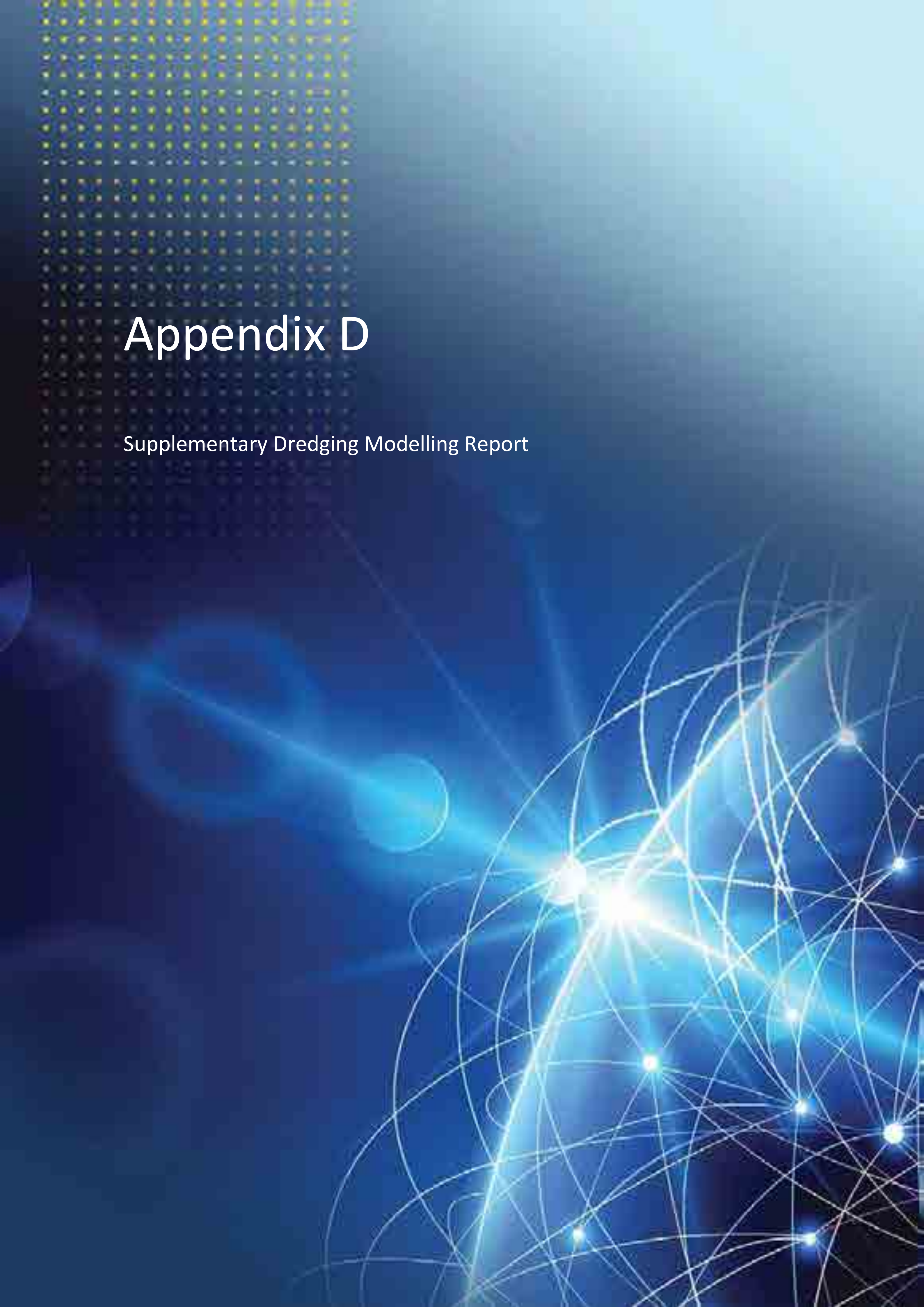

Appendix D

Supplementary Dredging Modelling Report

NCIS-5 – HMAS Coonawarra

Supplementary Dredging Modelling Report

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Summary

This report provides supplementary dredge plume modelling assessment further to the work carried out by KBR in 2022 and reported in *NCIS-5 – HMAS Coonawarra Dredging Modelling Report,* which was *Appendix F* of *NCIS-5 – HMAS Coonawarra - Dredging and Dredged Material Management - Referral Report*.

The information contained herein responds to the Northern Territory Environment Protection Authority (NT EPA) '*Table of additional information to be included in Supplementary Environmental Report'*, addressing requests for additional information in the NT EPA's 'Notice of Direction'.

This supplementary report expands upon previous studies undertaken, capturing the following key aspects:

1. Implementation of 3-dimensional hydrodynamic and sediment transport modelling as a refinement to previous 2-dimensional vertically averaged modelling
2. Review of additional available datasets and validation of the modelling, including historic dredge monitoring records
3. Review of source term information against published values applied in the guidelines
4. Expanded modelling of sediment deposition and fate

The far-field dredge plume simulations undertaken in the initial KBR (2022) Referral Report modelling were modelled using Delft-PART. This previous work was based on 2D vertically averaged hydrodynamic modelling and covered various combinations of dredge types, turbidity sources & locations and seasonal wind conditions to predict the suspended sediment concentrations above background. Multiple sediment sources were input into the model to simulate the various coincident dredging and dredged material disposal activities. In total, 12 scenarios were presented, with the largest turbidity plumes being associated with the cutter suction dredge (CSD) dredging, and discharge of fine dredged materials into the nearshore area about 300 m south of the HMAS *Coonawarra* harbour. 'Tide Only' (i.e. no wind) model scenarios indicated the highest turbidity above background (i.e. most conservative) estimates due to the absence of wind induced dispersion / mixing.

The further assessments presented in this report therefore focus on the impacts due to the CSD activity (i.e. CSD with direct discharge of fine sediments in the nearshore area) under 'Tide Only' conditions as it contributes to the highest suspended sediment load, thus providing conservative predictions of the maximum impact areas associated with the proposed dredging.

Historic observations from past dredging campaigns were used in establishing a conceptual understanding of how dredge plumes behave in the vicinity of the site and for validation of the model. Unique to this project, similar dredging activities were undertaken during 2006 and 2013 dredging campaigns and these are therefore directly applicable to the currently proposed dredging and discharging works. Data from these past campaigns provided confidence in the understanding of the key mechanisms for the generation and dispersion of dredge plumes, which were then translated into more detailed modelling. This understanding was then applied to the detailed 3D modelling presented herein.

Validation of the 3D model hydrodynamics (water level, current speed and direction) and sediments (recorded NTU values) consisted of comparing the model results to measured timeseries and depth profile data from the two previous dredging campaigns. The objective of the validation was to confirm that 3D model behaviours were representative of the actual situation.

This Supplementary Environmental Report (SER) provides further details on the modelling validation process as an expansion to previous work. The modelling presented herein has been simulated using coupled 3D hydrodynamic and sediment transport modelling as a refinement to previous works. In addition to 3D hydrodynamic validations, validation to turbidity measurements was also made. The validation predominantly focused on the 2013 dredging campaign as it represents the most recent and comprehensive collection of data. A high-level comparison to the 2006 dredging campaign is also provided.

Despite inherent limitations in the data collection, the data review and filtering identified a selection of representative measurements to enable a comparison to the model. The model was able to replicate similar plume behaviours in line with the measurements, notwithstanding the inherent limitations of the modelling and field data collection. The validation exercise showed that there is reasonable confidence that the model is able to appropriately capture fundamental behaviours of the plumes, including the distributions of concentration of the plume in both the horizontal extents, and vertical distribution, with some conservatism.

The 3D modelling results were also compared against the previous 2D vertically averaged model indications. This comparison showed that the 3D modelled plumes are very similar to the previously reported 2D modelled plumes. Therefore the previous 2D work remains relevant and it appears that both the 2D and 3D models are able to accurately simulate the dredge plume behaviours. The previous 2D modelling undertaken for the Referral can therefore be relied on to accurately simulate impacts, however the 3D model now provides increased granularity for undertaking future assessments.

The modelling confirms that the dispersion of elevated suspended sediment concentrations produced by dredging and disposal is mainly driven by the tidal current behaviours, with a pronounced flood and ebb tide direction propagating the plume within a narrow band towards the north and south of the site. This behaviour was also observed in the 2006 and 2013 dredging campaigns and aligns with the documentation to date in the Referral document.

1 Introduction

1.1 GENERAL

The Department of Defence (DoD) are proposing to expand their facilities within the HMAS Coonawarra harbour basin to accommodate new Arafura Class Offshore Patrol Vessels (ACOPV) being delivered to the Royal Australian Navy (RAN) under the SEA1180 project.

This expansion requires deepening of the HMAS Coonawarra basin by dredging to provide safe all-tide access for these deeper draft vessels.

The primary objective of the modelling is to provide input into an assessment of the predicted impacts of the dredging to fulfill the requirements of the SER (Supplementary Environment Report) process, making reference to the relevant aspects of the application of published guidance for these assessments, including the Western Australian Marine Science Institution (WAMSI) *Best practice guidelines for modelling for EIS studies* (Sun et al 2020)

This update expands upon previous studies undertaken, focussed on the following key aspects:

1. Implementation of 3-dimensional modelling as a refinement to the previous 2-dimensional vertically averaged modelling
2. Review and presentation of additional available datasets and validation of the modelling by comparison with these data sets
3. Review of source term information against published values referenced in the Guidelines (Sun et al 2020)
4. Expanded modelling of sediment deposition and fate
5. Review of the dredge program based on further contractor advice

The work focuses on far-field sediment behaviours which may impact the broader Darwin Harbour environment in areas relevant to NT jurisdiction.

The purpose of this study is to expand on the previous 2D modelling work, and to investigate the dispersion and fate of the dredged material plumes, and the potential settlement behaviour of the plume material in Darwin Harbour. The purpose of this updated work is to provide greater confidence in the prediction of far-field plume dispersion and settlement behaviour.

1.2 REPORT STATUS

This report has been provided as supplementary information for the proposed NCIS-5 HMAS Coonawarra dredging discussed in the *NCIS-5 – HMAS Coonawarra Dredging Modelling Report* – Appendix F of *NCIS-5 – HMAS Coonawarra - Dredging and Dredged Material Management - Referral Report* submitted by KBR in 2022.

This information provides a further development of the dredge plume modelling carried out in response to the Northern Territory Environment Protection Authority (NT EPA) '*Table of additional information to be included in Supplementary Environmental Report'* which requested the following:

- Provide further justification to support the use of a 2D hydrodynamic model for the prediction of dredge plume impacts
- Provide details and sources of field observation datasets used in the development, calibration and validation of the model to predict plume extents, specifically addressing:

  - Field observations of total suspended solids (consistent with Section 3 of the WAMSI Guideline)
  - Conceptual model development (consistent with Section 4 of the WAMSI Guideline)
  - Model implementation of source terms, sediment fractions and implementation of 2D vs 3D modelling (consistent with Section 5 of WAMSI Guideline)
  - Baseline and model input data requirements for validation of the model (consistent with Section 5 of the WAMSI Guideline)
- Describe the composition of TSS (Total Suspended Sediments)
- Describe how sediment deposition modelling has been developed
- Demonstrate that the nearshore disposal site is suitable for the avoidance of potential significant impacts to marine ecosystems

This supplementary report documents the modelling methodology, updates and additional information used in assessing the impacts of proposed dredging activities and is to be read in conjunction with the Referral submission (KBR 2022a).

2 Supplementary Modelling

2.1 APPLICATION OF THE WAMSI GUIDELINE

The WAMSI guideline (Sun et al 2020) (Referred to herein as the ‘Guideline’) is considered one of the main sources of published advice for dredge plume modelling for Environmental Impact Assessments (EIAs) in Western Australia. This Guideline has been referenced by NT EPA.

The focus of the Guideline is to provide direction on the approach to modelling for use in the assessment of potential impacts on benthic communities and habitats from the effects of sediment introduced to the water column by dredging and disposal activities. The Guideline provides a point of reference and is intended for dredging projects where detailed modelling studies are required to assess environmental impacts on sensitive receptors located in the vicinity of the project. The focus of the Guideline is mainly on the assessment of large capital dredging projects and recognises that simplified approaches are appropriate for other types of dredging projects (for example small capital projects or maintenance projects) which may not require the highest level of impact assessment and may not need fully detailed and extensive modelling.

The modelling to date has taken into consideration relevant aspects of these guidelines given the project size, project context and the conceptual understanding of the physical and environmental processes at the site (discussed in Section 2.2.2). This study focuses on the prediction of far-field (passive) impacts of dredge plumes and will inform other assessments presented in the SER which documents the presence of benthic habitat communities and the assessment of Zones of Impact and Zones of Influence.

The following key steps within the Guideline (in Figure 2.1) have been followed in preparing the modelling and are discussed further in subsequent sections of this report (Section references provided). Reference to the relevant sections of the Guideline is also made.

2.2 BACKGROUND INFORMATION

2.2.1 Project requirement

The HMAS *Coonawarra* basin is currently maintained to a bed level of -9.1 mAHD (-5.0 mLAT). The design dredge depth for the current NCIS-5 dredging works is RL –9.8 mAHD (RL –5.7 mLAT). This is based on a draft of 4.5 m to the underside of the design vessel propeller plus a total under keel clearance of 1.2 m (1.0 m navigation clearance and 0.2 m siltation allowance).

This provides a minimum navigational water depth of approximately 4.5 m at all levels of the tidal range for the existing range of vessels homeported within the basin.

The NCIS-5 development is currently proposed for delivery. A separate eastern wharf development has been included in the assessment to reflect future basin development plans if desired (referenced as ‘Future Eastern Wharf Dredging’). The scope of these works staging of this development is consistent with previous assessments and is described further in the Referral and the SER.

2.2.2 Conceptual understanding of key processes

The Guideline (Section 4) recommends the development of a conceptual model of the site to inform the model development and identify data collection needs. The conceptual ‘model’ refers to a schematic understanding of the site and provides a summary of existing knowledge of the receiving environment, including sources, sinks and transport pathways for fine sediment. The conceptual model assists in identifying ambient and dredge-related sediment transport processes to be examined in further detail.

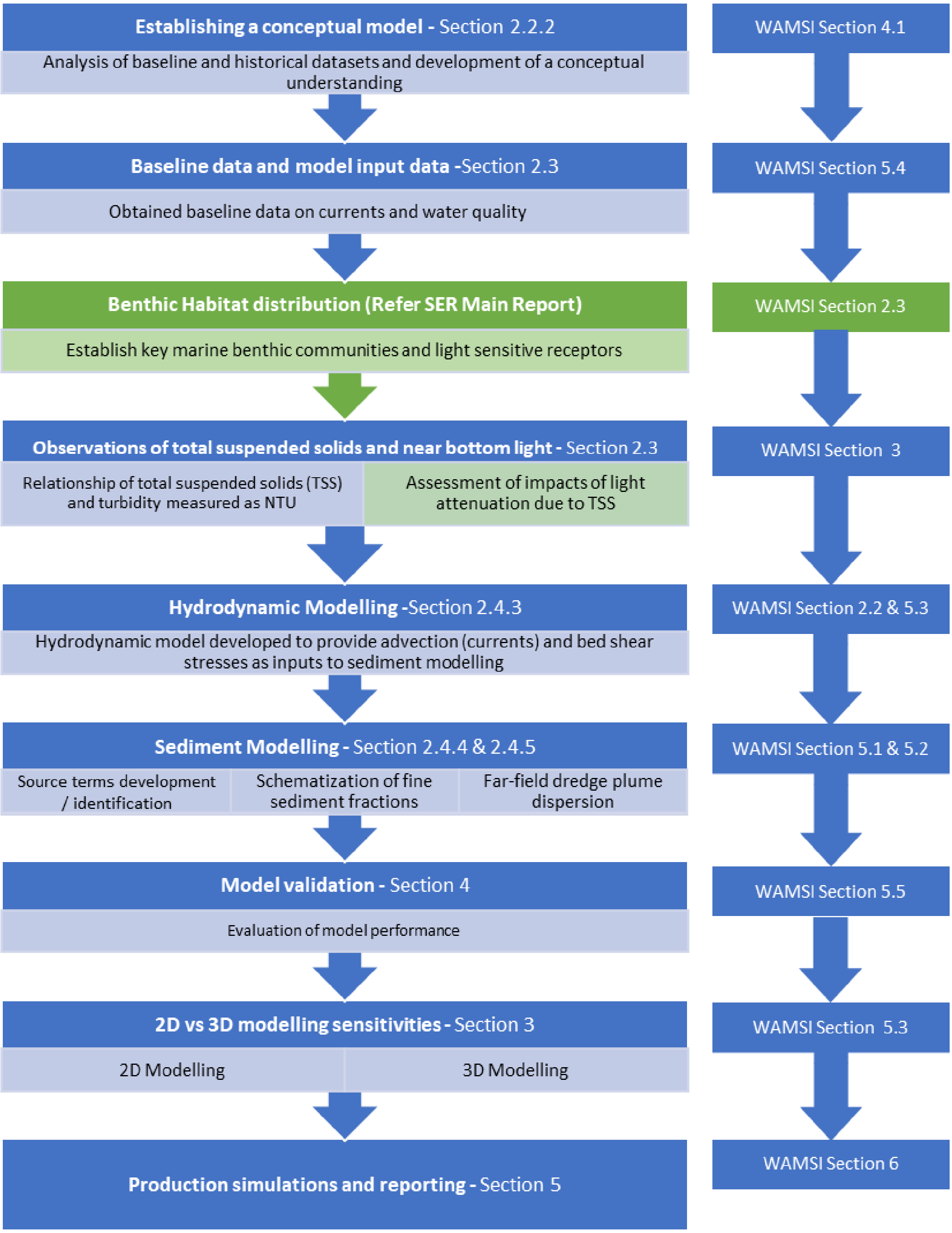


Figure 2.1 Steps in the application of the WAMSI guidelines

Uniquely to this project, the dredging activities being proposed are similar to works undertaken during two previous dredging campaigns in July 2006 and September-October 2013. In addition, there have been several comprehensive data collection exercises at the site to characterise the bed material and investigate the water and sediment flow behaviours, which are known to be complex. During the SER process, further information has been assessed to deepen this understanding.

This conceptual understanding of the site is supported by physical evidence from cited studies, field investigations and data from past dredge campaigns (described in the following sections). There is reasonable confidence in the understanding of the main processes which generate and distribute sediment at the site in ambient conditions, and during dredging activities.

The following is understood about the physical processes at the site:

- Daily variation in turbidity is dependent on the tidal currents. Darwin has a large tide range, and asymmetric currents, with stronger ebb (outgoing) tidal currents at the site, than flood (incoming) tides.
- Normal tidal currents are strongly bi-directional with current measurements close to the site showing a pronounced 105°N to 140°N ebb current directions (coming from) and 280°N to 355°N flood current directions (coming from) which remains consistent throughout the depth profile, indicating that the large astronomical tide is dominating the current field
- The high-energy hydrodynamic environment (as a result of the large tide range) prevails in both ‘wet’ and ‘dry’ season settings. Current speeds near the proposed discharge location exceed 0.5 m/s on almost all tides and 1.0 m/s during the spring tides and would persist for the entire duration of dredging.
- Natural sediment plumes are comprised of very fine marine muds (silts and clays) which are easily re-suspended in high energy settings (i.e. by strong tidal currents). These sediments are visible as plumes, which are generated and carried by the strong tidal currents along a north-westerly to south-easterly pathway, following the eastern coastline and bathymetric features (i.e. the northern sand bank).
- The fine natural suspended sediment material is consistent with the fine material to be dredged from the HMAS *Coonawarra* basin which is mostly accumulated sediments since past dredging campaigns.
- During neap or ‘quieter periods’, sediment can settle in shallower nearshore margins where low currents/low energy environments prevail for a short period of time (for example during neap tides). During higher energy spring tide periods, this material can resuspend, recirculating fine sediments throughout the harbour, and contributing to background total suspended sediment (TSS) levels.
- The estuary also has a number of eddies which prevail during most tidal cycles, located near sand shoals and inshore areas which can also contribute to the re-suspension and mobilisation of fine sediments in shallow nearshore margins. These observations were captured on a broad scale in the modelling undertaken to date and are observable in aerial imagery and raw current datasets. The effect of this process is less pronounced close to the project site (due to strong bidirectionality of the currents)
- The higher currents and higher energy environment close to the project site are not conducive for the settlement of fine materials (as fine material requires a long period of time with low current conditions to settle out of suspension). These conditions are therefore sufficient to keep the dispersed fine sediment in suspension. These fine suspended sediments circulate throughout the harbour as a highly variable background (‘baseline’) turbidity, the distribution of which is evident in aerial imagery. This process also applies where fine sediments are

introduced into the water column in nearshore areas (such as through dredging), with sediments quickly dispersed in the direction of the currents.

- Heavier sediments tend to mobilise as a bed load. They are generally too heavy to contribute to a total suspended sediment load throughout the water column but are measured as a high turbidity very close to the bed. This phenomenon is observed in near-bottom readings of turbidity and in the formation of bedforms (mainly sand) present in high-resolution survey data. This phenomenon is a separate process to the generation of fine suspended sediment load, in the water column and is pronounced mainly in spring tide conditions (higher energy), and less obvious in the neaps.
- Most freshwater runoff occurs during the January to March wet season. In the dry season, the water column is vertically well-mixed (Williams et al, 2014). Some 'wet season' density layers may form due to the input of a high volumes of freshwater flow to the system, however by the time these flows reach the entrance to Darwin Harbour, the strong tidal currents produce well mixed conditions through the water column (both currents and salinity/densities)

During the SER process, the field data has been updated and re-visited to improve the understanding of the harbour processes in the project area. The resulting conceptual understanding is therefore supported by physical evidence from the cited studies, field investigations and data from past dredge campaigns (described in the proceeding sections).

Some of these processes are observable in aerial imagery. A summary of the conceptual processes and the observable sediment plume behaviours is provided in Figure 2.2 to graphically demonstrate the above understanding.

Base aerial imagery provided in Figure 2.2 shows typical ebb tide behaviours, captured during a spring tide period in the dry season. Prior to the captured timestep there was no rainfall recorded in the Darwin Harbour catchment for a period of approx. 90 days prior and no significant wind events were occurring, meaning suspended sediments observed are not runoff generated. The imagery therefore depicts the sediment transport pathways as a result of normal tide behaviours ('tide only'), with visual sediment plumes used as a 'tracer' to depict hydrodynamic behaviours.

2.3 BASELINE AND INPUT DATASETS FOR PASSIVE (FAR-FIELD) PLUME MODELLING

The collection of data is required in accordance with the Guideline to provide confidence in the validity of findings from the numerical modelling. Confidence in the model is tied to the type, amount, quality and consistency of data available to limit this uncertainty, combined with the model's ability to use as a direct input and/or agree with this data (through validation). A summary of important baseline data for hydrodynamic and sediment transport modelling is provided in Section 5.4.2 of the Guideline including:

- Bathymetric data
- Metocean data
- Water physical parameters
- Sediment characteristics (geophysical and geotechnical) and;
- Sediment load data

Inadequate knowledge of these datasets can provide a source of uncertainty in the numerical models. The Guideline groups these sources of uncertainty into three key areas. The following table (Table 2.1) summarises how the three key areas of uncertainty (listed in Section 4.2 of WAMSI) have been addressed to limit the sources of uncertainty in the numerical modelling. All the key categories noted in the Guideline have been addressed.

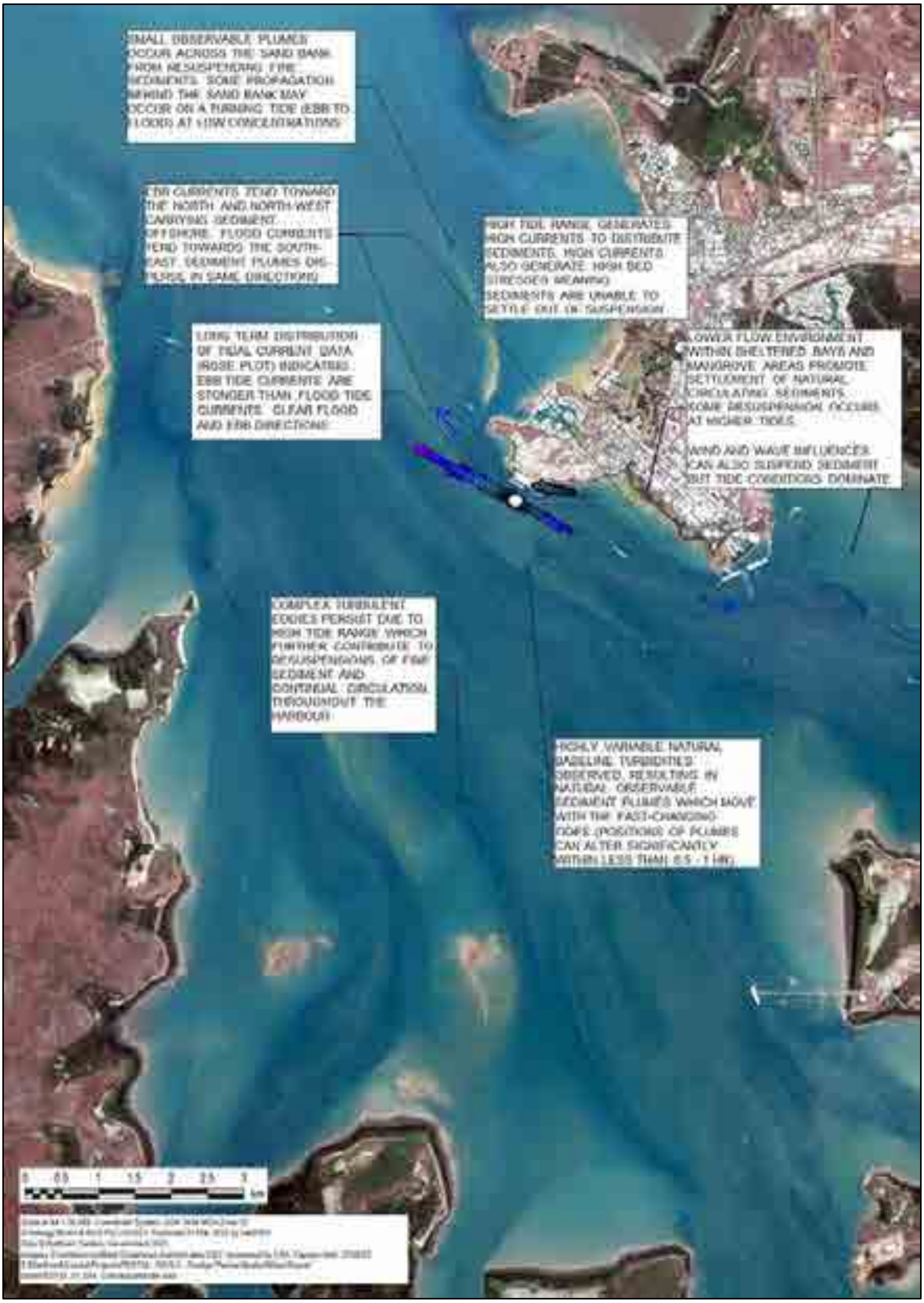


Figure 2.2 Conceptual understanding of the hydrodynamic and sediment processes at the site

The datasets referred in Table 2.1 are discussed in *NCIS-5 – HMAS Coonawarra Dredging Modelling Report (Appendix F of the NCIS-5 – HMAS Coonawarra Referral Report)*. Discussion on new datasets is provided further in subsequent sections. Their application to the modelling is described in further detail in Section 2.3 *Modelling Approach* and Section 4 *Model Validation* of this SER report.

These datasets have been incorporated in the model development and validation, providing confidence that the model predictions are representative.

Additional information and validation has been presented in this SER to further improve confidence in the hydrodynamic and sediment model results, and thus the impact predictions. Of particular relevance to the modelling is the inclusion of further historic dredging monitoring data obtained during this SER process, which is directly relevant to the proposed dredging and discharging activities.

Table 2.1 Sources of uncertainty and how they are addressed

Area of uncertainty	Parameters	Uncertainty addressed via:
Environmental variability		*Data collection via the following:*
	Bathymetry	Collection of high-resolution hydrographic survey data
	Wind	Analysis of wind data long-term records (sourced from the Bureau of Meteorology)
	Waves	Site-specific data collection and review of historic model hindcasts
	Currents	Site specific data collection of currents (speed and direction) via ADCP
	Inflows	Review of density profile datasets from field data to establish whether density gradients (an indicator of base fresh-water inflows) are present and significant to the dredging activity
	Sediment supply / availability	Sediment characterised via targeted sediment sampling and geotechnical data collection (boreholes and PSD) to determine dredge discharge composition (mainly fines)
Model parameter uncertainty	Seabed roughness	Hydrodynamic model validation
	Shear stress thresholds	Estimation of shear stress thresholds using accepted published guidance and site-specific data (i.e. Particle size distributions, PSD)
	Seabed sediment flux	Review of historic baseline datasets to understand background suspended sediment fluctuations.
Source term uncertainty	Dredge method	Review historic dredging to establish dredge and disposal methodology; sought industry advice on dredge methodology
	Schedule and production rates	Review of dredge productivities based on historic dredging and confirmed via consultation with the dredging industry
	Source term magnitude	Source term estimation using published guidance, validation against historic dredging to confirm far-field behaviours agree with the historic measurements
	Settling velocity	Estimation of published settling velocities based on known sediment parameters from site-specific geotechnical data collection (boreholes and PSD)

Bathymetry

The bathymetric datasets used to develop the models and remains consistent with the bathymetric dataset developed in *NCIS-5 – HMAS Coonawarra Dredging Modelling Report (Appendix F of the NCIS-5 – HMAS Coonawarra Referral Report)*. This data still represents the most relevant available information known to describe the site and broader Darwin Harbour bathymetry.

Physical Environment

The Guideline describes the collection of baseline data including geotechnical, hydrodynamic and sediment data to inform the conceptual model and for use in calibrating and validating models. Extensive site-specific investigations have been undertaken with the purpose of limiting uncertainty and ensuring the modelling is fit for purpose, consistent with the Guideline.

The following detailed site investigations and assessments (in Table 2.2) have been undertaken specifically at the site and apply to the HMAS *Coonawarra* NCIS-5 package of work. A summary of the application of these datasets to the modelling is provided. These datasets cover the key elements in the Guideline.

Table 2.2 Summary of site-specific reference data

Parameter	Reference	Purpose
Current measurements	RPS Australia (2017)	Deployment of ADCPs to investigate current behaviours at the site, used in validating hydrodynamic modelling
Geotechnical investigation and interpretation	GHD (2018) N2263: SEA1180 DSSC Consultancy Marine Geotechnical Investigation Factual Data Report, HMAS *Coonawarra* GHD (2018) N2263: SEA1180 DSSC Consultancy Marine Geotechnical Interpretative Report, HMAS *Coonawarra*	In May 2018 a site-specific geotechnical investigation was undertaken to provide data for engineering and environmental purposes. This data has been used to establish the subsurface soil conditions for dredging activities Further investigation was undertaken in November 2020 to determine the physical and chemical characteristics of the proposed dredged material within the harbour basin. Geotechnical investigations were used to characterise source materials within the dredge extents
Geophysics survey	GBGMaps (2020) Marine Geophysical and Hydrographic Survey, HMAS Coonawarra Darwin NT (Ref; 70578 Rev 1):	Sub bottom profiling, side scan sonar, continuous marine seismic refraction) to map bedrock topography and sub-surface stratigraphy. Geophysics survey was used to delineate between 'hard' residual material and fine marine sediments within the dredge extents.
Marine sediment sampling and analysis	GHD (2019) N2263: SEA1180 DSSC Consultancy Marine SAQP Implementation Report. GHD (2021) N2263: SEA1180 DSSC Consultancy NCIS-5 CDR A2 – HMAS Coonawarra Marine Sediment Assessment Report	In June 2018, marine sediment sampling and analysis was undertaken to determine the physical and chemical characteristics of the sediment within the proposed NCIS-5 current works areas. Further marine sediment sampling and analysis was undertaken in 2020 to confirm material properties in the vicinity of the future eastern wharf development area. Sediment sampling and analysis

Parameter	Reference	Purpose
	Williams et al (2014) *Sediment transport and bed material testing to support the Darwin Harbour sediment transport model*	investigations have been used to characterise dredged sediments. Sediment properties were compared with other sources of local data via desktop investigation to confirm the dredge material with background sediments in Darwin.

Benthic habitat and light-dependent receptors

Existing benthic habitat survey information was reviewed and used to develop a site-specific field survey scope. This project specific survey was carried out on 16-18 January 2023. It collected data across the predicted 'zone of impact' and priority areas within the 'zone of influence' determined using the outcomes of the assessment in the Referral.

The surveyed benthic habitat in the zone of impact and zone of influence was found to be predominately bare substrate with sparse presence of filter feeders. Benthic habitat types strongly dependent on benthic light availability were not detected. The principal mechanisms of concern for the sparse filter feeder benthos are direct sediment effects from suspended and settled sediment. Nonetheless, further baseline data collection to improve the understanding of the relationship between suspended sediment and light availability has been commissioned and is scheduled for the dry season. Further assessments of the susceptibility of specific benthic habitat types is presented in the SER Main Report.

Suspended sediment observations

In line with Section 3 of the Guideline, field observations of baseline sediment transport processes, and monitoring of an increase in suspended sediment (TSS) due to dredging activities are important to understand the impact of suspended sediment. This information is also required to establish the relationship between field measurements and model outputs (for example, understanding relationships between the measured and modelled units) and to establish the dredge plume contributions (for example understanding the dredge contribution versus natural background inputs).

The main source of Total Suspended Sediment (TSS) introduced into the water column during dredging will be discharged sediments dredged from the HMAS *Coonawarra* basin, discharged at the nearshore discharge location. The physical and chemical properties of these sediments have been extensively investigated and are well-understood.

In addition, a proportion of the total suspended solids will be from background sources. As described in Section 2.2.2, the main sources of background suspended sediment in Darwin Harbour are from a continual natural circulation of sediments being re-suspended and re-deposited throughout Darwin Harbour.

The following is understood about the material from each source:

Suspended sediment due to dredging

The dredge material has been characterised from the two geotechnical and two marine sediment sampling campaigns. In total 42 sites were investigated via either boreholes or sediment samples collected across the site and showed a relatively consistent geology within the dredge extents and depths. Sampling/borehole locations and sediment properties are fully reported in the Referral document.

Interpretive reports identified 3 main material types between the upper surface and the design dredge level, with material mainly comprising of:

- Soft marine silts and clays (‘fines’)
- Weathered phyllite / schist material
- Hard phyllite / schist material and rock

The ‘fine’ material (less than 63µ m diameter) discharged from the dredge will be the main contributor to TSS during dredging. This material is a recent accumulation of sediments within the surface layers of the dredge area that have settled within the calmer waters of the HMAS *Coonawarra* basin. When discharged to the nearshore discharge location, the fine marine sediment material will remain in suspension for an extended period, resulting in the observable dispersed dredge plumes, like those that have been measured in previous campaigns.

Larger sediment fractions, such as the weathered phyllite and schist material (sand and gravels), fragmented rock and clay ‘ball’ material will settle close to the discharge location (in the near- and mid-field) and have been assessed separately to fine suspended sediments (instead focusing on the impacts of the initial ‘blanketing’ in proximity to the disposal site). These materials are a small proportion of the overall dredge volume.

Anticipated quantities of these materials are presented in Section 2.4.6.

Plume measurements from monitoring during previous dredging campaigns were available from the 2006 and 2013 maintenance dredging campaigns for the HMAS *Coonawarra* basin. The past dredging involved the use of a mid-sized cutter suction dredge to target fine sediment material. Material was disposed via hydraulic discharge at (or close to) the proposed nearshore discharge site. The equipment and fine material being targeted in the maintenance dredging were similar to that anticipated for the upcoming NCIS-5 works and future eastern wharf dredging. The observations of TSS are therefore directly relevant to the proposed work. Comparisons between the collected measurements and the model were made as part of the model validations (discussed in Section 4).

Baseline suspended sediment

There is a highly variable sustained background sediment load within the water column throughout Darwin Harbour, including at the project site. This background sediment load comprises of very fine marine sediments. Previous monitoring prior to the commencement of the 2013 dredging has provided a reasonable understanding of this background suspended sediment.

Published assessments have also been reviewed, including previous laboratory testing of TSS reported in East Arm. A description of the known baseline TSS characteristics are as follows:

- The material that circulates throughout Darwin Harbour is known to be very fine and takes a long time to settle. As such, it tends to circulate throughout Darwin Harbour, and only settles and accumulates within low flow areas such as within sheltered harbours, embayment’s and mangrove areas. Surface sediments are newly accumulated within HMAS *Coonawarra* basin since the last dredge campaign. It is this fine natural background TSS material that settles inside the HMAS Coonawarra basin to form the sediment within the surface layers of the dredge area. As discussed in earlier sections of Section 2.3, the physical properties of this material have been extensively investigated through geotechnical and sediment sampling of the site (summarised in Section 2.5 and fully reported within the Referral Report).
- Sampling and laboratory testing of Darwin Harbour background TSS has been documented by Patterson and Williams (2014), prepared for the Australian Institute of Marine Science (AIMS). This study provides some guidance on background TSS levels and sediment fall velocities which were reviewed during the Referral Report, and for this SER. The review findings confirm very low sediment fall velocities associated with the fine marine sediment. Hence these fine sediments are expected to remain in suspension as a TSS load for extended periods of time.

This is typical of marine sediments in the presence of vigorous currents and is consistent with the understanding of the nature of the surficial sediments within the proposed dredge area.

The contribution of the background suspended sediment concentrations to the assessment of the 'Zone of Impact' and 'Zone of Influence' has been included by adding a representative background to the dredging model suspended solids results). TSS concentrations have been related to turbidity measurements using a 1 mg/L = 1 NTU relationship, adopting published, Darwin-specific values. The relationship adopted was established via a thorough desktop review during the Referral stage (and documented in the Referral Report). Further published information since the Referral has been reviewed however this relationship still represents the best available information to date.

The SER provides details of recommended background values from desktop study and analysis of the baseline dataset and discusses the evaluation of the areas of impact as a consequence. Further collection of baseline turbidity measurements is scheduled to support the upcoming proposed dredging to confirm the relationship between TSS and NTU.

2.4 MODELLING APPROACH

2.4.1 Description of previous modelling

Comprehensive modelling of hydrodynamics and suspended sediment plumes from dredging is documented in the Referral Report, KBR (2022a) *NCIS-5 – HMAS Coonawarra Dredging Modelling Report (Appendix F of the NCIS-5 – HMAS Coonawarra Referral Report)*.

The planned developments considered were the 'current NCIS-5 works' and a future expansion within the eastern area of the HMAS *Coonawarra* basin.

Modelling was undertaken using the Delft modelling suite on a 2D domain for hydrodynamics, which then formed the inputs for sediment plume modelling in Delft3D-PART.

In total, 12 scenarios were modelled in previous assessments to predict the suspended sediment concentrations above background, covering proposed dredge types, disposal activities, source locations, and seasonal wind conditions.

Multiple sediment sources were input into the model scenarios to simulate the various coincident dredging and dredged material disposal activities as follows:

- Discharge of sediment into the nearshore environment (associated with CSD activities)
- Cutter suction dredging (CSD) losses due to the action of the cutter head (near bed)
- Backhoe dredging (BHD) including; losses due to action of the backhoe excavation of the bed (near bed), plus losses due to barge filling activities

The purpose of the modelling was to understand the spatial distribution of dredge plume concentrations attributed to the proposed dredging activities, to then feed into additional assessments which established predicted 'Zone of Influence' and 'Zone of Impact'.

The modelling covered a one-month period of dredging, modelling near-continuous dredging during the work hours each day as a conservative representation of the prototype dredging program. In practice there would be periods of no dredging, resulting in a longer overall program.

This study also captured the plume sensitivity analysis to various wind, tide only and dredging scenarios, indicated that Zones of Influence and Impact are governed by the tide (with 'Tide only' scenarios having the largest far-field effect due to reduced mixing and dispersion).

The modelling undertaken in the Referral identified that the largest extents (and hence the most conservative impact assessments) were from the CSD activities and associated discharge of fine materials into the nearshore area, located approximately 300 m south of the HMAS *Coonawarra* harbour. The BHD sourced dredge plume was found to be smaller and confined mainly to within the HMAS *Coonawarra* basin extents. The CSD scenario has now been the basis for the additional modelling and assessments in the SER.

2.4.2 Project context

The modelling works presented in this document is an expansion to the previous modelling described in Section 2.4.1. This current work has been prepared in response to queries from the NT EPA (described in Section 1.2) on the work described in the Referral.

This SER presents additional modelling, principally focussed on the 'current proposed NCIS-5 dredging works'; however, the information and outcomes are also relevant to the future proposed Eastern Wharf development planned for several years following completion of the NCIS-5 works.

The Referral documents have advised a duration of dredging as '2 to 3 months'. This timeframe includes dredging in two stages to account for the varying hardness of the bed material types expected to be encountered within the dredge area. This staged approach applies to both this proposed NCIS-5 dredging, as well as dredging to facilitate any future eastern wharf expansions that were documented in the Referral.

Recent Contractor advice on the likely dredge program aligns with earlier estimates of the timeframes of 'productive' dredging. 'Productive' dredging refers to the period of time that the dredge is continually operating (at full capacity), excluding allowances for dredge equipment relocation, downtime, weather delays or periods during the overall dredging period when there is no or low discharge.

Previous and current assessments have been developed conservatively assuming a constant discharge during each dredging day, dredging every day for a 1-month duration for each activity (consistent with the Referral Report). Consequently, the assessments of sediment plume generation are deliberately slightly conservative, given that during periods of lower discharge or no discharge the sediment plume will decay (reduce), with associated periods of reduced stress in the receiving environment.

The supplementary assessments presented in this report focus on the impacts due to the cutter suction dredge (CSD) dredging and the associated pumped discharging as this was found to contribute to the broadest 'Zones of Influence' and 'Zones of Impact' in previous sensitivity analyses. The 3D modelling presented herein is applicable to other scenarios (for example BHD dredging and discharge into barges), however the focus of this work was determining the impact areas for the key environmental receptors (i.e. benthic habitat).

2.4.3 Hydrodynamic Model

Tidal hydrodynamics are the dominant process for suspending and moving sediments throughout Darwin Harbour.

A 3D model has been prepared to examine the performance of the 2D vs 3D models and confirm the applicability of existing 2D modelling for the purposes of assessing dredge impacts.

Hydrodynamic modelling was undertaken using Delft3D (D-FLOW) to simulate tidally driven hydrodynamics in Beagle Gulf and Darwin Harbour.

An initial 2D model was prepared to enable simulation of multiple dredging scenarios. The modelling is described in *NCIS-5 – HMAS Coonawarra Dredging Modelling Report (Appendix F of the NCIS-5 – HMAS Coonawarra Referral Report)* and was developed with a combination of nested domains to enable a fine resolution of the site. The 3-dimensional hydrodynamic model was then developed, using the existing 2D model as it's basis.

The 3-dimensional model was prepared on the 'Darwin' base grid described in the *NCIS-5 – HMAS Coonawarra Dredging Modelling Report (Appendix F of the NCIS-5 – HMAS Coonawarra Referral Report)F* report. The model focuses primarily on the behaviour of the passive (far-field) plume, the resolution of which remains unchanged in the far-field extent between the 2D and 3D model. A 5-layer, equidistant sigma grid was used to represent the vertical.

A figure showing the 'Darwin' model grid and extents used in the latest 3-dimensional modelling is provided in Figure 2.3.

2.4.4 Suspended Sediment Model

Suspended sediment plume prediction modelling was undertaken using offline coupled hydrodynamics and particle tracking (PART) models within the Delft3D modelling suite.

D-WAQ PART is a Lagrangian random walk particle tracking model, which is based on the principle that the movement of substances in water can be described by a number of discrete particles that are subject to advection due to the currents and by horizontal and vertical dispersion.

The model is capable of predicting the extent, duration and intensity of passive dredge plumes. The model simulates the mid and far-field plume associated with the proposed dredging Near field initial spreading/mixing as the discharge leaves the source are not assessed in this model.

Plume dispersion in the PART model relies on the hydrodynamics and sediment settling parameters to predict the extents and movement of the plume with time (capturing changes due to tidal and current variances).

D-WAQ PART fundamentally operates as a 3D-model, even when adopting 2D modelled hydrodynamic inputs (i.e. Quasi-3D), by applying idealised vertical current distributions (i.e. superimposing a logarithmic velocity profile over depth on a 2DH Delft3D-FLOW simulation).

The use of a random walk particle tracking model, using 2D hydrodynamic model flows as input is consistent with the recommendations in the Guideline (Section 5.3.5) which advises that "*Particle tracking and offline advection-diffusion sediment transport models that resolve the vertical coordinate can be applied to 2D hydrodynamic model output to produce quasi-3D results for sites where the hydrodynamics are adequately resolved by a 2D model. Particle tracking models should employ a random walk process that reproduces a vertical turbulent eddy diffusivity that is estimated from the depth averaged current and local roughness.*".

Hence, whilst the previous work discussed in *NCIS-5 – HMAS Coonawarra Dredging Modelling Report (Appendix F of the NCIS-5 – HMAS Coonawarra Referral Report)* is suitable; the 3D hydrodynamic model flows have been applied to the PART model to provide more granularity.

Previous modelling reported in *NCIS-5 – HMAS Coonawarra Dredging Modelling Report (Appendix F of the NCIS-5 – HMAS Coonawarra Referral Report)* therefore remains relevant; however 3D hydrodynamic and sediment behaviours have now been modelled as a refinement to previous studies, focussed now on the scenario that produced the broadest impacts.

A 3D hydrodynamic flow field is obtained from the 3D Delft3D-FLOW hydrodynamic simulation and coupled with the PART model.

2.4.5 Sediment Deposition Modelling

Sediment deposition was investigated using two models taking into consideration the primary objectives of each:

1. **Assessment of the deposition of coarse sediments near to the discharge location**

An assessment of the deposition of coarse sediments was undertaken to investigate the area of impact due to blanketing of material and the potential formation of shoals (in the instance where coarser material may not readily redistribute under hydrodynamics).

Initial assessments of the extents of the predicted deposition area were prepared in the Referral and have been further confirmed using more sophisticated modelling.

Figure 2.3 3D Model Grid extents

Modelling of the deposition depth of coarse sediments was undertaken to inform the effects on the Area of Impact. Deposition of coarse sediments was modelled using Delft3D-PART to take into account the varying settling velocity of the different sediment fractions in the dredged material discharge. The PART model simulates the deposition of particles in a theoretical bed load layer using these settling velocities and modelled fluid bed shear stress. Three fractions were modelled: fine gravel, coarse sand and medium sand.

2. Assessment of the fate of fine sediments

Initial assessments of the fate of the fine sediments reported in the Referral were made using modelled bed stresses to establish areas fine material deposition (based on critical bed stress thresholds of erosion and deposition).

Additional modelling has been undertaken to refine the extents further.

The fate of sediments was simulated in the 3D Delft3D-FLOW model with directly coupled sediment transport potential and dynamic morphology. The Parthenaides and Krone critical shear stress model was used to simulate erosion and accretion. The native bed was assumed to be indurated and only the fine sediment content above background was simulated, i.e. only the fine sediment derived from the dredging activities was modelled. The model advised the sediment thickness as a result of erosion and sedimentation of this fine sediment over the 1 month simulation period.

2.4.6 Dredging work method description

The expected duration of productive dredging is expected to be 2 to 3 months. This duration is based on assumed dredge productivities discussed in *NCIS-5 – HMAS Coonawarra Dredging Modelling Report (Appendix F of the NCIS-5 – HMAS Coonawarra Referral Report).*

From contractor's advice, it is anticipated that the proposed dredging works will commence in the 3rd quarter of the calendar year, which aligns with the timing of past dredging campaigns (July and November for 2006 and 2013 campaigns respectively) which occurred predominantly during the 'dry season'. The site-specific data collection (Section 2.2.2 of this document), including data collected during past dredging campaigns is therefore relevant to the period of anticipated dredging.

Dredging is proposed to be undertaken in various stages based on the types of material intended to be dredged. The CSD dredging of finer materials will occur before the BHD dredging.

A breakdown of proposed dredging activities and timing is described in Section 3.3.2 of the Referral and summarised in Table 2.3. The NCIS-5 development ('Current NCIS-5 dredging works') is currently proposed for delivery. The proposed future eastern wharf development dredging work is not included in this report but was examined in the Referral to produce the similar impacts as the current dredging work.

A one-month dredging duration was used in the modelling and was selected based on a conservative estimate of productivity (refer Section 2.5.1 Source Rates) combined with the volume of material expected to be dredged. The selected modelling period also captures two spring and neap tide cycles. This ensures that both a "higher" and "lower" spring-neap cycle is captured, as there are longer-term variations in the tide in Darwin. This one-month modelling period is long enough to ensure that fully developed plumes are modelled (i.e. long enough to be beyond the modelling "ramp up" period)

Table 2.3 Summary of proposed dredging activities

Timing	Activity	Quantity	Duration
Current NCIS-5 Dredging Works			
1	CSD to remove upper layers of accumulated marine sediment and dredgeable residual sediment. Material proposed for nearshore discharge.	79,000 m^3*	1 – 2 months
	BHD to remove lower layers of harder residual sediments.	6,000 m^3*	1 – 2 months
Future Eastern Wharf Dredging Works			
2	CSD to remove marine sediment and dredgeable residual sediment. Material proposed for nearshore discharge.	66,000 m^3*	1 – 2 months
	BHD to remove lower layers of harder residual sediments	43,000 m^3*	1 – 2 months
* Allowance for an additional 300 mm of over-dredging across the site has been assumed, potentially adding approximately 16,000 m3 to the anticipated dredge volume for the NCIS-5 current works			

The modelled dredging assumes 9 hours of dredging per day, each day of the week. As per the Referral document, dredging operations are intended to be carried out over an approximate 12-hour normal workday during daylight hours (for example 6.30am to 6.30pm). Approximately 80% of that time is considered productive dredging, with the remainder associated with other operations (e.g. barge movements, crew transfers and start-up/shut down).

Based on the modelled duration and productivities, the model actually represents approximately 102,000m3 of fine material being dredged and discharged within the one-month period within the model. This is in an overestimate from the expected quantities of dredging to account for uncertainties (Refer to the Referral Report and *NCIS-5 – HMAS Coonawarra Dredging Modelling Report)* and Section 2.4.

It is also acknowledged that the volume split between the CSD activity and BHD activity may vary, with the possibility of some harder materials being cut with a CSD once encountered on site. The conservative volume represented in the modelling (and therefore considered in modelling assessments) is high enough to accommodate this possibility.

The short duration, high intensity modelled dredging campaign might not be realised. It has been adopted for conservatism. Latest contractor advice suggests an overall program of about 3.5 months of dredging activities (i.e. establishment, disestablishment, moving the dredging, maintenance, breakdowns and productive dredging); however the intensity of productive dredging (and discharging) remains consistent with what has been assessed in the Referral Stage, and in this SER assessment.

As noted in Section 2.4.2, these assumptions result in a model sediment plume that is intentionally somewhat conservative, because during periods of low or no discharge the sediment plume will decay (reduce), with associated periods of reduced stress in the receiving environment compared with the modelling.

2.4.7 Schematisation of the Sediment Fractions

The basis of understanding of the material to be dredged is determined from several site-specific geotechnical and sediment sampling investigations. An extensive investigation of the physical and chemical properties of the material was undertaken for the site over several activities. Over 42 sites within the HMAS *Coonawarra* harbour were investigated by either borehole or sediment sampling providing a high level of coverage across the site within the dredge extents and therefore high confidence in the types of material being encountered. An overview of these investigations is provided in Section 3 of *NCIS-5 – HMAS Coonawarra Dredging Modelling Report (Appendix F of the NCIS-5 – HMAS Coonawarra Referral Report)*.

Section 5.2 of the Guideline provides guidance on the schematisation of the sediment characteristics, with a focus mainly on allocating modelling efforts to the most important processes. Fine sediment is the primary source of suspended sediment in the far-field as the associated settling velocity is very low and therefore likely to remain suspended for a long period of time, contributing to a widely dispersing plume in the far-field. On the other hand, coarser material contributes mainly to initial settling and 'blanketing' close to the near-field. The 3D model therefore focuses mainly on the distribution of this fine sediment and associated impacts in the far-field. The fine sediment properties used in the suspended sediment modelling are discussed in Section 3.1.3 of *NCIS-5 – HMAS Coonawarra Dredging Modelling Report (Appendix F of the NCIS-5 – HMAS Coonawarra Referral Report).*

Other coarse materials (for example gravels, coarse sands and consolidated clay balls) settle faster (higher settling velocities). A modelling assessment was carried out separately to quantify coarse fraction, using settling velocities calculated in Furguson & Church, 2004.

Based on these site investigations, the material was rationalised into four main categories for further modelling assessments:

Table 2.4 Sediment fractions

Description	Fall Velocity (m/s)	Source
Fine Material (Marine sediment)		
Fine fraction (<63µ)	3×10^{-4}	Furguson, & Church, 2004
Coarse Materials (Weathered phyllite / schist material and coarse fragments)		
Fine Gravel (>3mm)	0.30	Furguson, & Church, 2004
Coarse Sand (>0.6mm)	0.09	Furguson, & Church, 2004
Medium Sand (>0.2mm)	0.03	Furguson, & Church, 2004

2.4.8 Source Term Definition

Dredging source terms were represented as a mass flux of fine suspended sediment in the model. Characteristic settling velocity for each of the sediment fractions were input separately.

In line with Section 5 of the Guideline, the estimation of far-field source terms is dependent on the dredging equipment, work method employed, bed characteristics of the site and metocean conditions and are ideally adopted from specialised field measurement campaigns conducted during actual dredging works. Further details of the source term derivation were requested to confirm the model input data used is consistent with the approach in the Guideline.

The approach to estimating the source terms for input into the models followed the recommendations within the Guideline (in particular WAMSI Section 9 – Appendix A) as follows:

Schematisation of the work method, dredging cycle and plume sources

There are three key activities which contribute to the suspension of sediment associated with the proposed dredging activities. The sediment sources associated with these activities have been summarised in Table 2.6 and are described in more detail in the Referral Report.

Table 2.5 Sediment sources associated with the proposed dredging equipment and activities

Equipment	Operating Mode	Source
CSD	Dredging	• Losses from the CSD Cutter head, represented as re-suspension at the bed • Bed erosion induced by propellers or bow thrusters
	Discharging	• Sediment load discharged in the nearshore through direct pumping of material
Mechanical (Backhoe, 'BHD')	Dredging	• Losses from the BHD bucket due to resuspension during dredging through bed impact/excavation Losses from the bucket when transferring the barge • Manoeuvring
	Disposal	Not applicable

The dominant source of the dredging sediment is the nearshore discharge point, located 300 m offshore from the HMAS *Coonawarra* western breakwater (as advised in the previous scenario-based 2D modelling in *NCIS-5 – HMAS Coonawarra Dredging Modelling Report (Appendix F of the NCIS-5 – HMAS Coonawarra Referral Report*).

Source term rates estimation

Section 5.1.1 of the Guideline describes a procedure for far-field source term rates estimation, based mainly on empirical methods, and supported by field measurements where available.

Source terms used in the modelling were derived from several sources of published guidance, including the references presented in the WAMSI Guideline where applicable. Conservative estimates on the production and loss rates for the likely dredge equipment were adopted, utilising information on similar equipment to the ones utilised for past maintenance campaigns at the site. Discussion on production rates of the selected dredge equipment is provided in *NCIS-5 – HMAS Coonawarra Dredging Modelling Report (Appendix F of the NCIS-5 – HMAS Coonawarra Referral Report*). Recent contractor information indicates that the proposed dredging plant is similar to that used in the past campaigns and therefore source terms and production rates presented in the Referral Report remain unchanged.

A summary of the published sources of information adopted for the various dredging activities proposed at the site are provided in Table 2.5. Whilst the pipe discharge location is the main source, references for all sources have been provided and are primarily based on the following:

- **Dredge head source terms** – Dredge head source terms were derived from published guidance. Comparison was made to the cited source Becker et al (2015) (referenced within the WAMSI guidelines, Section 5.1 and Appendix A) to confirm consistency with the Guideline.
- **Discharge source term** - Per Section 6.3 (p.50) from Des Mills and Hans Kemps, June 2016, '*Generation and release of sediments by hydraulic dredging: a review*', WAMSI Dredging Science Node Report, Theme 2 Project 2.1 indicates that sediment discharge from a pipeline is not well researched. Advice on the source terms for discharge activities is therefore limited. Discharge in the model was therefore calculated based on the production (pump) rate of the dredge and sediment:water content ratios described in the Referral Document. Confirmation of the discharge source rates was therefore confirmed via validations to historic dredging, with

the source term adopted reasonably able to replicate realistic far-field processes from the historic dredge activities (discussed in Section 5.1).

Table 2.6 Conservative source term assumptions in dredge-plume modelling

Parameter	Justification	Reference
Dredge discharge	Discharge rates are derived from the dredge production rate and estimated solids content of the slurry described in *NCIS-5 – HMAS Coonawarra Dredging Modelling Report (Appendix F of the NCIS-5 – HMAS Coonawarra Referral Report)*. A fixed discharge source term is not covered in general published guidance or WAMSI. The adopted production rates adopted would be considered on the higher end of production for a small-medium CSD.	Derived from the total amount of available fines (equations 3 to 5 in Becker et al, 2015), minus losses from the CSD cutter (referenced above)
Losses from CSD cutter head	Losses primarily relate to the release of material from the cutter head of the dredge. Source rates adopted in the modelling are equivalent to a cutter head fraction $\sigma_b \approx 0.01$ which aligns with published approximations cited in Laboyrie et al (2018), as referenced in WAMSI Section 9 - Appendix A.	CIRIA, 2000; Bray et al.,1997; Laboyrie et al., 2018 (WAMSI Section 9 - Appendix A)
Losses from BHD	Losses primarily relate to the release of material from the bucket of backhoe dredges. Leakage rates (loss rates) were adopted from published references and factored upward to conservatively account for: 1. additional losses due to prop jets and barge overflows 2. minor losses from filling activities at the barge (next to the backhoe) Source rates (due to losses from the BHD) are equivalent to a bucket loss fraction $\sigma_b \approx 0.07$ which is on the higher end of cited values in WAMSI Section 9 - Appendix A for Backhoe dredgers. The source rate adopted for a large backhoe dredge is conservative compared with other plume modelling in the region.	CIRIA, 2000 (referencing Kirby and Land 1991); Bray, et al, 1997

Application of the source terms over the model grid

This discharge is a semi-stationary source point which remains within a single model grid cell for the duration of the dredging. It is proposed to discharge directly within the upper to mid-water column (at approx. 5 to 10 m depth below the water surface). This approach is similar to past dredging activities.

Positions of the CSD and BHD were tested using the 2D scenario-based modelling in the Referral Report and a conservative position was assumed for the source term.

3 2D and 3D Model justifications

Analysis of available hydrodynamic and water quality datasets has been used to review the applicability of the 2D and 3D models for plume prediction.

The use of a 2D model in place of a 3D model was linked to a review of 'mixed' conditions at the site, using hydrodynamics, water quality and sediment profile datasets as indicators.

Hydrodynamics or sediment plumes that are not well-mixed can exhibit a pronounced 3D (vertical) structure, leading to a requirement to adopt 3D modelling techniques to better predict plume extents and behaviour in accordance with the Guideline.

Whilst the field data from Darwin Harbour indicates strong vertical mixing and an absence of 3D vertical flow or sediment patterns, by way of acknowledging this advice within the Guideline, a 3D hydrodynamic and sediment transport model was developed to:

- Elucidate any 3D hydrodynamic processes that might be influencing plume dispersion (horizontal circulation)
- Compare the 3D model indications with the previously reported 2D vertically averaged model's indications by way of confirming the suitability of the use of the 2D model as a predictive tool

Density distributions

In line with the guidance in WAMSI, it is generally appropriate to assume that in instances where there is a barotropic water body (i.e. where the water density varies only with pressure; density variations due to temperature or salinity changes are small), conditions at the site can be assumed to be well-mixed and therefore, a 2D vertically averaged model is adequate for the prediction of dredge plume behaviours for assessing impact areas.

Water density field data was collected during the 2013 dredge campaign and was reviewed. The data collected during the dredge campaign was during the September/October period, prior to any wet-season events. The data collected showed a well-mixed vertical density structure exists at the site in most profiles reviewed, a selection of which are presented in Figure 3.1, taken at the start of the dredging (18th September 2013).

Water density variations (such as from river flows) are not expected to have a significant influence on circulation patterns that would affect the project area given the large magnitude of the tidal currents. In particular, the literature suggests that the Darwin Harbour estuary is reasonably well mixed vertically during dry season conditions, which aligns with the proposed period of dredging.

Some density variations may exist during the wet season months due to high rainfall flow inputs, however this baroclinic effect is likely to be marginal close to the project site given that flow field is dominated by the tide throughout the year (regardless of wet or dry season conditions).

Longer term salinity records were also reviewed from the Darwin NRS Buoy (AIMS data station) and have been used to infer density variances with depth over a longer timescale to establish whether seasonal conditions (mainly wet vs dry season) introduce any significant density gradients, and hence indicate periods of reduced vertical mixing. Review of data from the 'new' station, installed February 2015 to May 2022, and 'old' station July 2010 to 2015 was undertaken. Figures 3.2 and 3.3 show timeseries of the two long-term datasets. The periods shown were selected as there was overlapping data at more than one depth in the measurements. There are clear variations in salinity due to seasonal conditions (wet season which typically indicates a lower salinity level compared with dry season), but in both records the salinity measurements at different depths indicate similar levels of salinity (i.e. the salinity profile with depth are relatively consistent), and thus are not expected to cause stratification relative to the vertical mixing due to the relatively strong turbulent tidal flows. Thus well mixed conditions are expected by the time the flows reach the Darwin Harbour entrance.

Hydrodynamic and sediment distributions

The guideline also states that “*The use of a 2D model to simulate hydrodynamics and TSS is justified in locations where the currents (and turbulence) are persistently strong with limited spatial and temporal variability*.”

Based on the reviews of field data, and as demonstrated with the measurements presented in the proceeding sections, there has been no evidence of a pronounced 3-dimensional hydrodynamic or suspended sediment behaviour that would significantly affect the prediction of far-field plumes using a 2D vertically averaged modelling. As expected, the dominance of the large tide range in Darwin, and thus the persistence of strong currents overwhelms buoyancy forces.

A sample of measured current roses and class frequency plots (histograms) were provided in *NCIS-5 – HMAS Coonawarra Dredging Modelling Report (Appendix F of the NCIS-5 – HMAS Coonawarra Referral Report)*, demonstrating a pronounced flood and ebb direction, which remains consistent at various depths throughout the water column. The measurements presented were from the ‘Bed 2’ ADCP site, close to the proposed discharge location (shown in Figure 3.4). The measured current roses captured directional frequency distribution of the currents and included wet and dry season variabilities. Hydrodynamic conditions for two periods were presented as part of the 2D model validation, indicating relatively consistent hydrodynamic behaviours for the two validation periods (May 2017 in the dry season and November 2017 on the cusp of the wet season).

Additionally, a selection of current measurement profiles taken from the same nearby ‘Bed 2’ ADCP (Figure 3.4) is provided below and shows a well-mixed vertical structure during a limited period of data capture in the wet season in December 2017 to January 2018 (Figure 3.5). Data is provided for a selected spring and neap tide period, showing representative flood and ebb conditions. Comparing this data, and the validation datasets in Section 4, the vertical profiles in both wet and dry season look to be well-mixed.

Given that the sediment behaviours at the site are primarily governed by these currents (discussed in Section 2.2.2), suspended sediment profiles from past measurements are also observed to be well-mixed by the time the sediment reaches the far-field.

The use of the 2D model to simulate the advection and diffusion of the dredged sediment plumes generated by the various dredging scenarios (presented in the Referral Report) remains relevant, however a 3D model was still developed to further assess the main scenario.

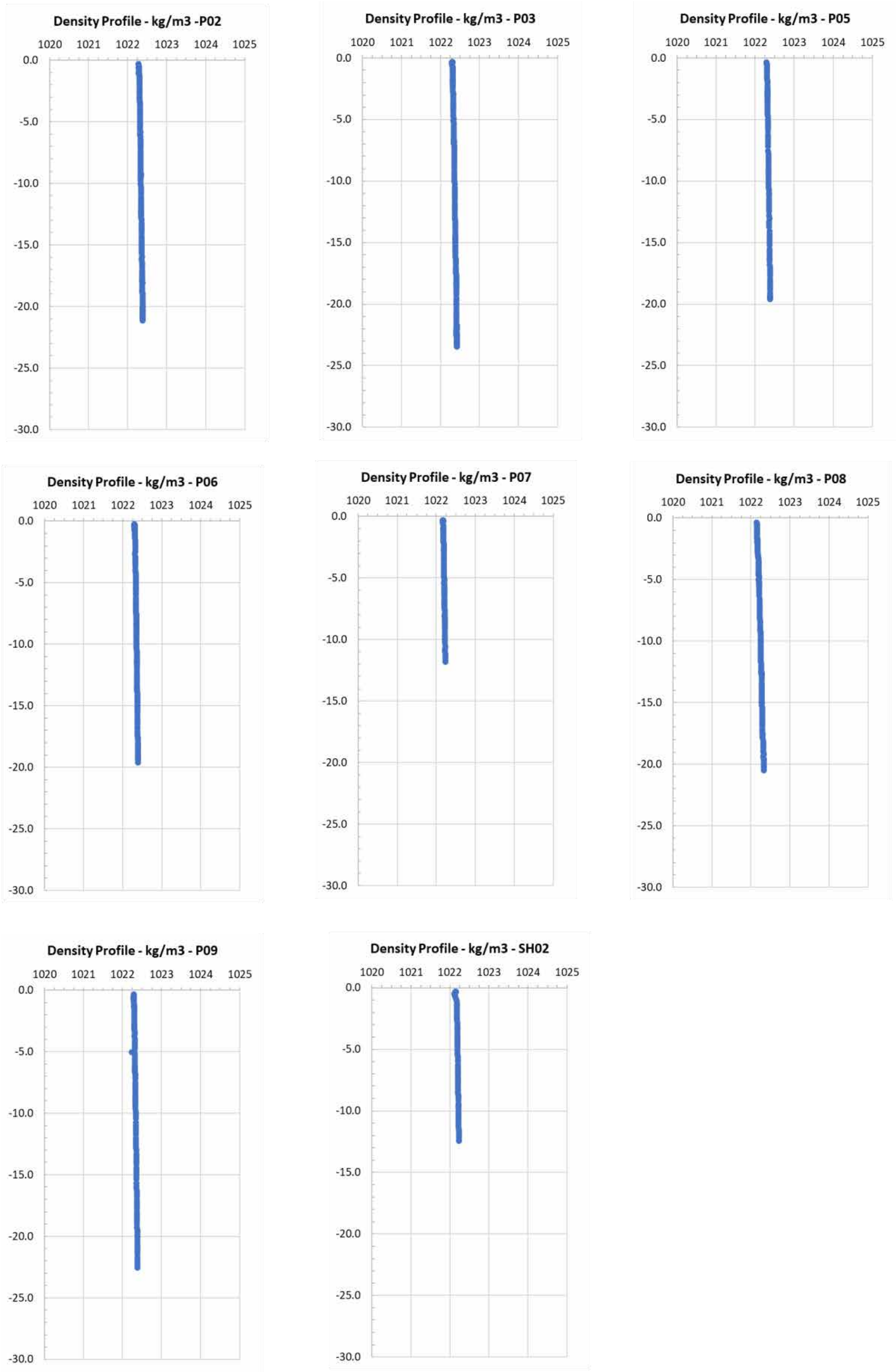


Figure 3.1 **Density profile measurements – 18 September 2013 (Refer Figure 4.9 for locations) vertical scale: depth [m]; horizontal scale NTU = TSS [mg/L]**

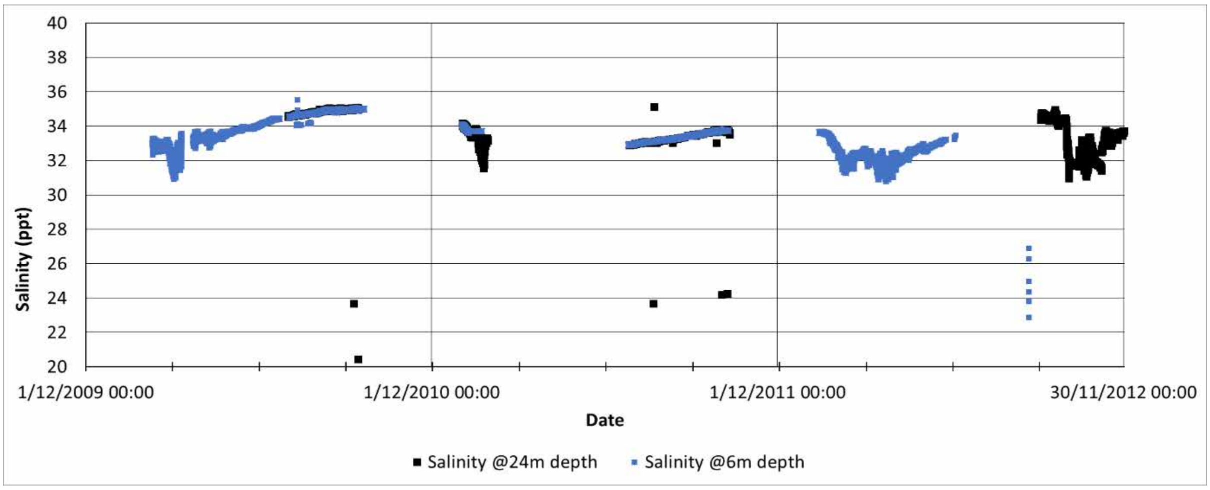


Figure 3.2 Daily salinity measurements at depth (ppt) – NRS station – 2010 to 2015

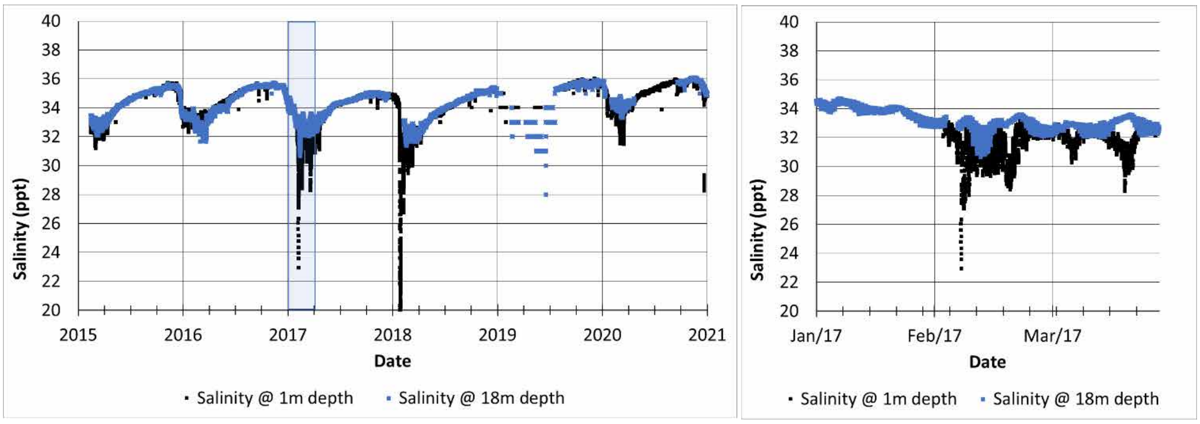


Figure 3.3 Daily salinity measurements at depth (ppt) – NRS station – 2015 to 2022 (left) and inset dataset of the 2017 wet-season (right)

Figure 3.4 Data validation sites – ADCP Data

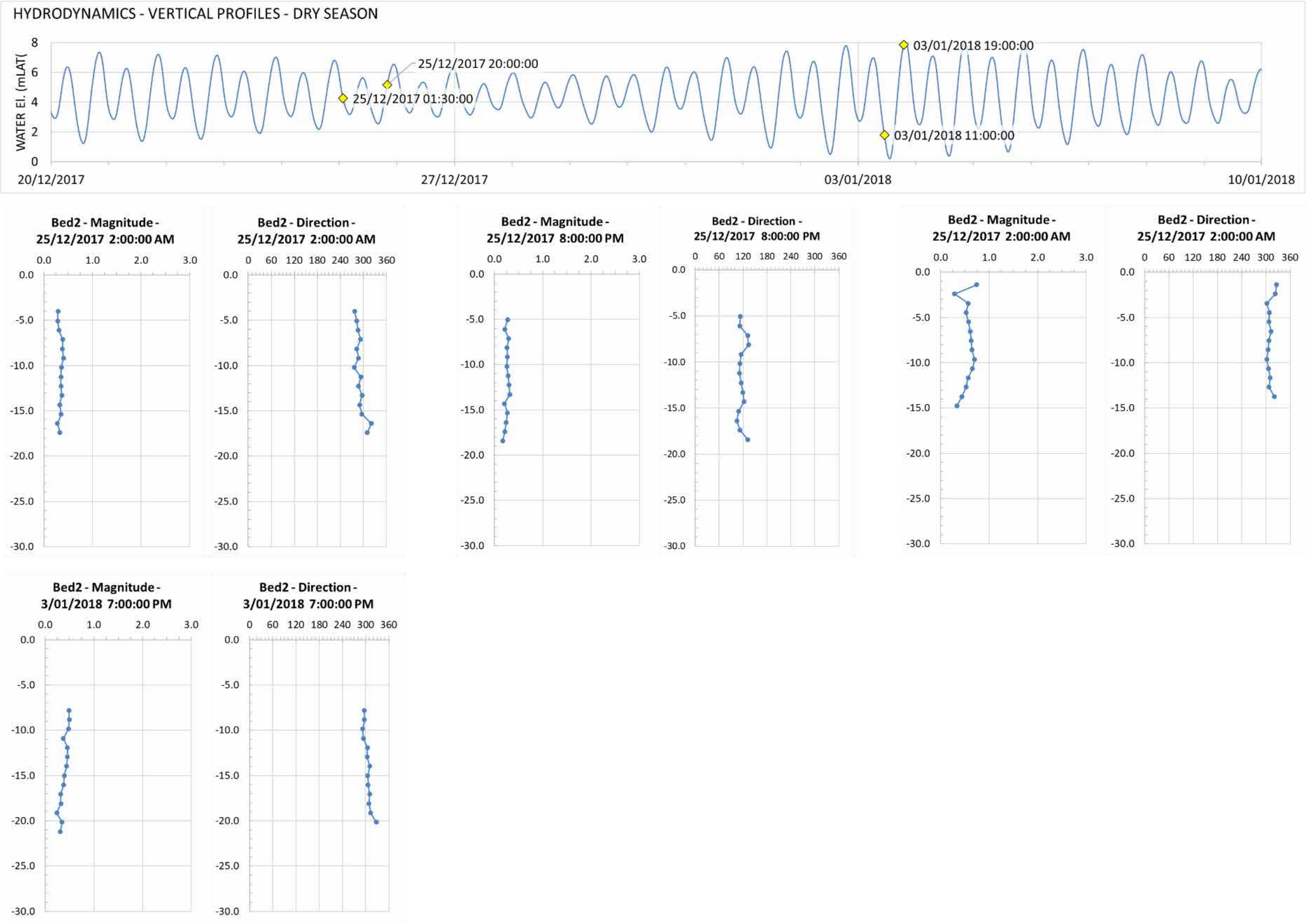


Figure 3.5 Current vertical profile measurements – 'Bed2' ADCP – Wet Season - Dec – Jan 2018

4 Model Validation

4.1 OVERVIEW

Additional validations of the 3D model were carried out to further improve confidence in the hydrodynamic and sediment model results, and thus improve the additional impact assessments in the SER Main Report.

Validation of the 3D model hydrodynamics (water level, current speed and direction) and sediments (recorded NTU values) consisted of comparing the model results to measured timeseries and depth profile data.

The validation exercise (discussed in subsequent sections) was used to supplement earlier validations carried out on the 2D modelling in *NCIS-5 – HMAS Coonawarra Dredging Modelling Report (Appendix F of the NCIS-5 – HMAS Coonawarra Referral Report)*. The main objectives of the validation were to confirm the 3D model behaviours were representative of the prototype situation, and to confirm key inputs to the modelling that were validated in previous versions of the model remained relevant.

4.2 HYDRODYNAMICS

Input datasets

A site-specific data collection campaign was undertaken to confirm the hydrodynamics at the site using data collected by bed-mounted Acoustic Doppler Current Profilers (ADCPs). The ADCPs captured the water velocity profile in ‘bins’ through the water column which facilitated visualisation of any 3D behaviour at the site.

Figure 3.4 shows the locations of the data collection sites used in validating the hydrodynamic modelling. These datasets represent the closest data collection sites to the discharge point and are thus most relevant to the propagation of dredge plumes resulting from the proposed dredging and discharging activities.

Data from the period 1 November to 1 December 2017 was reviewed, as this period captured a large tide with close to a HAT to LAT tide range. Capturing this period provided confidence that the Darwin tidal prism could be appropriately represented. It was also considered that this period represents a conservative spring tide situation (where strong spring currents would be anticipated to advect the plumes the furthest). The validation period also captured a spring-neap-spring period.

Timeseries validation

Figure 4.1 and Figure 4.2 shows comparisons between the modelled and measured current timeseries for a one-month period at the nearby ADCP ‘Bed 2’ site. Comparisons are also shown in Appendix A for each of the three ADCP sites. Comparison is made between the bed and surface layers of the model, and the upper and lower ‘bins’ collected in the field. Comparisons shown capture both the magnitude and direction of the currents.

The modelled and measured hydrodynamics show good agreement for both the current magnitudes and directions at each of the three sites.

Figure 4.3 is also provided which compares the measured data at the ‘Bed 2’ ADCP site (located close to the proposed discharge location) with the 2D model result and 3D model results at the surface, middle and bottom of the water column. The comparison shows that both the 2D and 3D model datasets can reasonably represent the hydrodynamics at the site.

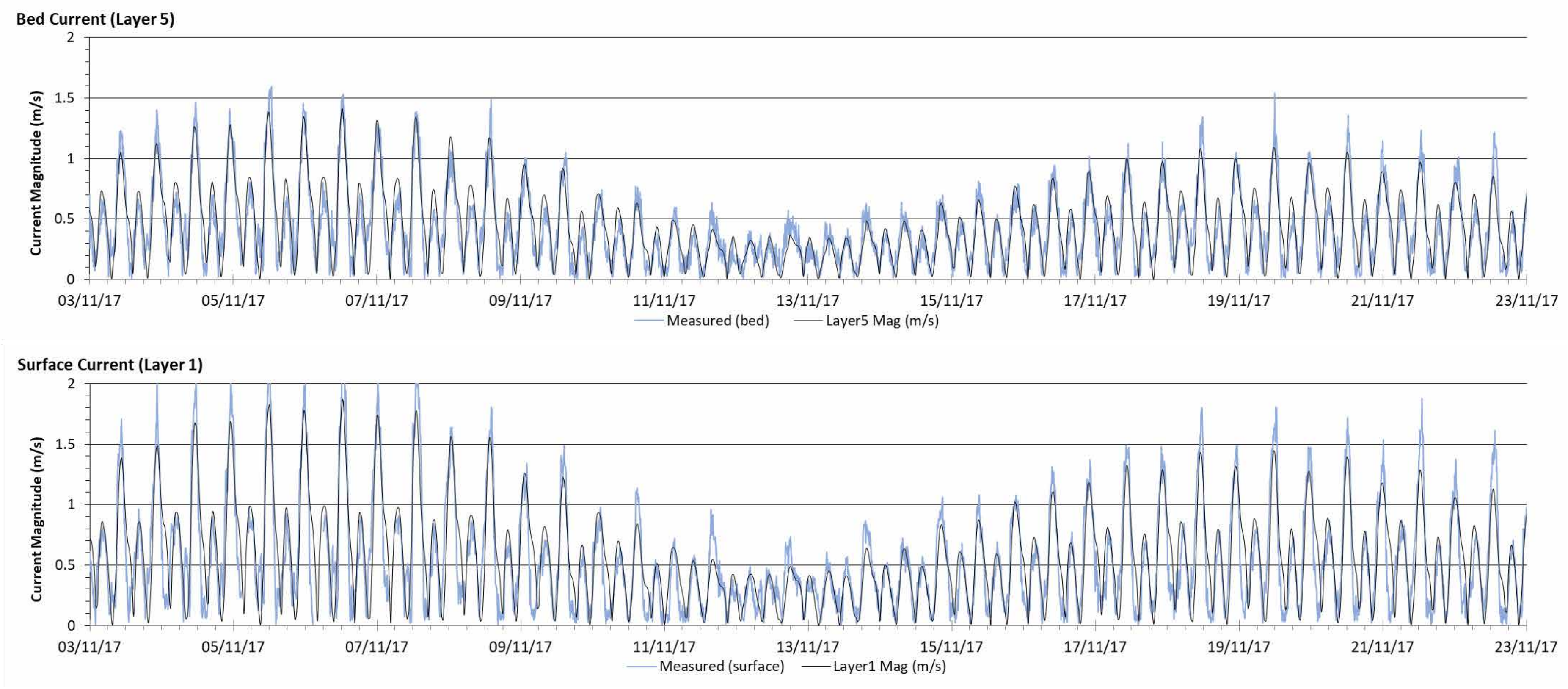


Figure 4.1 ‘Bed 2’ ADCP Output Location – Current Magnitude (m/s) – Surface and Bed layer comparisons – Modelled vs Measured

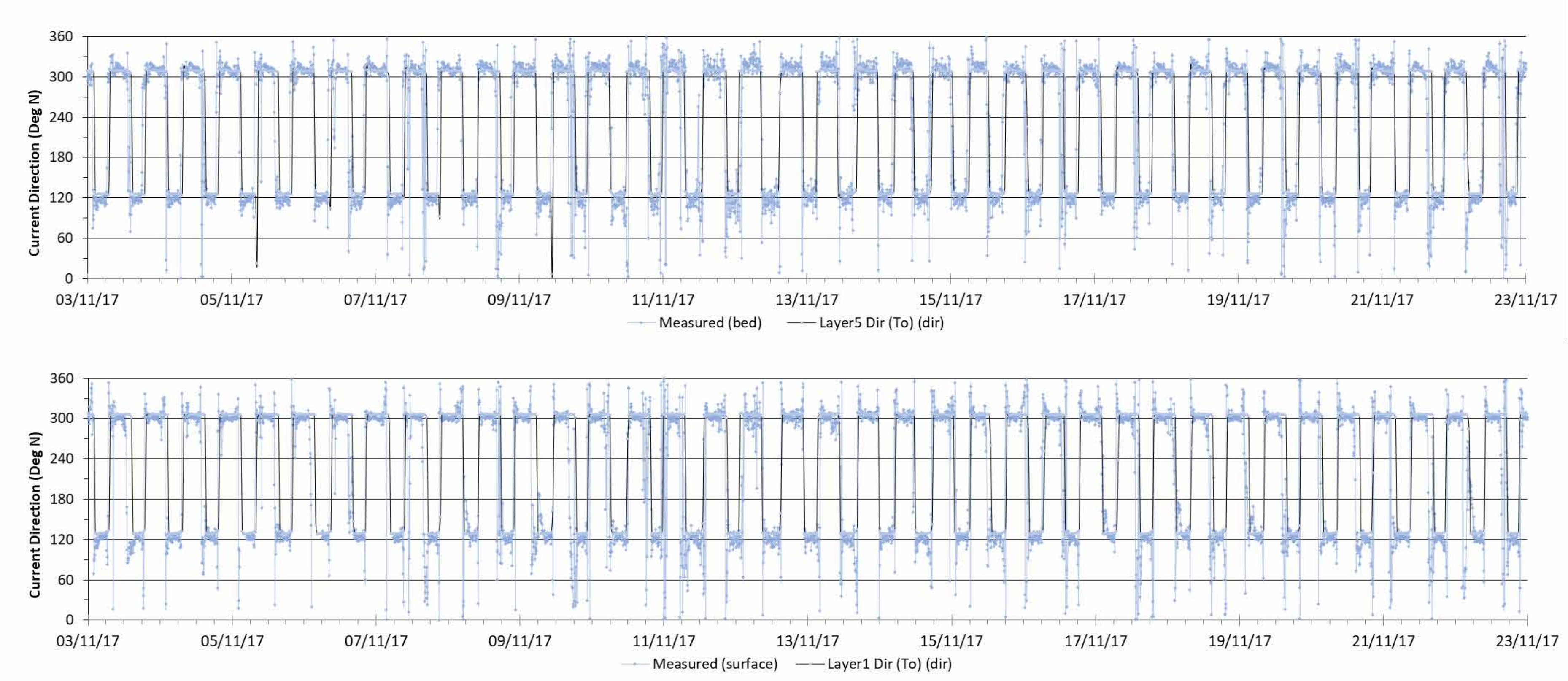


Figure 4.2 **'Bed 2' ADCP Output Location – Current Direction (deg. N) – Surface and Bed layer comparisons – Modelled vs Measured**

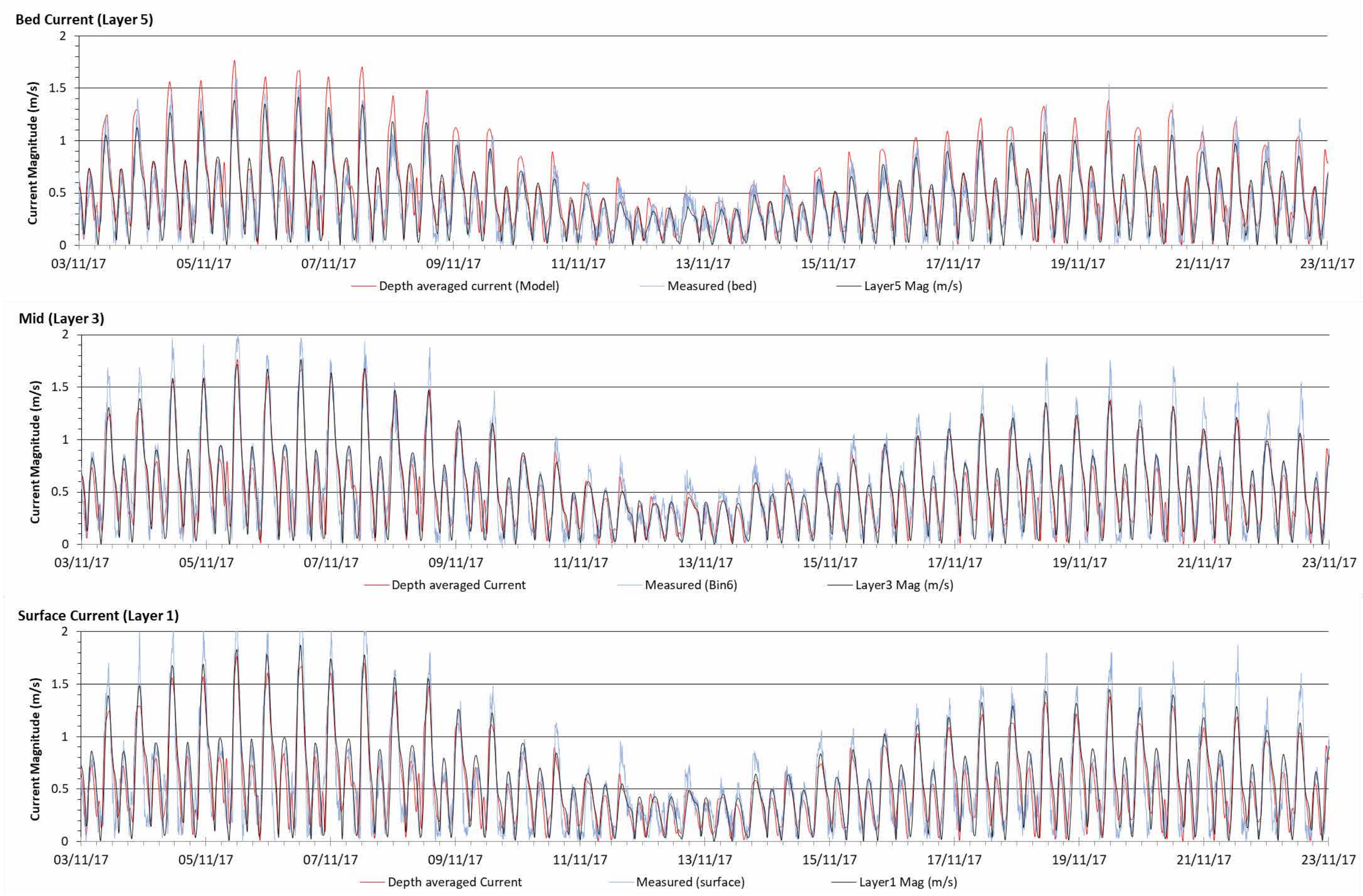


Figure 4.3 **'Bed 2' ADCP Output Location – Current Magnitude (m/s) – Surface, Mid and Bed layer comparisons – 2D and 3D Modelled (compared with measurements)**

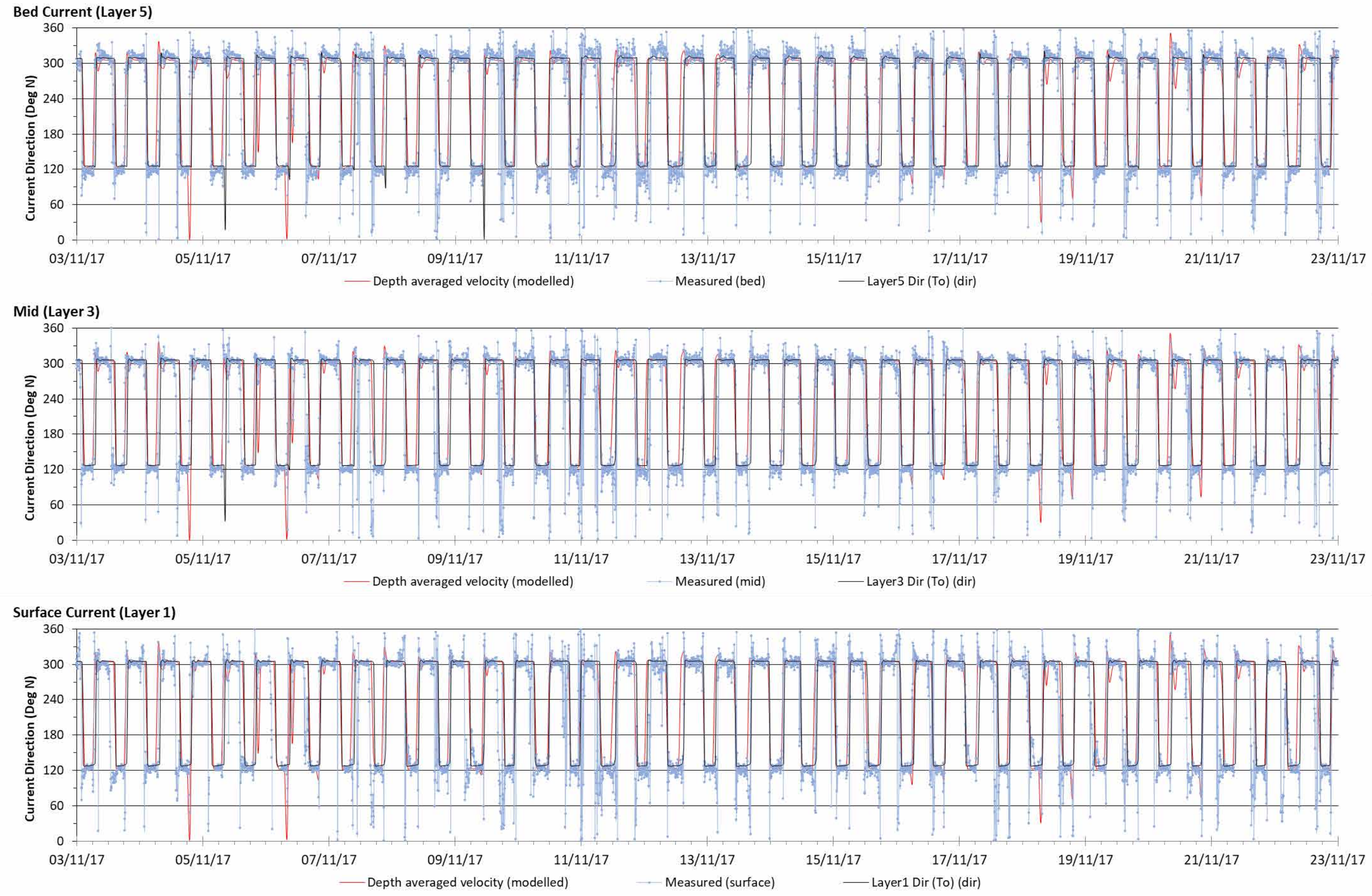


Figure 4.4 ‘Bed 2’ ADCP Output Location – Current Direction (°N) – Surface, Mid and Bed layer comparisons – 2D and 3D Modelled (compared with measurements)

3-dimensional depth profiles

Modelled current profiles were reviewed to confirm that the vertical distribution of current magnitude and direction was reasonably representative of the prototype current distributions. A selection of depth profiles is provided in Figure 4.5 to Figure 4.8, showing comparisons for each of the three reported ADCP sites. The vertical profiles shown capture a selection of times to show the vertical current behaviours during flood and ebb tides during both spring and neap tide periods.

The model and measurements show a well-mixed vertical distribution of current speed and magnitude at each site, with no pronounced 3D variability.

Overall, the model was found to successfully simulate prototype hydrodynamics at the project site and is considered fit-for-purpose for this study.

4.3 SUSPENDED SEDIMENT

4.3.1 Historic observations

Unique to this project, the proposed CSD dredging and nearshore discharge activities are the same as previous dredging works undertaken in 2006 and 2013. The dredge method, equipment types and production rates proposed for this campaign are all similar to these past campaigns.

Historic observations from past dredging campaigns were used in establishing a conceptual understanding of how dredge plumes behave in the vicinity of the site (discussed in Section 2.2.2). The observations were derived from field monitoring which focused on monitoring the extent of discharge sediment plumes during dredging. The measurements made during the monitoring of these works are also an indicator for the predicted dredging plume behaviour for the current proposed dredging and discharging works.

This data was discussed in Section 5.4 of *NCIS-5 – HMAS Coonawarra Dredging Modelling Report (Appendix F of the NCIS-5 – HMAS Coonawarra Referral Report)*, however further data from the monitoring of these campaigns was obtained during the SER process which has enabled further evaluation and direct validations of the modelled suspended sediment indications.

Comparison between the historic observations and the model provide greater confidence in the model predictive performance. The following sections describe the datasets utilised for validation of the sediment models.

The validation predominantly focused on the 2013 dredging campaign as it represents the most recent and most extensive collection of data. Comparison to the 2006 dredging campaign is also provided for completeness.

2013 Validation Period

In 2013, dredge monitoring involved the installation of three continuous data loggers, in addition to daily monitoring of turbidity as depth profiles at various points within the observed dredge plume over the dredge campaign (which ran from 18 September to 19 October 2013). The 2013 validation model simulated the period 18 September 2013 to 4 October 2013. This period was selected as the measured data is thought to provide reasonable reliability during dredging based on a data review and analysis, with an overlap between both the raw data logger measurements and handheld depth probe measurements throughout this period. There were some inherent limitations to the data collected during 2013 (For example some data does not clearly indicate the presence of a dredging sediment plume, discussed further in the following sections). The full dataset was analysed and from that, a subset of data was identified which was sufficiently representative to enable comparison with the modelled case.

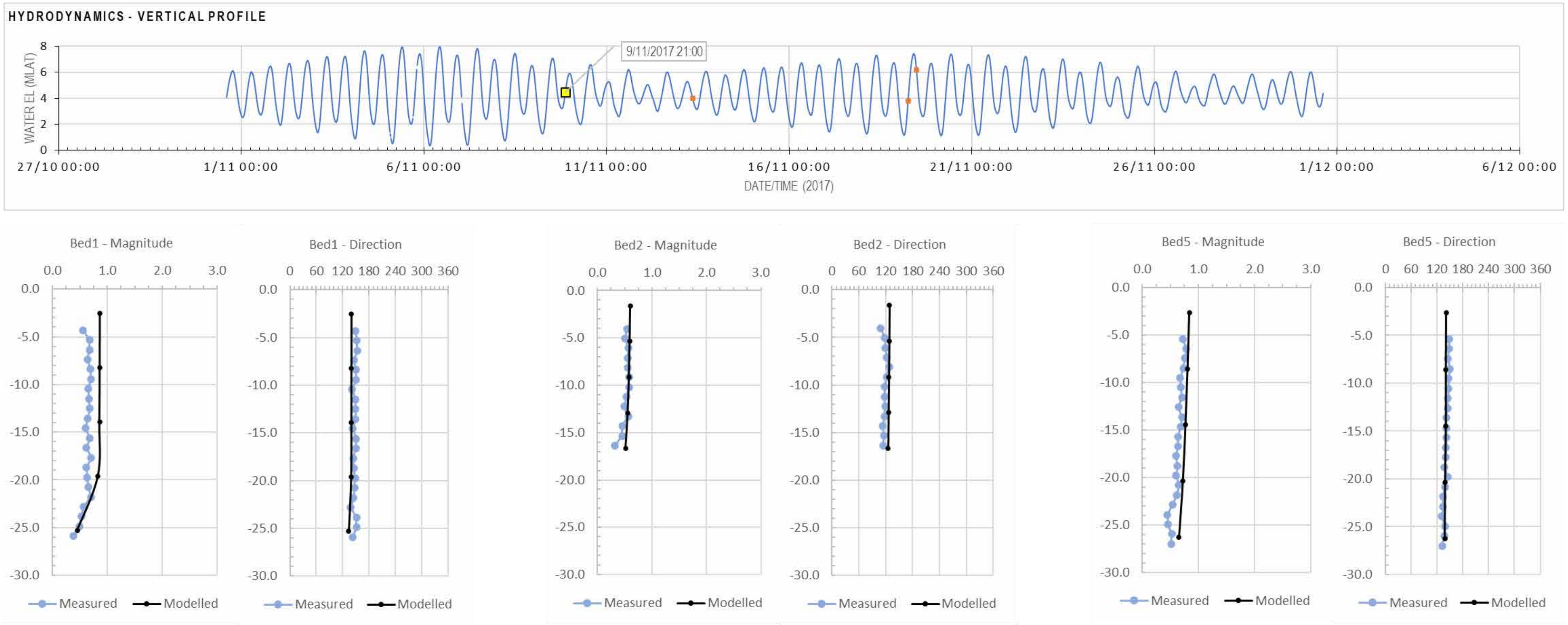


Figure 4.5 **Comparative depth profiles – Current Speed (m/s) and Direction (deg. N) – Modelled vs Measured – Neap flood tide**

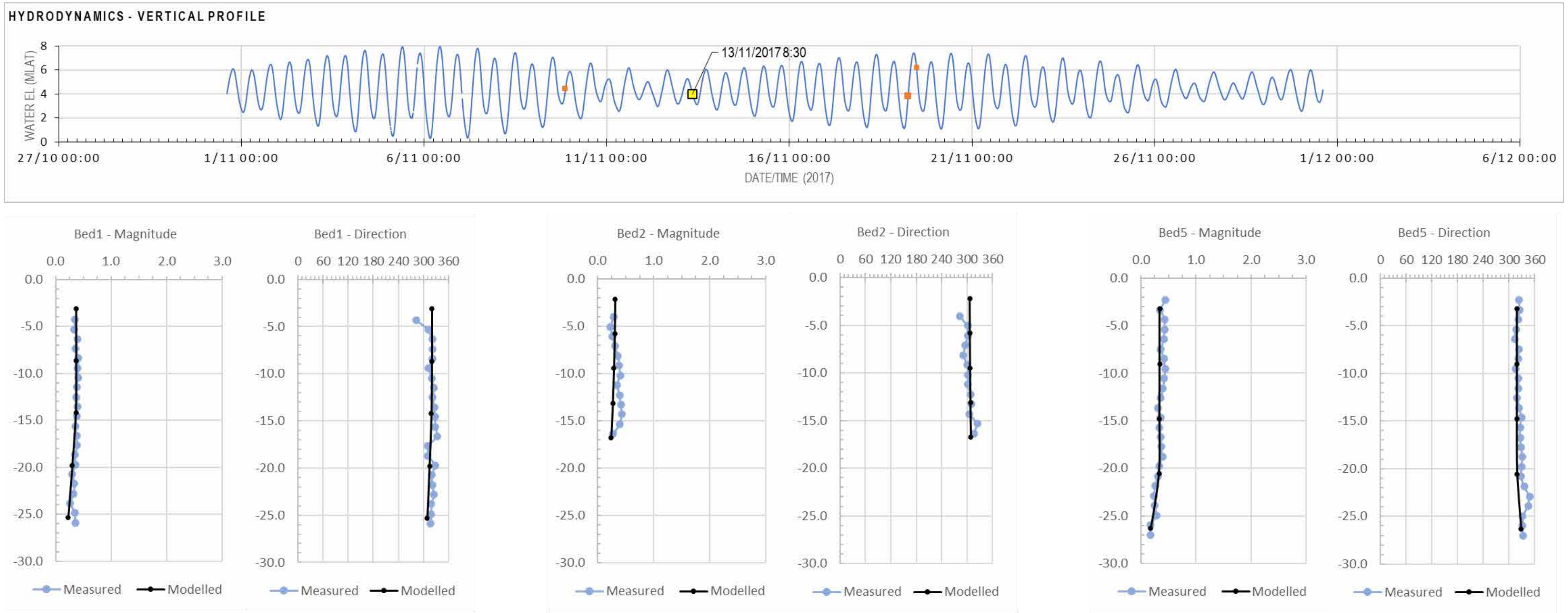


Figure 4.6 **Comparative depth profiles – Current Speed (m/s) and Direction (deg. N) – Modelled vs Measured – Neap ebb tide**

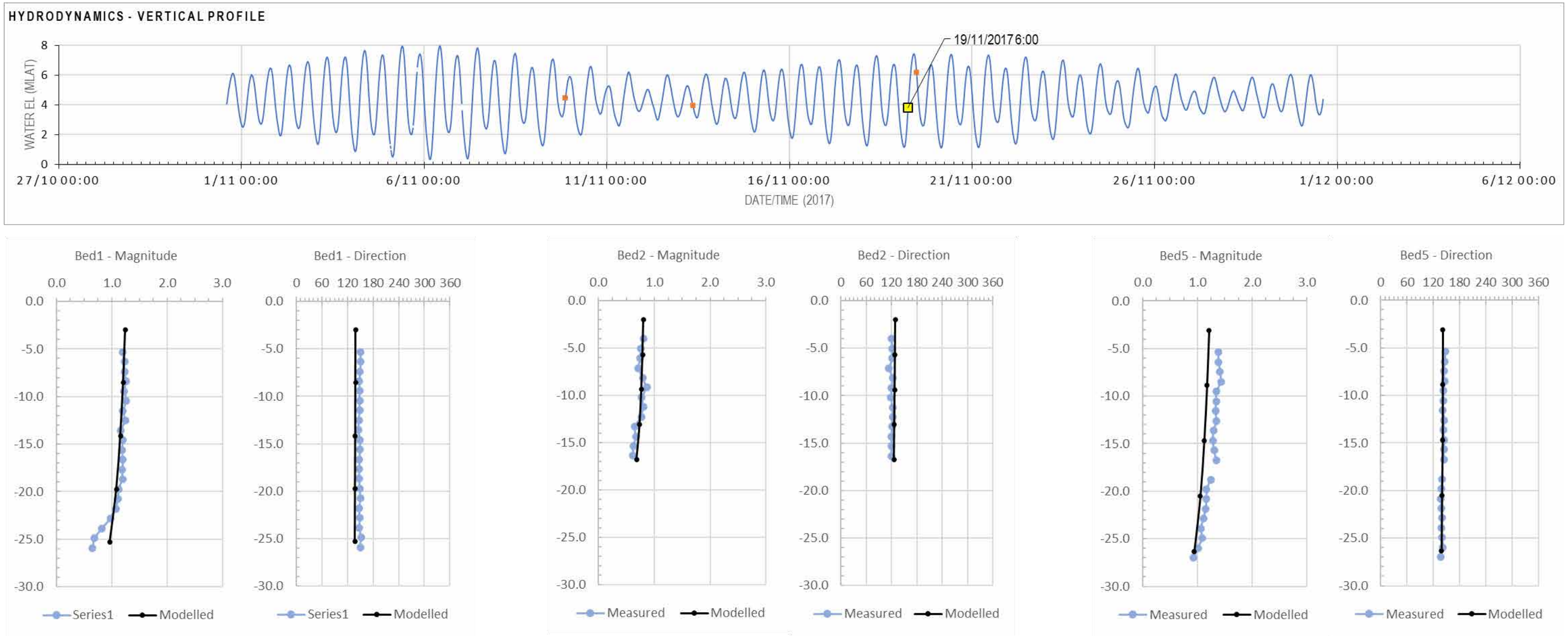


Figure 4.7 **Comparative depth profiles – Current Speed (m/s) and Direction (deg. N) – Modelled vs Measured – Spring flood tide**

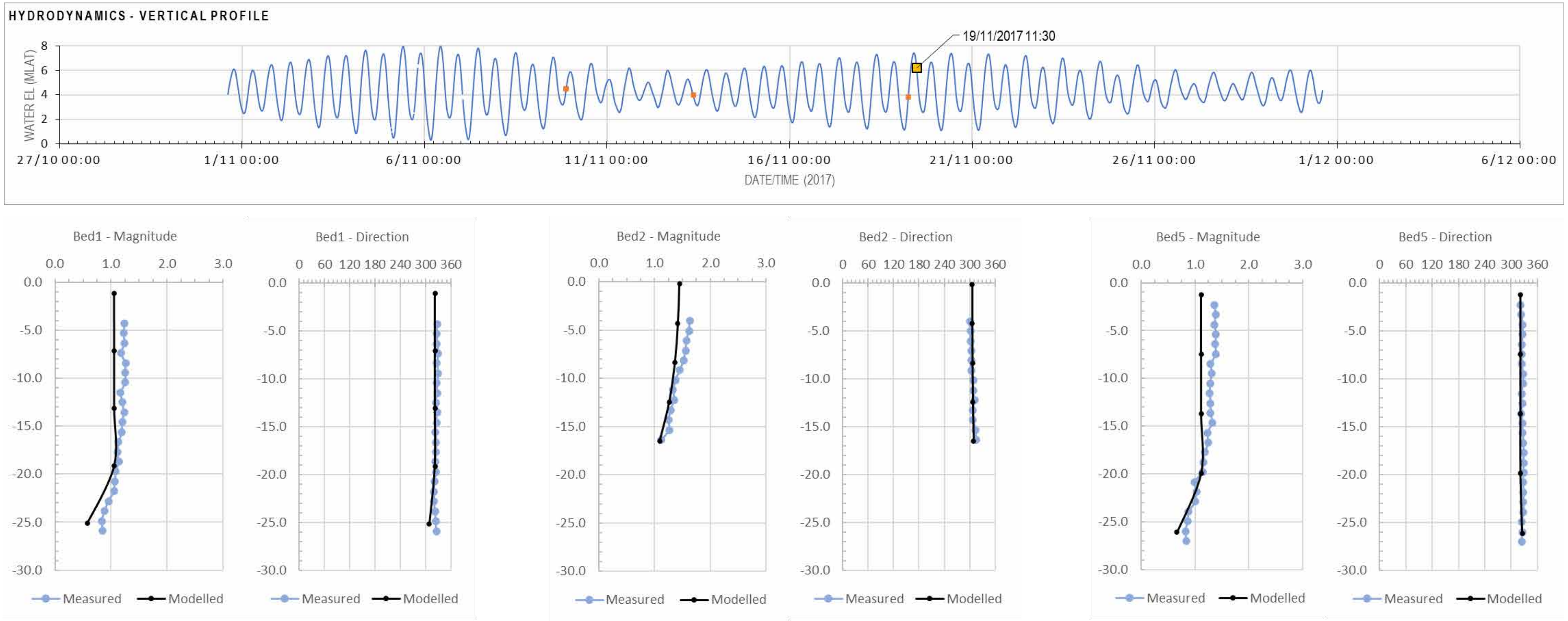


Figure 4.8 **Comparative depth profiles – Current Speed (m/s) and Direction (deg. N) – Modelled vs Measured – Spring ebb tide**

Sediment plume characterisation profile measurements

Daily sediment plume profile monitoring was carried out throughout the dredge campaign. The monitoring occurred within approximately 3-4 hours of the presumed start of dredging each day. Turbidity (NTU) vertical depth profiles at a number of points throughout the visible plume extent were recorded. The NTU readings were used to describe the dredge plume behaviour.

The large volume of data was reviewed and sorted so it could be matched to tide, dredge operations, location, to best enable comparison to the new 3D model predictions.

The 3D model was re-run for the 18 September to 4 October 2013 validation period, matching the timing of the tide (spring-neap-spring) within the dredging period.

The validation exercise consisted of comparing measured depth profile data to the 3D model outputs. The number and position of the depth profile locations varied from day-to-day. Not all profiles taken detected the presence of a plume. This would have been due to factors such as the practicality of locating the plume extents in the field, interruptions with the dredging, or later start times to the dredging than assumed. Unusable data was removed from the analysed dataset based on a visual assessment. The selection of the representative data that best described the plume was used for comparison in the following sections to verify the model’s ability to represent realistic plume behaviours.

As would be expected for a field data set recorded 10+ years ago by others, there are some inherent limitations in obtaining a direct match between the field data measurements and the model. Notwithstanding this, the reasonably close comparisons between model and prototype show that modelling reasonably replicates key prototype plume behaviours. In particular, the comparisons focus on the representation of the far-field sediment plume as this is what has the potential to affect sensitive receptors and is the main input to the impact assessments.

Profile measurement – 18th September 2013

The validation period 18 September 2013 was found to have a good overlap between the measured datasets (capturing the start of dredging and overlap with baseline data collection). There was also reasonable confidence in the background TSS concentrations from a review of the profile measurements and data logger timeseries which were clearly outside of the area of influence from the dredging activity at that time.

The modelled extent of the plume is provided in Figure 4.9. To enable comparison between the model and measurements, a background value of +4 NTU was added to the model result to account for the baseline turbidity which are not captured directly in the model. Comparison between the measurements and the model are provided in Figure 4.10.

The measurements were captured on an ebb tide approximately 2-3 hours from the presumed start of dredging for the day. Measurements were collected over a 3-hour period, so it is acknowledged that, due to dynamic conditions at the site, direct match to all recorded points is constrained. Nonetheless, the purpose of the validation exercise is to confirm that the model can capture correct plume behaviours in the far-field.

Profile sites P02, P06 and P09 have slightly elevated turbidity readings when comparing against the turbidity readings at other sites which indicate a low-concentration plume recorded at these sites. The remaining sites show lower measurements and are expected to be outside of the plume extent.

Profile P03 appears to be outside the plume, as indicated by slightly lower turbidity readings which are more representative of the background value (approx. 4 NTU). This was further confirmed by a review of the results from data loggers. This also aligns with modelled plume extents.

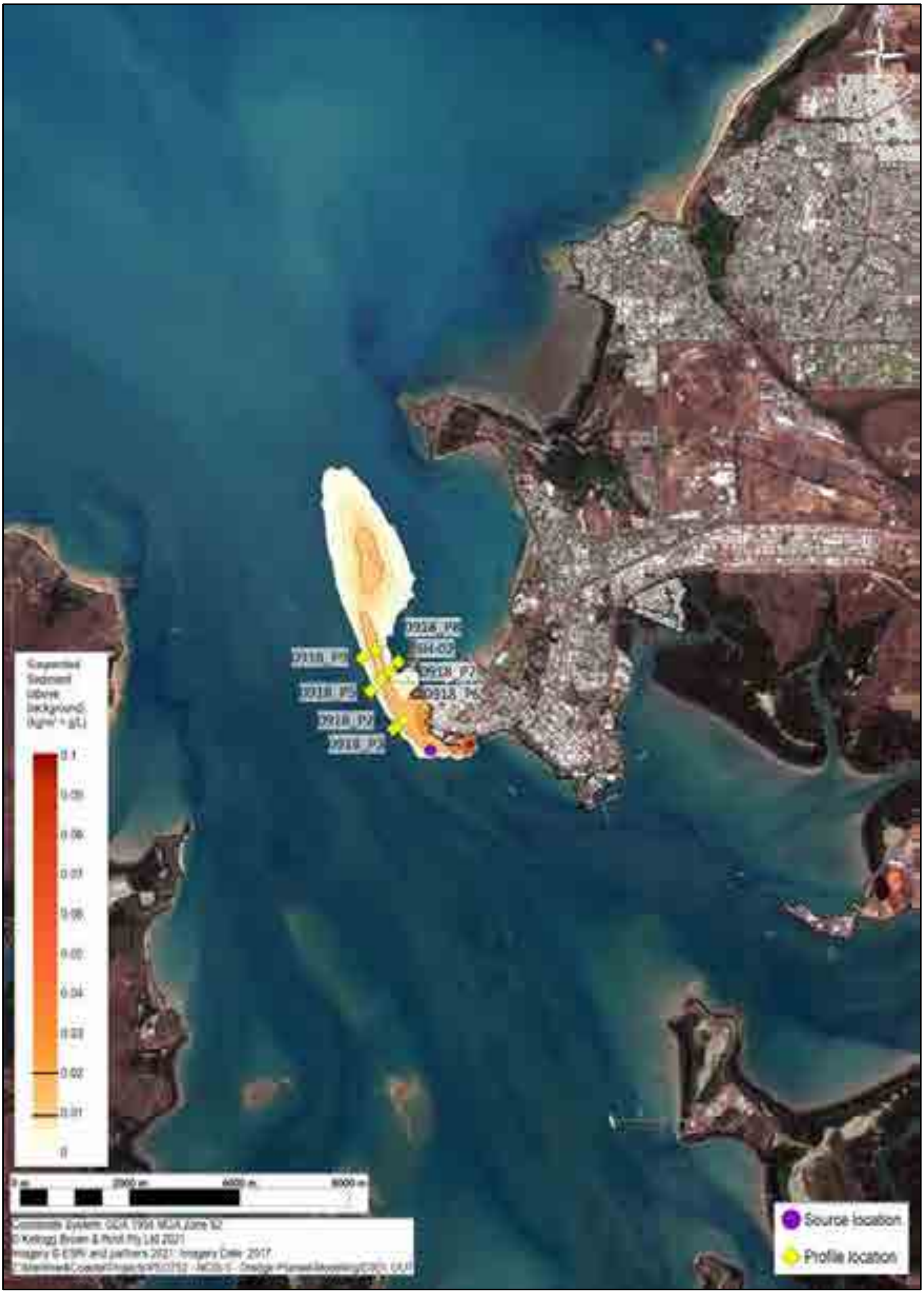


Figure 4.9 Suspended sediment concentrations above background – Depth-averaged instantaneous result with 18/9/13 monitoring locations

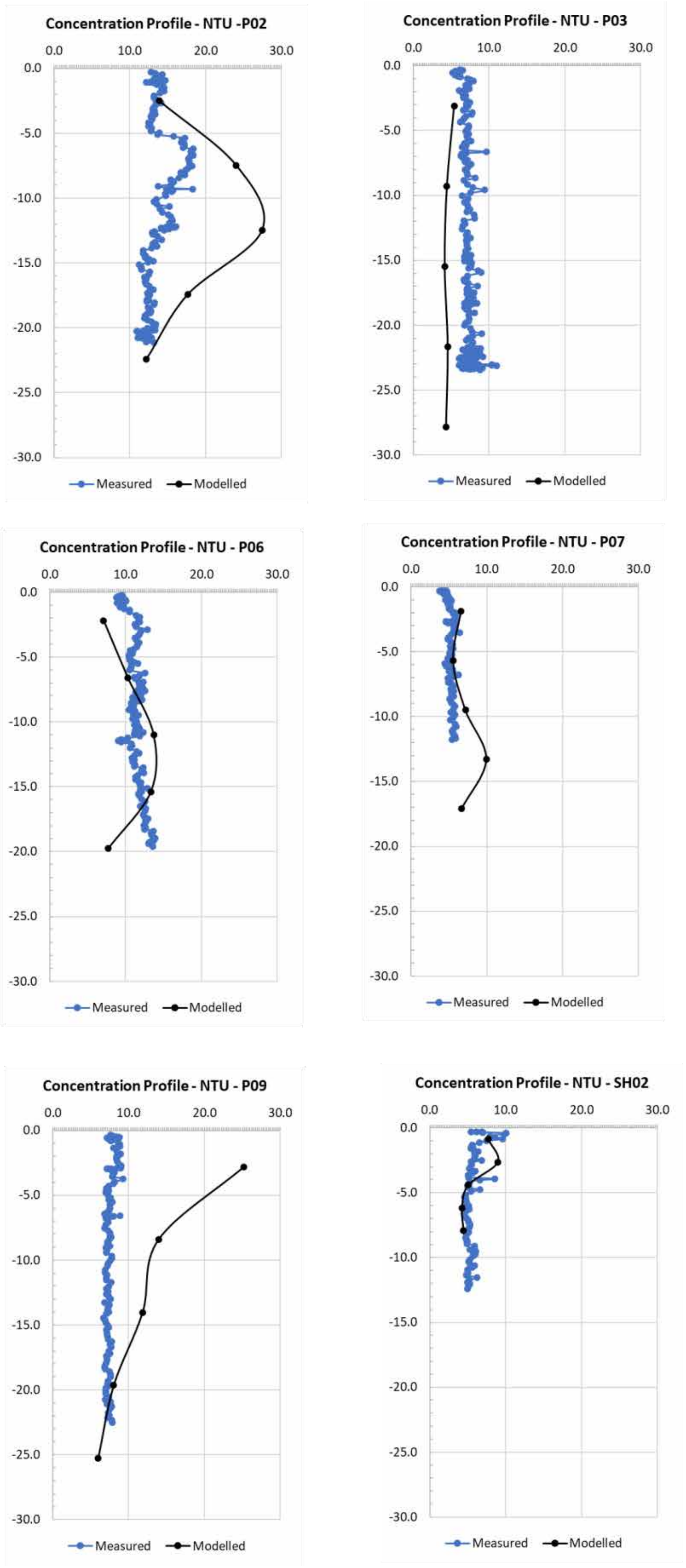


Figure 4.10 **Modelled turbidity profile comparisons to measurements taken 18/9/13 vertical scale: depth [m]; horizontal scale NTU = TSS [mg/L]**

Generally the modelled plume exhibits similar behaviours to the field measurements, indicating a relatively narrow plume extending to the north on the ebb tide.

The plume profile measurements all indicate a relatively well-mixed condition. The model slightly overpredicts the 3-dimensionality of the plume at most sites. The concentrations reported by the model are therefore slightly conservative. The slight over-prediction is considered suitable for the purposes of this study.

Profile measurement – 1st October 2013

The data presented in Figure 4.12 for the 1 October 2013 shows the modelled and measured turbidity at four depth profile measurement sites on a flood tide (Shown in Figure 4.11).

Overall there is reasonable agreement between the measurements and the modelled data, acknowledging the limitations (discussed in earlier sections).

The model conservatively underpredicts the vertical mixing, particularly close to the discharge site (in the near-field and mid-field extents), hence overpredicts concentrations. This is shown as a pronounced elevated concentration higher in the water column as a result of the modelled discharge (shown in P08, P09 and P12). Some elevated concentrations may have been contributed by the dredge due to the propagation of the plume on the flood tide. The dredge is usually contained within the basin, but it was conservatively assumed the dredge was operating close to the entrance in the model (given that actual details of the dredge position unknown) Given that there were uncertainties in the dredge activity for the day, the model is considered to perform well given the constraints and unknowns about the dredging operation.

In the far-field point (P11), the result captured the edge of the main part of the plume, with modelled and measured data showing the same mixed conditions in the vertical turbidity profile, again showing good agreement with the position of the plume and vertical distribution of concentrations in the far-field.

Other comparisons to measured and modelled datasets for the 2013 campaign have been provided in Appendix B and exhibit similar behaviours, presenting a collection of flood and ebb tide conditions.

Data logger measurements

Three bed-mounted turbidity data loggers were installed for the duration of the 2013 dredging program. The positions of these data loggers are shown in Figure 4.13. The loggers captured an approximately 1-week period prior to commencement of dredging (10 September 2013 to 17 September 2013) and then continuously operated throughout the dredging period from 18 September to 2013. Data was truncated to 4 October 2013 as there were obvious data issue (likely biofouling) which affected the data following that date.

There were some inherent limitations in comparing the data logger measurements with the model as the bed-mounted data readings captured bed load processes which did not represent total suspended solids (i.e. fine sediments distributed throughout the water column) which were being represented in the model. Nonetheless, the logger measurements would have included a component of dredge related sediment dispersed in the water column.

To enable comparison between measured and modelled datasets, the Delft3D PART model was run for the period 18 September 2013 to 4 November 2013 for a representative tide series (aligning with the spring-neap period from 2013). While there are no records of the actual dredging that took place day-to-day, the timing of dredging activities and sources rates were presumed consistent with current proposed activities. The discharge location position was the same for past and currently proposed dredging.

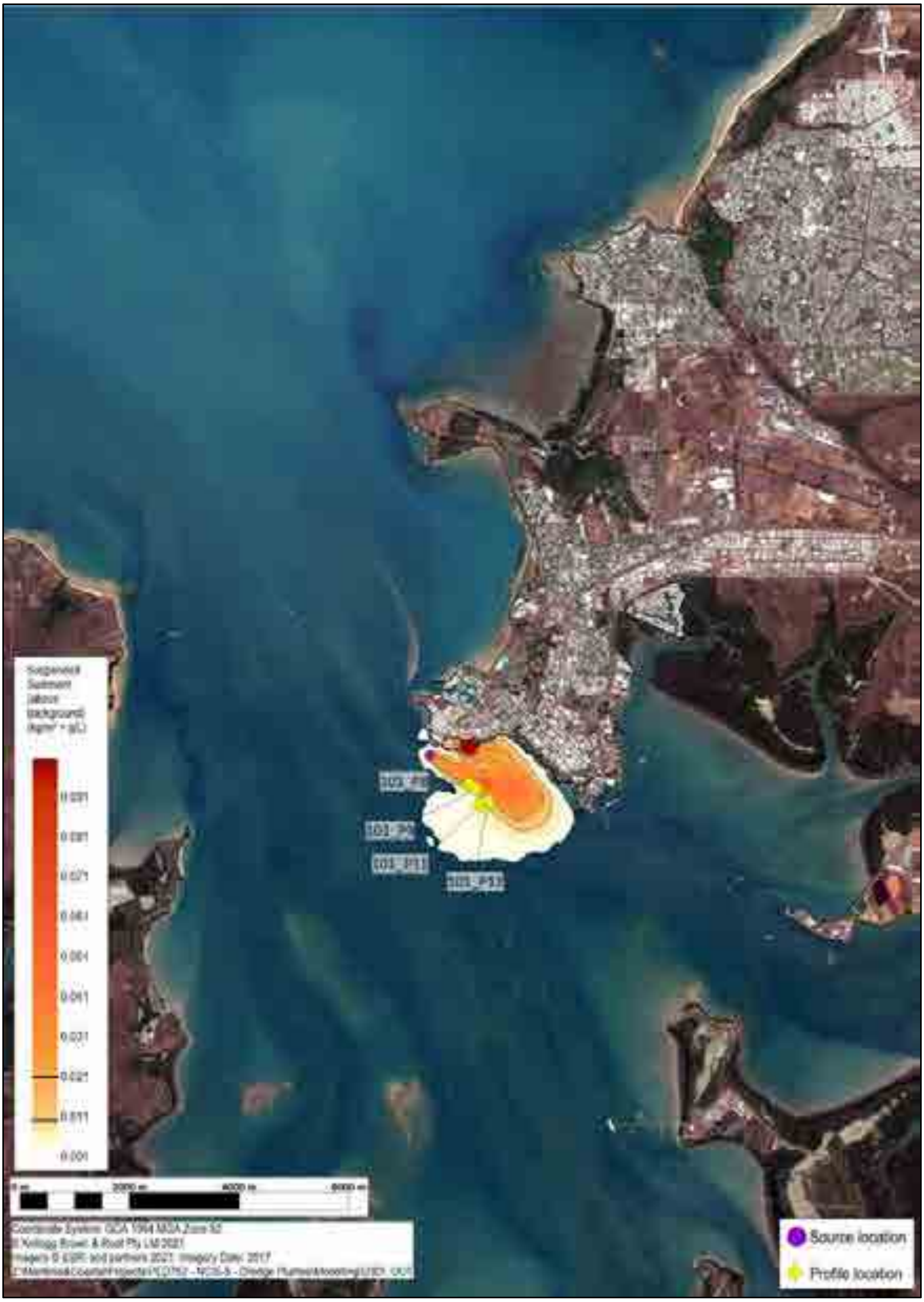


Figure 4.11 **Suspended sediment concentrations above background – Depth-averaged instantaneous result and 1/10/13 monitoring locations**

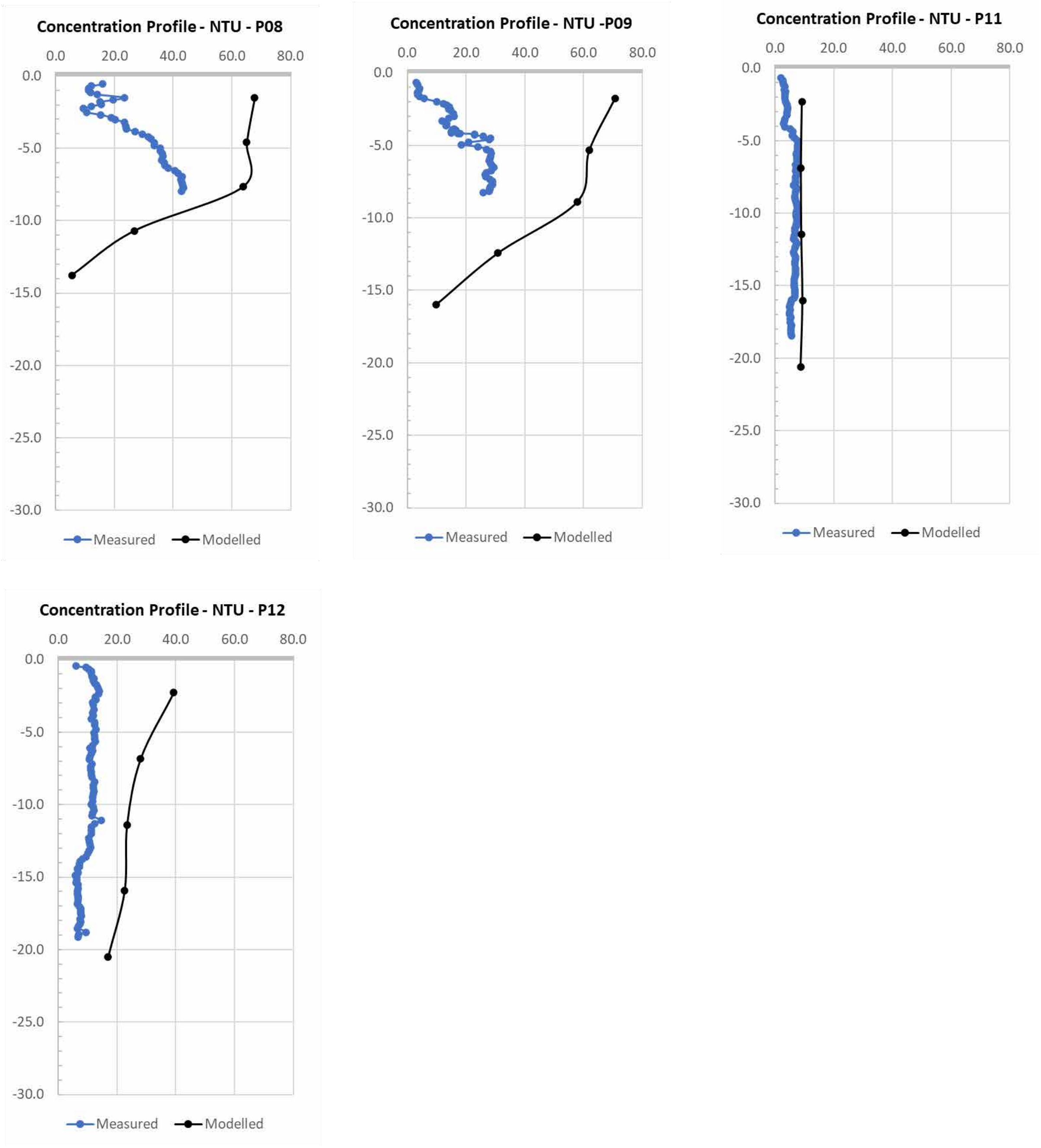


Figure 4.12 Vertical turbidity profile comparisons to measurements taken 1/10/13 vertical scale: depth [m]; horizontal scale NTU = TSS [mg/L]

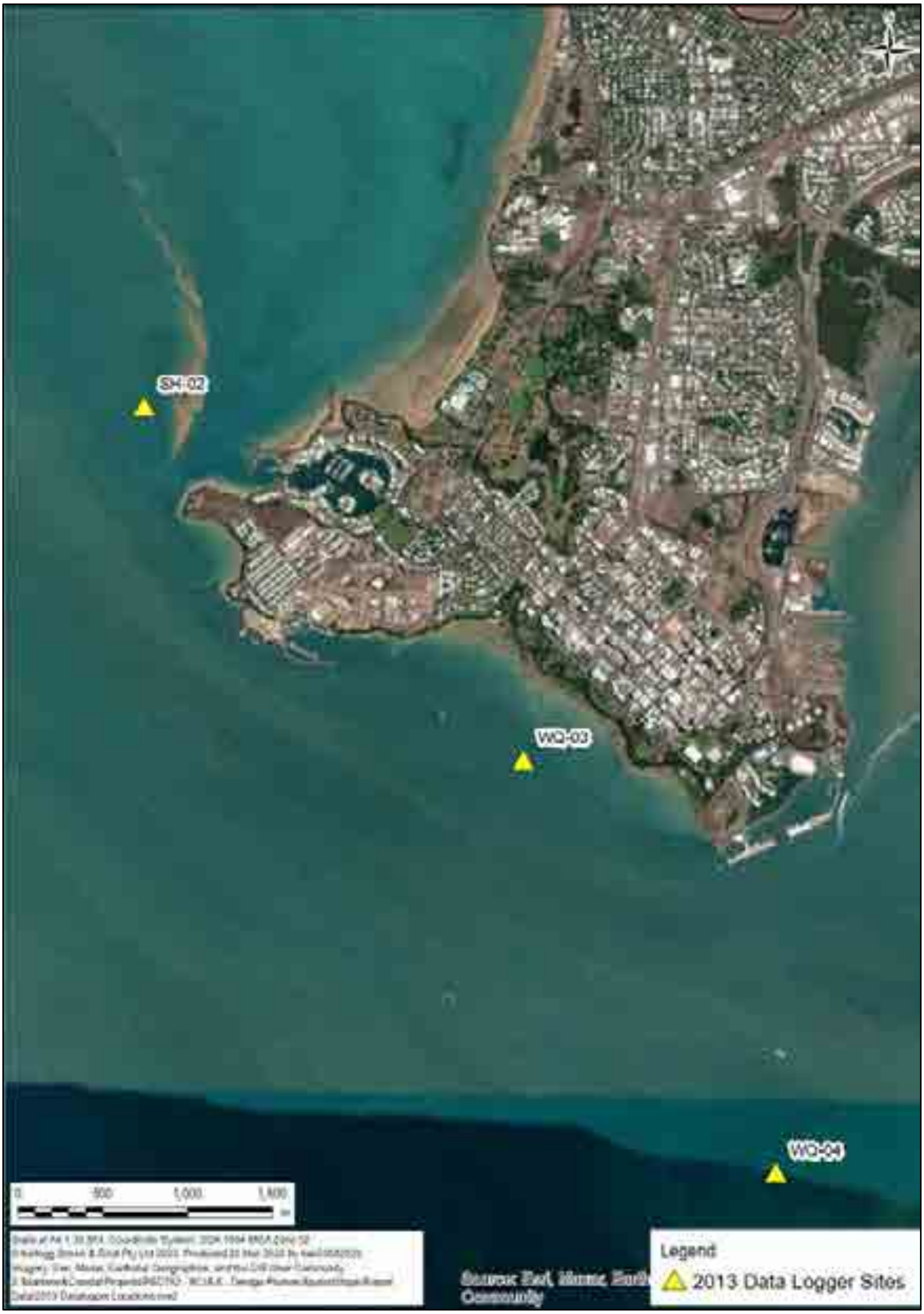


Figure 4.13 **2013 bed-mounted turbidity data logger sites**

A comparison of the data logger turbidity measurements and concentrations within the bottom layer of the model are provided in Figure 4.14 to Figure 4.16. The model result was combined with a constant +4 NTU 'water column' background value, adopted from an analysis of the measured timeseries datasets leading up to, and immediately prior to start of the dredging and modelled period.

A constant adjustment was made to the model results to represent a comparable turbidity value; however it is acknowledged that background concentrations close to the bed have considerable fluctuations, with noticeable increases in background values during spring tides (as was shown in the pre-dredge baseline dataset). As such, the comparison with the model had some inherent limitations:

- **Station WQ-04 is representative of baseline conditions**. At the WQ-04 logger station, only a small signal for the dredge plume was observed in the model. Examination of depth profile measurements indicate this location was beyond the influence of the plume and indicates that this dataset is more representative of baseline TSS fluctuations rather than recording any notable dredge plumes effects (described in Section 2.2.2). The dataset is therefore not directly comparable to the model indications which primarily simulates elevated TSS effects attributed to the dredging/discharging.
- **Peak NTU readings are not necessarily representative of the suspended (water column) load**. All data loggers were bed-mounted. Sometimes they reported higher levels of peak NTU that were not present in the water column depth profile data collected at the same time. The data logger series is therefore not closely representative of a total suspended sediment load (i.e. where these sediments are being suspended into the water column). The measurements also capture a process of movement of bed material along the bed which is a somewhat separate process, and not directly representative of the dispersion of fine suspended solids concentrations which is the subject of the model.

Despite these limitations, the dataset offers a continual record and does include a component (a signal) of the fine sediment derived from the dredge discharge, which enables some comparison with the model. For example, at both SH-02 and WQ-03, a regular and repeatable "spike" in the recorded NTU values is evident outside of the highly variable background values. This repeating "spike" can be directly related to the daily dredging and discharging periods and is indicative of the arrival time and persistence of the dredge plume. The model shows a signal of the dredge plume at similar timing and duration, showing that the model represents the same phasing as the measurements, associated with flood and ebb tide plume propagation, both towards the northern and southern sites, SH-02 and WQ-03 respectively. Furthermore, during neap tide periods, where background 'bed resuspension' (saltation) turbidity is at its lowest, there is better agreement between the model and measured peaks, providing reasonable confidence that the model is appropriately capturing the upstream and downstream distributions of the plume over time, within the limitations of the data.

2006 Validation

Validations focused mainly on the 2013 campaign as it provided the most recent and comprehensive dataset, however a validation exercise was also carried out to compare plume extents and concentrations with the measurements collected during the 2006 dredging campaign. The validation exercise involved re-running the model for the 2006 dredge period, following the same process as the 2013 validation.

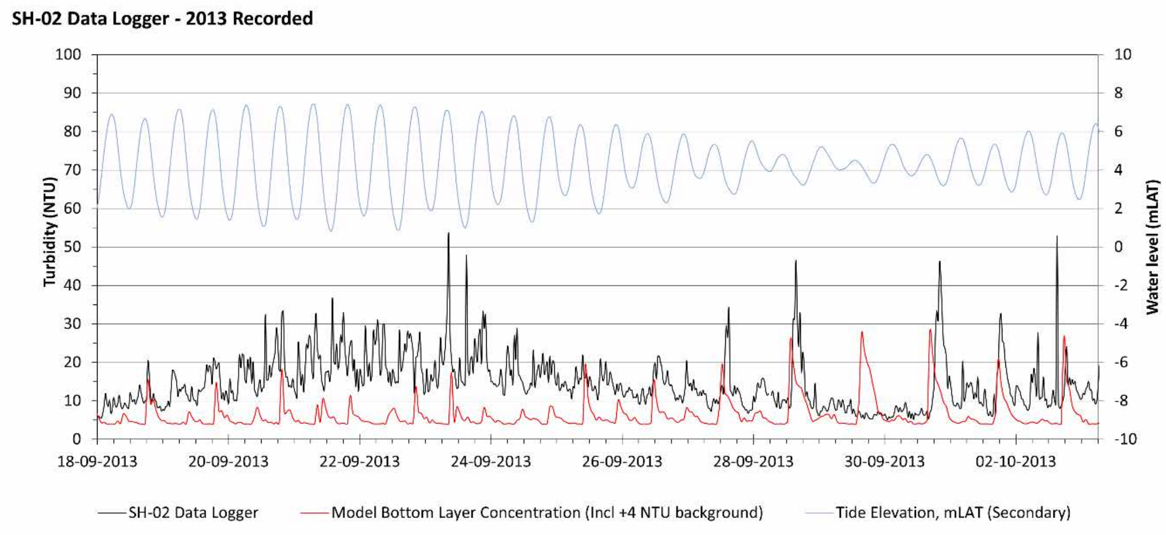


Figure 4.14 SH-02 data logger timeseries comparison

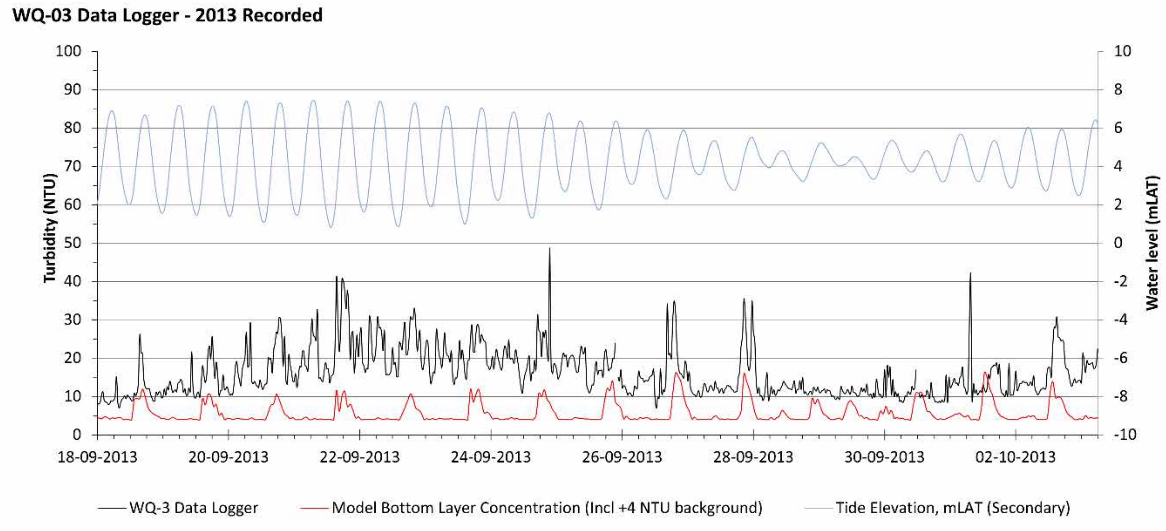


Figure 4.15 WQ-03 data logger timeseries comparison

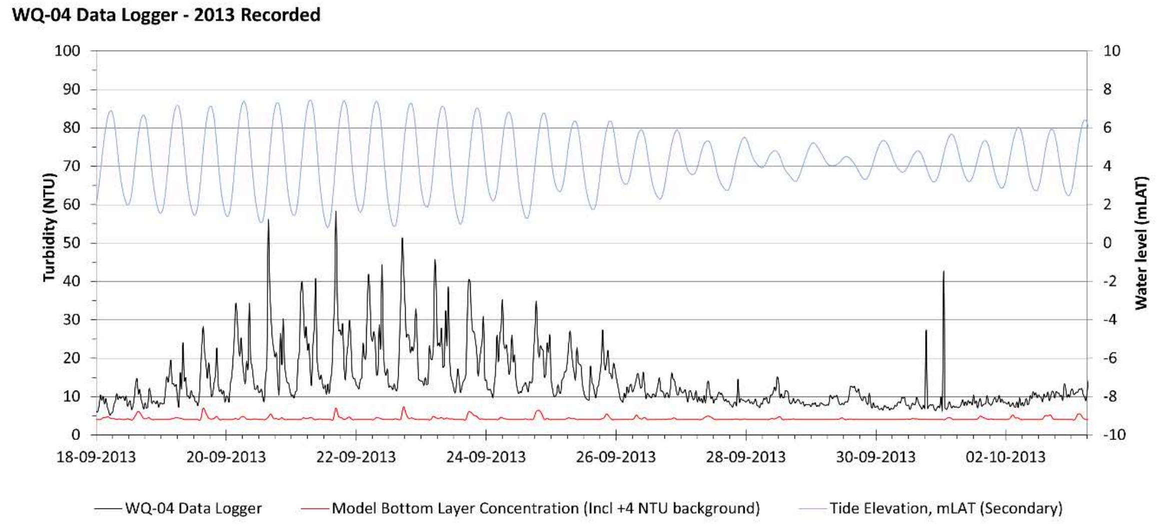


Figure 4.16 WQ-04 data logger timeseries comparison

The dredging monitoring involved the daily estimation of a visual plume extent, and field measurements of surface, middle and bottom turbidity readings at points throughout the presumed plume. These measurement locations varied from day-to-day. Measurements were taken within a few hours of the commencement of dredging (presumed 3 to 5 hours from commencement).

The 2006 validations had some inherent limitations:

- **Extended data collection timeframes are not comparable to a single modelled 'snapshot'.** Model outputs to simulate the location and concentration of a plume (above background) for a specific point in time. The data capture timeframes for the water quality measurements are across an approximate 2-hour period (varying from day-to-day based on plume observations made from the monitoring vessel). Because of the strong currents and fast-changing tide levels, plume extents and concentrations vary considerably within a period of 0.5 to 1 hour. Not all data 'point' measurements will therefore be representative of the same time capture for comparison purposes.
- **Visual plume extents are variable.** The field monitoring involved an initial visual estimation of dredge plume extents and approximating these locations on the water to capture the location of the plume and measure the turbidity. The timing of the initial data capture of the plume extents relative to the water quality field measurements is unknown. Further, there is uncertainty as to whether the plume extents being captured correspond to the dredging or capture background effects.

Within this context, some comparisons were able to be made between measurements and model results to confirm that the model was able to replicate main plume dispersion processes.

Plume Depth Profile Comparisons

Plume turbidity depth profile comparisons were made between the model and the measured datasets collected during the dredging in 2006. Daily monitoring was conducted during this campaign, with data being collected in the morning of each day of dredging. Turbidity results recorded were surface, middle and bottom readings for each, although the actual recorded depths of the raw datasets are unknown and difficult to obtain with the passage of time. Nonetheless, the dataset was reviewed, and a representative flood and ebb tide selected for comparison. Figure 4.17 and Figure 4.19 show the extents of the modelled plumes at a snapshot in time during the measurement period (2-4 hours typically). Depth profiles comparing surface, middle and bottom NTU readings are provided in Figure 4.18 and Figure 4.20.

Given the inherent limitations (described above), the modelled and prototype (measured) plume behaviours were generally able to represent similar concentrations which provides reasonable confidence in the model's ability to represent realistic plume conditions. Results showed relatively well-mixed conditions. As with validations to the 2013 dataset, the model had some underprediction of mixing (overrepresented 3D effects) at points close to the discharge location, generally leading to some conservativeness in the modelled versus actual which is considered appropriate for the overall purpose of the modelling.

4.3.2 Satellite Data Capture

Publicly available satellite captured imagery was reviewed as part of the validation exercise and to examine its use in monitoring plume extents during the proposed dredging campaigns.

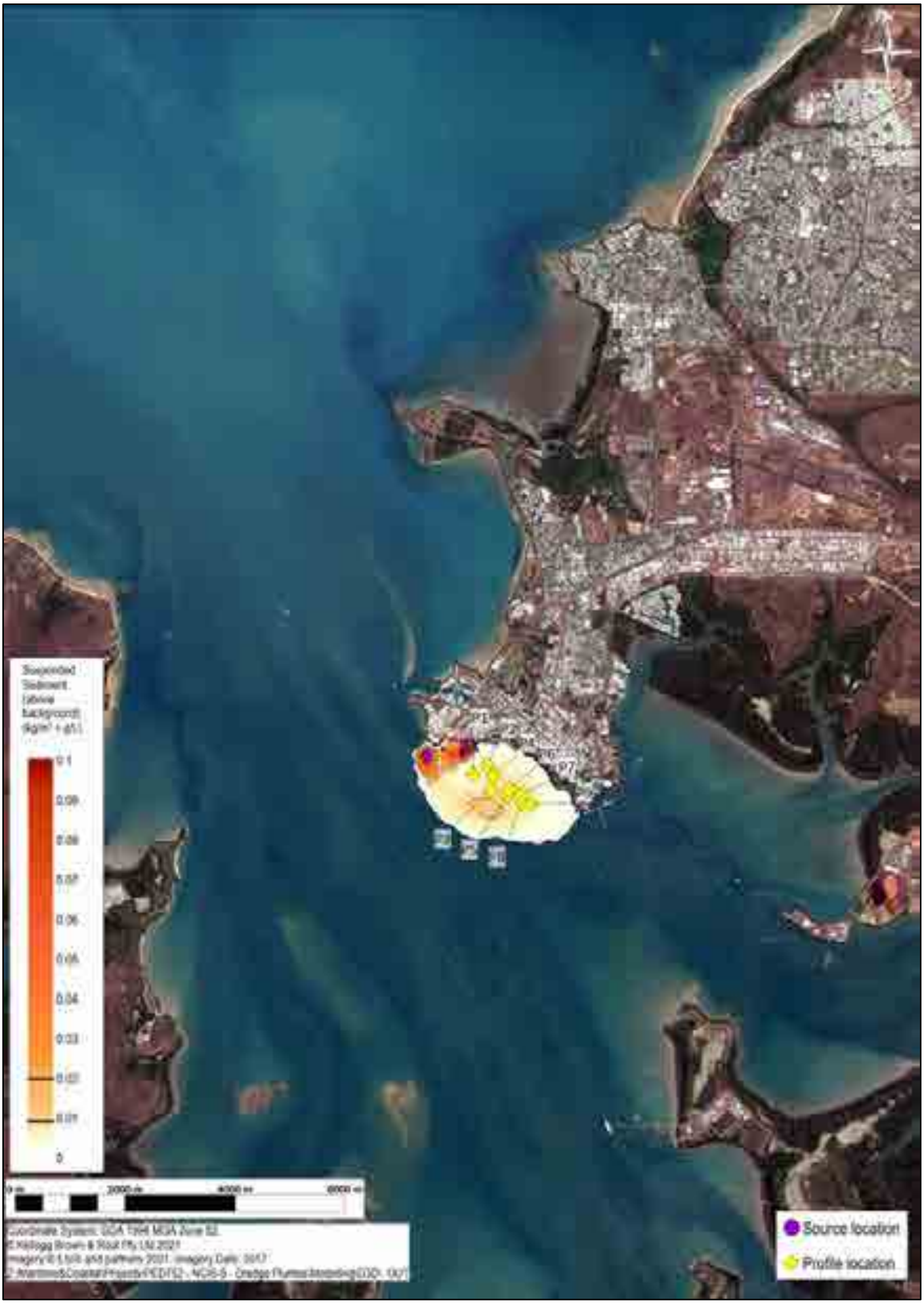


Figure 4.17 Turbidity monitoring sites at 04/07/2006 (compared to modelled plume extent)

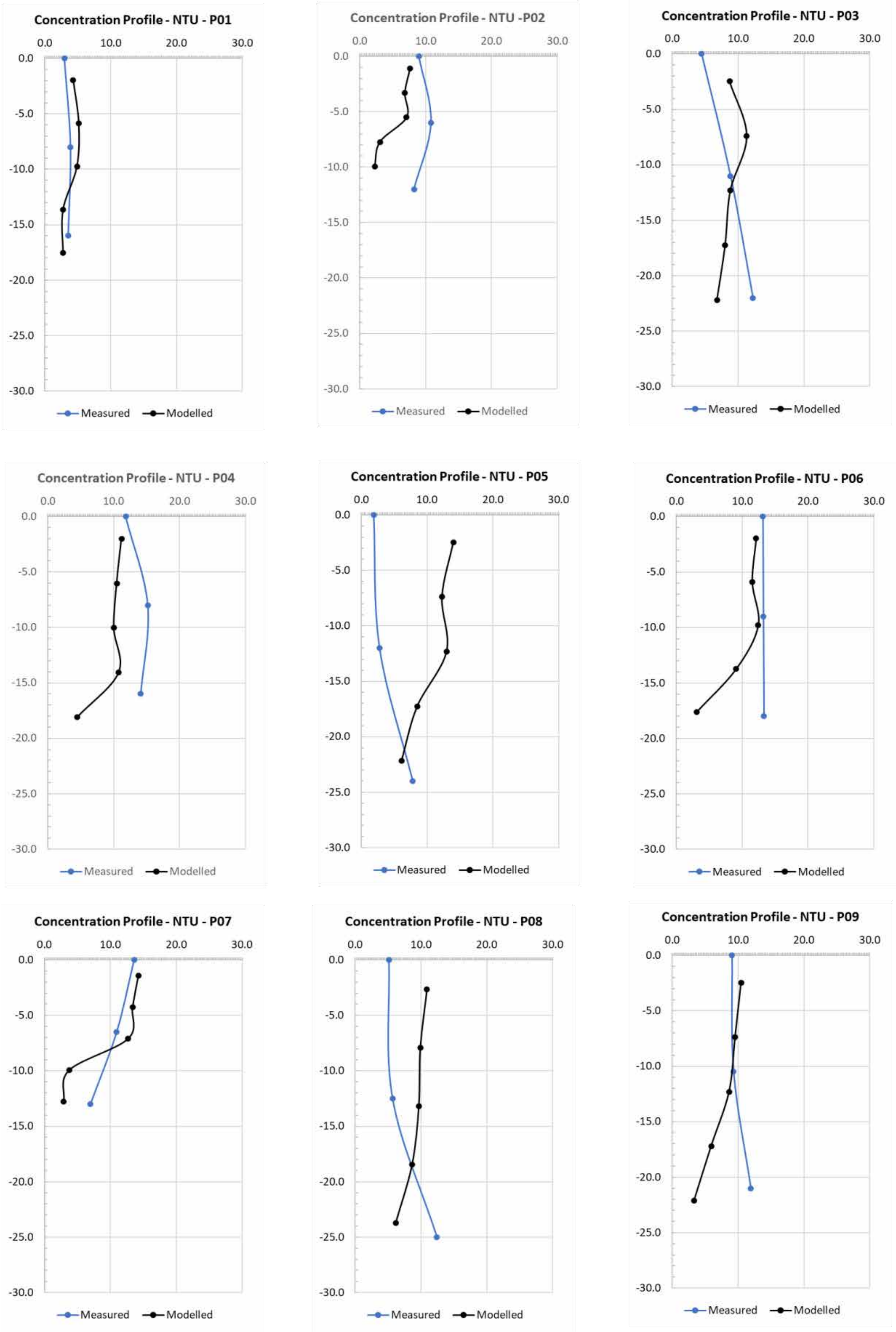
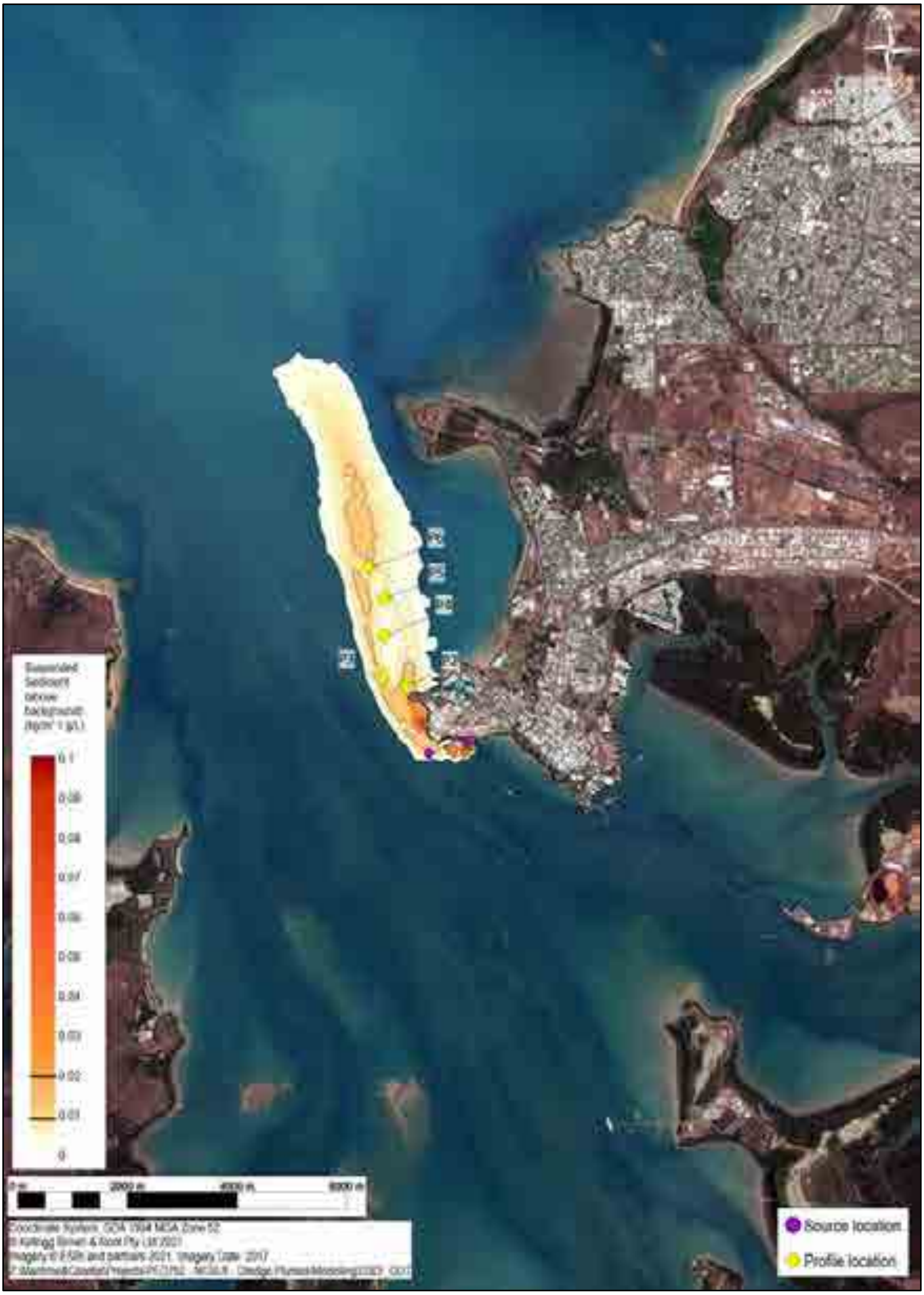


Figure 4.18 **Modelled turbidity profile comparisons to measurements taken 4/7/2006 – Flood Tide - vertical scale: depth [m]; horizontal scale NTU = TSS [mg/L]**



Coordinate System: GDA 1994 MGA Zone 52
© Kellogg Brown & Root Pty Ltd 2021
Imagery © Esri and partners 2021. Imagery Date: 2017

Figure 4.19 **Turbidity monitoring sites at 13/07/2006 (compared to modelled plume extent)**

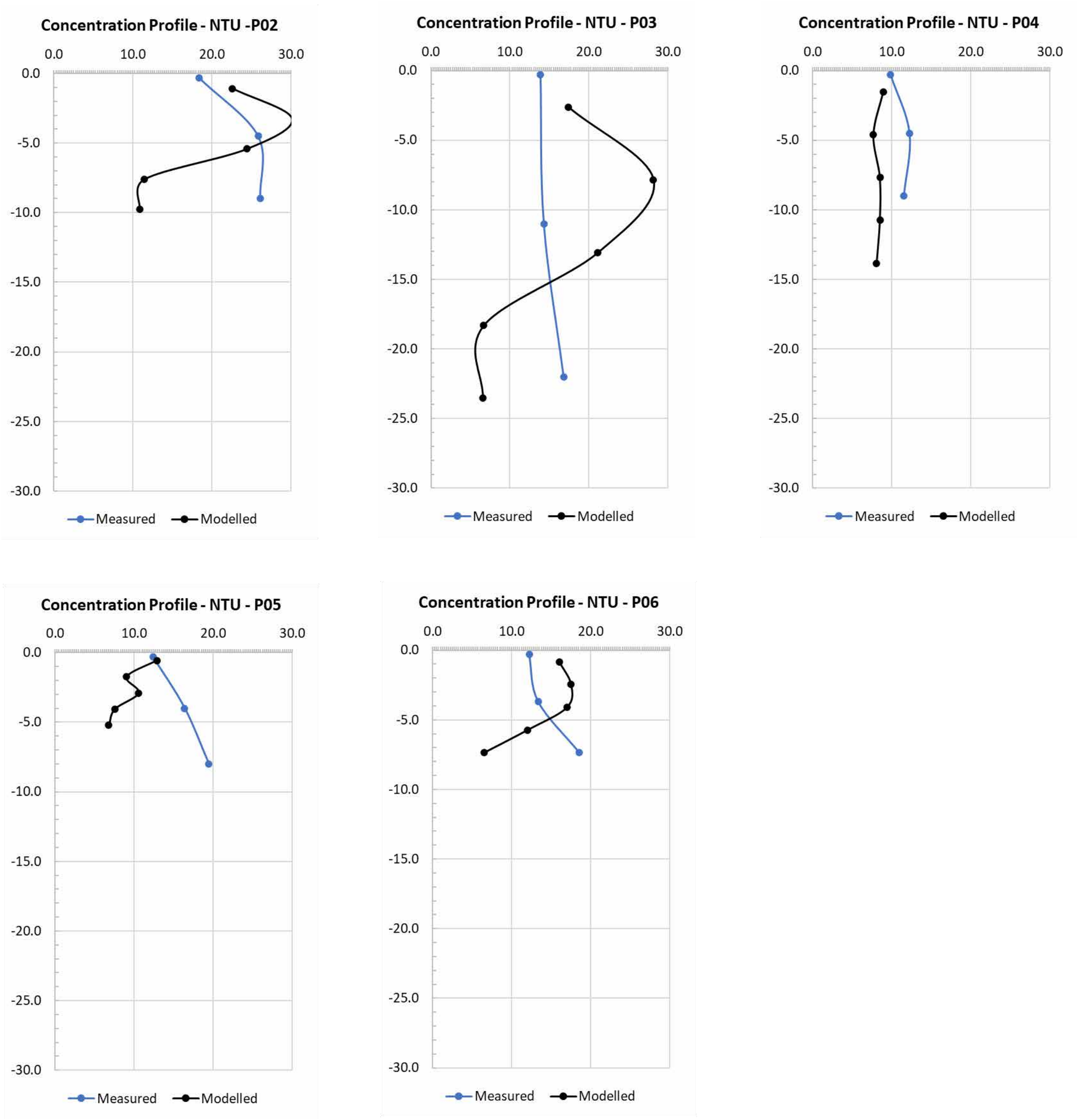


Figure 4.20 Vertical turbidity profile comparisons to measurements taken 13/7/2006 – Ebb tide - vertical scale: depth [m]; horizontal scale NTU = TSS [mg/L]

Limited available ‘Landsat’ satellite imagery was sourced within the dredge period for the 2006 and 2013 dredging campaigns. The images presented in Figure 4.21 and Figure 4.22 were selected as they were captured at a time when the dredge appeared to be operational for that day (confirmed by cross-referencing against field measurements during these two time periods). An extent of the visual dredge-related plume was inferred, aiming to exclude the extents of background turbidity to enable comparison to the model. The modelled plume from the same timestep was then overlaid.

While this methodology has some inherent limitations (i.e. uncertainty regarding dredge operation, inability to exactly match model time steps with the capture time and the lower resolution from the time, overall the comparison showed that the fundamental plume behaviours visually captured in the field were represented by the model. Both ebb tide and flood tide behaviours were able to be replicated, and with refinement and the higher resolution imagery now available, a reasonable comparison could be made for future campaigns.

Figure 4.21 Aerial imagery data capture – 26 September 2013

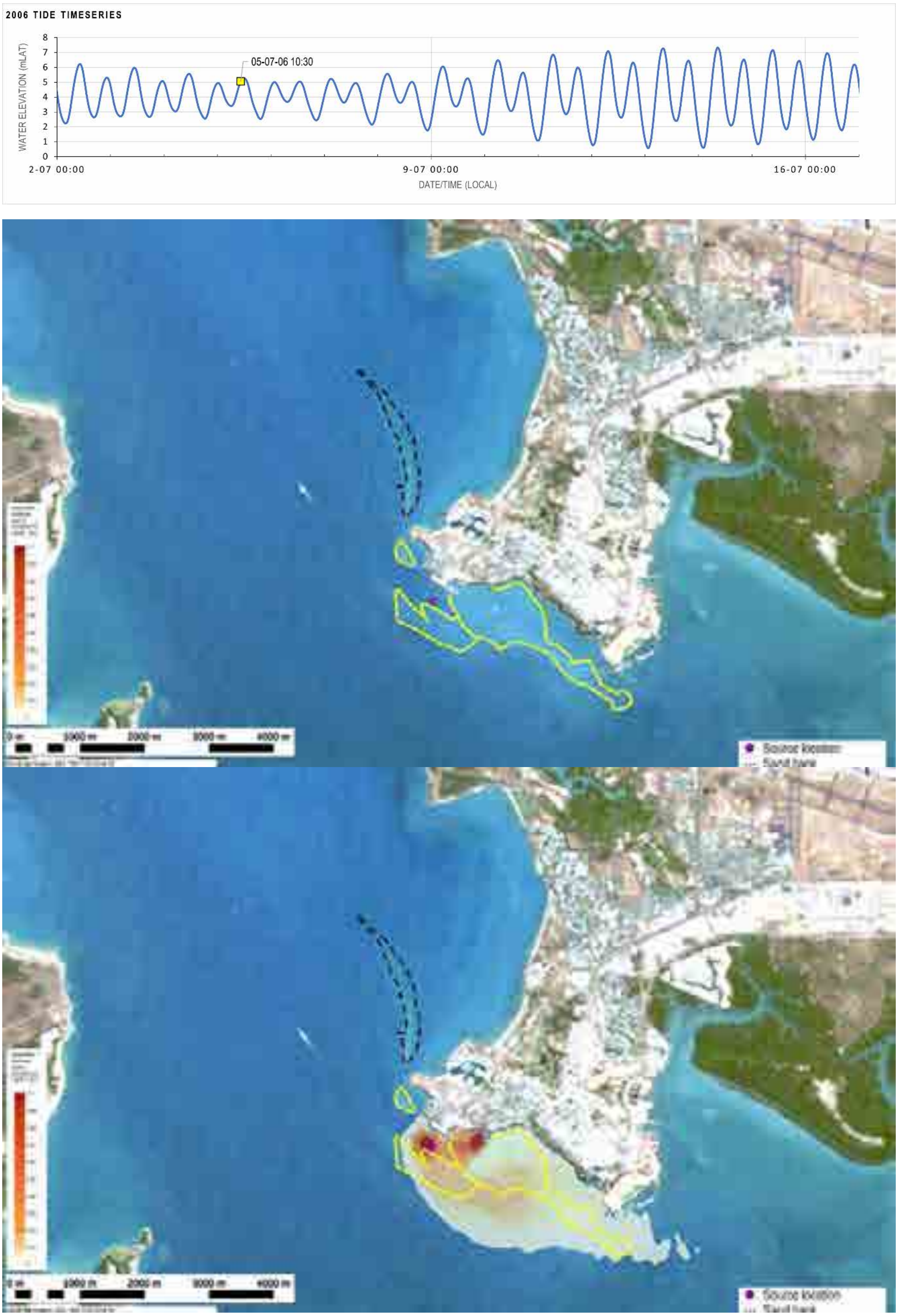


Figure 4.22 Aerial imagery data capture – 5 July 2006

5 Suspended Sediment Plume Dispersion

5.1 SEDIMENT PLUME PREDICTION RESULTS

5.1.1 Comparison to previous modelling predictions

This 3D modelling assessment for the SER focussed on the Cutter Suction Dredging (CSD) with nearshore discharge, given the much broader extent of the plume and deposition resulting mainly from the discharge activity. A full range of scenarios (discussed in Section 2.4.1 and presented in the Referral Report) was modelled in 2D, the results of which were used to establish the main scenario for further 3D modelling.

The dredge period was conservatively assessed for a tide only condition as it represents a worst-case scenario for plume dispersion locally at the site due to reduced mixing compared with scenarios that include wind (determined during the scenario-based modelling undertaken in *NCIS-5 – HMAS Coonawarra Dredging Modelling Report (Appendix F of the NCIS-5 – HMAS Coonawarra Referral Report*)).

The previous modelling also confirmed that plume behaviours were the same for the current NCIS-5 dredging and future eastern wharf dredging activities and as such, these latest results are applicable to the dredging of both extents.

5.1.2 Predicted instantaneous plume results

Figure 5.2 to Figure 5.5 show typical flood and ebb plume 'snapshots' for spring and neap tide conditions during the CSD discharge operations. The values shown represent a concentration above background. 'Snapshots' are instantaneous plots from the model at the specified time (with the output times provided in Figure 5.1). The outermost depth averaged suspended sediment concentration contour in these figures is 0.001 kg/m3 = 1.0 mg/L ≈ 1.0 NTU. This concentration would not be visible.

Figures in Appendix C are provided to show the initial 2D outcomes of the modelling (reported in the Referral Report), compared with the refined results from the 3D modelling. The outputs confirm that there are only minor differences from the results reported in the Referral Report.

These instantaneous plots show the extent of the plume running to the north and south-east of the site, aligned with the hydrodynamics. This observed behaviour is consistent with past measurements and previous modelling.

The 3D model was found to produce slightly less conservative predicted extents of the sediment plume compared with the 2D model. The model results are still considered conservative due to an underprediction of the mixing (and thus overprediction of concentration in upper layers of the water column) close to the source compared with past dredging measurements and previous 2D modelling. The 3D model is fit for purpose and has been used as an input to updated assessments in the SER Main Report.

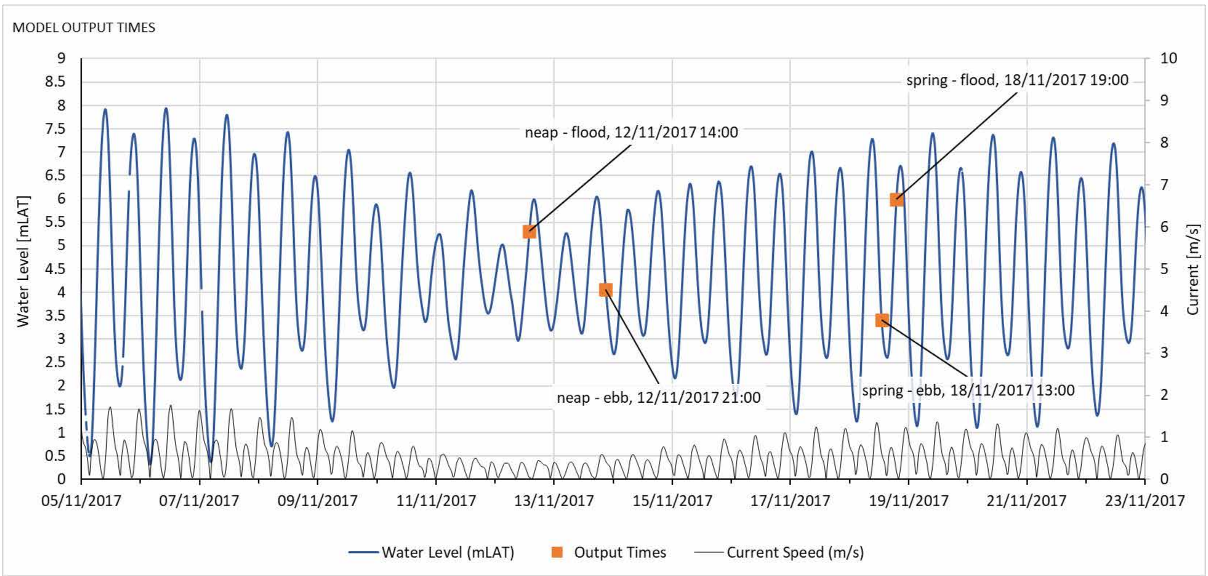


Figure 5.1 **Output timeseries – Instantaneous plume outputs**

As per previous predictions, the highest concentration of suspended sediment within the far-field extent of the plume was predicted during neap flood tide. The plume was found to disperse quicker on the faster ebb currents. The strongest ebb currents resulted in a narrow plume extent, propagating towards the north, and north-west. More plume dispersion is indicated on spring tides. This was also evident in the observations discussed in Section 4.3.

This behaviour was also observed in the timeseries reporting locations. In total six reporting locations were extracted from the model upstream and downstream of the discharge location, provided in Figure 5.7 to Figure 5.12. The reporting points are consistent with those in the Referral Report.

A depth-averaged and maximum turbidity is provided to show the variability (or lack thereof) in measurements throughout the water column. Maximum model indications at sites close to the discharge location were usually associated with the conservative representation of the discharge point, located in the second layer of the model (shown as a pronounced 3D profile in the model validations, described in Section 4.3.1).

Timeseries results are similar to the advice in the Referral Report. Results were episodic, aligning with the periods where the dredge was 'on' and 'off' in the model. The modelling indicates that dredging related turbidity reduced to close to Zero (i.e. background) each day once the dredge is no longer operational, indicating rapid dispersion and a fast recovery due to the strong tidal currents. Highest concentrations are noted at TS01, 02, and 06. No significant elevations were indicated at TS03 and TS04, or at TS06 during neap tide periods. Higher concentrations were observed at northern sites that fell within the narrow plume extent advected by the ebb tides. This was indicated by 'spikes' in the data, which quickly returned to lower concentrations or zero, especially during spring periods. By comparison, elevated model concentrations persisted for longer during the neap periods than during spring tides.

No significant elevated concentrations were noted in Fannie Bay (TS03 and TS04) which also aligned with previous findings.

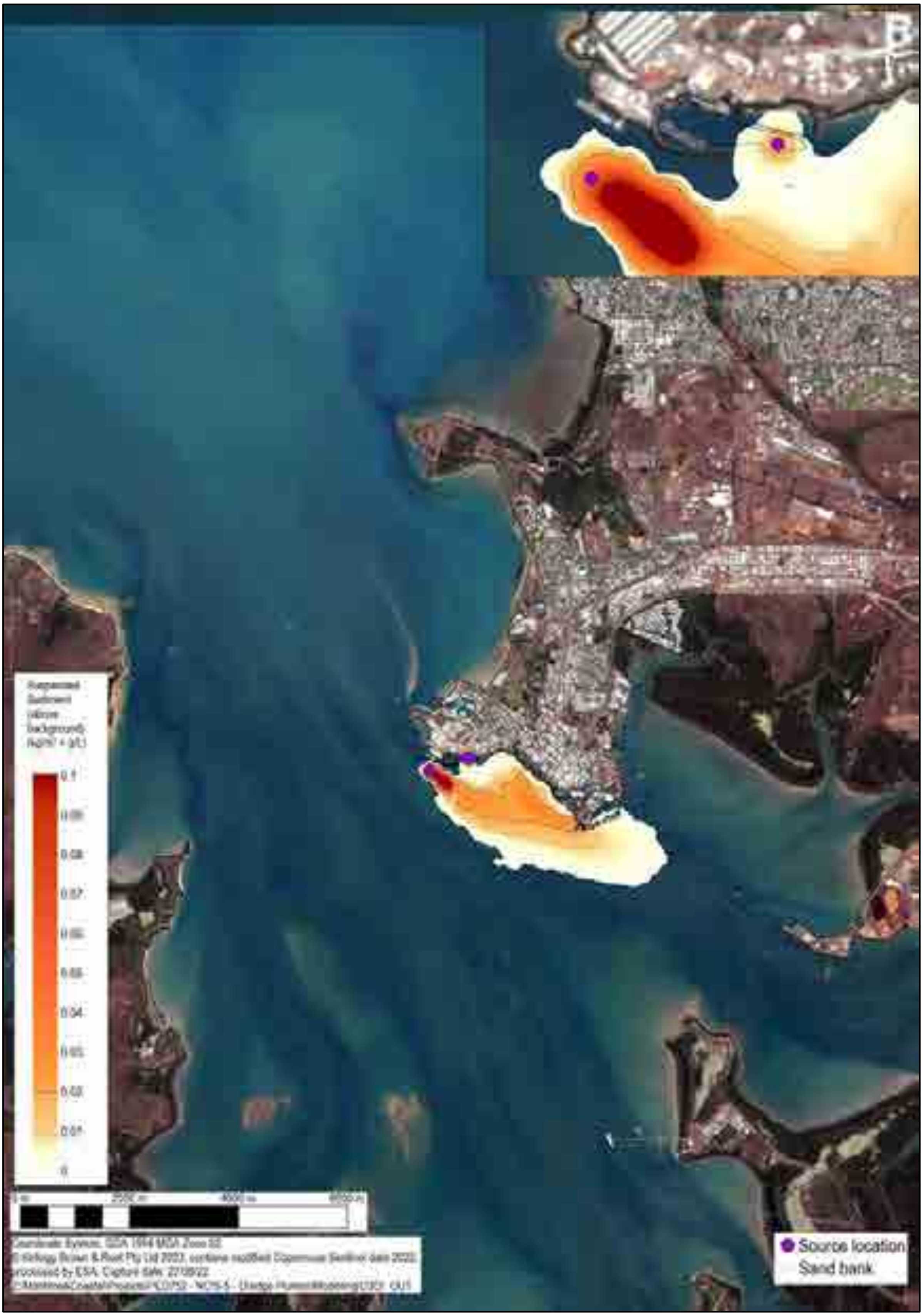


Figure 5.2 **Suspended sediment concentrations above background - Instantaneous result at 12/11/2017 14:00 – Flood tide, neap condition**

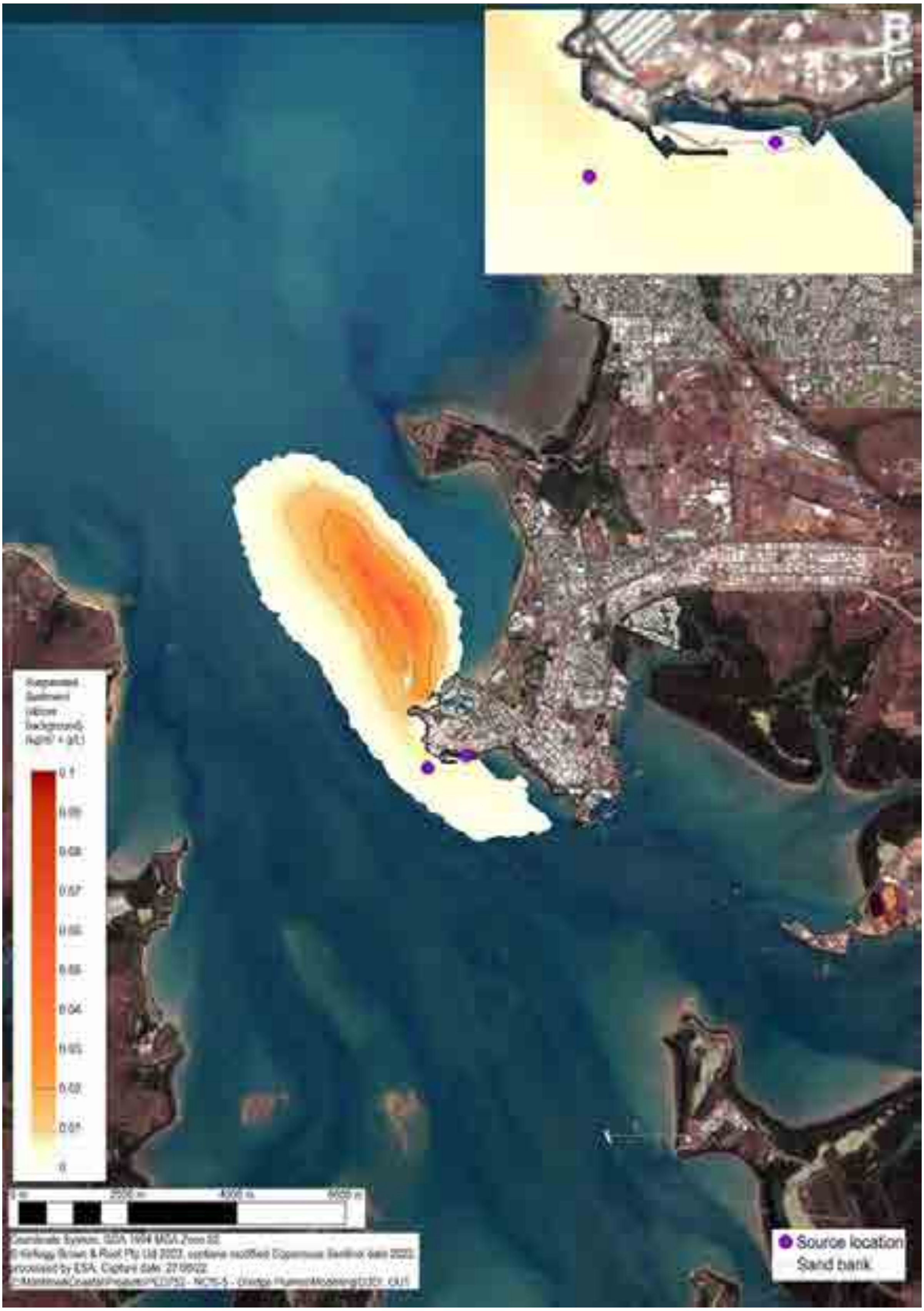


Figure 5.3 Suspended sediment concentrations above background - Instantaneous result at 12/11/2017 21:00 – Ebb tide, neap condition

Figure 5.4 Suspended sediment concentrations above background - Instantaneous result at 18/11/2017 13:00 – Ebb tide, spring condition

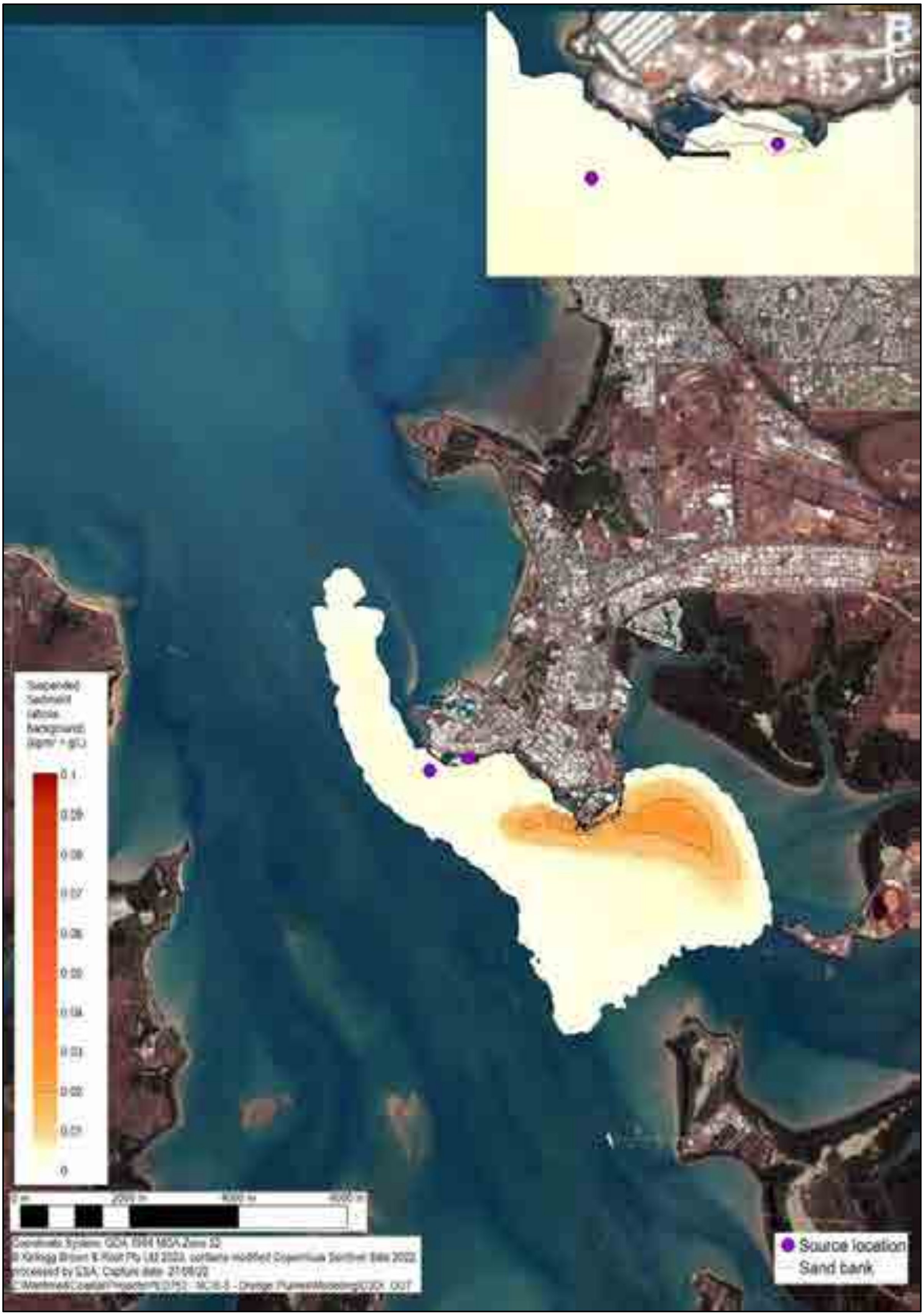


Figure 5.5 Suspended sediment concentrations above background - Instantaneous result at 18/11/2017 19:00 – Flood tide, spring condition

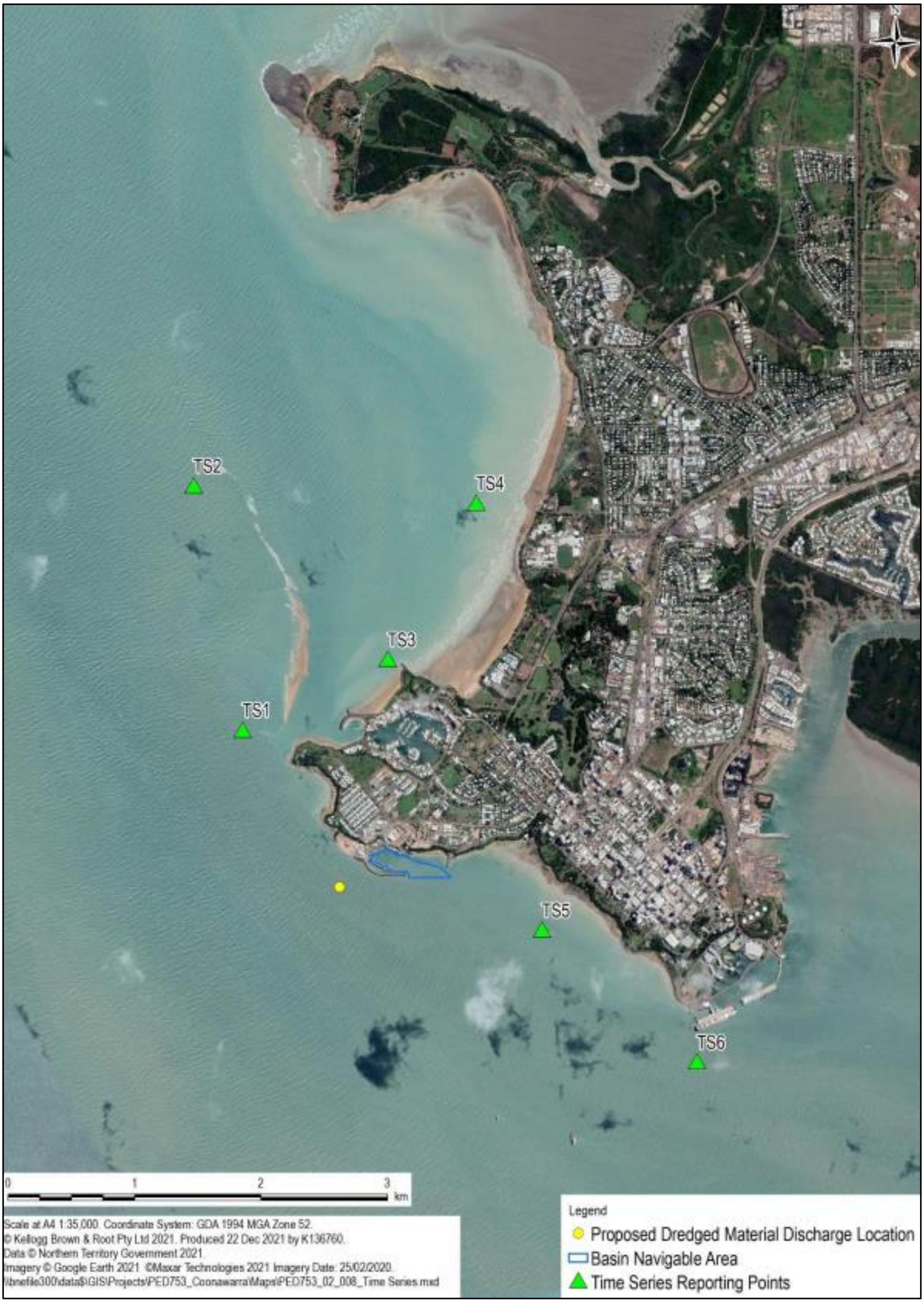


Figure 5.6 **Timeseries - modelled reporting points**

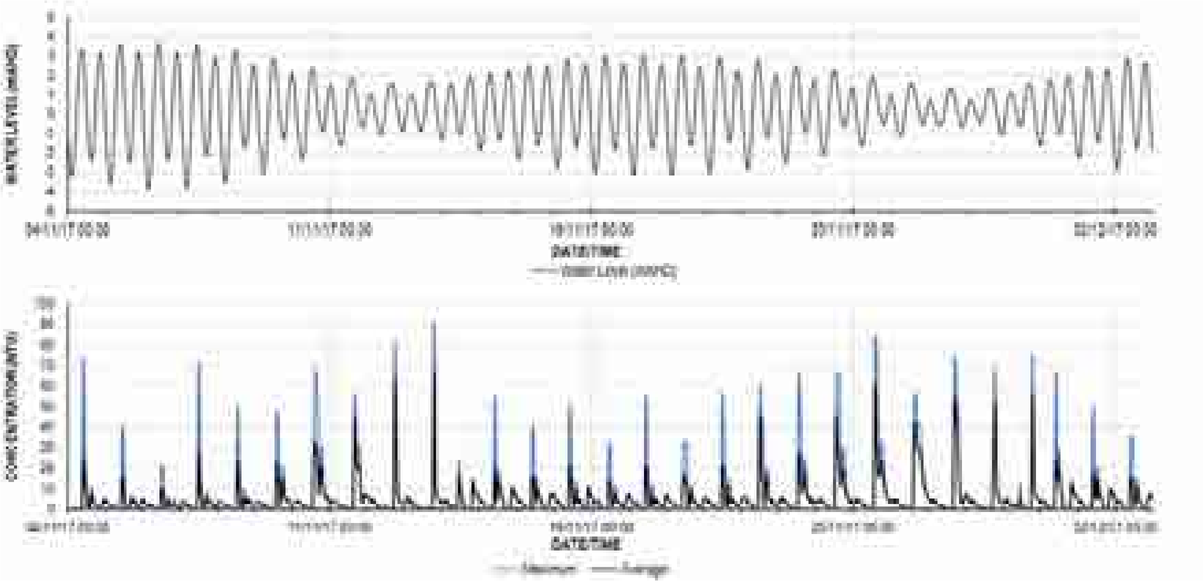


Figure 5.7 Timeseries output location TS01 – Suspended sediment concentration above background

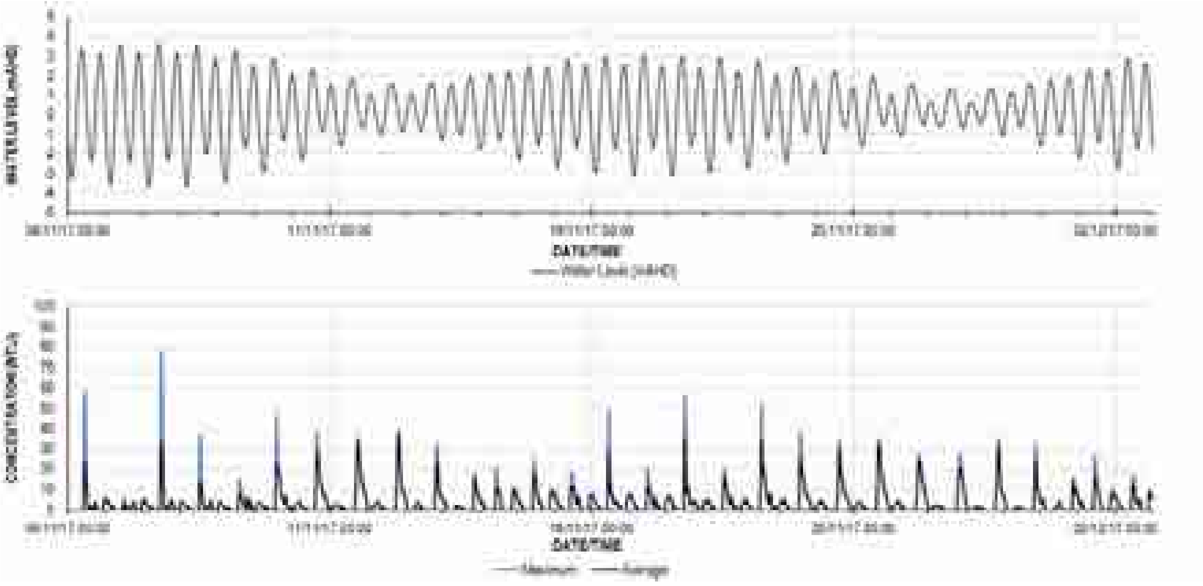


Figure 5.8 Timeseries output location TS02 – Suspended sediment concentration above background

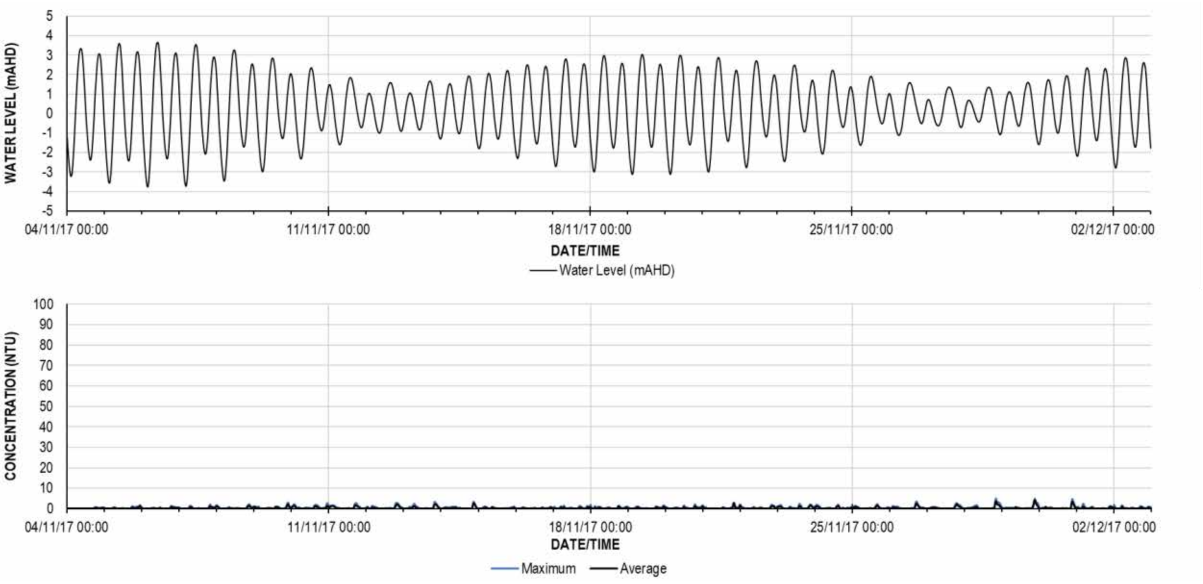


Figure 5.9 Timeseries output location TS03 – Suspended sediment concentration above background

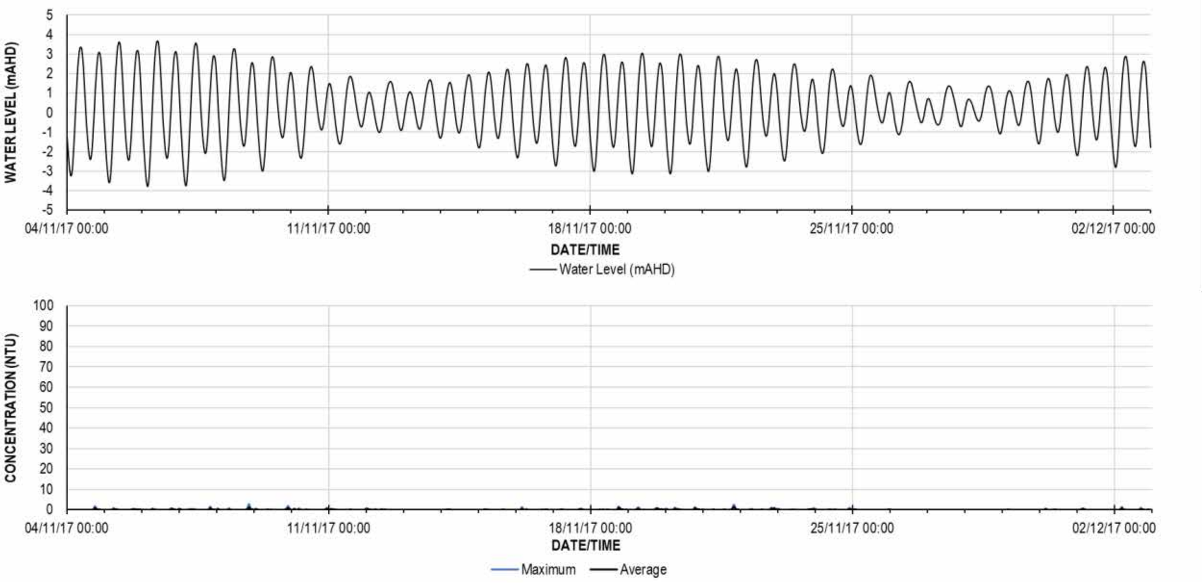


Figure 5.10 Timeseries output location TS04 – Suspended sediment concentration above background

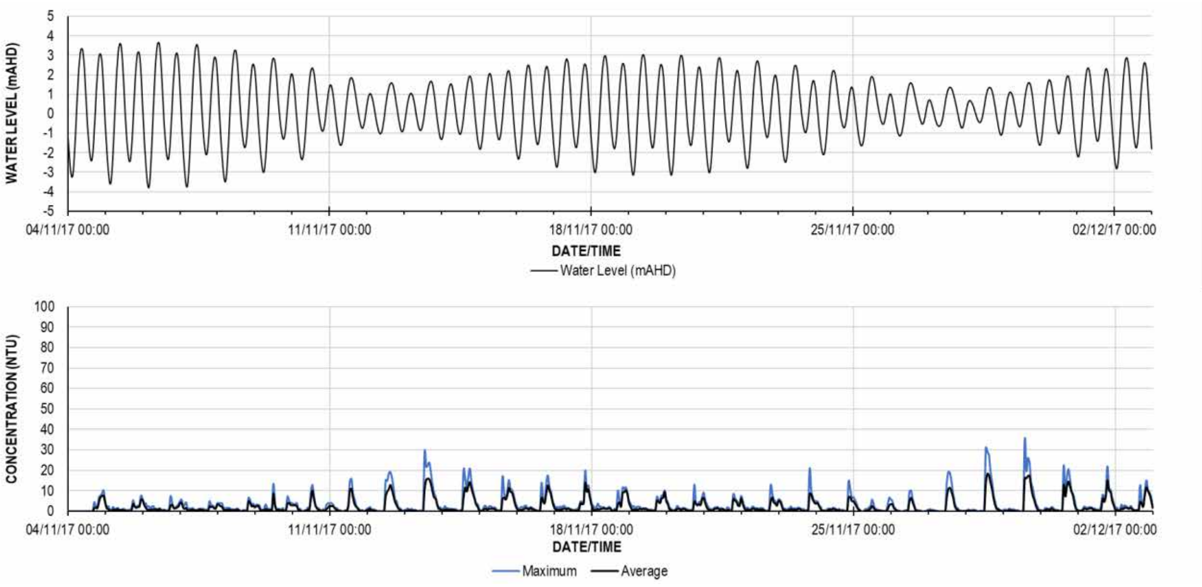


Figure 5.11 Timeseries output location TS05 – Suspended sediment concentration above background

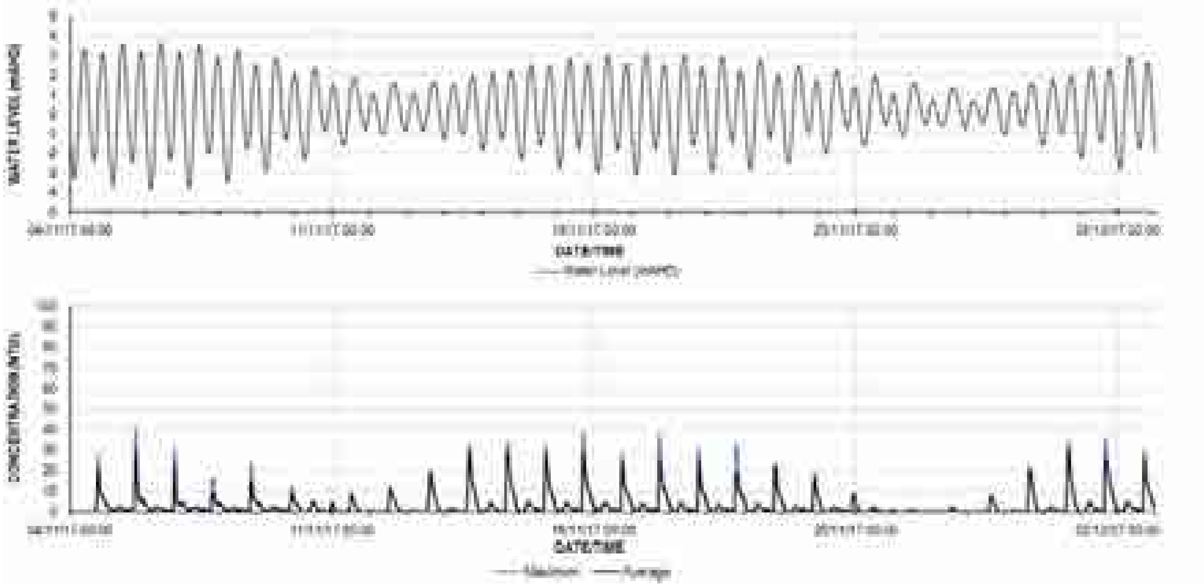


Figure 5.12 Timeseries output location TS06 – Suspended sediment concentration above background

5.1.3 Predicted percentile results

Frequency distributions of model depth averaged suspended sediment concentrations are provided in Figure 5.13 and Figure 5.14 as 90th and 95th percentile extents (i.e., 10% and 5% exceedances respectively). Values shown are the contribution of the dredging only and exclude background (which is added separately for assessments in the SER).

The plume shapes show similar patterns in spatial distribution but with a slightly larger extent than in the snapshots because they represent a probabilistic extent over the whole 30-day simulation period.

Elevated suspended sediment concentrations (e.g., >0.05 kg/m^3 or 50 NTU above background) are indicated but only close to the discharge location. The 0.02 kg/m^3 contour (20 NTU above background) is shown close to the discharge point and extends to the north-west and south-east approximately 1 to 1.5 km, aligning with the predominant current directions. The 0.01 kg/m^3 contour (10 NTU above background) extends further but remains less than 5 km to the north-west and south-east.

Consistent with the previous modelling for the Referral Report, the area impacted by an elevated suspended sediment concentration as a result of proposed Cutter Suction Dredging (CSD) works is contained within a narrow section extending approximately 5 km to the north-west and south-east of the site (to a 10 NTU or 0.01 kg/m3 concentration above background). The suspended sediment plume is not predicted to affect areas such as Fannie Bay, with the strong tidal currents directing the plumes in a consistent flood and ebb direction, due to the strong bi-directionality of the hydrodynamics. Some low-level concentrations are noted across the northern sand bank (approx. 5 to 10 km to the north of the site), but the concentrations reported are very low (in the order of 0.001 kg/m^3 = 1NTU) fall well within the natural background variability in concentration.

Figure 5.13 90th Percentile suspended sediment concentrations above background - CSD dredging with nearshore discharge - NCIS-5 current works

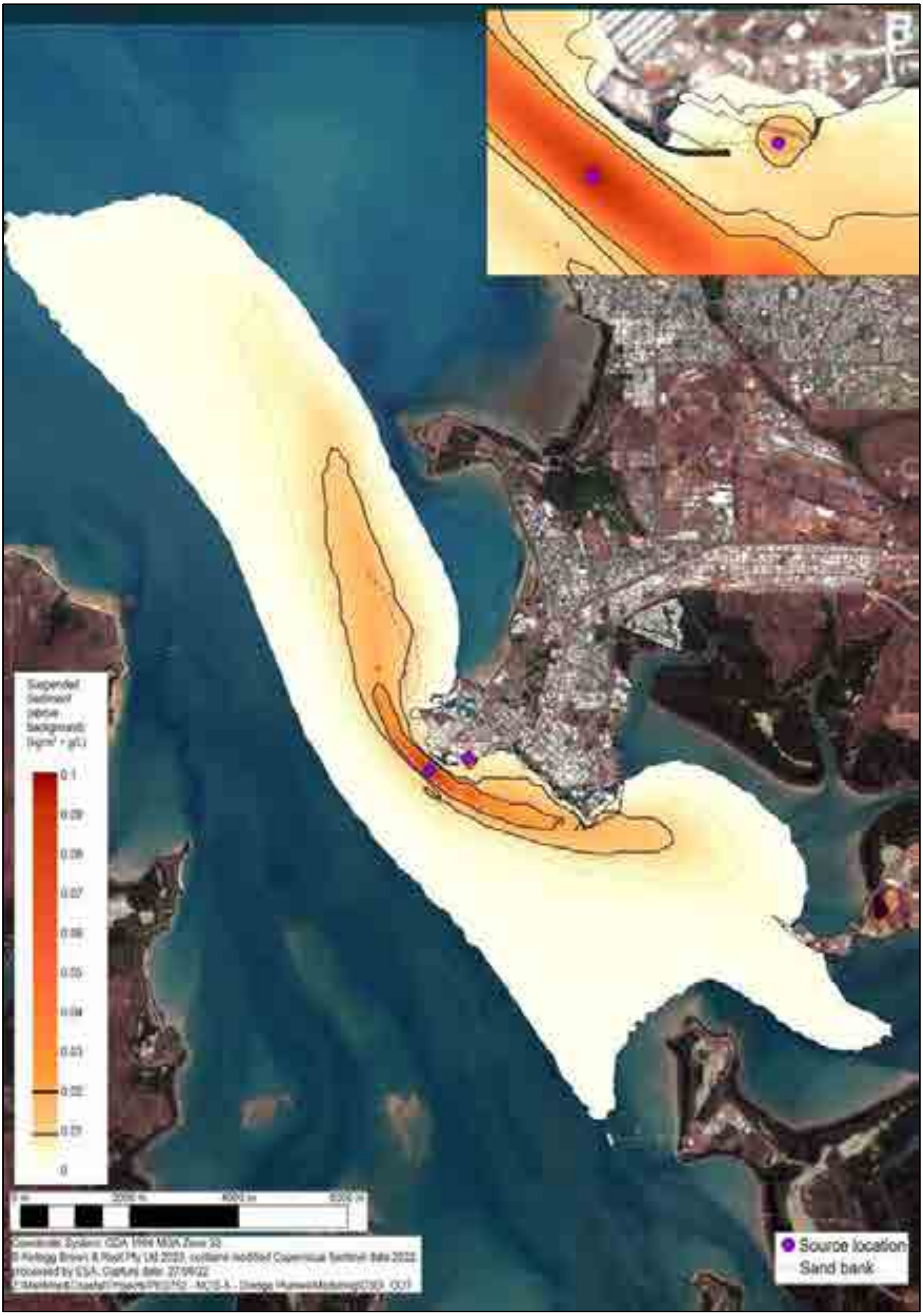


Figure 5.14 95th Percentile suspended sediment concentrations above background - CSD dredging with nearshore discharge - NCIS-5 current works

6 Sediment Deposition and Sediment Fate

6.1 MODEL BACKGROUND

Modelling of deposition has been separated into two assessments, each assessing different elements of impact:

Coarse deposition

Coarse deposition modelling predicts the initial settling of coarse material close to the discharge location. Larger sediment fractions, such as the weathered phyllite and schist material (sand and gravels), fragmented rock and cohesive clay fragments or 'balls' will fall quickly out of suspension. Areas of impact will therefore be within the near and mid-field extents (i.e. close to the discharge location), contributing to an initial 'blanketing' of this area. The distribution and thickness of this deposition is therefore assessed.

Initial deposition of coarse material is related to the type of material, the particle size and the settling velocity (described in Section 2.4.5).

Fine material deposition

There is a high natural baseline suspended sediment load within Darwin Harbour as a result of continual re-suspension and movement of fine marine sediments. The movement of these sediments (as well as sediments introduced during dredging) is highly dependent on the settling rate (in Section 2.5.2) and the bed shear stresses. Material will erode, re-suspend and deposit within areas where the critical threshold limits for shear stress at the bed are met. The bed shear stress depends on the water depth and current velocities.

Fine material from the dredging will continually settle and re-suspend as it is dispersed within Darwin Harbour, eventually becoming part of the natural continual circulation of sediments. The fate of these sediments (i.e. the location where it settles and is not resuspended) will be within 'quiet' areas with low bed stresses, such as foreshores, sheltered harbours, embayments and mangrove areas. The location, extent and thickness of this sediment following the dredging (i.e. after one month of continual dredging) has been assessed.

Critical erosion and deposition shear stress thresholds for fine sediments are presented in Table 6.1, derived using the widely accepted and published Parthenaides and Krone method.

Table 6.1 Input critical erosion and deposition stresses

Parameter	Value	Source
Critical shear stress for deposition	0.1 N/m^3	Parthenaides and Krone
Critical shear stress for erosion	0.2 N/m^3	Parthenaides and Krone

These critical threshold limits are applied as inputs to the fine sediment deposition and fate models to represent erosion and deposition processes.

6.2 COARSE DEPOSITION

Coarse deposition was modelled in Delft3D-PART to review the initial impact area anticipated as a result of the release of coarse-grained sediments from the discharge location. The modelling work confirmed that coarse-grained sediments quickly settle out of suspension, falling to the seabed within a short distance of the release point.

The source of this sediment is predominantly from the targeting of harder and transitional residual material (referred to as 'hard dredging').

Previous work presented in *NCIS-5 – HMAS Coonawarra Dredging Modelling Report (Appendix F of the NCIS-5 – HMAS Coonawarra Referral Report)* describes the process of deposition and estimated extents for coarse-grained gravel materials (generally grain sizes of 1 – 20mm). This work has been further expanded to capture a broader range of course material, including coarse gravel and sands which align with the weathered mica-shist material encountered within boreholes collected within the dredge area. Heavier materials, such as fragmented rock and 'clay balls' (consolidated clays as a result of dredging) would fall closest to the discharge location, within this extent. Some evidence of this material residing within the dredge areas from past campaigns was also noted when carrying out recent Benthic Habitat surveys.

The zone of deposition and thickness are presented in Figure 6.1, capturing the extents of the initial deposition of coarse sands and gravels. There is an approximately 500m extent of deposition where the coarse sand and gravels are deposited, aligning with the outcomes of preliminary estimates in the Referral Report.

The thicknesses represent an average thickness (in reality there would be high and low spots within the disposal area initially), however given the high currents and bed stresses at the site, material is likely to re-distribute within the disposal area as shown.

The anticipated quantity of material that may initially deposit close to the discharge area is approximately 8,100 m3 of coarse sands and gravels. This estimate is based on assumptions on the dredgability of material and the presence of hard material, inferred from past campaigns (Discussed in the Referral Report).

There is also the possibility that some, or all, of the suspected harder material could be removed by the CSD and discharged, and that if this occurred production rate (and therefore solids concentration in the discharge would be expected to be lower than assumed) while dredging in that material. Should this occur, an additional approximately 6,000 m3 of coarse sands and gravels designated as 'hard dredging' could also reside within this area, increasing the upper limit of predicted thicknesses from approximately 40 mm to 80 mm which is unlikely to contribute to any additional impacts in this area.

6.3 FINE SEDIMENT FATE

Fine sediment fate was modelled within Delft3D-FLOW as a morphological model as it is better able to capture the continual erosion and deposition of fine sediments (compared with PART modelling described above, which captures plume dispersion and initial depositions). Fine sediment fate was modelled for the same one-month period as the plume dispersion, representing a full dredging and discharging volume (albeit a slightly conservative volume of fines, as discussed in Section 2.5). Figure 6.2 shows the predicted areas of settlement of the fine sediments at the end of the one-month dredge period.

These areas are comparable to zones of low bed stress indicated in the modelling, as predicted in the Referral Report.

Areas where the bed shear stress is less than 0.1 N/m2 (dark blue in Figure) will result in deposition of material over the longer term. The areas of highest deposition align with areas of low bed stresses (for example areas where bed stresses are continually below the critical thresholds for deposition).

Modelling also confirms initial predictions in the Referral Report and identified in the conceptual model development (Section 2.2.2.) which predicted that it is unlikely that a significant proportion of released dredge sediments will remain close to the discharge location, given that the bed stresses in this area are very high.

Figure 6.1 Zones of coarse deposition and thickness (mm)

6.3.1 Short-term deposition

Some short-term temporary settling of fine material may occur within the extents of the plume during the turn of the tide where currents are lowest. The extents would be contained mainly within the Zone of Impact area (areas approximated by the ~20 mg/L contour in Section 5.1.3 and discussed in further detail in the SER). Given the very low settling velocities of the material, this temporary deposition would not be significant and will quickly be re-suspended and transported away from the site with the tides.

Bed stresses close to the discharge location are consistently high, exceeding critical erosion stresses (Table 6.1) by orders of magnitude (on a daily basis during spring tides especially). This leads to a continual erosion (resuspension) of the discharged material.

Some temporary settling of material may occur during neap tide periods (expected to only remain for a period of 3 to 4 days maximum) during the lower currents, and hence lower bed stresses exceed the thresholds less frequently. However, accumulations are quickly eroded away at the onset of the spring tides, reaching close to zero (less than 0.5 mm thickness) at the discharge location.

6.3.2 Longer-term deposition areas (Fate)

As shown in Figure 6.3, bed stresses at the margins of the intertidal area are very low and therefore promote the settlement of material. As a result, fine materials (marine sediments) generally fall out of suspension around small pocket beaches, on mangrove fringes and in low-flow areas (in river reaches and enclosed basins). Modelling of the fate of material supports this finding.

Model predictions indicate that there will be distribution of a thin layer of fines (less than 3 mm) attributed to the dredging settling in the low energy environments of Cullen Bay. Thin layers of fines are also predicted in the embayment to the east of the *HMAS Coonawarra* basin (less than 5 mm) and in artificially deepened areas at Fort Hill (less than 3 mm). The dispersion and settlement of fine marine sediments in nearshore areas and would be undetectable from the distribution of natural sediments that continually circulate via the same resuspension and deposition processes.

Figure 6.2 Zones of Fine Sediment Fate – Deposition thickness (mm) following dredging

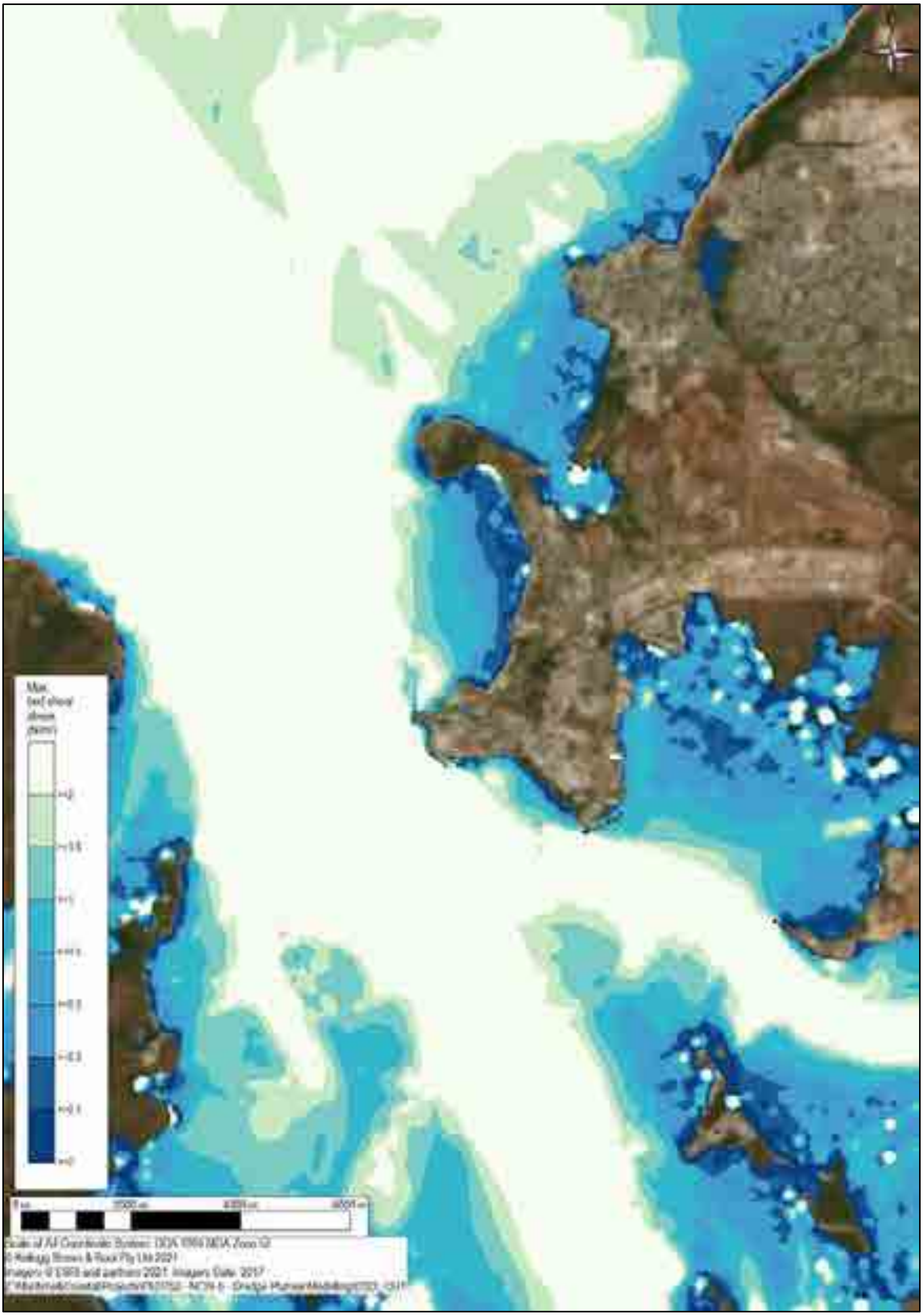


Figure 6.3 Maximum bed shear stress in Darwin Harbour (N/m²)

7 Conclusions

This report has been provided as supplementary information for the proposed NCIS-5 HMAS Coonawarra dredging discussed in the *NCIS-5 – HMAS Coonawarra Dredging Modelling Report* – Appendix F of *NCIS-5 – HMAS Coonawarra - Dredging and Dredged Material Management - Referral Report* submitted by KBR in 2022.

The outcomes of the supplementary modelling have been documented in response to the Northern Territory Environment Protection Authority (NT EPA) '*Table of additional information to be included in Supplementary Environmental Report'.* The following has been addressed in line with the request:

- Further justification to support the use of a 2D hydrodynamic model for the prediction of dredge plume impacts was presented. Nonetheless, a 3D model was still developed to assess the main scenario
- Additional discussion on the application of WAMSI Guidance including:
  - Presentation of additional field observations, including monitoring data from previous dredging campaigns and baseline (pre-dredge) data (consistent with Section 3 of the WAMSI Guideline)
  - Review and summary of conceptual understanding of key physical processes (hydrodynamics and sediment transport) was presented for the site (consistent with Section 4 of the WAMSI Guideline)
  - Review and summary of source terms adopted in the 2D and 3D modelling against published guidance (consistent with Section 5 of WAMSI Guideline)
  - Additional 3D modelling was carried out to supplement previous 2D scenario-based modelling, confirming that both modelling approaches are fit-for-purpose for the prediction of plume behaviours and the associated impact assessments
- Discussion of the composition of TSS (Total Suspended Sediments) was provided and used for input into additional sediment deposition modelling.

The performance of the dredge modelling has been improved through the integration of field data collected during the 2006 and 2013 dredging campaigns. Usefully, these previous dredge campaigns are comparable to the dredge activities currently proposed for the 'NCIS-5' and 'Future Eastern Wharf' works. Validations to both hydrodynamics and suspended sediment vertical profiles confirmed that the model was able to adequately simulate the complex hydrodynamic and sediment transport behaviours observed at the site. There is improved confidence that the model provides realistic plume predictions (albeit slightly conservative) for input into further assessments (see the SER).

Additionally, the assumptions regarding the dredge types, size and operation made in preparing the Referral documentation, were confirmed with recent Contractor advice thus providing greater confidence in the modelling reported in KBR 2020 and the associated impact assessment.

The 2D vertically averaged model was refined during the SER process to represent 3-dimensional effects to provide granularity. This further 3D modelling work has confirmed that there are no significant changes from the previous reported 2D modelling indications, and as such the previous scenario-based 2D modelling work remains relevant.

The 2D modelling undertaken for the Referral can be relied upon to accurately predict dredge plume behaviour, however the 3D model refinements now provide more granularity for undertaking future assessments.

The modelling presented herein focussed on the dredging and sediment disposal via a cutter suction dredge (CSD) method for the NCIS-5 current works development. Effects of wind and other scenarios presented in the Referral Report were considered, but and no-wind scenario was found to provide the most conservative estimate of the plume extent in the scenario-based modelling in previous studies and was therefore adopted for additional assessment of the dredging impacts (discussed in the SER). The validations and outcomes herein are relevant to these other scenarios.

The modelling confirms that the area impacted by elevated suspended sediment concentrations is governed by the tidal currents, with a pronounced flood and ebb tide directionality propagating the plume within a narrow width towards the north and south-east of the site. This behaviour was also observed in the 2006 and 2013 dredging campaigns and aligns with the documentation to date reported in the Referral document. Model predictions indicate no significant impacts to Fannie Bay would be expected.

Further assessment of settled sediment deposition was also undertaken to investigate two main impact mechanisms:

- Coarse sediment deposition –The distribution and thickness of coarse plume material on the bed, close to the proposed discharge location.
- Fine material deposition – The fate of fine sediments and the thickness of deposition in distant sheltered areas, such as foreshores and mangrove areas.

The modelled coarse sediment deposition of material was found to be confined predominantly to approximately 500 m extent, consistent with the previous advice in the Referral Report. Modelled deposition thicknesses were in the order of 40 – 80 mm.

Fine sediment accretions after a 1-month dredge period (following the discharge of approx. 102,000 m3 of material), resulted in deposition of fine sediment as a result of the dredging along the nearshore area east of HMAS Coonawarra, with predicted thickness of generally less than 3 mm and up to 8 mm in some locations closer to the base. This is unlikely to be detectable, given the normal range of sediment deposition and resuspensions in this area.

8 References

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KBR (2022b) *NCIS-5 – HMAS Coonawarra - Dredging and Dredged Material Management - Referral Report*

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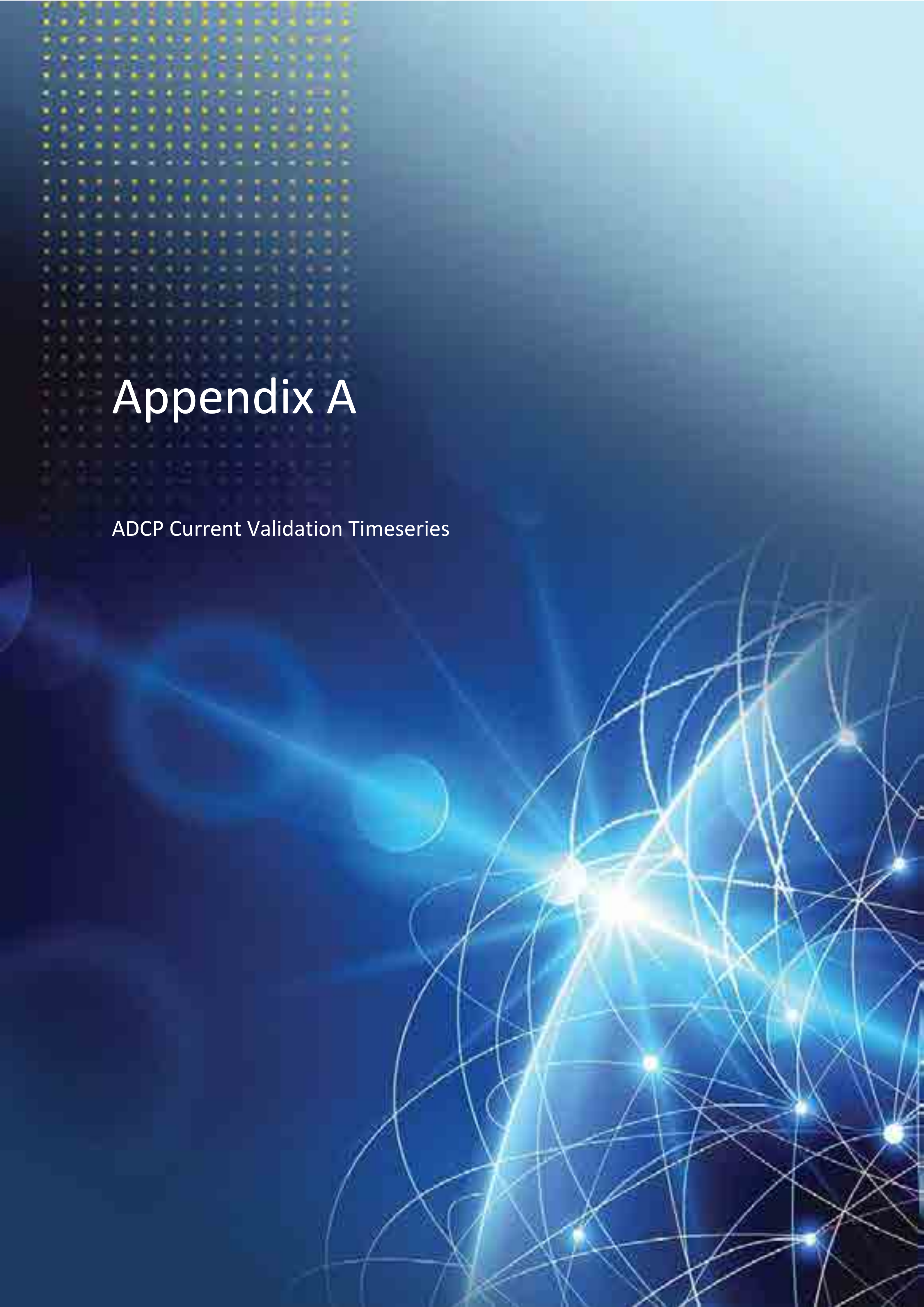
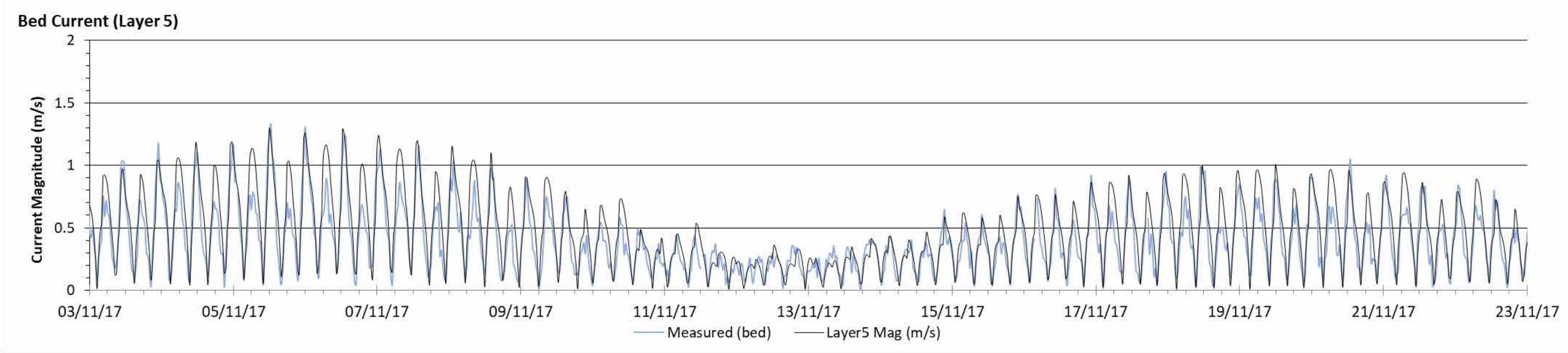


Appendix A

ADCP Current Validation Timeseries

Figure A.1 Data validation sites – ADCP Data


Bed Current (Layer 5)

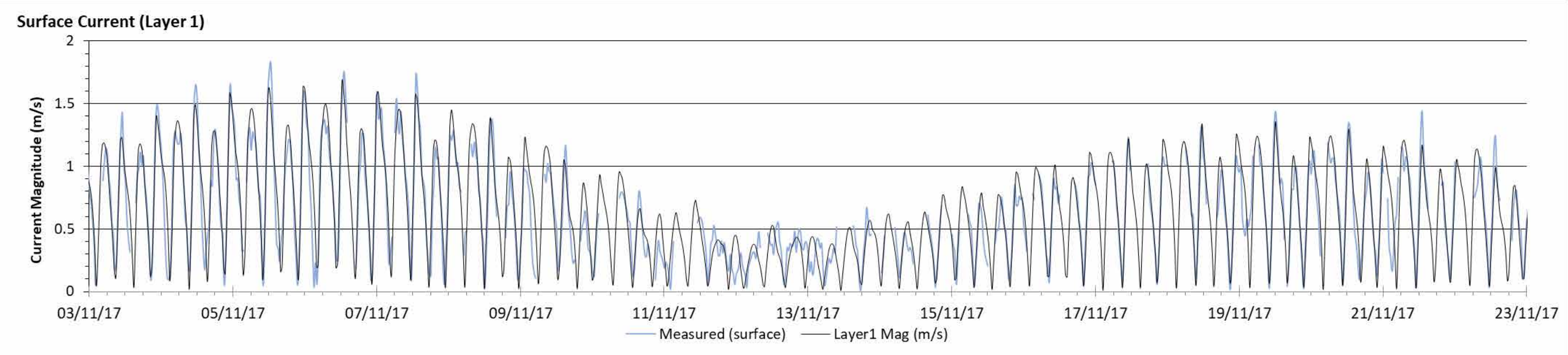
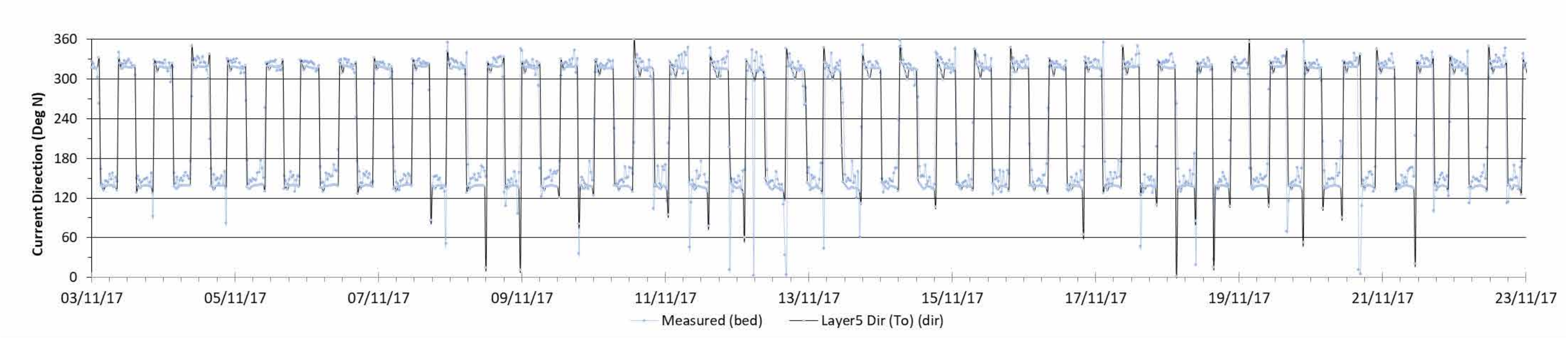

Surface Current (Layer 1)

Figure A.2 ‘Bed 1’ ADCP Output Location – Current Magnitude (m/s) – Surface and Bed layer comparisons – 3D Modelled vs Measured



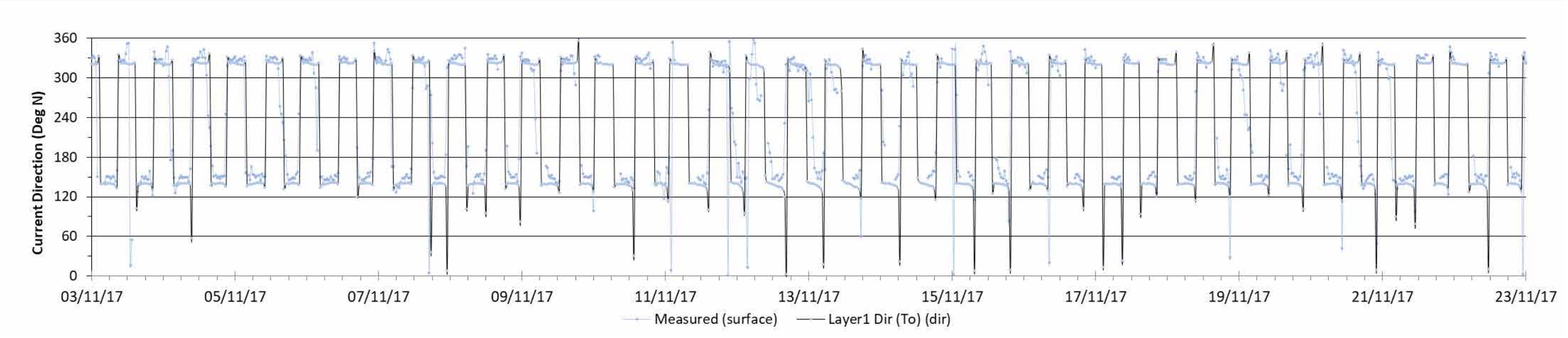


Figure A.3 ‘Bed 1’ ADCP Output Location – Current Direction (deg. N) – Surface and Bed layer comparisons – 3D Modelled vs Measured

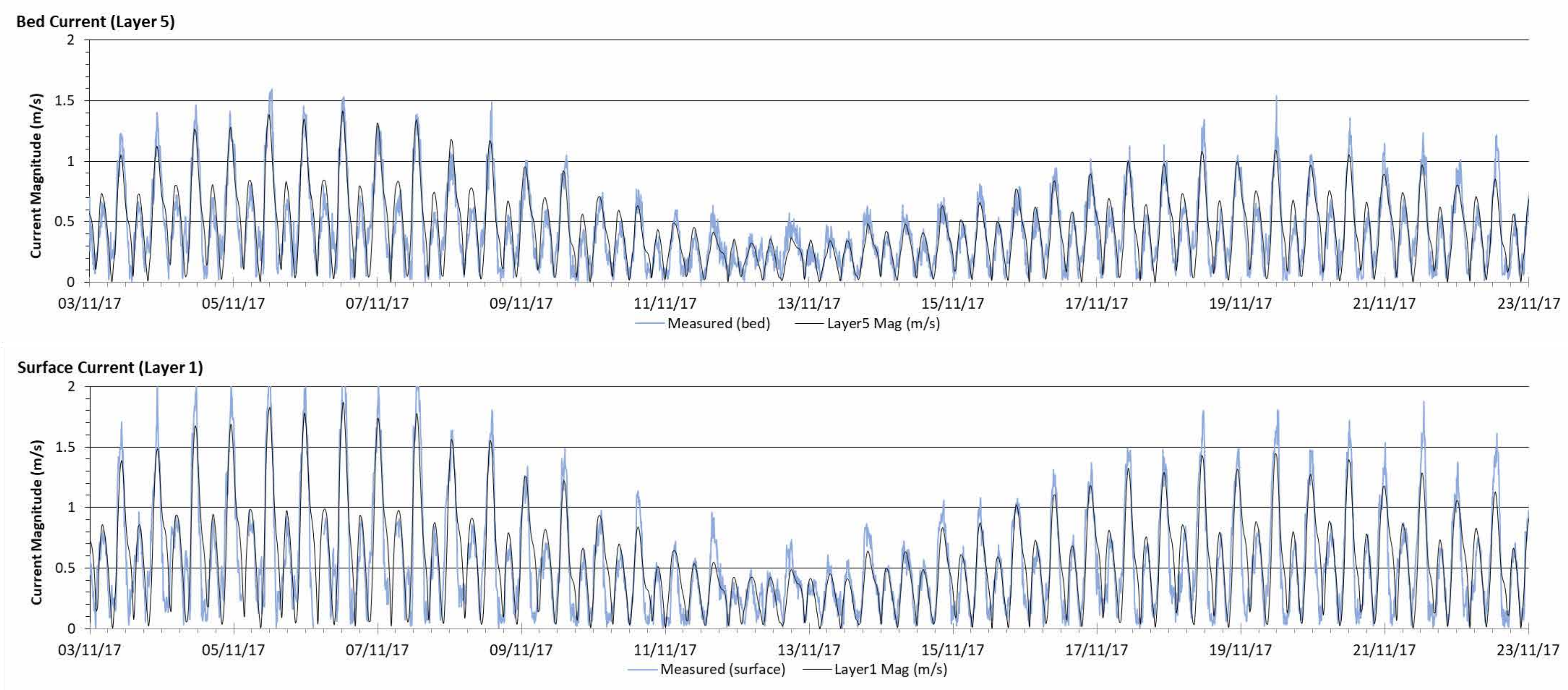


Figure A.4 ‘Bed 2’ ADCP Output Location – Current Magnitude (m/s) – Surface and Bed layer comparisons – 3D Modelled vs Measured

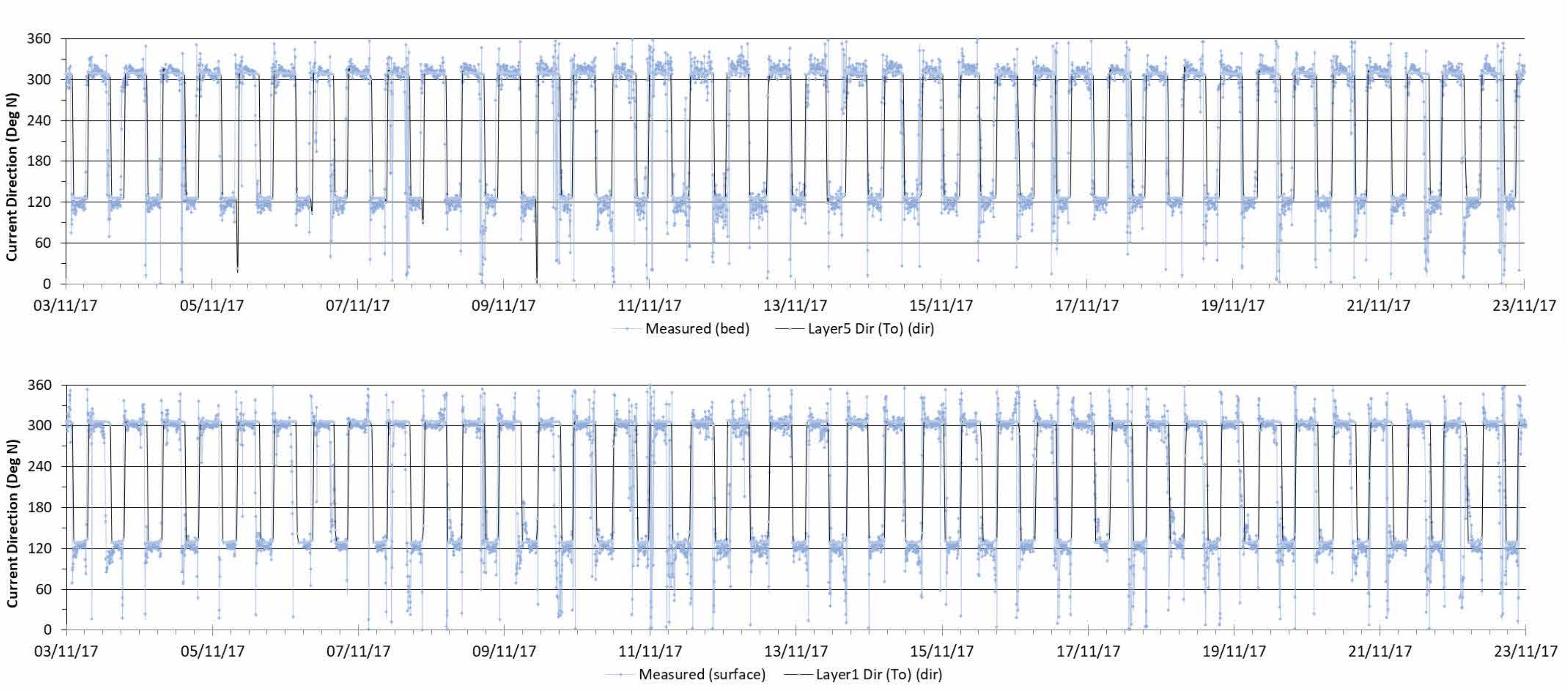
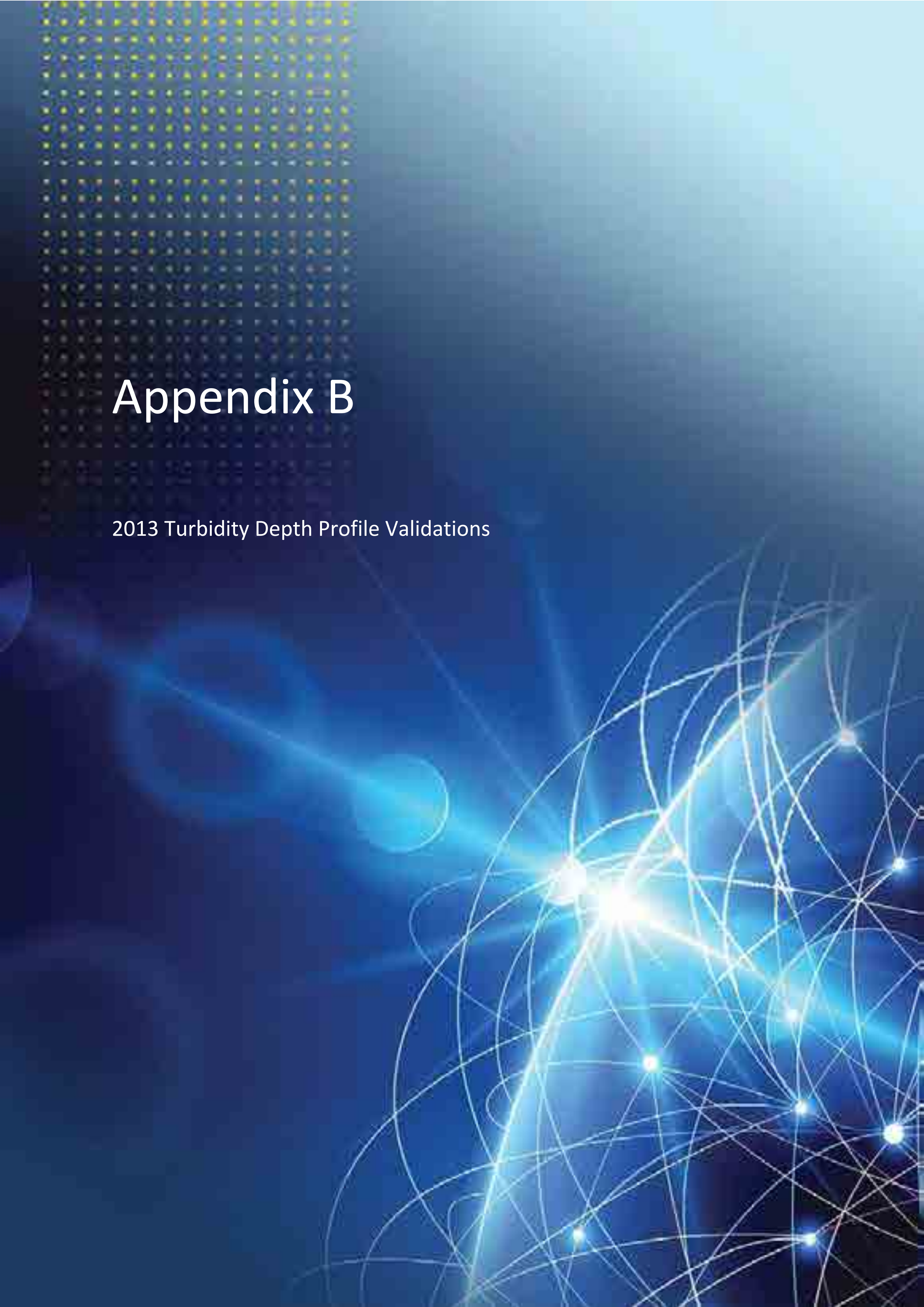


Figure A.5 ‘Bed 2’ ADCP Output Location – Current Direction (deg. N) – Surface and Bed layer comparisons – 3D Modelled vs Measured



Appendix B

2013 Turbidity Depth Profile Validations

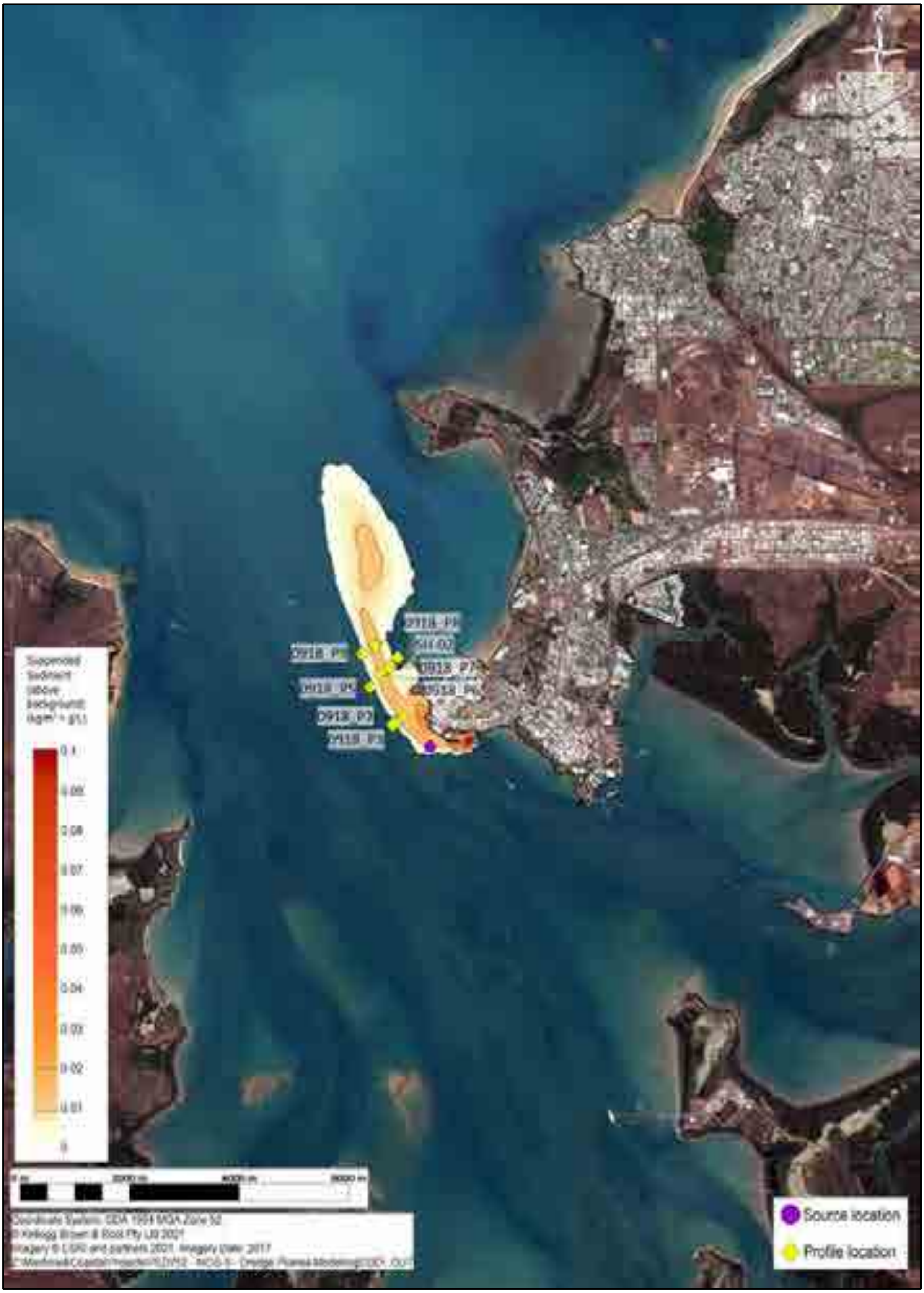


Figure B.1 **Modelled suspended sediment concentrations above background – Depth-averaged instantaneous result at 18/09/2013 11:00 (with depth profile locations)**

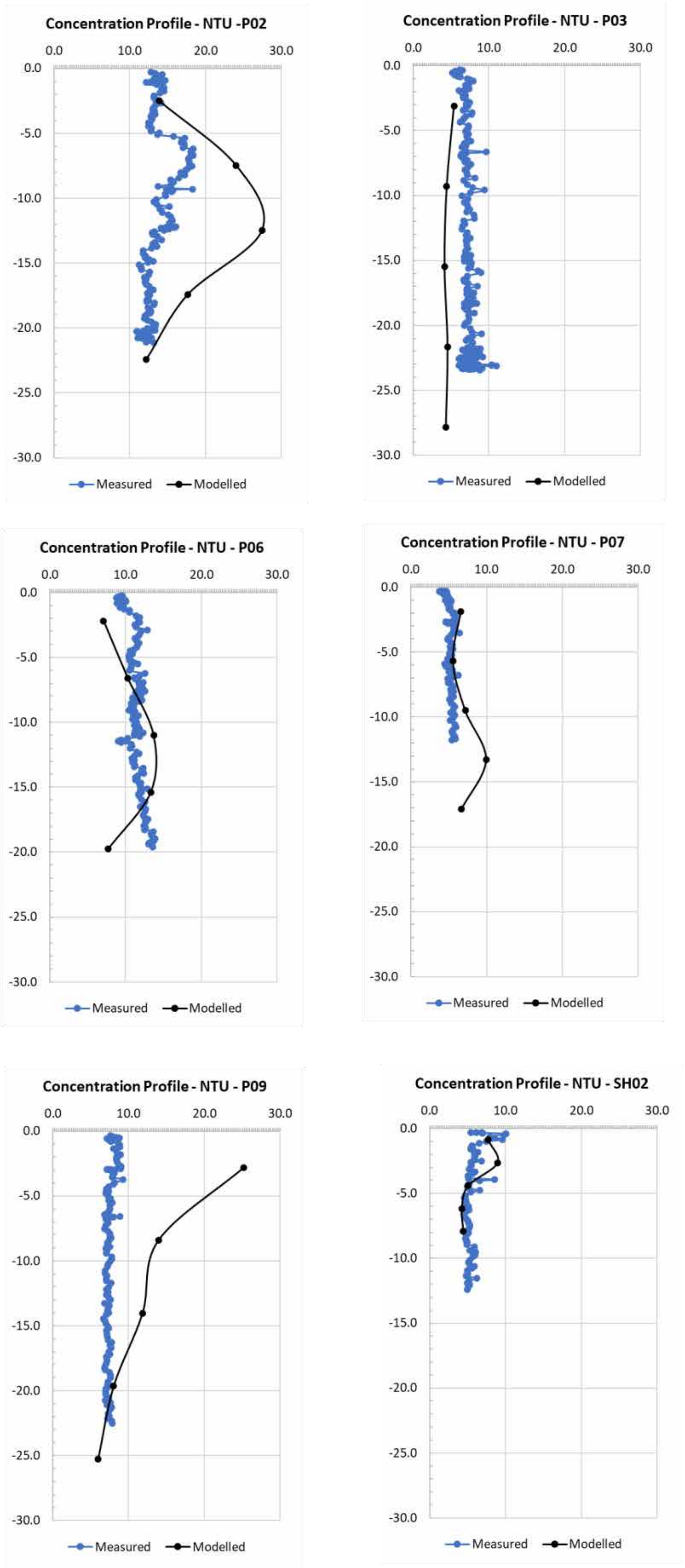


Figure B.2 Vertical turbidity profile comparisons to measurements taken 18/9/13 (+4 NTU background value added to modelling)

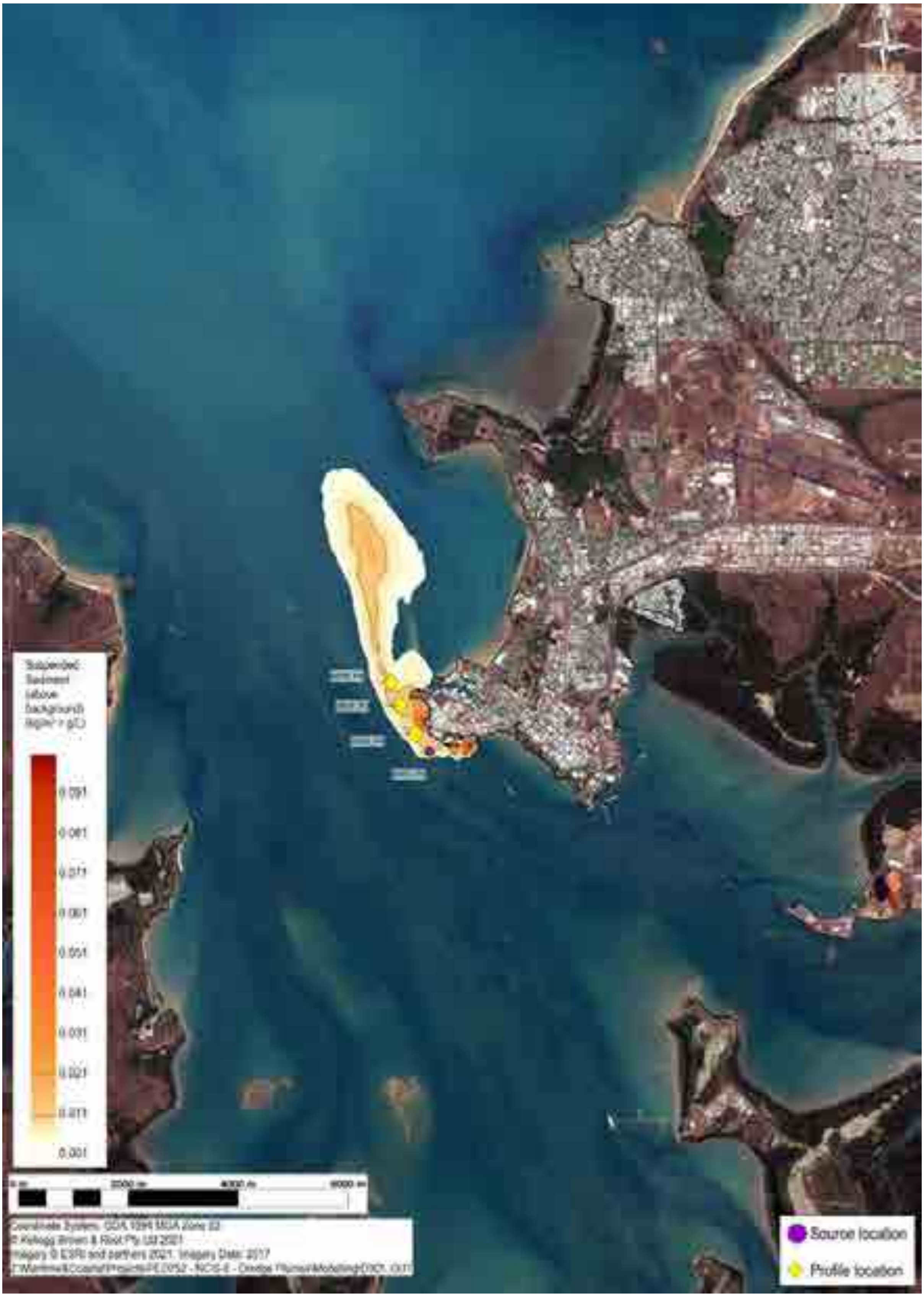


Figure B.3 Suspended sediment concentrations above background – Depth-averaged instantaneous result at 19/09/2013 08:30 with measured locations (with depth profile locations)

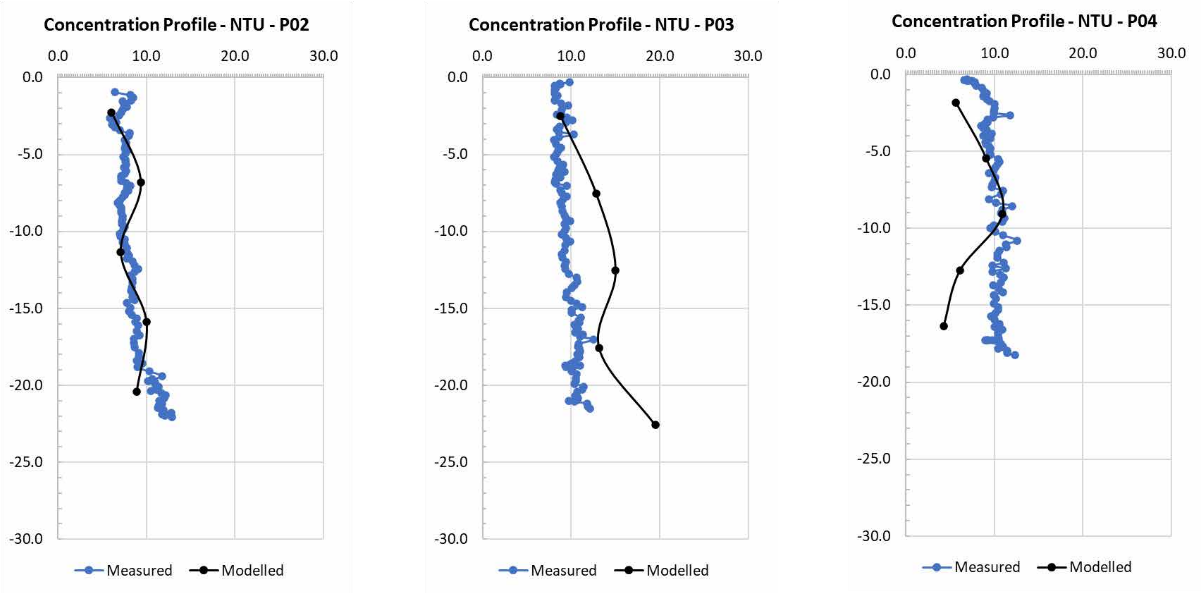


Figure B.4 Vertical turbidity profile comparisons to measurements taken 19/09/13 (+4 NTU background value added to modelling)

Coordinate System: GDA 1994 MGA Zone 52
© Kellogg Brown & Root Pty Ltd 2021
Imagery © ESRI and partners 2021. Imagery Date: 2017

Figure B.5 **Suspended sediment concentrations above background – Depth-averaged instantaneous result at 1/10/2013 08:30 with measured locations (with depth profile locations)**

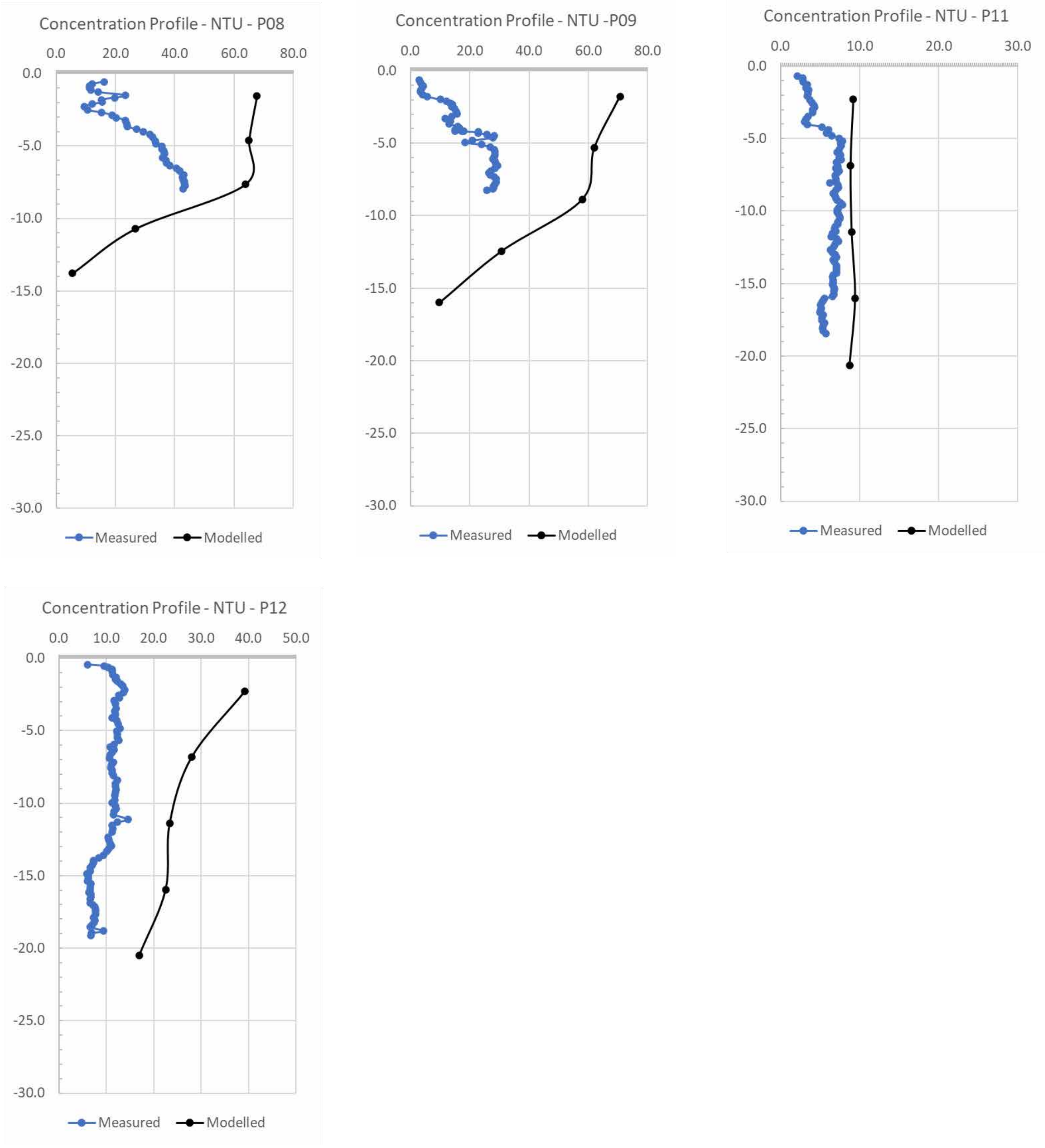


Figure B.6 Vertical turbidity profile comparisons to measurements taken 01/10/13 (+4 NTU background value added to modelling)

Appendix C

2D and 3D Modelled Snapshot Comparisons

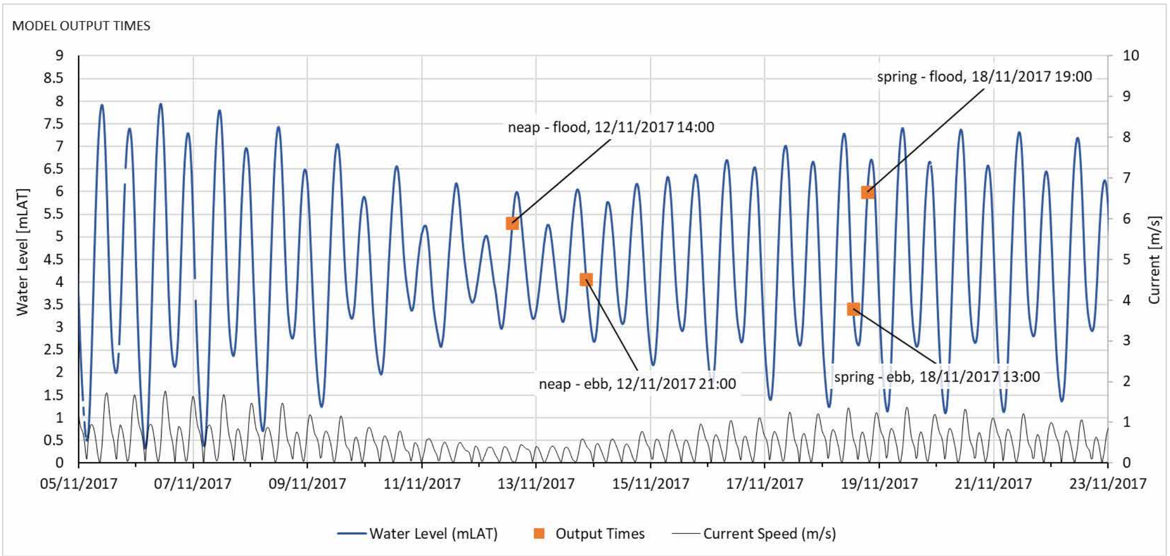


Figure C.1 **Output timeseries**

Figure C.2 Comparison of 2D (left) and 3D (right) modelled suspended sediment concentrations above background (depth-averaged) - Instantaneous result at 12/11/2017 21:00 – Ebb tide, neap condition

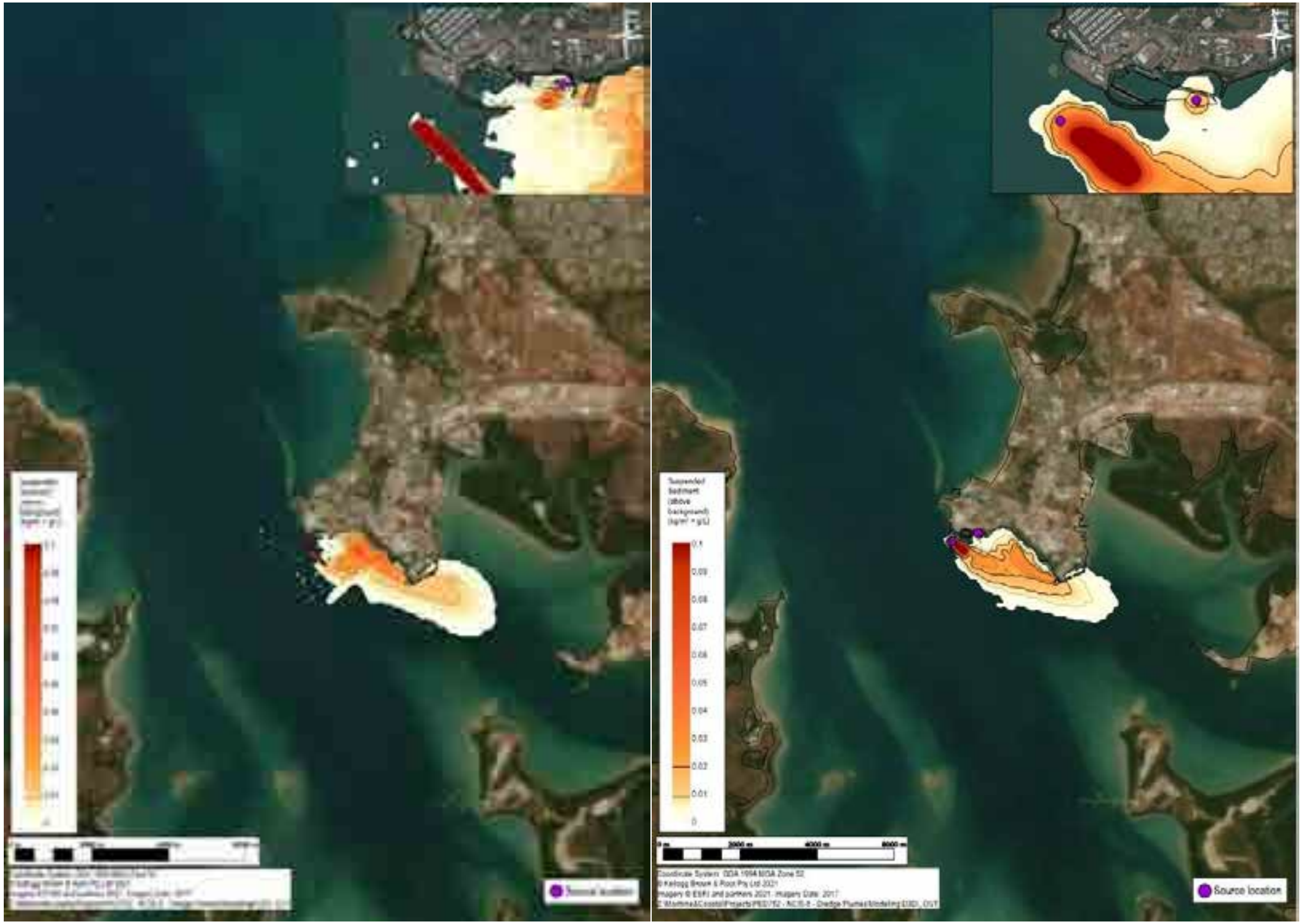


Figure C.3 Comparison of 2D (left) and 3D (right) modelled suspended sediment concentrations above background (depth-averaged) - Instantaneous result at 12/11/2017 14:00 – Flood tide, neap condition

Figure C.4 **Comparison of 2D (left) and 3D (right) modelled suspended sediment concentrations above background (depth-averaged) - Instantaneous result at 18/11/2017 13:00 – Ebb tide, spring condition**

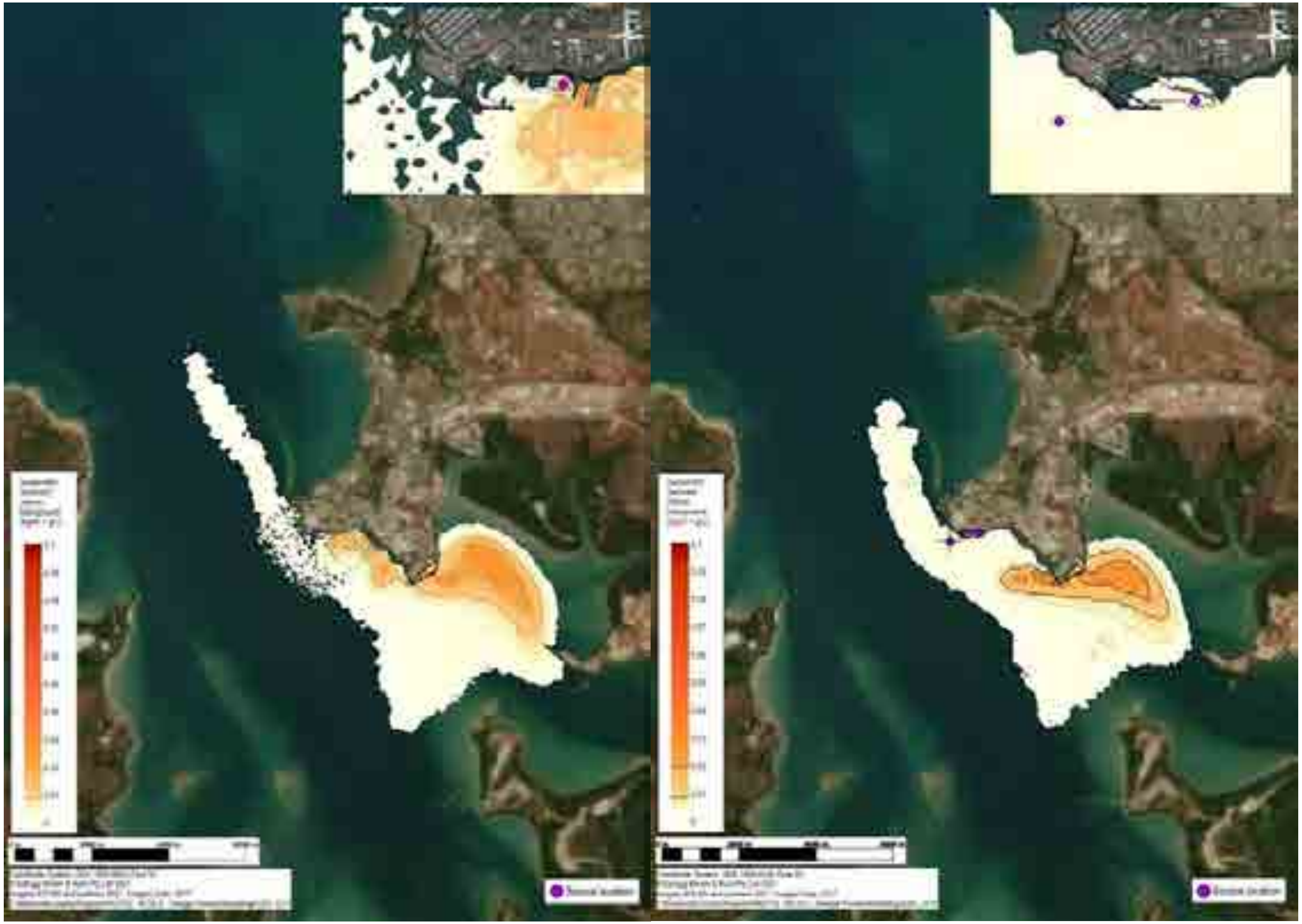


Figure C.5 Comparison of 2D (left) and 3D (right) modelled suspended sediment concentrations above background (depth-averaged) - Instantaneous result at 18/11/2017 19:00 – Flood tide, spring condition