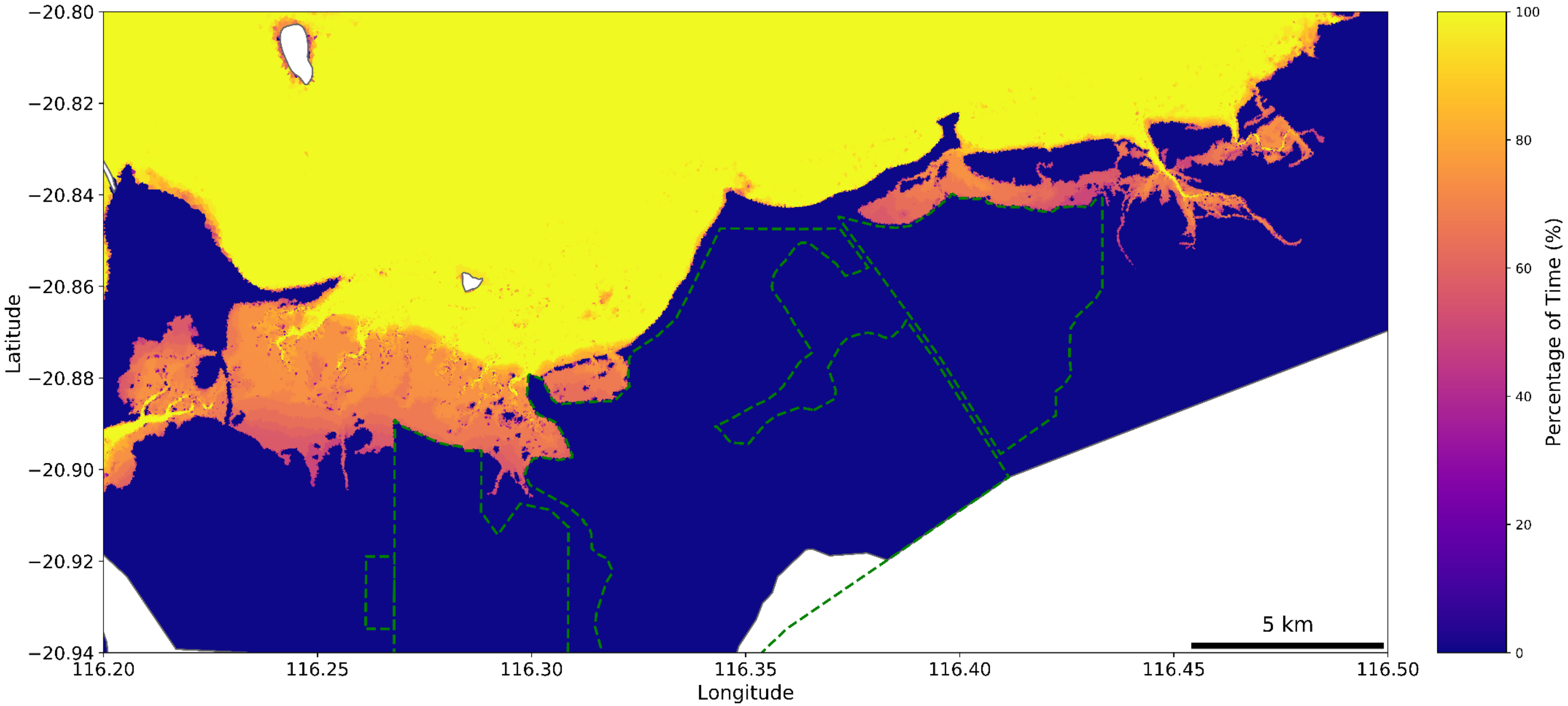

Figure 23: Percentage of time ‘wet’: Post-development (project bathymetry model – Scenario 7.2)

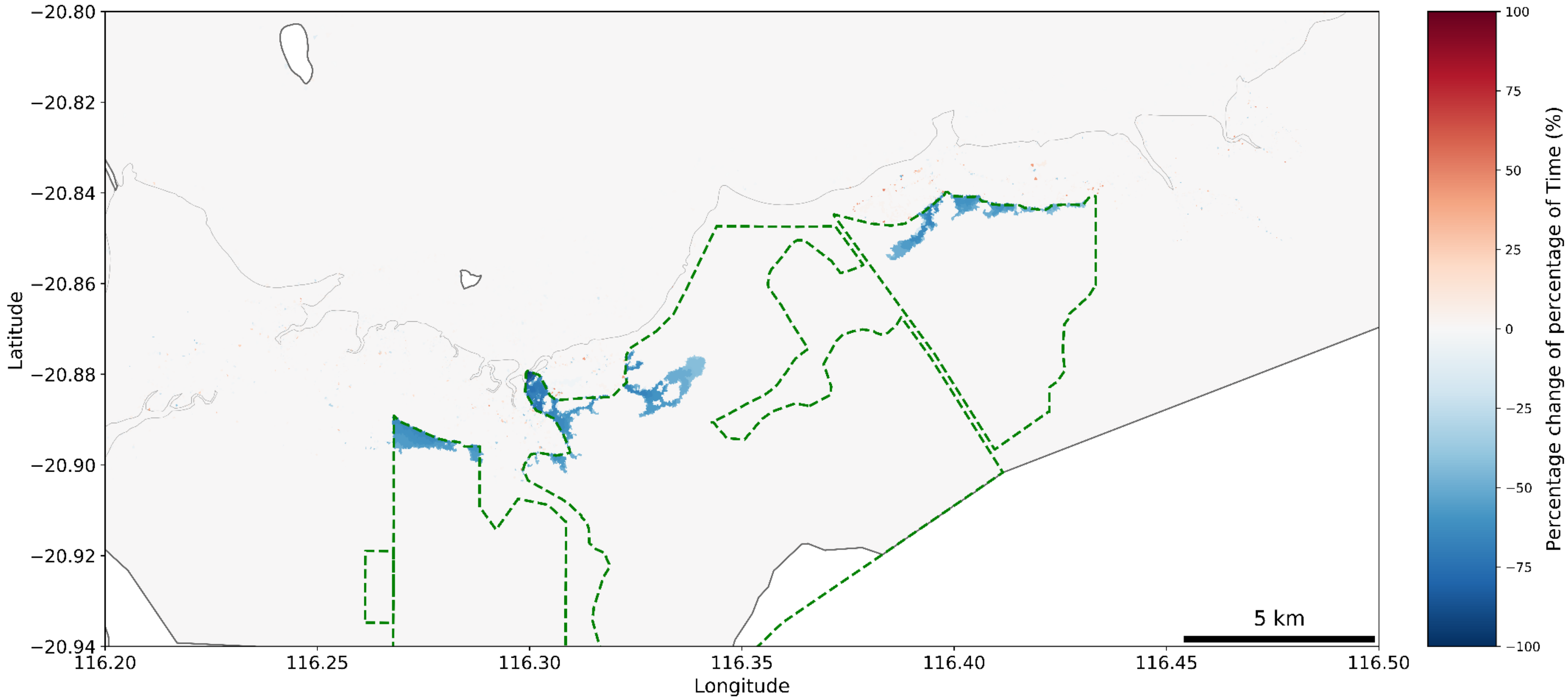

Figure 24: Difference in percentage of time ‘wet’ between pre- and post-development (blue= percentage of reduction in percentage of time ‘wet’; Red= increase)

4.2. Total water depth during high tide

Total water depth between the pre-project development model and the post-project development model simulations were compared on an hourly basis, leading up to and returning from the highest tide during the simulated period. The comparison is illustrated through a spatial map of the change in total water depth that would be observed post-development, calculated as 'total water depth modelled for the current condition' (simulation 01) minus 'total water depth post-development' (simulation 02), at three selected different points in time during the high spring tide: Figure 25, Figure 26 and Figure 27.

During flood tides and up to peak spring tide (Figure 25, Figure 26), the results show in red the areas that will experience an increase in instantaneous water elevation in the order of 10 cm. These are mostly identified along the northward facing walls of the crystallisers, at the northern most Concentration Pond walls, and east of the proposed intake station site. Clearly tidal flows that previously inundated the upper tidal catchment areas are now deviated or blocked by the proposed ponds. Soon after peak tides (Figure 27), the total water depth would be in the order of 10 cm lower north of the crystallisers because of a lower volume of water being trapped up the creeks that will be affected by the ponds. However, according to the tidal inundation modelling results, water would remain ponded for longer periods post-development compared to current conditions behind 40 Mile Beach (north of the ESSP ponds) and around the Barnard Ck mouth.

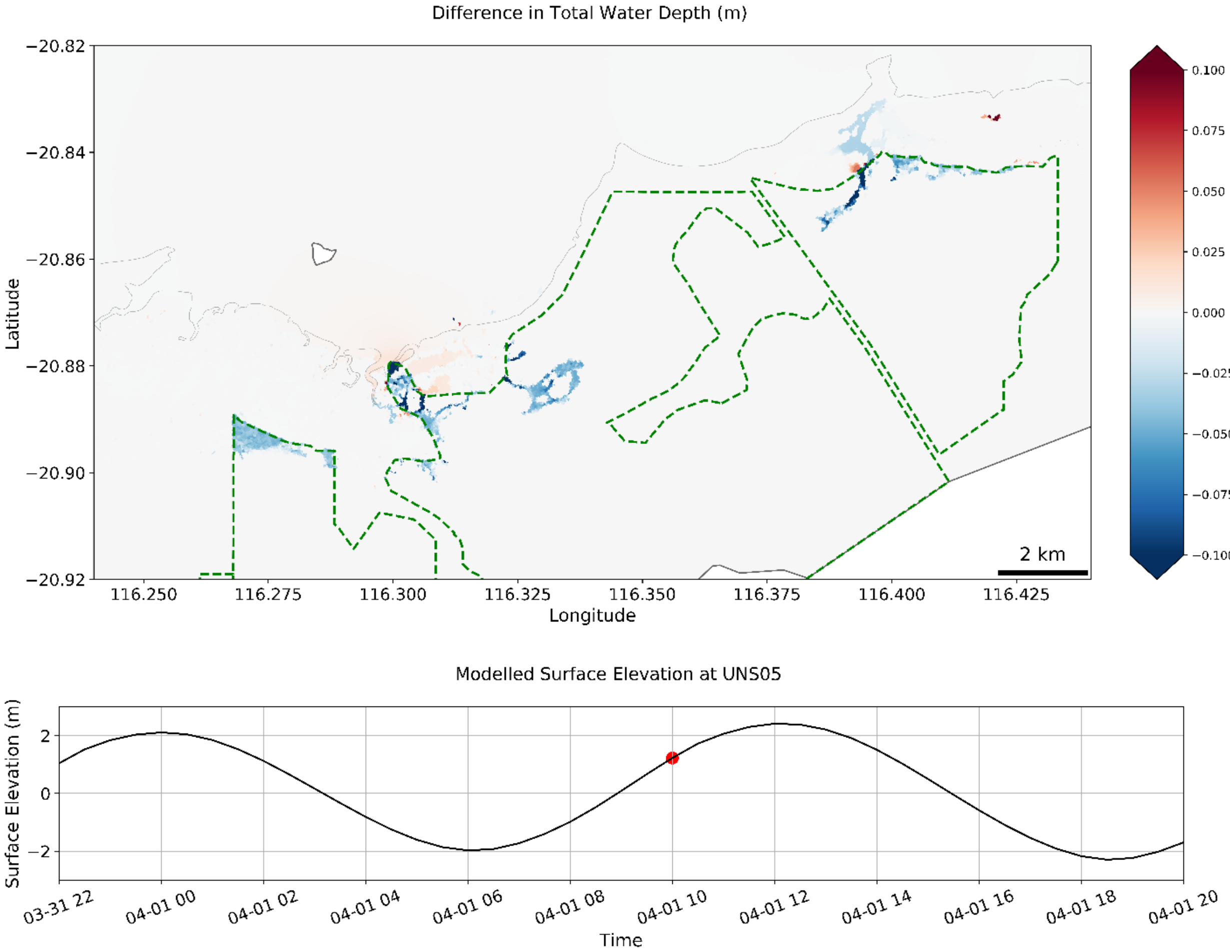

Figure 25: Instantaneous product of the difference in total water depth during flooding of peak high tide (01/04/2021 10:00 Western Standard Time (WST)): difference between post-project development model and pre-project development model

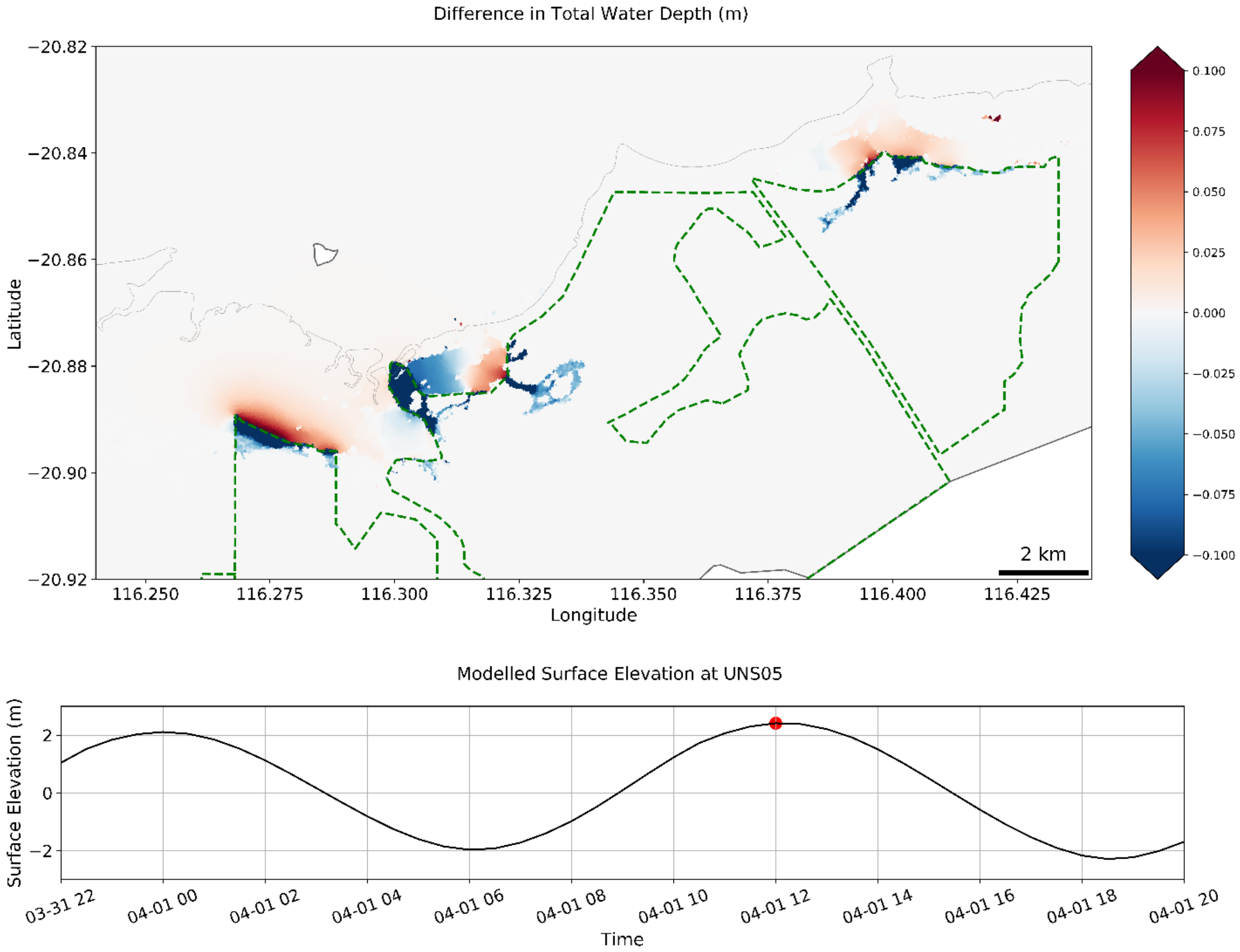

Figure 26: Instantaneous product of the difference in total water depth during flooding of peak high tide (01/04/2021 12:00 WST): difference between post-project development model and pre-project development model

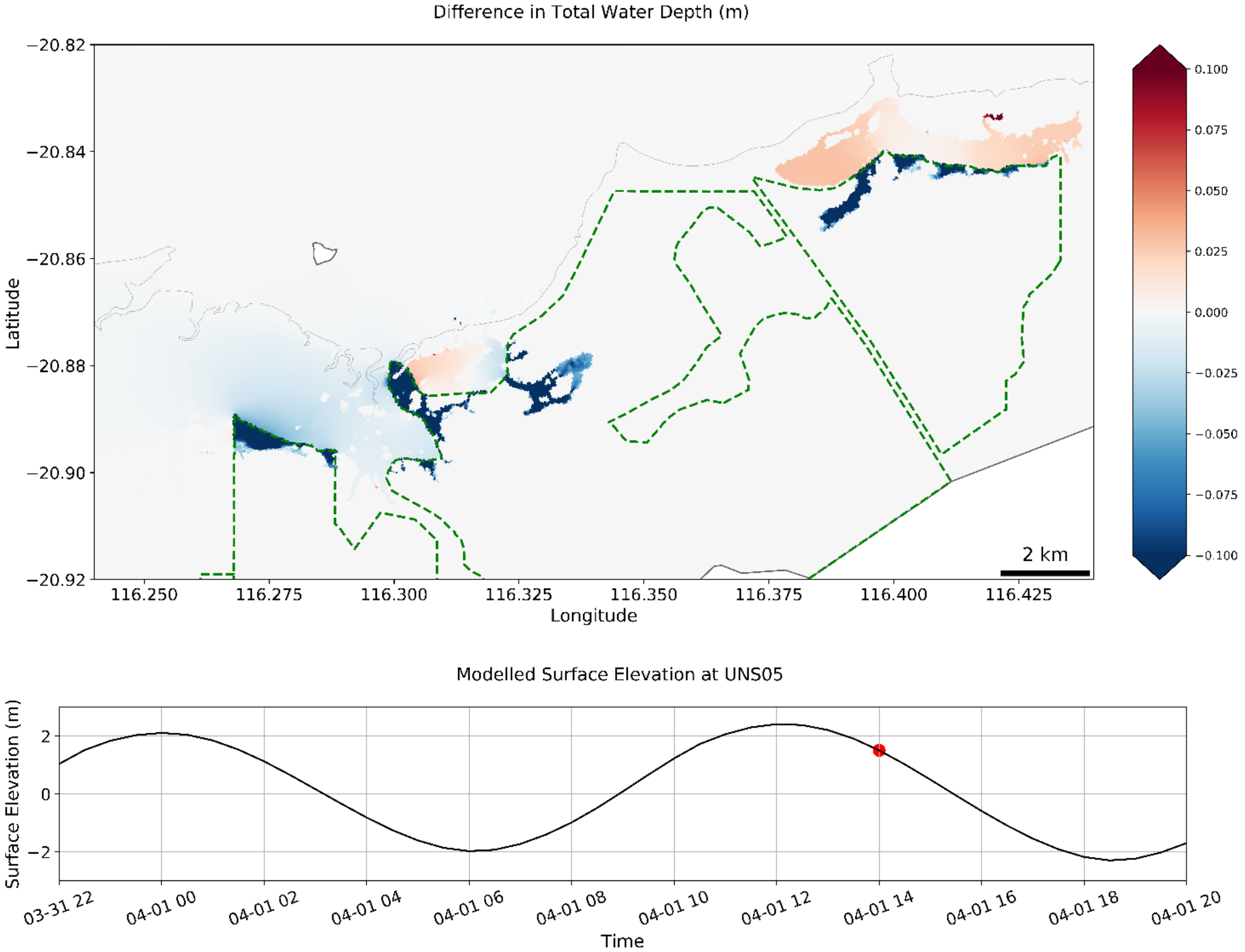

Figure 27: Instantaneous product of the difference in total water depth during flooding of peak high tide (01/04/2021 14:00 WST): difference between post-project development model and pre-project development model

5. Conclusions

Six (6) bathymetric and topographic datasets were considered for the DEM of the tidal inundation model. Through careful comparison of each dataset among the others, the GA and LiDAR datasets were identified as the primary two (2) inputs to the final DEM, with the other datasets being used to quality control the results of the merge. The resulting DEM was then further refined by the hydrodynamic modelling team during the calibration phase of the study.

A numerical model suitable for tidal inundation modelling was developed and validated using oceanographic and in-creek data collected for the ESSP. The timing and elevation of the modelled water levels matched remarkably well the measured water levels both inside Regnard Bay and in the in-creek site SIC02.

The tidal inundation regime under present and post-development conditions was modelled during a typical spring tidal period. Comparison of the results from these two model simulations showed that some creek flows will be reduced after pond emplacement. Though the percentage of time 'wet' before and after development differed little north of the ESSP, changes in the total water depth of the order of 10 cm will be experienced at some locations. Most notable changes are predicted north of the crystallisers, around the proposed intake structure, and behind 40 Mile Beach near the Barnard Ck mouth.

Maps of percentage of time 'wet' and 'change in total water depth' are available for comparison to BCH maps, therefore informing the EIA of the ESSP.

The validated tidal model is suitable to inform the report entitled 'Coastal and Intertidal Processes Assessment' (O2Me 2023d).

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