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Port of Gladstone Sustainable Sediment Management

Feasibility Assessment: Marina Sustainable Relocation

Final 1.1

Gladstone Ports Corporation
Technical Report
August 2020

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Gladstone Ports Corporation (GPC) commissioned Port and Coastal Solutions (PCS) to assess the feasibility of a number of alternative options to manage sediment from maintenance dredging for the Port of Gladstone (PoG). The options were identified as part of the Reduce and Beneficial Reuse components of the PoG Sustainable Sediment Management (SSM) Project. The options were assessed by stakeholders as part of the SSM Project and based on the outcome of this, GPC identified four (4) options for further evaluation. This report details the feasibility assessment for one of the options, the sustainable in-channel relocation of sediment from the Gladstone Marina. It involves pumping low concentration fine-grained sediment from the Marina to the edge of the Clinton Channel, with the aim of the sediment subsequently being transported within the Inner Harbour and providing additional sediment input to intertidal regions whilst not resulting in an increase in sedimentation in any dredged areas.

An options development was undertaken and as part of this a number of possible pipe discharge locations were considered. A site with depths approximately 10 m below LAT adjacent to Clinton Channel was preferred as it has higher current speeds the risk of any sediment which is not immediately transported away causing any issues to navigation are low. A medium Cutter Suction Dredger is proposed for the dredging, with the dredger potentially pumping between 40,000 and 50,000 m^3/yr of fine-grained sediment from the Marina to the edge of the Clinton Channel each year. Numerical modelling was undertaken as part of the feasibility assessment and the results predicted that any increases in SSC and deposition to sensitive receptors within Port Curtis resulting from placement at the Marina Dredge Material Placement Area (DMPA) are generally small relative to natural conditions. Based on these results, the risk of any impacts to nearby sensitive receptors is considered to be low.

When the dredge duration and cost of placement at the Marina DMPA are compared to ongoing onshore placement at the ponds adjacent to the Marina (despite the fact there will not sufficient future capacity in the ponds), placement at the Marina DMPA results in a 30% increase in cost and a 65% increase in time over a five (5) year period. This assumes that the onshore placement would be undertaken once every five (5) years, while the pumping to the Marina DMPA would be undertaken annually to ensure the sediment remained loosely consolidated.

Based on the findings of this feasibility assessment the approach of sustainable in-channel relocation of sediment from the Marina to the Marina DMPA is considered feasible. Based on the results from the numerical modelling the Marina DMPA appears to be dispersive meaning that it has the potential to be used as a long-term placement option. The numerical modelling results indicate that placing sediment at the Marina DMPA results in low suspended sediment concentrations (SSC) and deposition compared to the natural conditions at the nearby sensitive receptors. However, there remains uncertainty due to the complexity of the processes being modelled and so it is proposed that an initial pilot study be undertaken as well as ongoing monitoring to confirm that there is no significant build-up of sediment at the Marina DMPA and that the approach does not result in impacts to any sensitive receptors. Details of the pilot study, which proposes that at least two (2) loads of sediment from the Trailing Suction Hopper Dredger (TSHD) Brisbane is placed at the Marina DMPA, and the associated monitoring are provided.

1. Introduction

Gladstone Ports Corporation (GPC) commissioned Port and Coastal Solutions (PCS) to undertake desktop feasibility studies for alternative options to manage sediment from maintenance dredging for the Port of Gladstone (PoG). The options were identified as part of the Reduce and Beneficial Reuse components of the PoG Sustainable Sediment Management (SSM) Project. The options were assessed by stakeholders as part of the SSM Project and based on the outcome of this, GPC selected the following four (4) options for further evaluation:

1) Offshore Beach Nourishment: this involves the placement of sand sized sediment offshore of a beach with the aim of the sediment providing long-term nourishment for the beach;
2) Sustainable In-channel Relocation for the Liquefied Natural Gas (LNG) Region: this involves the release of fine-grained sediment from the LNG Terminals region in a naturally deep area close to Tide Island, with the aim of the sediment subsequently being transported within the Inner Harbour and providing additional sediment input to intertidal regions whilst not resulting in an increase in sedimentation in any dredged areas;
3) Habitat Restoration/Creation: this involves the placement of dredged sediment (could be either fine-grained or sand sized) with the aim of restoring or creating seagrass and/or intertidal shorebird habitat; and
4) Sustainable In-channel Relocation for Gladstone Marina: this involves pumping low concentration fine-grained sediment from the Gladstone Marina to the edge of the Clinton Channel, with the aim of the sediment subsequently being transported within the Inner Harbour and providing additional sediment input to intertidal regions whilst not resulting in an increase in sedimentation in any dredged areas.

This report is related to the feasibility of Option 4, the sustainable in-channel relocation for the Marina.

1.1. Project Overview

The SSM Project was identified by GPC as a prerequisite, to allow adaptive long-term environmental management of maintenance dredging, supporting sustainable development and minimising harm to the environment, Port, surrounding areas and communities.

GPC had discerned the need to further improve their understanding of the interactions between maintenance dredging operations (including sea disposal of dredged material) and the local and regional environment, in order to minimise environmental impacts and ensure the ongoing sustainability of these operations. To progress this need GPC previously entered an informal agreement with the Great Barrier Reef Marine Park Authority (GBRMPA), to investigate this interaction at the Great Barrier Reef Marine Park (GBRMP) - Port Limits boundary. All PoG infrastructure and activities occur within Port Limits, which are within the Great Barrier Reef World Heritage Area (GBRWHA) (as inscribed in 1981) but outside of the GBRMP, with the exception of oceanic areas to the east of Facing Island and the south-east of Wild Cattle Cutting.

Maintenance dredging is conducted to provide and operate effective and efficient port facilities and services under the *Transport Infrastructure Act 1994*. The PoG maintenance dredging and disposal activities associated with the main channels, swings basins and berth pockets are usually undertaken annually, with dredged material placed at the approved East Banks Sea Disposal Site (EBSDS - first approved in 1980). In addition, the sediment removed by maintenance dredging of some areas of the PoG (e.g. the Marina and the Boyne River) has historically been placed on land.

In association with obtaining a Sea Dumping Permit for maintenance dredging, a five (5) year Deed of Agreement (the Deed) was signed on the 14th August 2015, between GPC and the Department of the Environment and Energy[1] (DoEE) to:

- undertake research and monitoring relating to the consequences of dumping maintenance dredged material into the marine environment. It is noted that among other things the research and monitoring may include;
  - establishment of a quantitative sediment budget and sediment dynamics model for Port Curtis (the large natural harbour which the PoG is located within), Queensland, including quantifying impacts and extent of sediment transport and resuspension from Dumping Activities at the EBSDS with specific reference to sensitive receptors and potential impacts on the GBRWHA; and
  - monitoring changes in water quality (including turbidity and benthic photosynthetic active radiation (BPAR)) resulting from or as a consequence of dumping activities;
- investigate the possibility of avoiding or reducing the need for further dumping of maintenance dredged material into the marine environment, including the possibility of beneficially reusing the sediment; and
- report to the DoEE the results of any research, monitoring or investigation undertaken by GPC in accordance with the Deed.

The Deed reiterates GPC's existing commitments to monitor and manage maintenance dredging and associated sea disposal activities in an environmentally responsible manner. To address the requirements of the Deed, an 'Implementation Strategy' (the Strategy) was prepared by GPC and approved by DoEE, which provides a schedule of proposed programs to be conducted over the term of the Deed. The Deed forms part of GPC's Environmental Management System (EMS) which is certified to ISO 14001:2015, ensuring a robust risk identification, control and improvement process is implemented and maintained.

In addition to the Deed, a Maintenance Dredging Strategy (MDS) has been developed for the ports that are situated within the GBRWHA (DTMR, 2016). The MDS provides a framework for the sustainable, leading practice management of maintenance dredging. It is a requirement of the MDS that each Port within the GBRWHA develop and implement a Long-term Maintenance Dredging Management Plan (LMDMP). The LMDMPs are aimed at creating a framework for continual improvement in environmental performance. The Department of Transport and Main Roads (DTMR) have provided guidelines to assist in the development of the LMDMPs which can be applied to ports Queensland wide (DTMR, 2018). The guidelines note that the LMDMPs should include, as well as other aspects, the following:

- an understanding of port-specific sedimentation conditions and processes;
- management approaches (including dredge avoidance and reduction); and
- long-term dredging requirements based on sedimentation rates, port safety and port efficiency needs.

The SSM Project has therefore helped to fulfil the requirements of the Deed as well as providing input to the LMDMP. The feasibility assessments of the options shortlisted from the SSM Project will be used by GPC to determine which options should be considered further and potentially progressed to a trial to further assess feasibility.

1.2. Port of Gladstone

The majority of the PoG is located within Port Curtis on the east coast of Queensland, approximately 525 km north of Brisbane (Figure 1). Port Curtis is a macro-tidal estuarine system that includes an intricate network of rivers, creeks, inlets, shoals, mud banks, channels and islands. Strong tidal flows, wind and swell wave energy and riverine input from

[1] DoEE has now changed to the Department of Agriculture, Water and the Environment (DAWE).

the Calliope and Boyne catchments, contribute to the sediment transport processes which influence the region.

In the 2018/19 financial year the PoG handled 124 million tonnes of commodities. This was predominantly made up of coal, alumina/aluminium related products and LNG, although other products including cement, petroleum, industrial chemicals, grain and containers were also handled (GPC, 2017).

The PoG covers 4,448 hectares (ha) of land which includes more than 700 ha of reclaimed land. There are 10 main wharf centres, which together comprise 20 wharves (Figure 1):

1. RG Tanna Coal Terminal: four (4) wharves;
2. Barney Point Terminal: one (1) wharf;
3. Auckland Point Terminal: four (4) wharves;
4. Fishermans Landing: four (4) wharves;
5. South Trees: two (2) wharves;
6. Boyne Wharf: one (1) wharf;
7. Curtis Island LNG Precinct, Australia Pacific LNG (APLNG): one (1) wharf;
8. Curtis Island LNG Precinct, Queensland Curtis LNG (QCLNG): one (1) wharf;
9. Curtis Island LNG Precinct, Gladstone LNG (GLNG): one (1) wharf; and
10. Wiggins Island Coal Terminal (WICT): one (1) wharf.

Figure 1. PoG wharf locations (GPC, 2017).

The PoG consists of approximately 50 km of shipping channels to ensure safe navigation from the entrance of the Port to the wharves (Figure 2). Sediment management practises are undertaken to ensure that the depths of the channels and berths are maintained at their original declared depths (Table 1). The sediment management practises include maintenance dredging, bed levelling and drag barring. Annual maintenance dredging and bed levelling/drag barring practises are undertaken in the PoG, with some areas requiring sediment management at least annually while others require less frequent management. The annual maintenance dredging of the PoG has historically been undertaken by the Trailing Suction Hopper Dredger (TSHD) Brisbane and for this assessment it is assumed that the ongoing maintenance dredging will be undertaken by a similar dredger.

Table 1. PoG Channels and associated declared depths for maintenance dredging (GPC, 2015).

Channel	Declared Depth (m LAT)
Outer Harbour	
Wild Cattle Cutting	-16.1
Boyne Cutting	-16.1
Golding Cutting	-16.1

Channel	Declared Depth (m LAT)
South Bypass Channel	-7.3
Gatcombe Channel	-16.3
Gatcombe Bypass	-12.5
Inner Harbour	
Auckland Channel	-15.8
Auckland Bypass	-6.8
Clinton Channel	-16.0
Clinton Bypass	-13.0
Targinnie Channel	-10.6
Jacobs Channel	-13.0
Marina	-4.5
WICT departure channel	-16.0

Capital dredging has historically been undertaken in the PoG as the Port has grown. Most recently, between 2011 and 2013, capital dredging associated with the construction of three (3) Liquid Natural Gas (LNG) terminals and the Wiggins Island Coal Terminal (WICT) was undertaken. Table 2 provides details of the maintenance and capital dredging, which has been undertaken at the PoG when sediment has been placed at the EBSDS over the last 12 years.

Table 2. PoG dredging volumes where sediment was placed at the EBSDS over the last 12 years.

Year	Maintenance Dredging (in-situ m^3)	Capital Dredging (in-situ m^3)
2007	160,972	
2008	17,995	
2009	282,000	
2010	0 (dredging was at start of 2011)	
2011	309,000	
2012	150,000	5,113,475
2013	0 (dredging was at start of 2014)	
2014	550,366	
2015	68,000	
2016	455,000	
2017	209,456	
2018	211,102	
2019	231,855	
Total (2007-2019)	**2,434,644**	**5,113,475**

Note: PoG Sea Dumping Permit requires to report in-situ cubic metres delivered by the dredger to the EBSDS. For maintenance dredging the in-situ cubic metres are derived from dredge logs hopper dry tonnes by applying a conversion of factor of 1.1 (e.g. 1 m^3 (in-situ) = 1.1 tonne (dry weight)).

Capital dredging has been reported as in-situ cubic metres, taken from contract documentation as calculated between pre-dredge hydrographic surveys and the contract design dredge depth. This calculation can be considered indicative of the amount delivered to EBSDS.

It is important to note that Table 2 does not include the volume of sediment removed from the Marina and a number of other areas of the PoG (e.g. Boyne River) as the TSHD Brisbane has not been able to undertake the dredging of these areas due to depth and manoeuvrability constraints. The dredging of these areas has typically been undertaken by cutter suction dredgers (CSD) and to date the sediment from these areas has been placed on land. Historic maintenance dredging of the Marina has included the removal of 352,000 m^3 (in-situ volume) in 2009 and 305,000 m^3 (in-situ volume) in 2015. Maintenance dredging of the Marina is planned for 2020, with the sediment again being placed at an onshore placement area adjacent to the Marina. There is only sufficient capacity at the onshore site for the sediment from the 2020 maintenance dredging campaign, with no other suitable onshore sites available close to the Marina.

The PoG can be separated into Inner and Outer Harbour regions as different sediment transport processes influence them; the Outer Harbour region extends from the Wild Cattle Cutting to the Gatcombe Channel and the Inner Harbour is the area inshore from Auckland Channel, which is sheltered from offshore wave activity by Curtis and Facing Islands (Figure 2).

1.3. Report Structure

The report herein is set out as follows:

- background information relative to the proposed alternative option is provided in **Section 2**;
- development of the option is detailed in **Section 3**;
- a summary of the results from the numerical modelling is given in **Section 4**;
- the feasibility assessment of the option, along with recommendations, is presented in **Section 5**; and
- a summary of the key findings from this assessment is provided in **Section 6**.

Unless stated otherwise, levels are reported to Lowest Astronomical Tide (LAT). Volumes presented throughout are in-situ cubic metres calculated from surveyed bathymetry.

Figure 2. Port of Gladstone declared channels and sea disposal site.

2. Background

This section provides details of the sustainable relocation option proposed as part of the reduce assessment for the PoG SSM Project (PCS, 2019a). In addition, further justification as to why the sediment management option is required is provided.

2.1. Option Details

Recent industry guidance has been promoting the approach of sustainable relocation where the dredged sediment is retained within the marine environment and within the natural sediment system (CEDA, 2010; RHDHV, 2016). This is because it has been recognised that the complete removal of dredged sediment (and especially sediment from maintenance dredging) from a natural system has the potential to alter the morphological evolution and ecological functioning of the system (Laboyrie *et al.*, 2018). Therefore, the overall aim of the sustainable relocation approach is to maintain and/or supplement the natural sediment supply to ensure the natural processes and habitats of the system are sustained.

As part of the stakeholder consultation process all possible relocation options were scored and the Marina sustainable relocation option came out as the equal third ranked option, with the same score as ongoing placement at EBSDS (Table 3).

Table 3. Summary of scores for existing alternative options (GPC, 2019).

Option	Score
Existing Approach – Placement at EBSDS	133
1) Offshore Beach Nourishment	143
2) Sustainable Relocation, LNG Terminals Region	139
2) Habitat Restoration, Seagrass	139
3) Sustainable Relocation, Marina	133
3) Habitat Restoration, Coastal	133
3) Jet Arrays	133
4) Onshore Beach Nourishment	130

2.2. Requirement

For the PoG the approach of sustainable relocation has been considered as the quantitative sediment budget developed as part of the SSM Project identified a potential for insufficient new sediment being available in Port Curtis to balance the deposition requirements to keep up with predicted future sea level rise (PCS, 2019b). The natural response of many intertidal habitats, such as mudflats and mangroves, to sea-level rise is to accrete to ensure that the elevation of the habitat relative to the tidal levels remains the same. However, the sediment budget predicted that there is the potential that some intertidal areas might not be able to accrete at a comparable rate to maintain a stable relative sea level. As such, if natural sediment which has recently deposited in dredged areas is consistently removed from the system and placed offshore in a retentive placement area, there is a risk that the habitats in Port Curtis cannot accrete as quickly as sea level rise, which could result in a change in both the flora and fauna in the area. Therefore, the approach for the PoG involves the dredging of recently deposited sediment and the subsequent release of it into the active sediment system, where some of it will subsequently be transported to areas which rely on an ongoing supply of sediment.

2.3. Analogues

The approach of sustainable relocation of dredged sediment is not a commonly practised solution in Australia, although there are a number of locations globally where it is adopted. Examples of three (3) analogues from Europe are provided below:

- Scheldt Estuary: in 2001 alternative relocation sites in subtidal areas near sandbars and in deep parts of secondary channels within the estuary were implemented (TIDE, 2013). The aim of these alternative relocation sites was to promote the morphological management of the estuary system and ensure that ongoing maintenance dredging did not result in a deficit of sediment to the system while also enhancing the functioning of ecosystems in the estuary. The majority of sediment which is dredged within the estuary is located to placement sites within the estuary, with almost 25 million m^3 relocated within the estuary in 2010. To help optimise and refine the relocation sites ongoing monitoring is undertaken which is used to help inform what type and volume of sediment is placed in them each year. The monitoring included a silt tracer study of four (4) different sites to investigate the retention and dispersion of sediment from potential relocation sites. Research to investigate the morphological implications of placements in a channel to the adjacent intertidal zone found that there was an expansion of the intertidal zone and an increase in its bed level (de Vet *et al.*, 2020);
- Mud Motor: the Mud Motor was a pilot study developed in the Netherlands to test whether dredged sediment could be placed through sustainable relocation to provide a semi-continuous source of sediment to nearby saltmarsh areas (Figure 3). The aim of the mud motor was therefore to supplement and accelerate the natural marsh growth without resulting in a direct disturbance. Numerical modelling was undertaken to determine the preferred location for the placement site, which was in a natural tidal channel which leads to the intertidal area requiring regeneration. The average annual maintenance dredging volume of the adjacent Port of Harlingen is 1.3 million m^3 and as part of the Mud Motor pilot study approximately 300,000 m^3 and 170,000 m^3 was placed at the Mud Motor placement site in 2016 and 2017, respectively, with the remaining volume being placed at the other approved placement sites (Baptist *et al.*, 2019). The dredged sediment was placed by bottom dumping through the hopper doors. Extensive monitoring was undertaken as part of the pilot study, which included the release of 100 kg of very fine tracer particles in two (2) different colours mixed with the dredge material in the hopper of the dredger and released at two (2) sites, in-situ loggers and repeat bathymetric surveys. Results from the monitoring showed that sediment was transported from the Mud Motor placement site to the intertidal area requiring regeneration, but it was not possible to prove that the mud motor contributed to increased sedimentation in this area (partially due to the high natural variability) (Baptist *et al.*, 2019). It is worth noting that the results from the tracer study showed that the approach resulted in more sediment being transported onto the intertidal areas towards the high water areas and with consistent increase in deposition over time compared to the modelling which predicted more transport in an alongshore direction and limited deposition on the upper intertidal areas. It was noted that following the cessation of placement at the Mud Motor in 2017, no long -term effect from the Mud Motor was observed. This could be related to limitations in the field monitoring or could indicate that the sediment placed at the Mud Motor had already been transported away from the placement site and was likely widely dispersed over a large area. Therefore, it is possible that for a beneficial reuse approach such as this to result in measurable benefits it is necessary for the activity to continue for a longer period, with a larger total volume of sediment being placed; and
- Humber Estuary: high suspended sediment concentrations (SSC) in the estuary mean that substantial maintenance dredging is required in a number of locations. The whole of the Humber estuary (subtidal and intertidal), including the navigation channels, has been designated as an area of nature conservation importance under the European Union (EU) Habitats and Birds Directives. One of the listed features is the estuary status which means that the structure and functioning of the estuary is protected. Scientists are of the

opinion that sediment is naturally being lost from the estuary and that this is hindering the ability of the mudflats and saltmarsh to accrete in line with sea level rise. This is causing deterioration in the status of these habitats and reducing the favourable condition of the whole estuary. Therefore, if the sediment removed by maintenance dredging is also removed from the system the effect would be exacerbated. Placement sites within the estuary were therefore identified, with many of these specifically selected to be dispersive (Figure 4). It was subsequently found that sediment placed in the dispersive sites was generally transported into the background suspended sediment load quickly (over a single tidal cycle). The dredged sediment is released as close as possible to the location where it was dredged to help maintain the sediment in the system so that it can continue to carry out its natural morphological functions (SedNet, 2014). Approximately 7 million m^3 is deposited annually within the estuary system at the designated placement sites (CEDA, 2010).

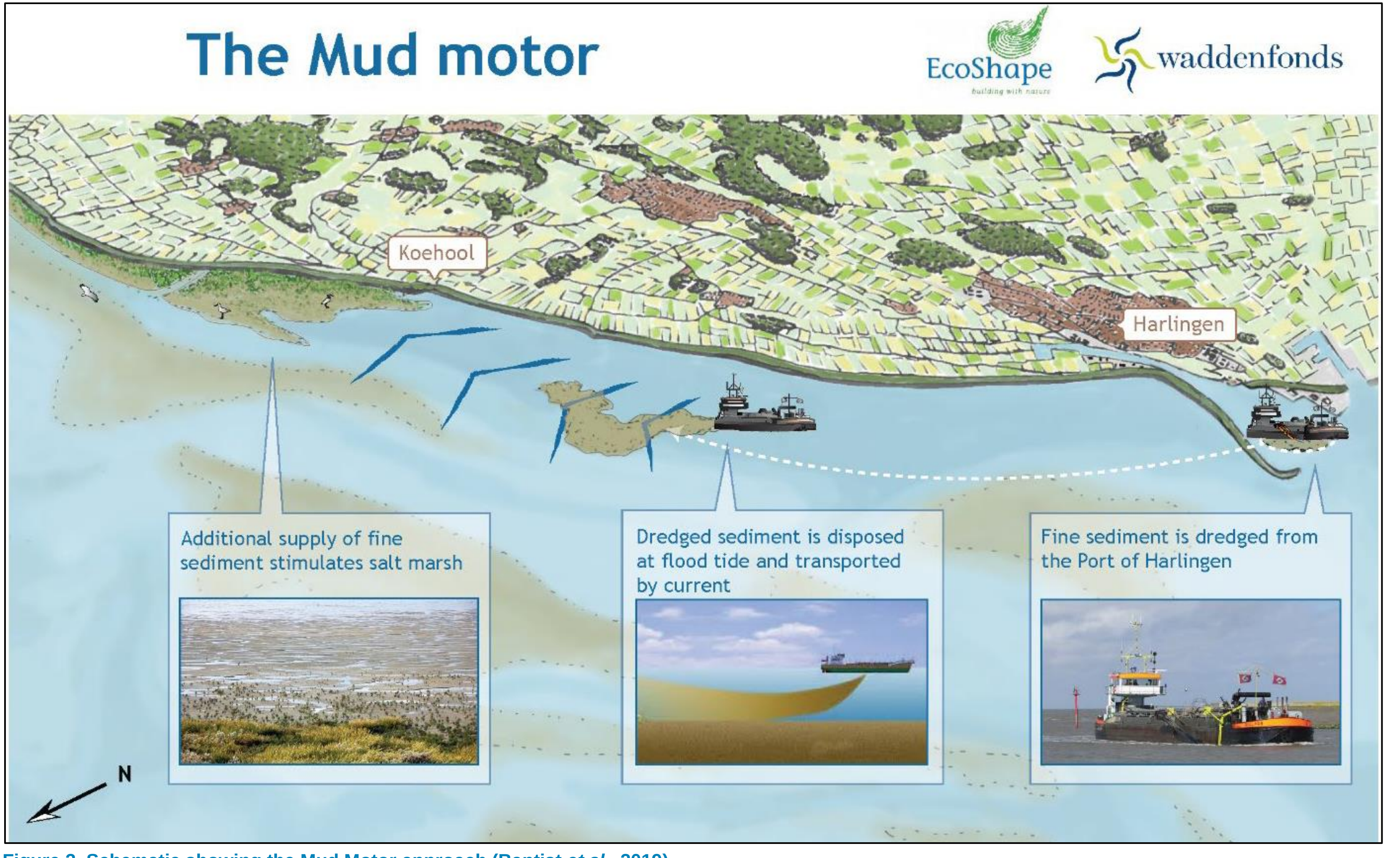

Figure 3. Schematic showing the Mud Motor approach (Baptist *et al.*, 2019).

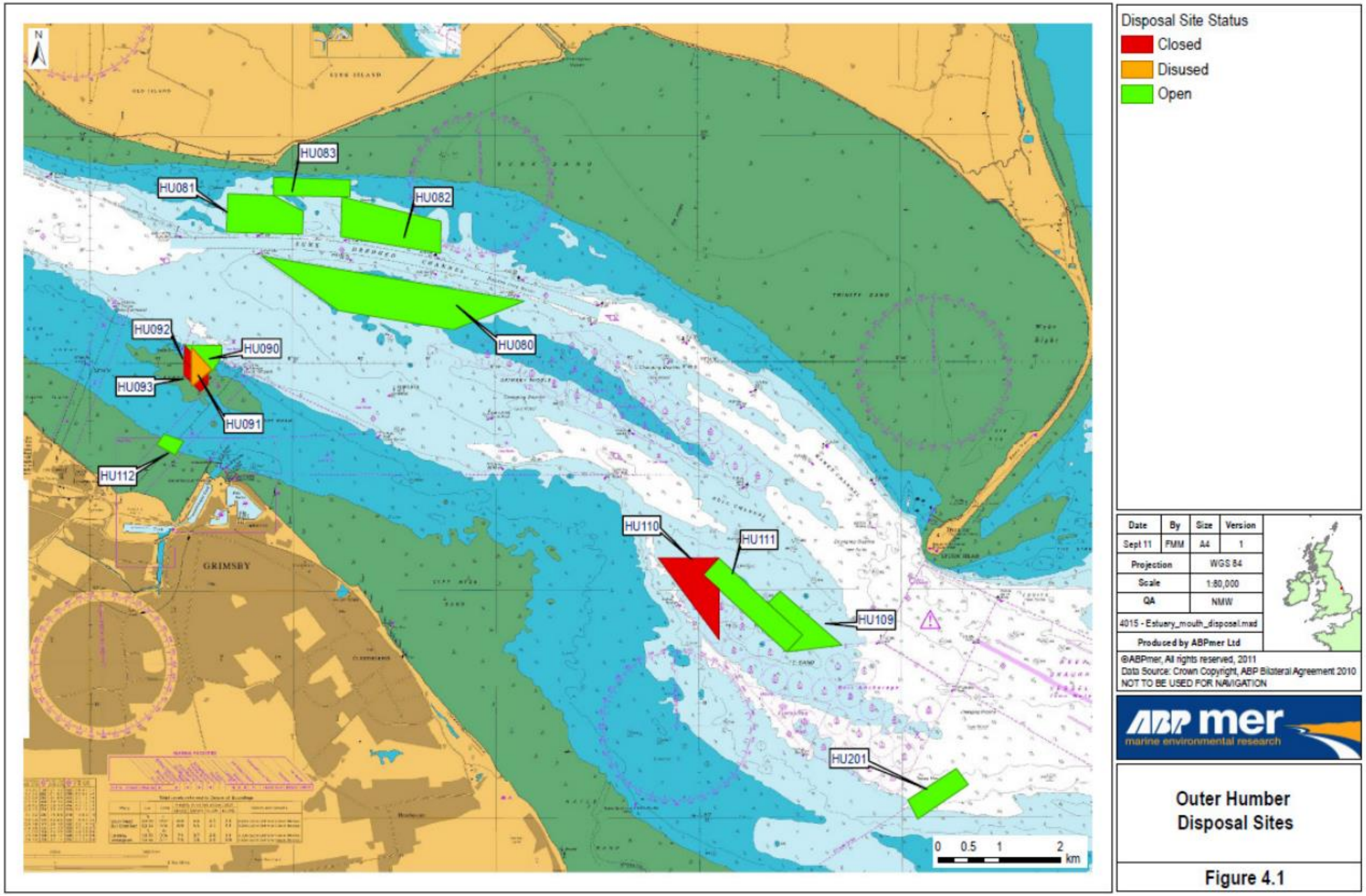

Figure 4. Dredge material disposal sites in the Outer region of the Humber (Lonsdale, 2013).

3. Option Development

For this feasibility assessment it is necessary to further develop and refine the Marina sustainable relocation option. The option development includes confirming the proposed placement site, detailing the volume and frequency of sediment, specifying the dredging approach and estimating the cost so this can be compared to the cost of placing the sediment onshore (although in the future this approach will no longer be possible).

As part of the option development, dredging contractors have been consulted to ensure that the placement site and the dredging approach are realistic.

As previously noted in Section 2.1, the option is aimed at keeping sediment in the natural system to help maintain and/or supplement the natural sediment supply to ensure the natural processes and habitats of the system are sustained.

3.1. Site Selection

As part of the PoG SSM Project reduce assessment a dredging approach (CSD pumping sediment from the Marina, see Section 3.3 for further details) and a potential pipeline release location (Marina DMPA) for sediment from the Marina was identified close to the Clinton channel directly north of the Marina (PCS, 2019a). The site was selected on the basis of the following:

- relatively high tidal current speeds occur in this area which will promote the transport of suspended sediment away from the release location;
- it is located close enough to the Marina so the total pipeline length during dredging would be less than 1,500 m which is the maximum distance that a CSD could pump the sediment without requiring an additional booster station; and
- it is a naturally deep area (approximately 7 m below LAT) and is directly adjacent to the designated channel leading to the tug berths where depths are maintained at 7.5 m below LAT.

A number of alternative sites have been considered for the pipeline release location (Marina DMPA) as part of this study, with additional sites to the west and east as well as the original location being moved so that it is adjacent to the Clinton Channel (Figure 5). It was determined that there was an increase in the risk of sedimentation in adjacent berths due to the alternative sites located to the west and east (Release 1 and Release 3). Therefore, the preferred location for the Marina DMPA is the Release 2 location in Figure 5, which is in a similar location to the site proposed in the reduce assessment. The site has been moved so that it is closer to the Clinton Channel as higher current speeds occur there and the natural and dredged depths are deeper (approximately 10 m below LAT) which reduces the risk of any sediment which is not immediately transported away causing any issues to navigation.

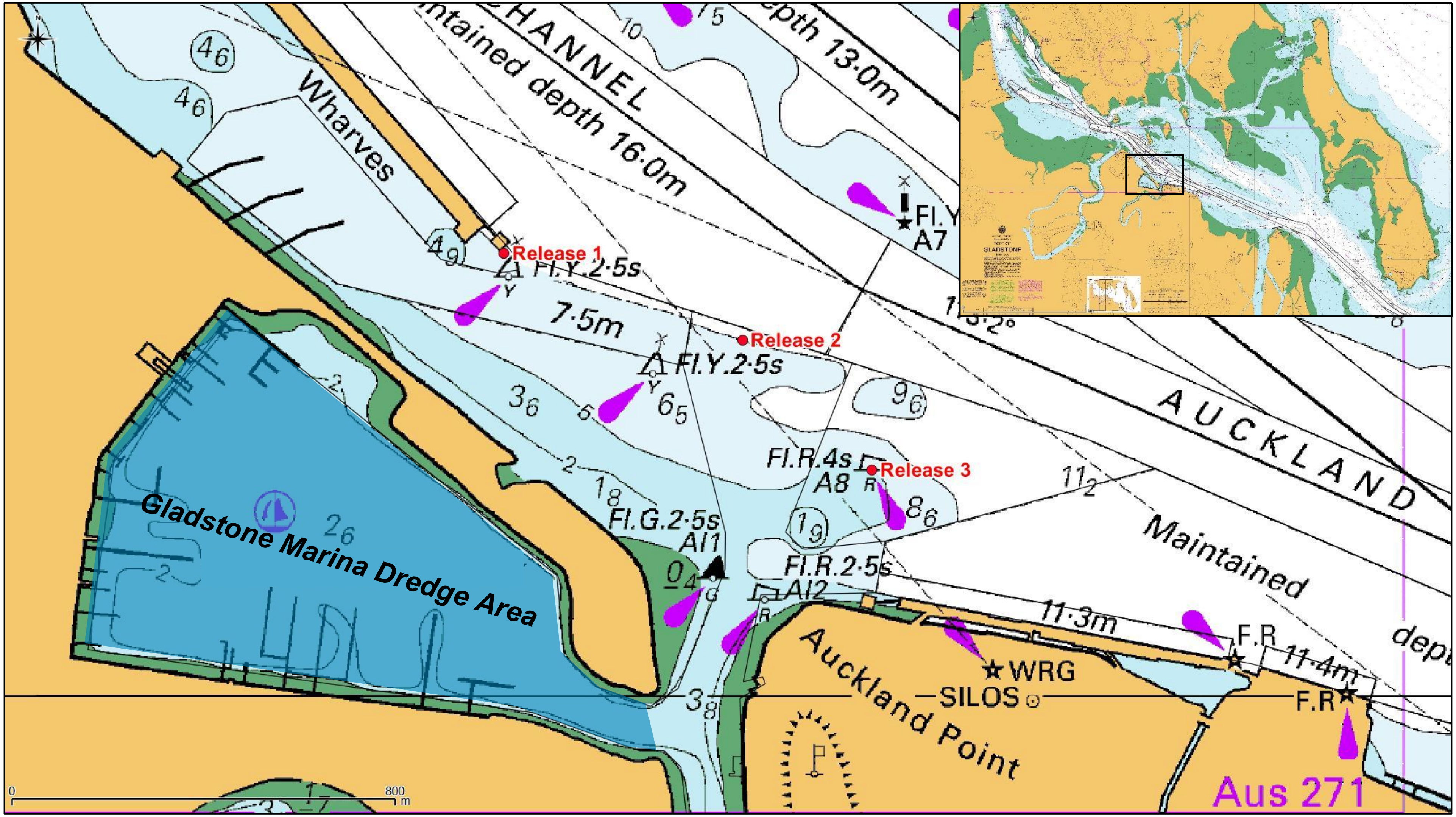

Figure 5. Sustainable relocation pipeline release sites considered for the Marina along with the Marina dredge area (blue polygon).

3.2. Sediment Requirements

As the primary aim of the sustainable relocation approach is to keep sediment which is removed from Marina by maintenance dredging in the natural sediment system, it is important that sediment which is released at the Marina DMPA has the potential to subsequently be resuspended and transported away from the area. As such, the material needs to be fine-grained sediment which can be transported in suspension. As the sediment from the Marina has historically been placed on land, it is also important to ensure that the sediment is uncontaminated and suitable for unconfined sea disposal according to the National Assessment Guidelines for Dredging (NAGD) (Commonwealth of Australia, 2009).

Based on sediment sampling in 2015 and 2017 (AMA, 2015 & 2017) the sediment in the Marina is consistently fine-grained (~95% silt and clay) with very little coarser sediment present. In addition, the results from both years of sampling found that the sediment was suitable for dredging and unconfined sea disposal in accordance with the NAGD (Commonwealth of Australia, 2009).

Analysis of historic bathymetric data of the Marina found that the ongoing sedimentation in the Marina was in the order of 40,000 to 50,000 m^3/yr. As noted above, this sediment is fine-grained sediment which is transported into the Marina in suspension during the flooding tide and then deposited and subsequently trapped in the Marina due to the calm conditions. The approach would be required to manage all of the ongoing sedimentation (40,000 to 50,000 m^3/yr) which occurs in the Marina.

3.3. Dredging Approach

There are numerous different dredging approaches that could be adopted as part of the Marina sustainable relocation approach. However, the exact dredging approach can only be confirmed once the dredging has been tendered and responses received. Therefore, for this assessment the dredging approach adopted is what is considered the most likely approach based on discussions with GPC and dredge contractors.

It is assumed that the dredging will be undertaken by a medium CSD which is similar to what was adopted for the previous 2009 and 2015 maintenance dredging campaigns. As noted by the dredge contractors, to ensure sufficient velocity at the underwater release location, it has been assumed that the dredger would be using a 300 mm pipeline, while for the onshore placement a 400 mm pipeline has historically been adopted. The pipeline within the Marina would be floating and then from the Marina to the Marina DMPA the pipeline could either be floating or on the seabed or a combination of the two (2). The underwater release location would likely be positioned close to the seabed and be orientated so that the discharge is towards the location of higher flows (i.e. towards Clinton channel).

The frequency and associated volume of sediment to be dredged per campaign has the potential to be adjusted based on the results of initial campaigns. It is proposed that campaigns should initially be undertaken annually to ensure the sediment to be dredged has been recently deposited and is therefore loosely consolidated. If these campaigns are successful and there is no evidence of a build-up of sediment at the pipeline release location, or in any adjacent berths or areas of the channel, the campaigns could be adjusted to be less frequent such as every two (2) or three (3) years (or more).

3.4. Cost Estimate

To estimate the time and cost implications of the Marina sustainable relocation approach compared to the existing approach of placing the sediment onshore it is necessary to make a number of assumptions:

- a medium sized CSD will be used for the dredging (for both approaches), with a daily charge rate of $15,000;

- the dredger would operate for 12 hours per day (6am to 6pm to adhere with Gladstone Regional Council noise restrictions) with an average production rate of 1,300 m^3/day when pumping to the Marina DMPA. The production rate would be increased to 2,150 m^3/day when pumping to the onshore placement site (due to a larger pipe diameter being used);
- the mobilisation/demobilisation cost for the dredger and pipeline would be $100,000 per campaign;
- the cost of the pipeline and initial installation for the sustainable relocation option is likely to be in the order of $500,000; and
- the sustainable relocation dredging is undertaken annually with a volume of 40,000 m^3/yr dredged, while the onshore placement is undertaken every five (5) years with a volume of 200,000 m^3 dredged.

Based on the above assumptions, the duration of time and associated costs for the maintenance dredging of the Marina has been estimated for the two (2) placement options below:

- Onshore: the placement of 200,000 m^3 of sediment from the Marina to the adjacent onshore placement area is estimated to take 93 days and the dredging is expected to cost $1.5 million. Based on previous campaigns, the onshore management of the sediment is also expected to cost approximately $1 million. Based on this, the total cost of the onshore placement is predicted to be $2.5 million every five (5) years; and
- Sustainable In-channel Relocation: the placement of 40,000 m^3/yr of sediment from the Marina to the proposed Marina DMPA is estimated to take 31 days to complete and cost $570,000 per campaign. Therefore, the total dredging cost over five (5) years would be $2.8 million plus the additional $0.5 million for the pipeline. The total cost over the first five (5) years is predicted to be $3.3 million, while the ongoing cost after that is predicted to be $2.8 million (every 5 years). The cost would be lower ($100,000 mobilisation cost per year) if the frequency of the sustainable relocation could be reduced to be less than annually. For example, if instead of five (5) annual dredging campaigns it was assumed that three (3) campaigns (i.e. biennial campaigns) could be undertaken over five (5) years then there would be a reduction in costs of $200,000.

4. Numerical Modelling

To further assess the feasibility of the Marina sustainable relocation option, numerical modelling has been undertaken. The aims of the modelling are to optimise the approach to minimise sedimentation within the dredged areas of the PoG and to predict any impacts due to plumes resulting from the initial release of the sediment at the Marina DMPA and also the subsequent transport and ultimate fate of the sediment. Therefore, the modelling will help to determine whether the approach could impact any sensitive receptors and will also help to determine the likelihood of the sediment being transported to intertidal and subtidal habitats that require ongoing sedimentation.

The numerical model adopted for this study was the same BMT TUFLOW FV model of the PoG which was adopted as part of the PoG SSM Sediment Budget assessment (BMT, 2019a). The model has undergone extensive calibration and validation processes as part of previous projects, with the most extensive being as part of the Gatcombe and Golding Cutting Channel Duplication Project Environmental Impact Statement (EIS) (BMT, 2019b). The calibration and validation has included the following:

- Hydrodynamics: long-term water level and Acoustic Doppler Current Profiler (ADCP) current profile data as well as current velocities across key transects over a full tidal cycle;
- Waves: long-term data from the Gladstone waverider buoy as well as data from ADCPs;
- Sediment Transport: the ambient (natural) sediment transport model was calibrated and validated using more than 12 months of in-situ measured turbidity data. However, the model has not been calibrated for erosion/deposition and so uncertainty remains as to the accuracy of the model for these parameters; and
- Dredge Plume: the source terms of plume generation during dredging activities have been developed over a period of time and are based on input from expert dredging consultants and measurements carried out during monitoring of dredging activity by boat-mounted ADCP (BMT WBM, 2017).

The model was further refined and validated as part of the SSM Project, and an additional model calibration exercise was undertaken using data collected specifically as part of the SSM Project during monitoring campaigns in 2018 and 2019 (BMT, 2019a). This included additional data from in-situ monitoring during both natural conditions and over the duration of a maintenance dredging campaign and ADCP transects during natural conditions.

Despite the extensive model calibration and validation exercises which have been undertaken it was noted as part of the PoG Sediment Budget that there were limitations and uncertainties with the numerical model (PCS, 2019b). These were mainly due to the complexities of the processes which the model is trying to replicate and were specifically associated with sediment transport and the erosion and deposition of sediment. Therefore, the results from the numerical modelling can be used to assist in the feasibility assessment by providing an indication of the potential behaviour of the placed sediment, but it must be noted that there is some uncertainty in the results. Despite these uncertainties, it is considered that the model can be used as a tool to compare different placement options and can therefore be used to help determine whether alternative placement options might be feasible.

4.1. Optimisation

To determine whether the sedimentation resulting from the placement of dredged sediment at the Marina DMPA differs significantly as a result of when during the tide the sediment is released, initial model simulations have been undertaken. The modelling has assumed that six (6) hours of discharge has been undertaken with the time of the discharge centring on either the flooding tide, high water, the ebbing tide or low water. The discharge has been assumed to be ongoing during the six (6) hours around that tidal state over a 14 day spring-neap tidal cycle. The discharge has been modelled as a release in the bottom 1 m of the water column at the release location which has a depth of approximately 10 m below LAT.

A summary of the results from the simulations is shown in Table 4. The results show that, on average, 7% of the sediment released at the Marina DMPA is predicted to be deposited in the PoG channels and berths after 14 days of sediment being released. In addition, less than 2% of the released sediment is predicted to remain within sustainable relocation site over the 14 days. The results show that although there is some variability between the releases at the different points in the tide, the time of release does not alter the amount of the sediment predicted to be deposited in sensitive receptor locations, with 5% predicted to be deposited in areas where seagrass has historically been observed (the potential impacts are assessed in more detail in Section 4.3) and 0% predicted in coral reefs. The relatively high deposition in historical seagrass regions shows that the approach is successful as these areas cover the majority of the intertidal zone in Port Curtis and therefore represent the areas which require ongoing sedimentation. The areas where the highest sedimentation is predicted by the modelling are the area between Fishermans Landing and WICT and the area between Barney Point and South Trees Inlet.

As the results show only small differences in the amount of sediment predicted to be deposited in the dredged channels of the PoG, and no sedimentation at any reefs, no tidal constraint will be assumed for the longer duration model simulation. This means that the modelling will assume that the dredger can place sediment throughout the tidal cycle at the Marina DMPA.

Table 4. Percentage of placed sediment deposited in different areas.

Release Time	Channels (%)	Historical Seagrass (%)	Reefs (%)
High Tide	5	11	0
Ebb Tide	6	12	0
Low Tide	8	17	0
Flood Tide	7	16	0
Average	7%	14%	0%

4.2. Assumptions

The numerical modelling has been undertaken to represent the placement of sediment as realistically as possible based on the details provided in Section 3. A number of additional assumptions have also been required:

- the model was used to simulate the release of 50,000 m^3 (approximate upper volume for an annual campaign) and 200,000 m^3 (approximate volume for a five (5) yearly campaign) during a single maintenance dredging campaign;
- the duration of the release of sediment at the Marina DMPA was 38.6 days for the 50,000 m^3 and 154.3 days for the 200,000 m^3. The total model simulation time was three-months for the 50,000 m^3 and six-months for the 200,000 m^3 to allow natural reworking of the placed sediment to occur over a combination of spring and neap tidal conditions, following the completion of the works;
- the source term assumed for the discharge was 9 kg/s, based on the sediment being medium consolidated silt and clay (dry density = 300 kg/m^3 (Van Rijn, 1997));
- the dredge discharge will be continuous for 12 hours per day (i.e. daylight hours), followed by 12 hours with no discharge;
- the assumed sediment composition was 5% sand, 40% silt and 55% clay;

- the discharge of water through the pipeline was 0.3 m^3/s, with the water flow towards the Clinton Channel (to the north);
- the water and sediment discharge was released in the near-bed layer of the mode (the vertical cell of the water column closest to the seabed); and
- model results were analysed over the duration of the release, with the final deposition results extracted at the end of the simulation.

4.3. Results

A summary of the key modelled results for the two (2) different placement volumes is provided in the following sections. Further details of the modelling results can be found in BMT (2020).

Plots of the model results have been provided by BMT (2020) as both map plots showing the spatial extent of the turbidity and deposition and time series plots showing how the turbidity and deposition vary over time. Time series plots have been created at sensitive receptor sites located within Port Curtis (Figure 6).

Modelling results of suspended sediment have been provided by BMT in both nephelometric turbidity units (NTU) and SSC in mg/l. The conversion factor adopted by BMT to change between these two units was 1.6 (e.g. 1 NTU = 1.6 mg/l), this was developed based on previous water quality monitoring and sampling in the PoG (BMT WBM, 2016). It is important to note that it is not possible to develop a standard conversion between NTU and SSC. The conversion will vary depending on factors such as the instrumentation, sediment type and the natural and anthropogenic conditions and therefore it is proposed that a new conversion will be developed as part of any future monitoring undertaken for the PoG feasibility studies.

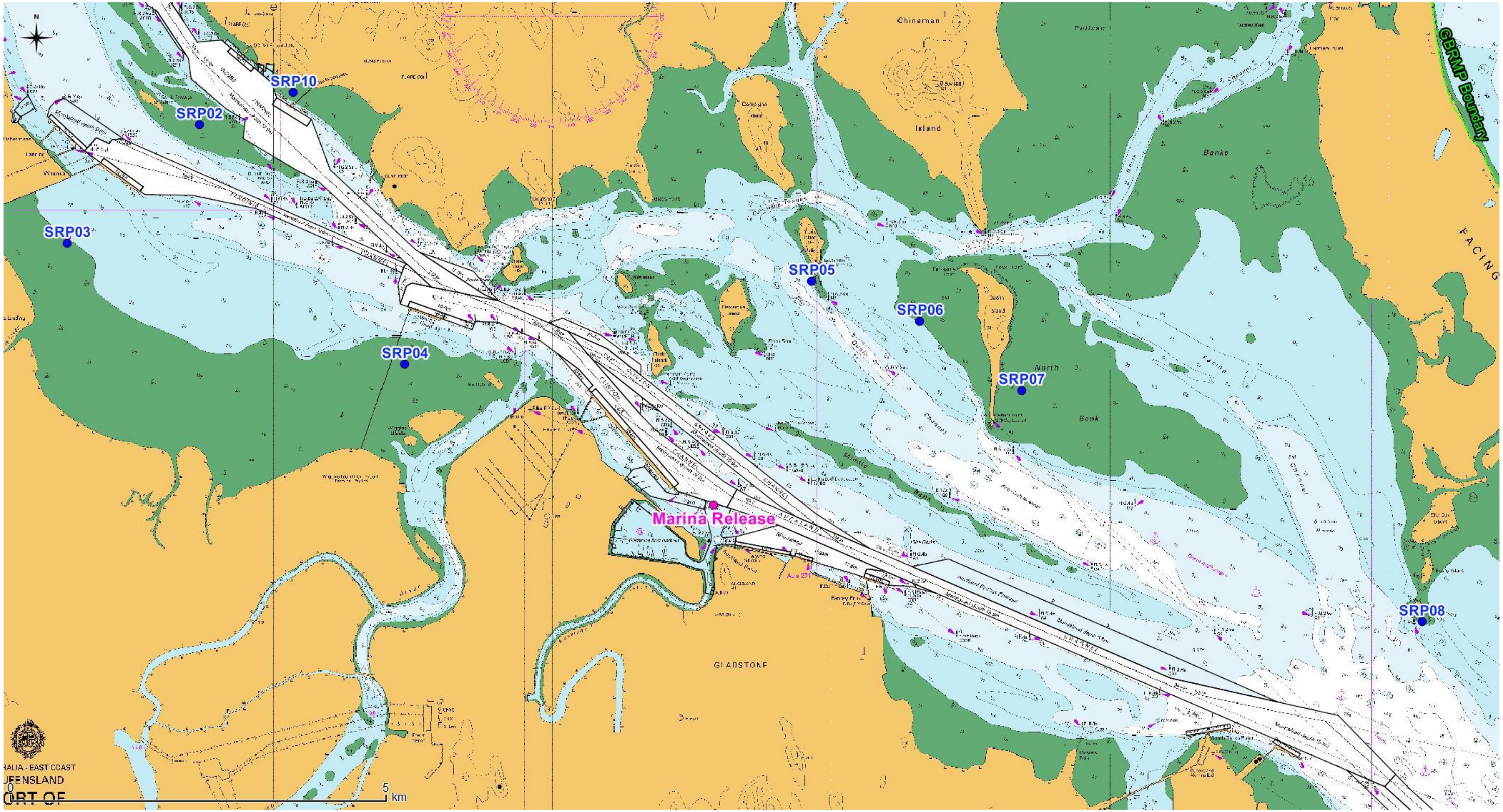

Figure 6. Location of sensitive receptor model output points relative to the Marina release location.

4.3.1. Annual Volume

To show the model predicted spatial distribution of turbidity resulting from the option, the maximum 95th percentile turbidity was calculated over a two-week sliding window over the course of the three-month simulation. The 95th percentile represents the value that the turbidity was below for 95% of the time over the two-week window, and then the maximum value for each model cell was selected out of all the two-week sliding windows included in the three-month simulation. The model predicted maximum 95th percentile turbidity as well as the predicted final deposition thickness at the end of the three-month simulation are shown in Figure 7 to Figure 9. The model predicted deposited sediment present in various areas at the end of the three-month simulation is summarised in Table 5.

The turbidity plot shows that the only areas where the turbidity is predicted to exceed 3 NTU above background are directly adjacent to the Marina DMPA. The maximum 95th percentile turbidity shows that suspended sediment is predicted to be transported along the main channels of the PoG extending north to Fishermans Landing and south to the Gatcombe Channel. In addition, suspended sediment is also predicted to be transported up the Calliope River. Away from the main channels the turbidity is predicted to remain low, with 95th percentile values of less than 1 NTU present throughout much of Port Curtis.

The final deposition plot (at the end of the model simulation) shows that there is predicted to be widespread deposition within Port Curtis, with most of the deposition predicted to be over the extensive intertidal and shallow subtidal areas and not directly in the main navigation channels (although some sediment is predicted to be deposited along the edge of the channels, predominantly to the west of the channels between Fishermans Landing and South Trees wharf). The summary of the model predicted sediment deposition after three-months (Table 5) shows that almost none of the released sediment was predicted to be retained within the DMPA region, although just over 3% was predicted to be transported back into the Marina. More than 15% of the sediment is predicted to be deposited in the historic intertidal seagrass regions (mainly in the area between Wiggins Island and Fishermans Landing, but also in the area between Barney Point and South Trees Point and the area around Quoin Island), but as previously noted these regions represent much of the intertidal zone in Port Curtis which are the areas that the approach is aimed at supplying sediment to. The results also show that around 8% of the placed sediment is predicted to be deposited in the dredged channels of the PoG. A small amount of the sediment (0.1%) is predicted to be deposited at the coral reefs in Port Curtis, with the main area of coral reef at risk of increased deposition being the coral surrounding Turtle Island.

Table 5. Deposited sediment in different areas at the end of the simulation (after three-months) for 50,000 m^3 of sediment released at the Marina DMPA.

Area	Mass (t)	% of Total Mass
Marina DMPA region[1]	<1	0
Marina	490	3
Seagrass in Port Curtis	2,470	16
Coral in Port Curtis	20	<1
Coral offshore of Port Curtis	0	0
PoG Dredged Areas[2]	1,170	8

[1] the region extends approximately 120 m to the north-west and south-east of the release point and 50 m into the Clinton Channel.
[2] this excludes the Marina as this is included separately elsewhere in the table.
Note: total mass released as part of the simulation = 15,200 tonnes.

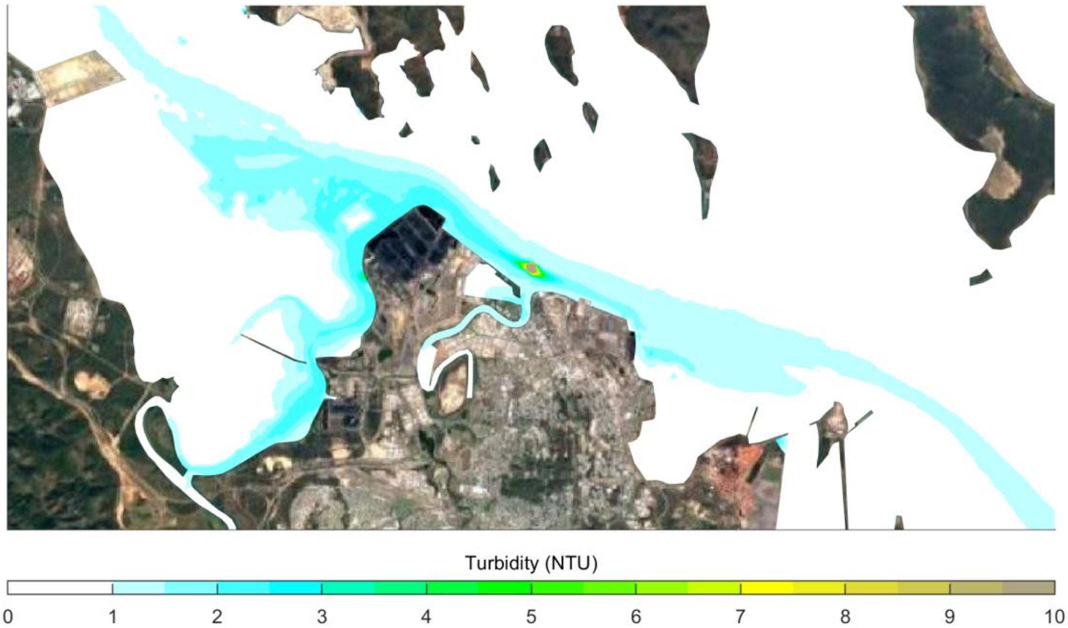

Figure 7. Maximum 95th percentile turbidity above background over two weeks for 50,000 m^3 of sediment released at the Marina DMPA (BMT, 2020).

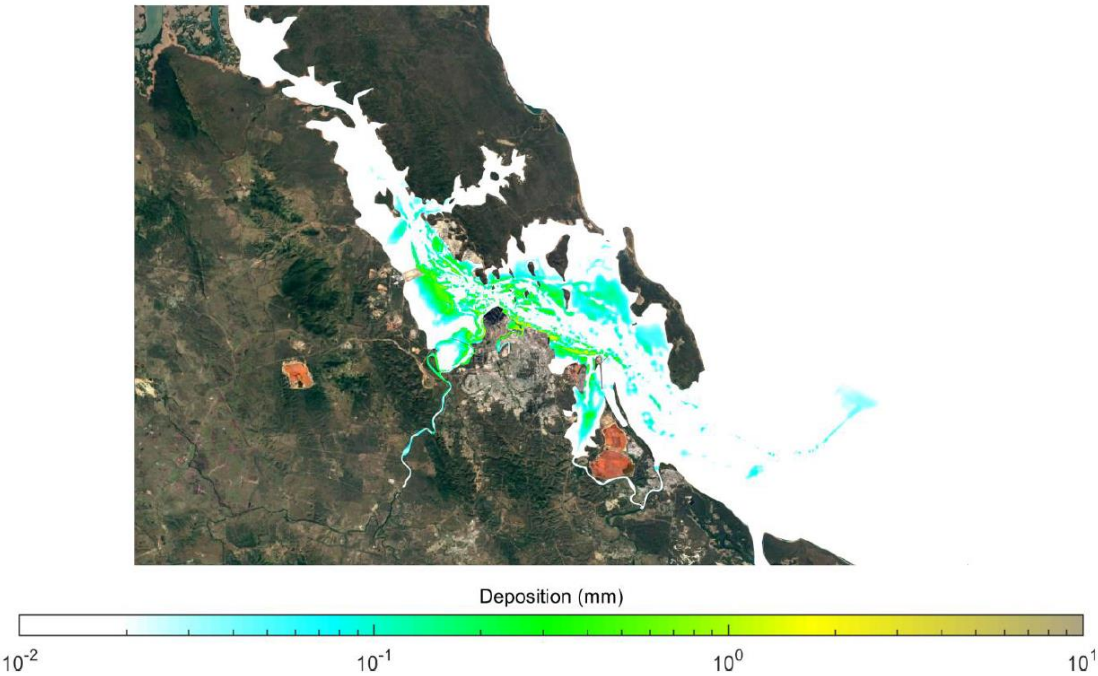

Figure 8. Final deposition of the sediment after three-months for 50,000 m^3 released at the Marina DMPA (BMT, 2020).

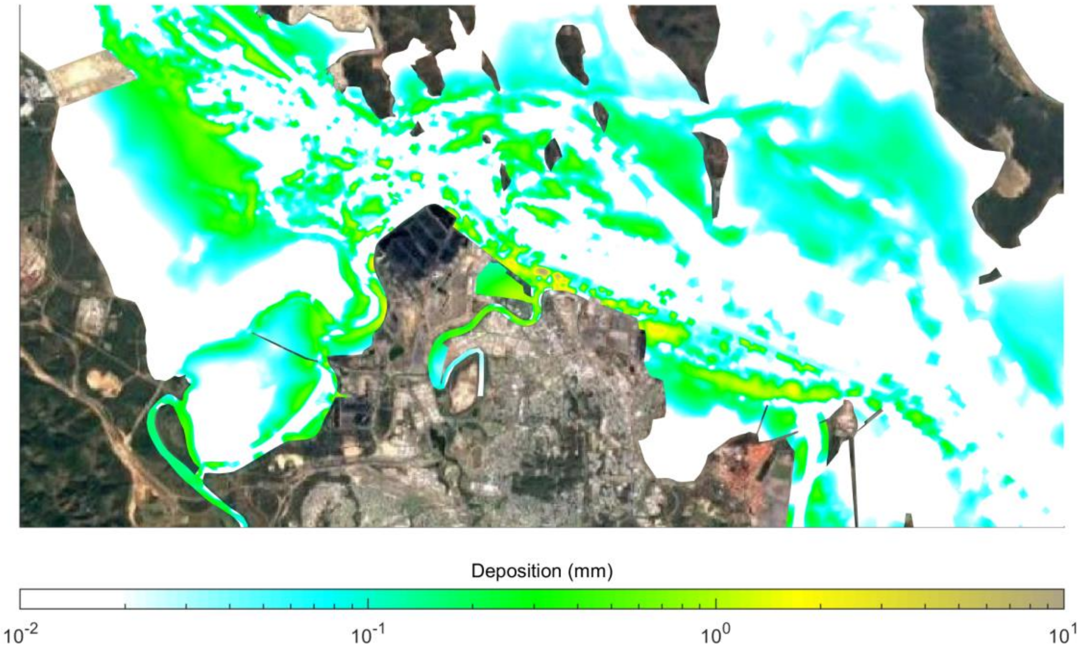

Figure 9. Close up of final deposition of the sediment after three-months for 50,000 m^3 released at the Marina DMPA (BMT, 2020).

Time series plots of the model predicted SSC and deposition resulting from the release of sediment at the Marina DMPA are shown at some of the sensitive receptor sites in Figure 10 to Figure 13. The model results suggest the following:

- the SSC resulting from the release of sediment at the Marina DMPA is predicted to be low relative to the natural conditions at the sensitive receptors. The SSC is predicted to remain below 1 to 2 mg/l at the sensitive receptor sites except for at SRP04 (seagrass site) where short duration spikes in SSC of more than 5 mg/l are predicted to occur due to the release of sediment at the Marina DMPA. However, the SSC due to the natural conditions is predicted to be two (2) to four (4) times larger than the SSC from the Marina DMPA sediment release; and
- the only site where the numerical modelling has predicted a build-up of sediment due to the release of sediment at the Marina DMPA was at SRP02 (seagrass site) with a build-up of 0.05 mm over a month. Over the same period the natural sedimentation is predicted to result in a build-up of 0.1 mm. As the sustainable relocation approach is aimed at providing a supply of sediment to allow naturally accreting habitats in Port Curtis to continue to accrete, this is considered to suggest that the approach is successful as opposed to indicating a potential impact to the seagrass.

The predicted mass of sediment in suspension and on the seabed over the duration of the three-month model simulation is shown in Figure 14. The plot suggests that the released sediment will be deposited relatively quickly following release and that 1.5 months after the cessation of the release less than 3% of the released sediment would be in suspension with the remaining sediment being deposited on the seabed.

As noted in Section 4, there are limitations and uncertainties associated with the model results which must be considered when interpreting the results. The model results predicting that the SSC resulting from the option at the nearby sensitive receptors is small compared to the natural variability has a relatively high confidence. However, there is more uncertainty associated with the deposition patterns predicted by the model given the inherent limitations in modelling sedimentation of fin-grained sediment accurately. Monitoring as part of a pilot study would be required to provide a better understanding of the deposition patterns associated with the option.

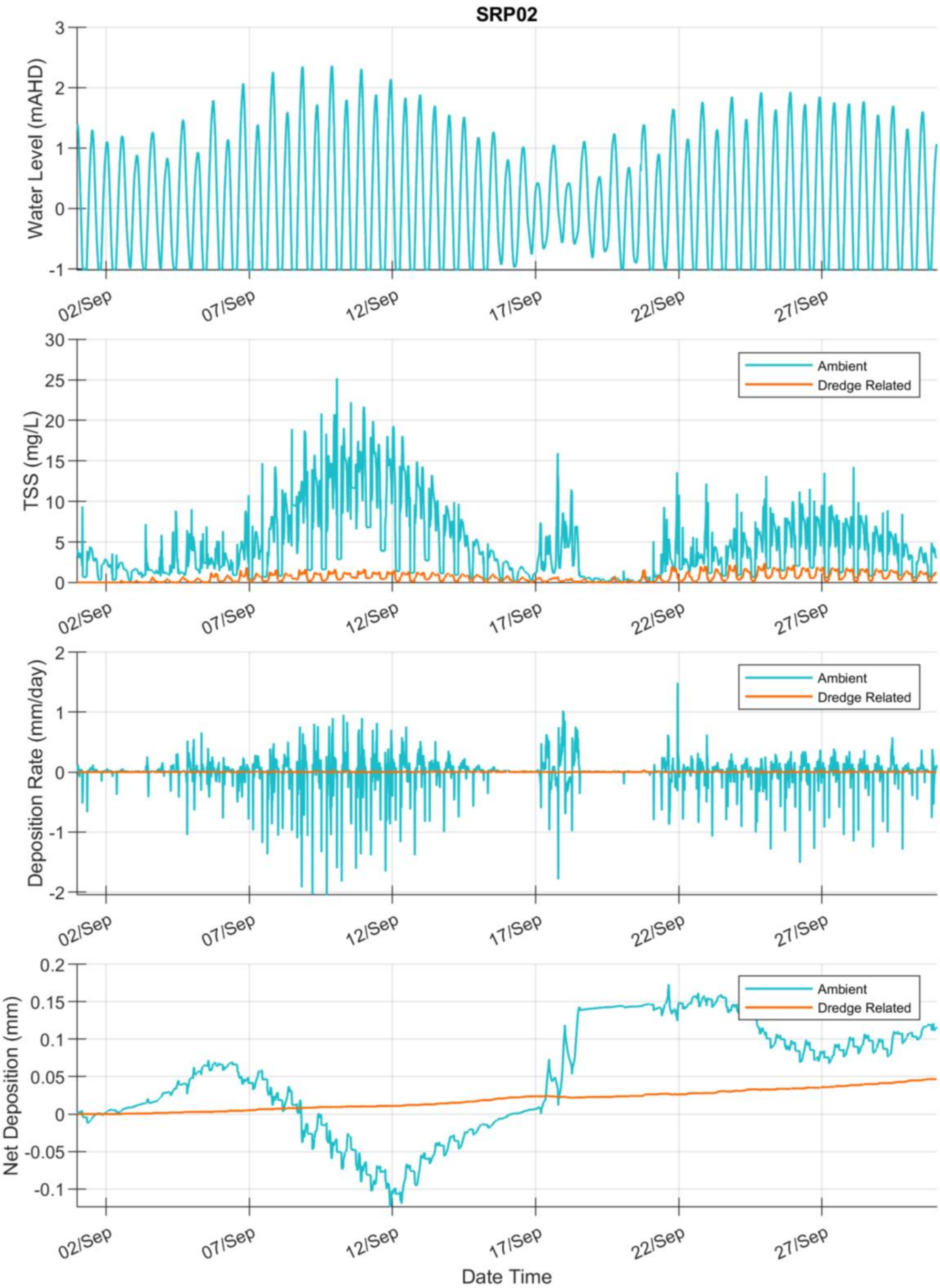

Figure 10. Time series showing natural (ambient) and dredge related SSC and deposition at SRP02 for when 50,000 m^3 of sediment is released at the Marina DMPA (BMT, 2020).

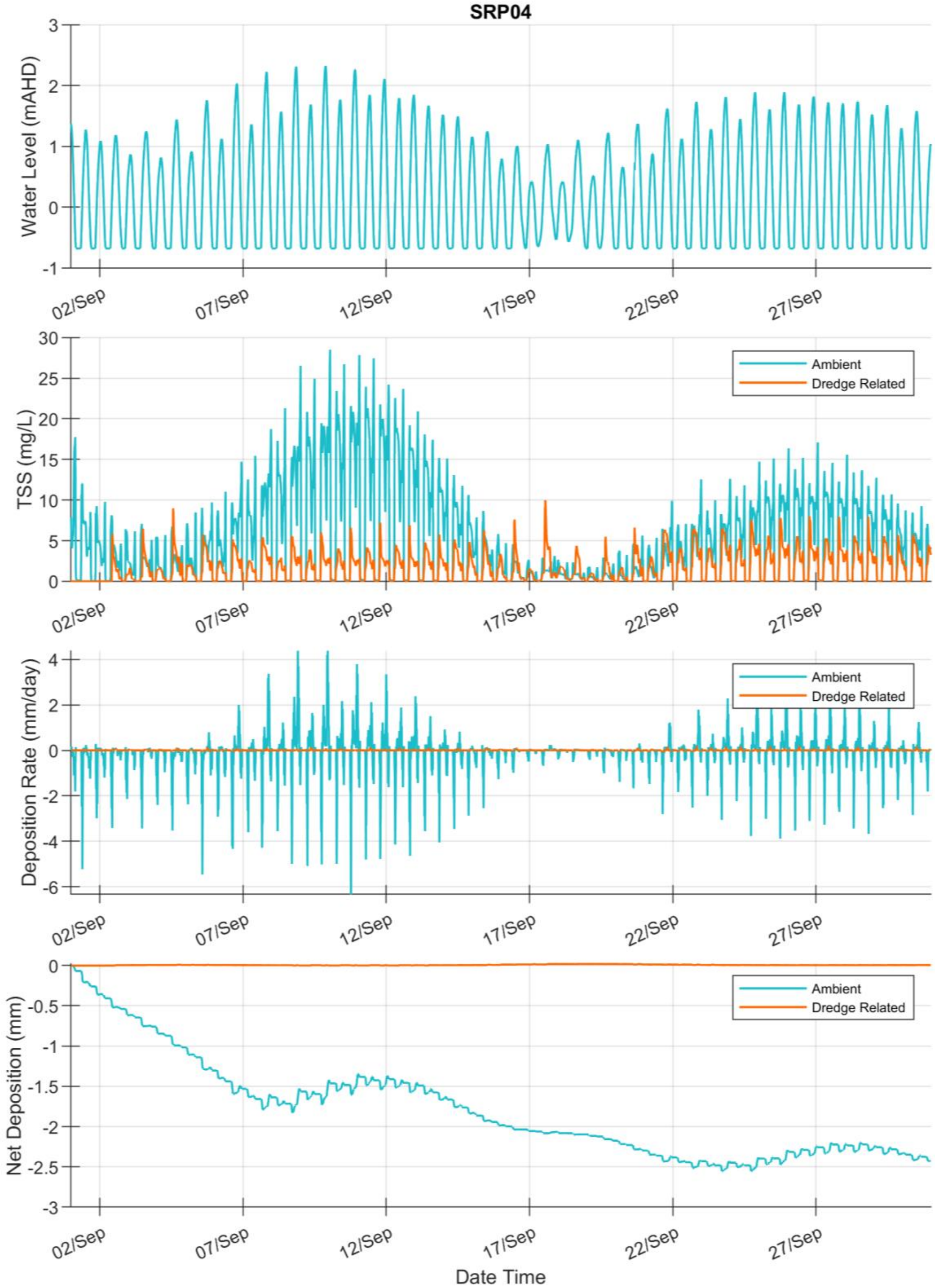

Figure 11. Time series showing natural (ambient) and dredge related SSC and deposition at SRP04 for when 50,000 m^3 of sediment is released at the Marina DMPA (BMT, 2020).

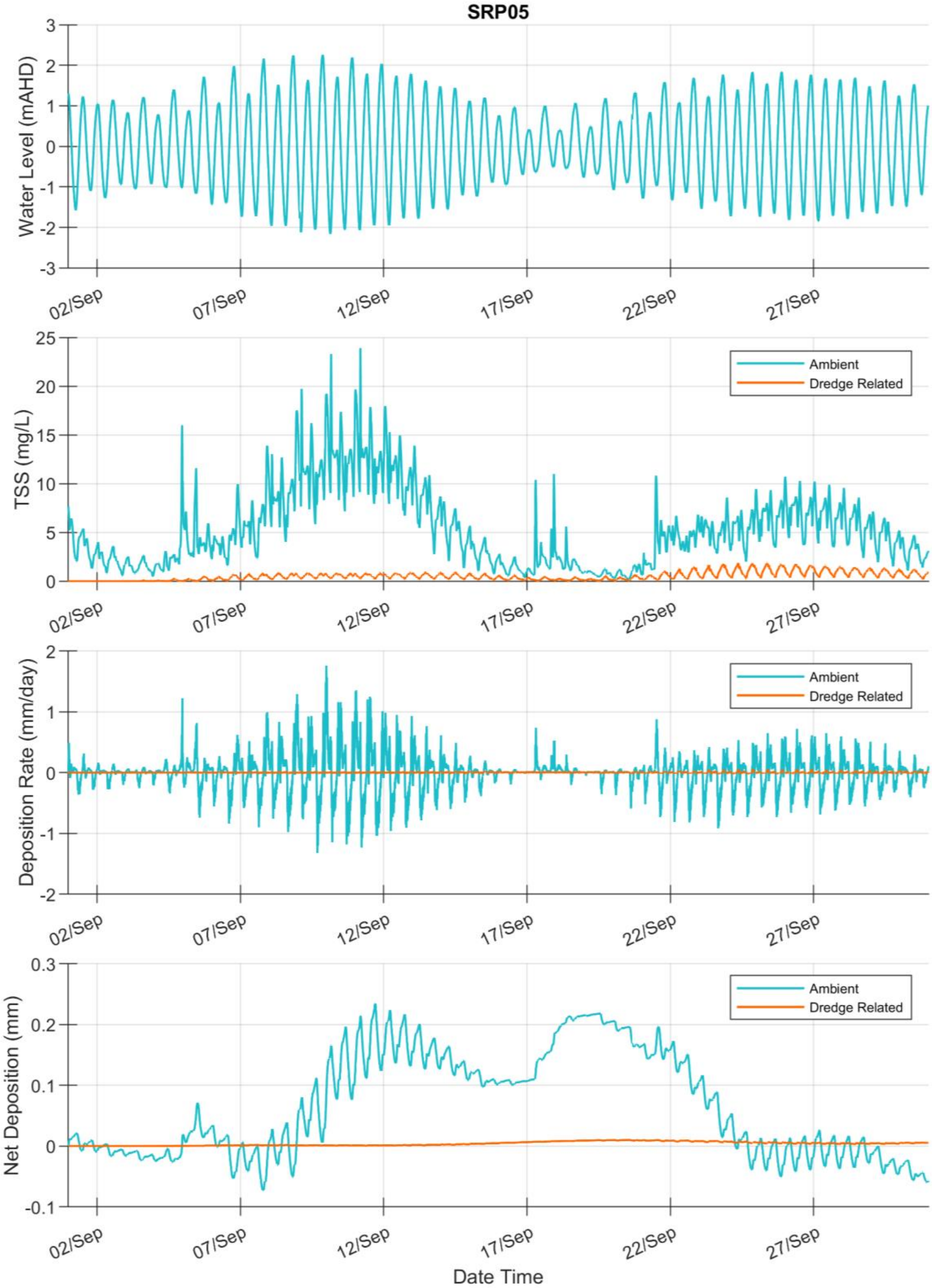

Figure 12. Time series showing natural (ambient) and dredge related SSC and deposition at SRP05 for when 50,000 m³ of sediment is released at the Marina DMPA (BMT, 2020).

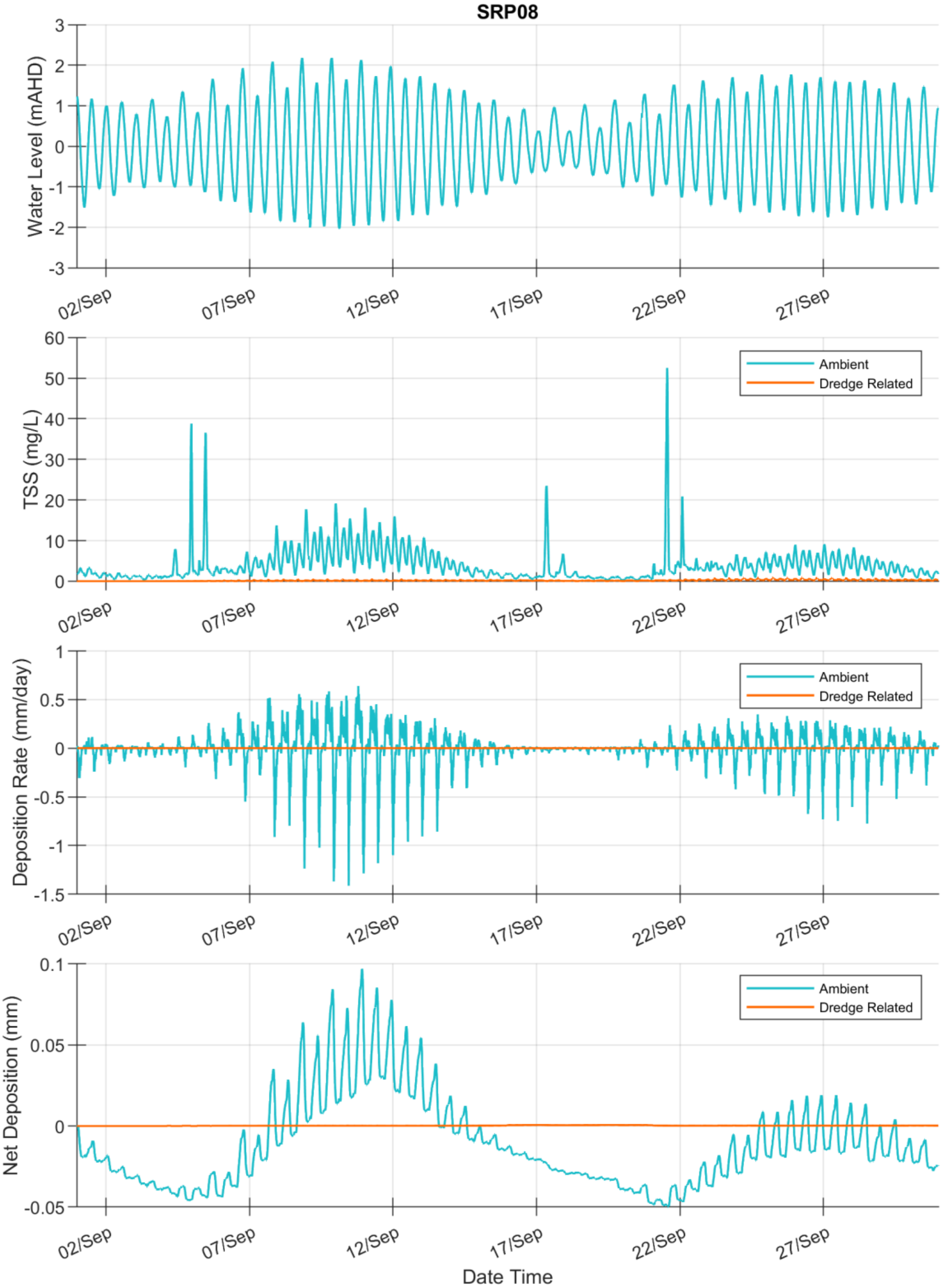

Figure 13. Time series showing natural (ambient) and dredge related SSC and deposition at SRP08 for when 50,000 m^3 of sediment is released at the Marina DMPA (BMT, 2020).

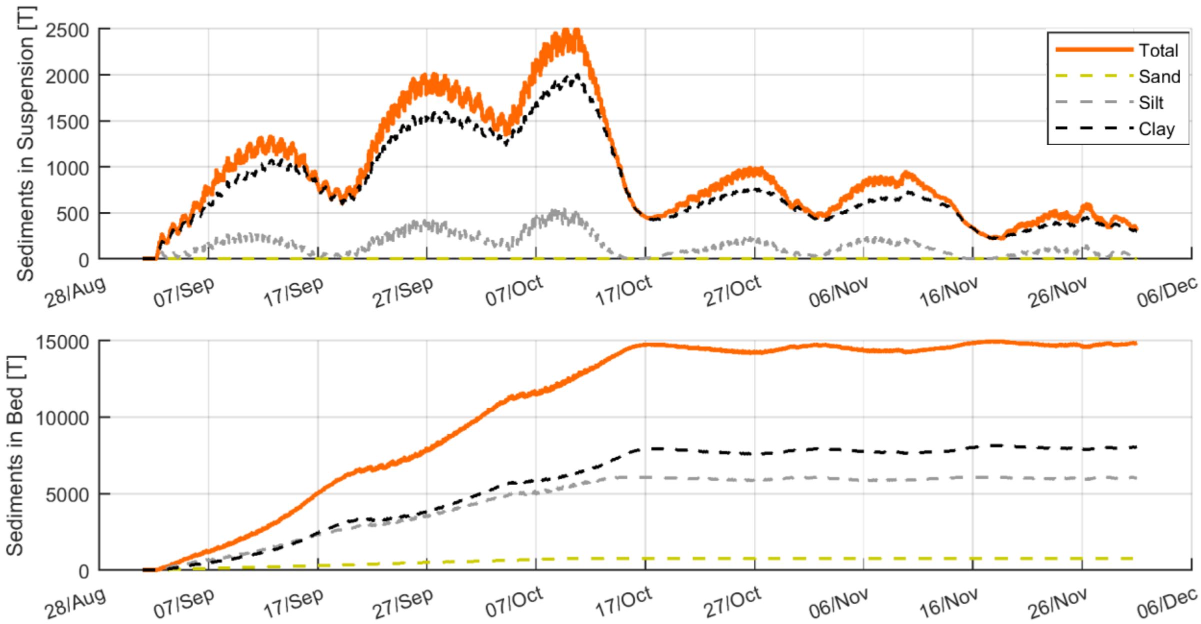

Figure 14. Time series of the mass of sediment in suspension and on the seabed over the 3 month model simulation for 50,000 m^3 of sediment released at the Marina DMPA (BMT, 2020). *Note: sediment release ended on 10th October 2018.*

4.3.2. Five Yearly Volume

The model predicted maximum 95th percentile turbidity calculated over a two-week sliding window within the six-month simulation as well as the predicted final deposition thickness at the end of the six-month simulation are shown in Figure 15 to Figure 18. The predicted deposited sediment present in various areas at the end of the six-month simulation is summarised in Table 6.

The turbidity plot shows a predicted larger extent and higher turbidity compared to the results for the 50,000 m^3 dredge volume. The 95th percentile turbidity is predicted to exceed 3 NTU along the southern side of the channel between Fishermans Landing and South Trees Island, the downstream 5 km of the Calliope River and the area of intertidal to the east of Quoin Island. The 95th percentile turbidity shows that suspended sediment is predicted to be transported throughout much of Port Curtis, but with very little sediment predicted to be transported offshore through the southern or northern entrances.

As with the 50,000 m^3 dredge volume modelling results, the 200,000 m^3 results also show that there is predicted to be widespread deposition within Port Curtis, with most of the deposition predicted to be over the extensive intertidal and shallow subtidal areas and not directly in the main navigation channels (although some sediment is predicted to be deposited along the edge of the channels, predominantly to the west of the channels between Fishermans Landing and South Trees wharf). The summary of the model predictions of sediment deposition shows that just over 2% of the released sediment is predicted to be retained within the DMPA region and just over 5% is predicted to be transported back into the Marina. Approximately 15% of the sediment is predicted to be deposited in the historic intertidal seagrass regions (mainly in the area between Wiggins Island and Fishermans Landing, but also in the area between Barney Point and South Trees Point and the area around Quoin Island), but as previously noted these regions represent much of the intertidal zone in Port Curtis which are the areas that the approach is aimed at supplying sediment to. The results also show that just over 7% of the placed sediment is predicted to be deposited in the dredged channels of the PoG. A small amount of the sediment (0.1%) is predicted to be deposited at the coral reefs in Port Curtis, with the main area of coral reef predicted by the model to be at risk of increased deposition being the coral surrounding Turtle Island.

Table 6. Deposited sediment in different areas at the end of the 200,000 m^3 at the Marina DMPA model simulation.

Area	Mass (t)	% of Total Mass
Marina DMPA region	1,270	2
Marina	3,040	6
Seagrass in Port Curtis	7,750	14
Coral in Port Curtis	70	<1
Coral offshore of Port Curtis	0	0
PoG Dredged Areas[1]	4,040	7

[1] this excludes the Marina as this is included separately elsewhere in the table.
Note: total mass released as part of the simulation = 54,300 tonnes.

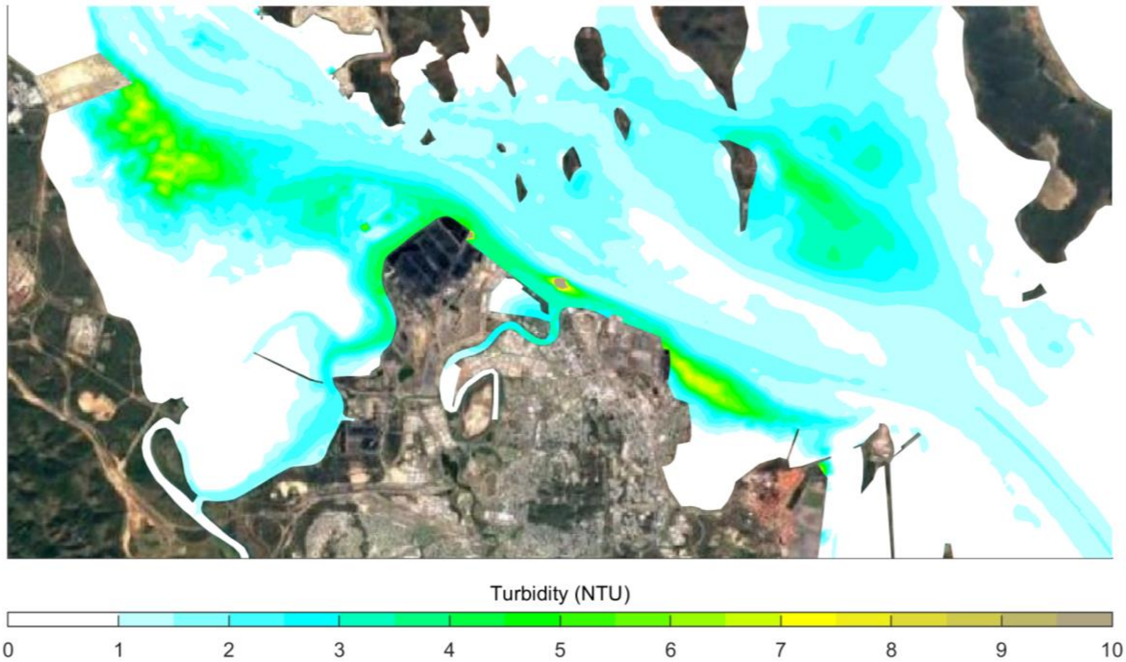

Figure 15. Maximum 95th percentile turbidity over two weeks for 200,000 m^3 of sediment released at the Marina DMPA (BMT, 2020).

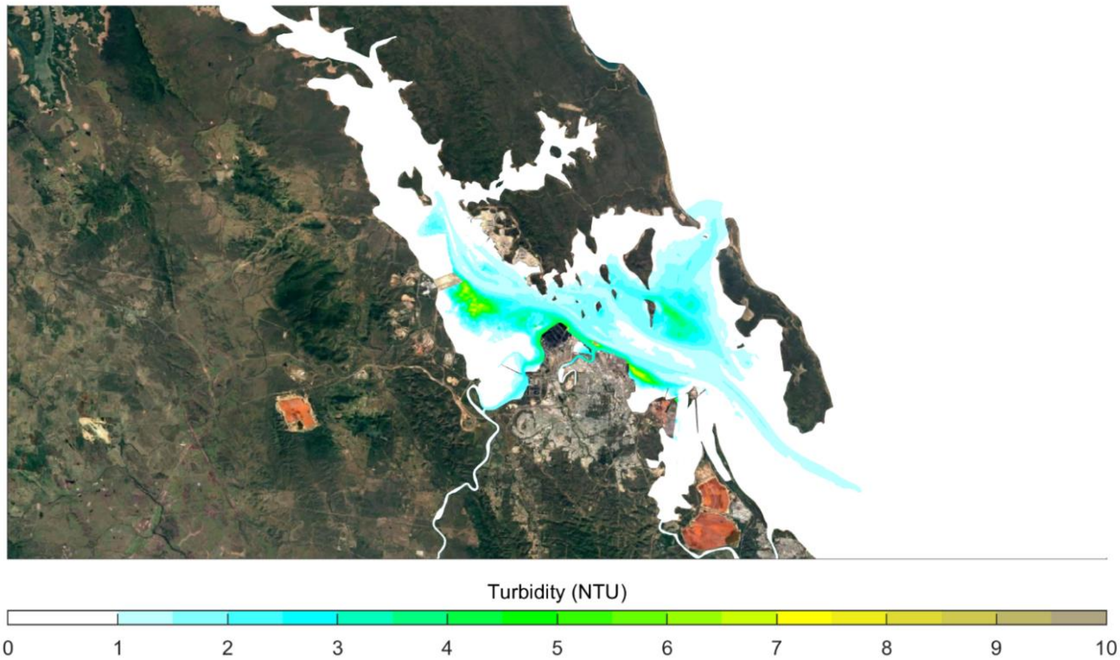

Figure 16. Zoomed out maximum 95th percentile turbidity over two weeks for 200,000 m^3 of sediment released at the Marina DMPA (BMT, 2020).

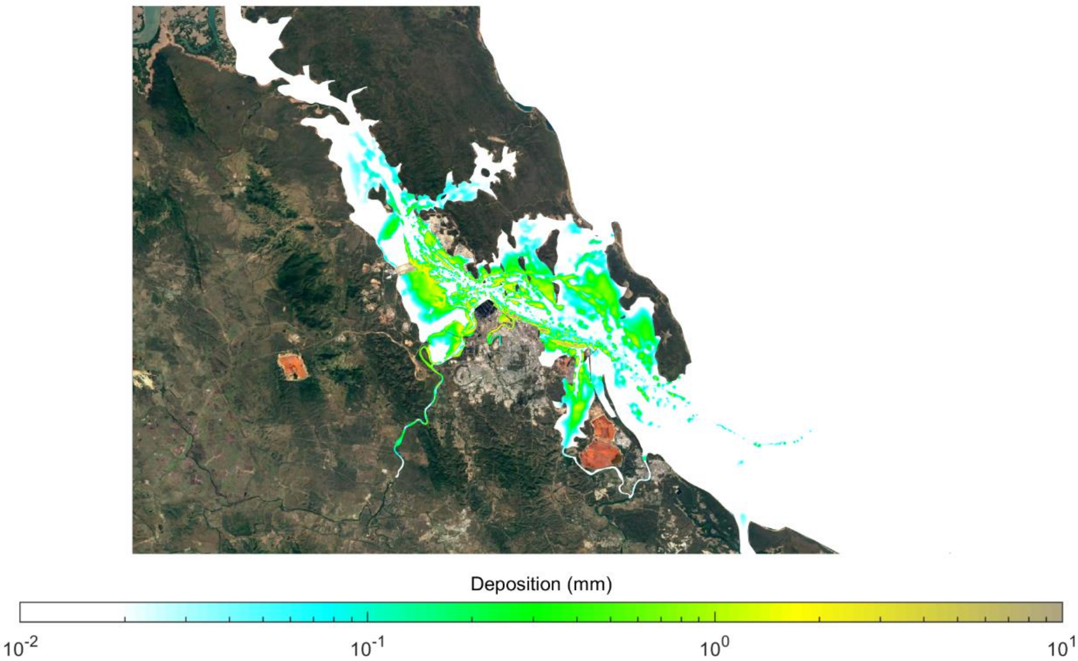

Figure 17. Final deposition of the sediment for 200,000 m^3 released at the Marina DMPA (BMT, 2020).

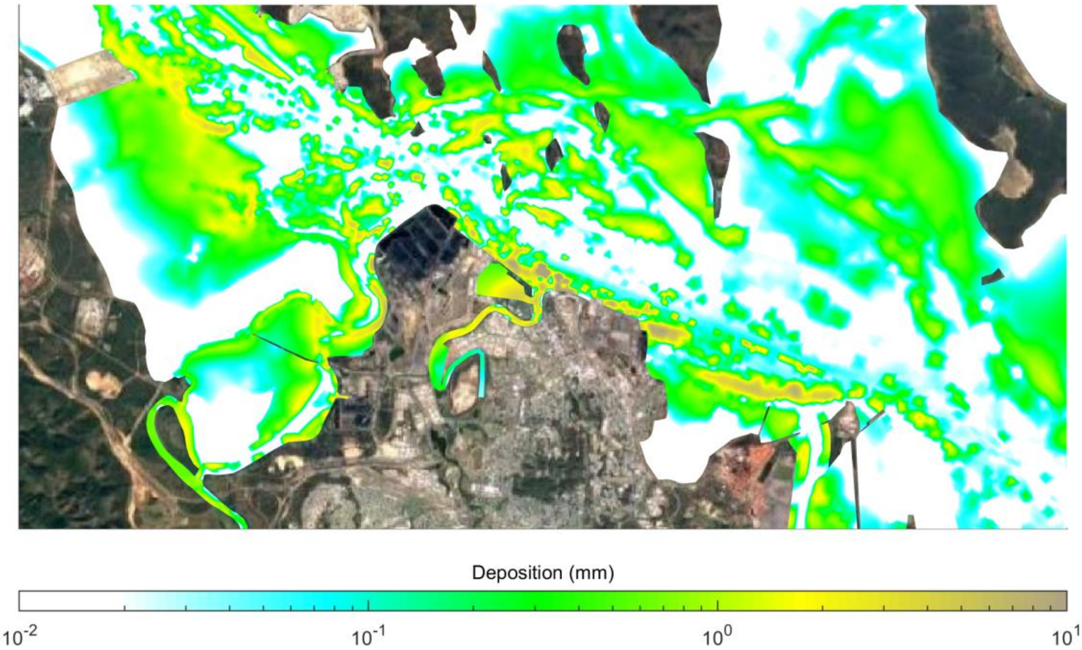

Figure 18. Close up of final deposition of the sediment for 200,000 m^3 released at the Marina DMPA (BMT, 2020).

Time series plots of the model predicted SSC and deposition resulting from the release of sediment at the Marina DMPA are shown at some of the sensitive receptor sites in Figure 19 to Figure 22. The model results suggest the following:

- the SSC resulting from the release of sediment at the Marina DMPA are predicted to be low relative to the natural conditions at the sensitive receptors. The SSC is predicted to remain below 2 to 3 mg/l at the sensitive receptor sites except for at SRP04 (seagrass site) where short duration spikes in SSC of more than 5 mg/l are predicted to occur during the release of sediment at the Marina DMPA (they quickly reduce once the release finishes at the start of February). However, the SSC due to the natural conditions is typically still predicted to be two (2) to four (4) times larger than the SSC from the Marina DMPA sediment release; and
- at the end of the six-month simulation, none of the sites are predicted to result in a net build-up of sediment due to the release of sediment at the Marina DMPA[2]. Therefore, the natural deposition and erosion at the sites is predicted to dominate the changes. However, the spatial map of deposition shows that widespread deposition is predicted to occur in Port Curtis due to the release at the Marina DMPA, with much of the deposition predicted to occur over the intertidal and shallow subtidal areas which was one of the aims of the approach.

The predicted mass of sediment in suspension and on the seabed over the duration of the six-month simulation is shown in Figure 23. The plot shows that the model predicts the released sediment to be deposited relatively quickly following release and that 1 month after the cessation of the release less than 4% of the released sediment would be in suspension with the remaining sediment predicted to be deposited on the seabed.

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[2] This differs to the results for the 50,000 m^3 of sediment at SRP02. This is due to the longer duration of the release and simulation, as it can be seen that up to the 6th December deposition did occur (which was after the end of the simulation for the 50,000 m^3 volume) and after this a change in metocean conditions (increased wind speeds) resulted in erosion of the deposited sediment at the site.

As previously noted, the limitations and uncertainties associated with the model results must be considered when interpreting the results. The model results show comparable increases in SSC resulting from the option at the nearby sensitive receptors as with the annual volume, this result is considered to have a relatively high confidence. However, there is more uncertainty associated with the deposition patterns predicted by the model given that the model hasn't been calibrated to deposition and that the natural and dredge related deposition temporal patterns differ significantly.

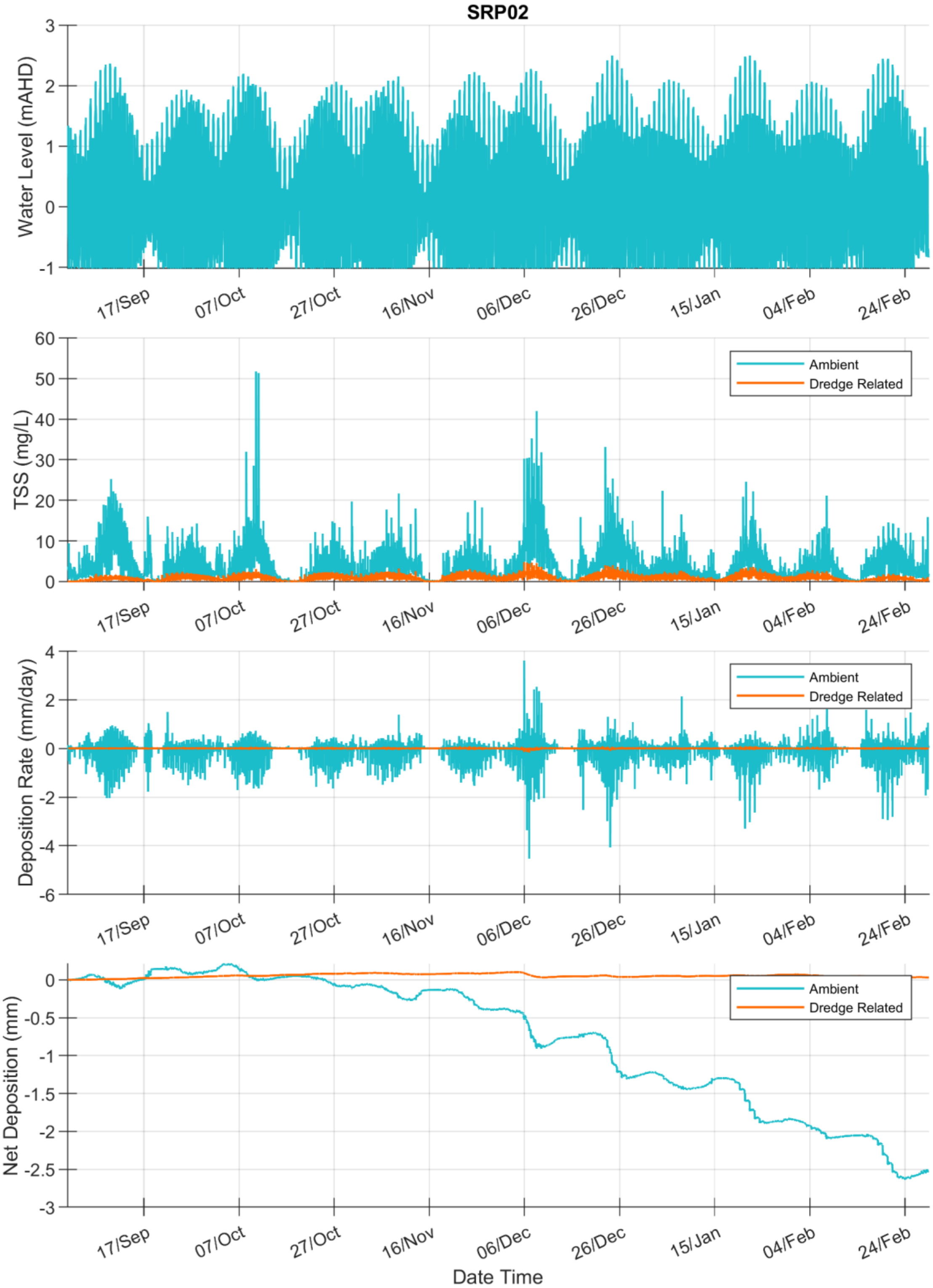

Figure 19. Time series showing natural (ambient) and dredge related SSC and deposition at SRP02 for when 200,000 m^3 of sediment is released at the Marina DMPA (BMT, 2020).

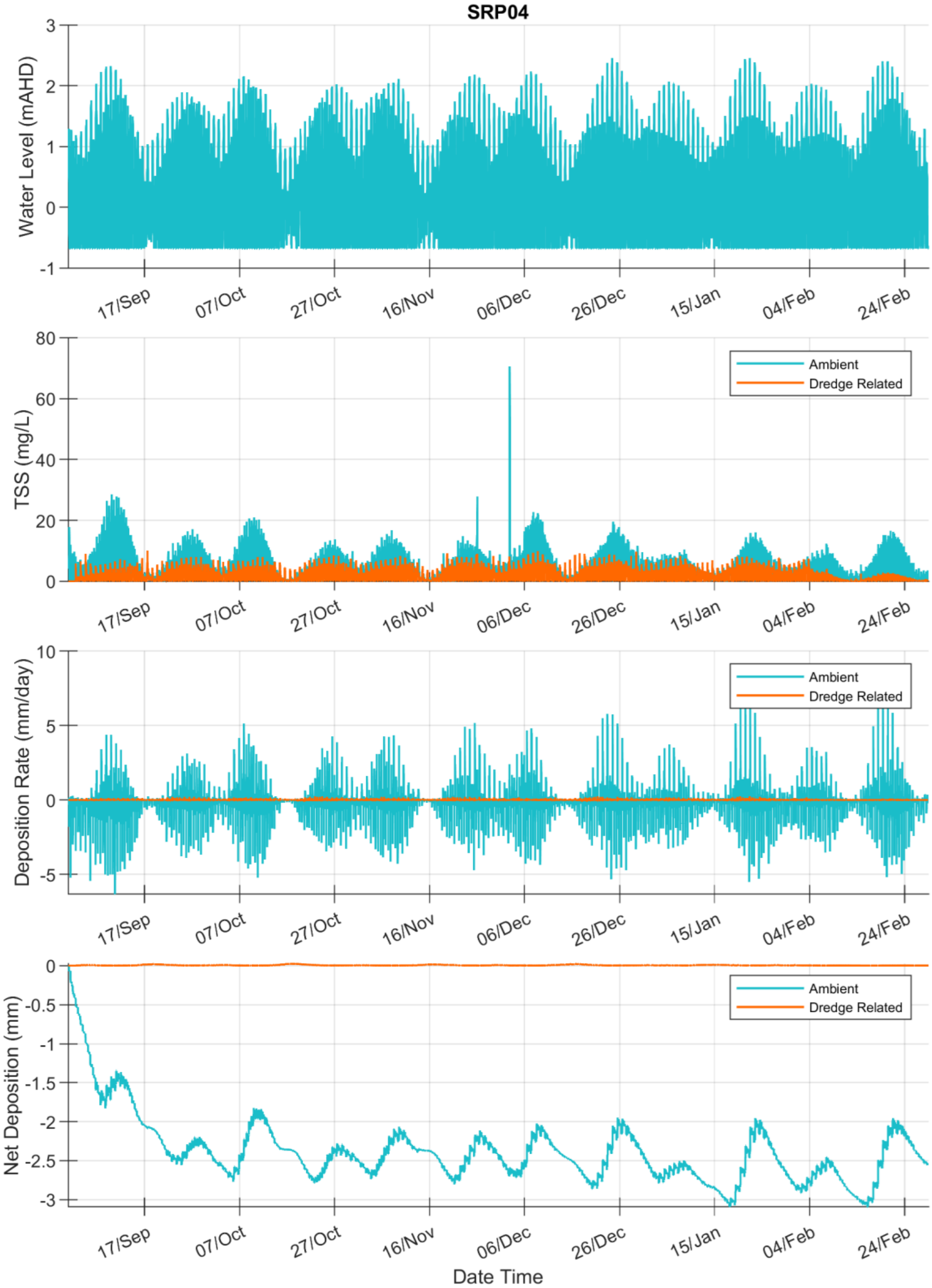

Figure 20. Time series showing natural (ambient) and dredge related SSC and deposition at SRP04 for when 200,000 m^3 of sediment is released at the Marina DMPA (BMT, 2020).

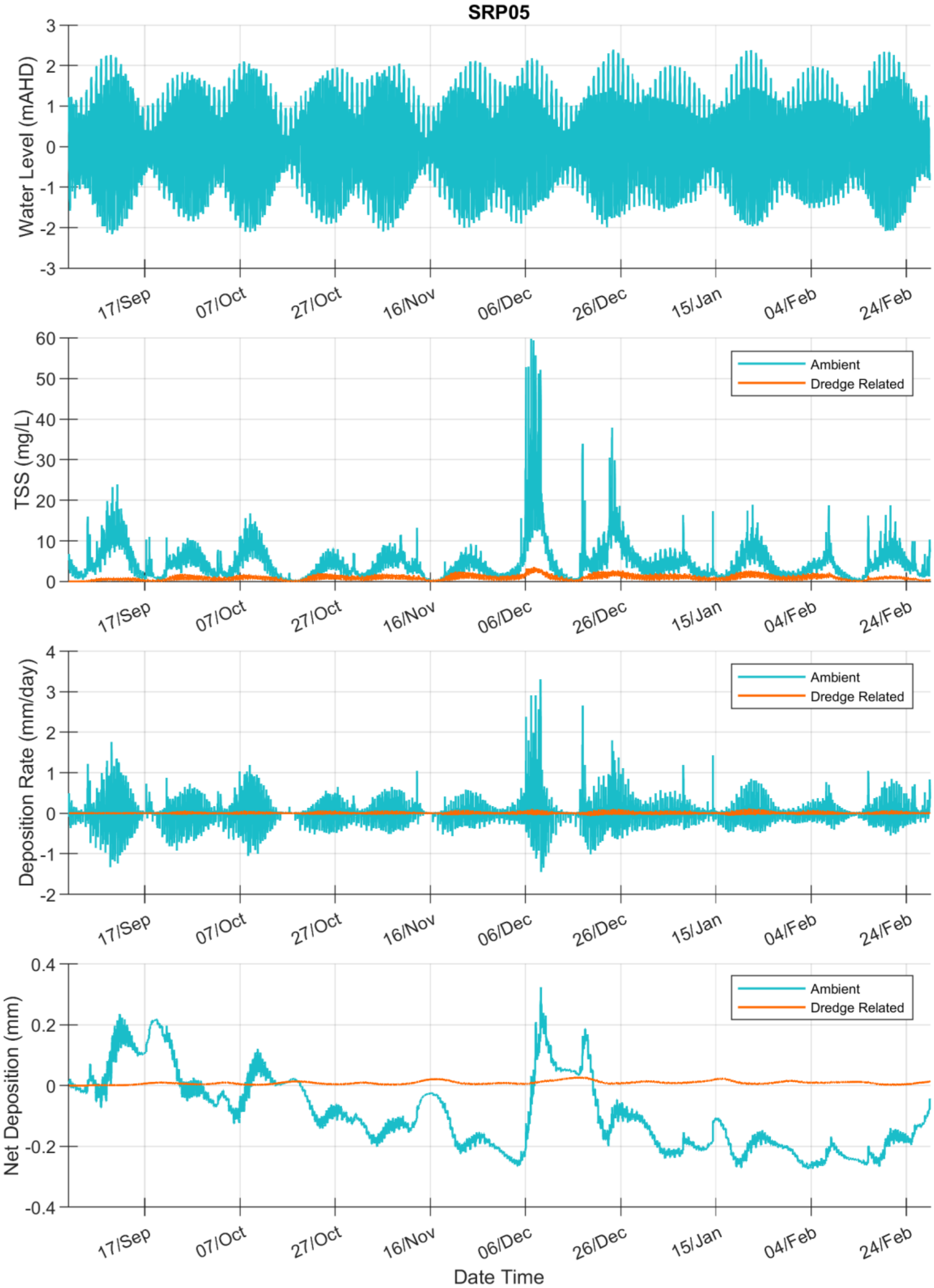

Figure 21. Time series showing natural (ambient) and dredge related SSC and deposition at SRP05 for when 200,000 m^3 of sediment is released at the Marina DMPA (BMT, 2020).

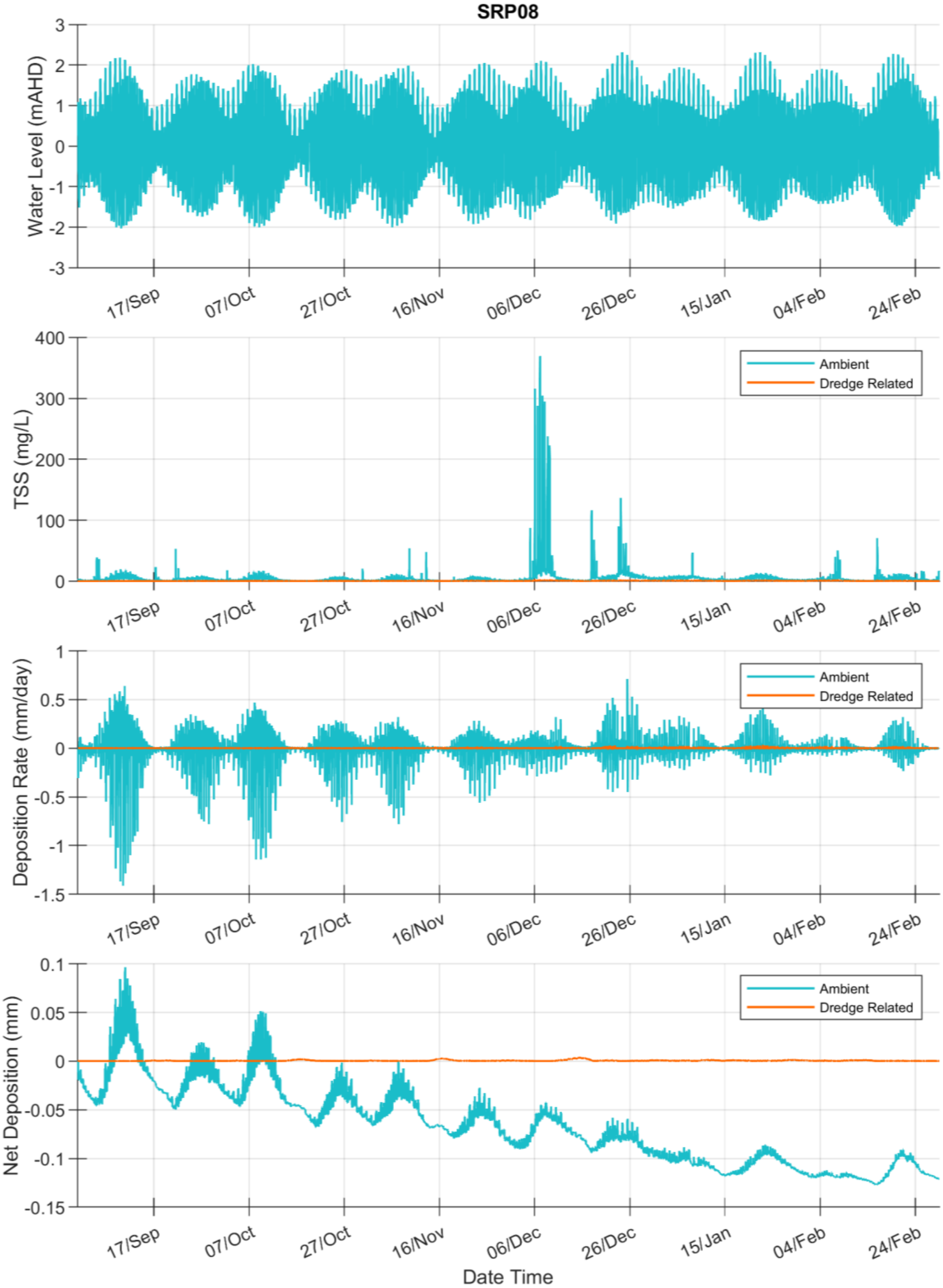

Figure 22. Time series showing natural (ambient) and dredge related SSC and deposition at SRP08 for when 200,000 m^3 of sediment is released at the Marina DMPA (BMT, 2020).

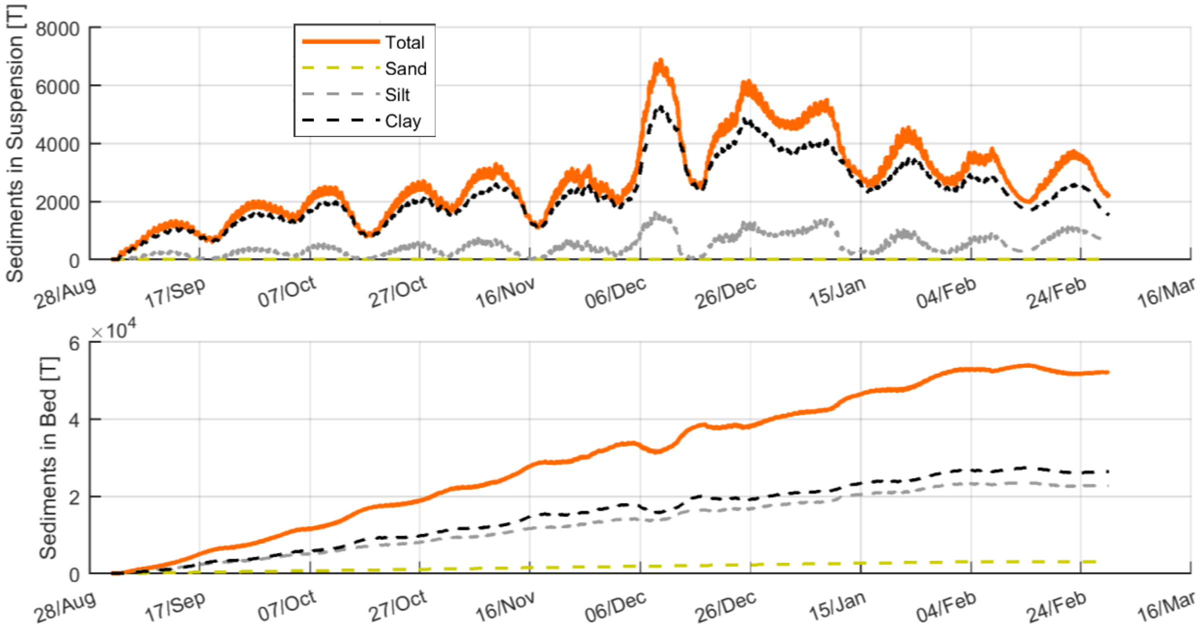

Figure 23. Time series of the mass of sediment in suspension and on the seabed over the 6 month model simulation for 200,000 m^3 of sediment released at the Marina DMPA (BMT, 2020). *Note: sediment release ended on 3rd February.*

5. Feasibility

This section provides a summary of the feasibility assessment for the sustainable relocation approach for the Marina and based on the results provides recommendations for further work.

5.1. Likelihood of Success

While considering the limitations and uncertainties associated with the model, the model predictions, along with other evidence and information, suggest that the proposed sustainable relocation approach using the Marina DMPA has the potential to be successful for the following reasons:

- the majority of the released sediment is predicted to be transported away from the Marina DMPA (i.e. the placement site is expected to be dispersive as was intended);
- the model suggests that the SSC of the sediment transported away from the Marina DMPA is predicted to generally be of a low concentration with the elevated SSC predicted to reduce quickly following completion of the dredging;
- the majority of the sediment is predicted to remain within the active sediment system within Port Curtis;
- the modelling results predict a widespread thin layer of sediment deposition throughout much of Port Curtis, with sedimentation predicted to occur in many intertidal and adjacent subtidal areas as was intended. The majority of the sediment is predicted by the model to be deposited to the west of the designated channels between Fishermans Landing and South Trees wharf;
- increases in SSC and deposition at the sensitive receptors within Port Curtis are predicted to generally be low relative to the natural variability. The only exception to this is predicted to be the historic seagrass area on the intertidal zone adjacent to Wiggins Island, where the relatively small increase in turbidity predicted is not expected to result in an impact to the habitat; and
- although some of the sediment placed at the Marina DMPA is predicted to subsequently be redeposited in the Marina and PoG channels, the model results suggest this is a relatively small amount (3 to 6% in the Marina and 7 to 8% in the dredged channels). This amount of deposition is unlikely to result in significant navigational impacts or increased maintenance dredging requirements, although it is important to note that there are some inherent uncertainties in the modelled deposition due to the complexities of the processes.

5.2. Impacts, Costs and Limitations

Based on a number of assumptions and considering the limitations of the numerical model, the results have predicted that increases in SSC and deposition at sensitive receptors within Port Curtis resulting from sediment being released at the Marina DMPA are generally small relative to natural conditions. The risk of any impacts to the sensitive receptors are likely to increase when the volume of sediment released at the Marina DMPA increases as even though the magnitude of predicted impacts to SSC at the sensitive receptors are similar, the risk of impacts is increased by the increased duration of the activity. In terms of potential impacts from deposition, the modelling predicts that the ongoing build-up of sediment released at the Marina DMPA varies depending on the metocean conditions, with the natural sedimentation generally predicted to be significantly larger than the sedimentation resulting from the release.

When the dredge duration and cost of release at the Marina DMPA are compared to ongoing placement onshore (regardless of the fact there is not expected to be sufficient capacity for future onshore placement beyond the 2020 maintenance dredge), placement at the Marina

DMPA is predicted to result in an increase in both time and cost. Over five (5) years the predicted cost of placing the sediment onshore is (assuming a single campaign) is $2.5 million, while the predicted cost of releasing the sediment at the Marina DMPA (assuming five (5) separate annual campaigns) is $3.3 million. The duration of the dredging is estimated to be 93 days if the sediment is placed onshore and 155 days (five (5) annual campaigns lasting 31 days each) if the sediment is released at the Marina DMPA.

It is likely that the Marina DMPA sustainable relocation site could be used as a long-term placement option given the dispersive nature of the site predicted by the numerical modelling. However, there remains some uncertainty with various aspects of the modelling. Carrying out field monitoring is critical in order to provide GPC with greater confidence in terms of the use of the Marina DMPA including how much sediment can be placed at the DMPA during each maintenance dredging campaign. To determine whether annual maintenance dredging campaigns should be undertaken or whether less frequent, larger volume campaigns would be preferable, monitoring would be required during an annual campaign to initially confirm that the approach is effective in terms of dredged sediment not returning to the Marina or channels and also does not have the potential to impact any sensitive receptors before any larger volume campaigns could be considered.

It is important to note that the dredging cannot be undertaken by the TSHD Brisbane as part of its annual maintenance dredging campaign as the vessel is too large to dredge in the Marina. As such, the dredging would require the mobilisation of a specific dredger as well as the installation of the pipeline.

5.3. Recommendations

Based on the findings of this feasibility assessment the approach of sustainable relocation of sediment from the Marina to the Marina DMPA is considered feasible. The findings suggest that the approach has the potential to provide the following benefits:

- it would help to keep existing natural sediment within Port Curtis and assist in distributing the sediment throughout the region. This in turn has the potential to help habitats accrete at a comparable rate to sea level rise which would reduce the risk of any changes to habitat due to increased water depths;
- based on the modelling results, it appears that the majority of the sediment released at the Marina DMPA is predicted to be transported away from the DMPA and distributed throughout much of Port Curtis. This is what the approach was designed to do, redistributing the sediment within Port Curtis and providing an ongoing sediment supply;
- the numerical modelling suggests a low risk of impacts to any other sensitive receptors due to the release as well as a low risk of any significant increased sedimentation in the dredged channels; and
- the option represents a 30% increase in cost relative to placing the sediment onshore and given the potential environmental benefits to Port Curtis, this is not considered to be a significant increase.

5.3.1. Pilot Study

As this feasibility assessment has found that the sustainable relocation of sediment from the Marina to the Marina DMPA to potentially be feasible, it is suggested that a pilot study should be undertaken. This will give the opportunity to further assess the feasibility of the approach through monitoring of the pilot study and will also act to reduce any uncertainties prior to making a decision as to whether this approach could be adopted as a long-term solution. Undertaking a pilot study along with monitoring is an important requirement prior to adopting long-term solutions as it provides physical measurements which, as noted by the analogue of the Mud Motor, can differ from numerical modelling results (see Section 2.3).

As noted in Section 5.2, the TSHD Brisbane is not able to dredge the Marina as it is too large. It is also not realistic to undertake a small scale pilot study using the dredging approach detailed in Section 3.3, with a medium CSD and pipeline, as the mobilisation costs and pipeline installation costs would be too high. Instead, in order to ensure that the placement replicates as closely as possible the proposed future dredging operations, it is proposed that the small scale trial could be undertaken by TSHD Brisbane during an annual maintenance dredging campaign for the PoG. This would involve the following:

- the TSHD Brisbane dredging one or more hopper loads of sediment from the LNG Terminals region (as this has a similar percentage of silt and clay (>90%) to the sediment from the Marina);
- sailing to the Marina DMPA and the TSHD Brisbane then lowering one of its suction arms to just above the seabed and then pumping the sediment out of the suction head (the dredger can reverse the dredging pump to allow it to pump sediment as well). The rate the sediment is discharged at will likely be higher than the rate expected for the Marina discharge using a CSD, but the results can still be used to better understand the dispersion and fate of the sediment released at the Marina DMPA; and
- once the dredging has been completed and the TSHD Brisbane has undertaken the agreed number of hopper loads it would sail to the next dredge area and continue dredging.

It is recommended that at least two (2) loads of fine-grained sediment from the LNG Terminals region is placed at the Marina DMPA, one during the flood and one during the ebb stages of the same tidal cycle. The dredge cycle is estimated to be approximately four (4) hours (assuming the pump out duration is approximately two (2) hours) and so it is possible for two (2) loads to be placed either side of high/low water immediately after each other. The pilot study could be undertaken as part of any annual maintenance dredging campaign, with no additional requirements in order for the TSHD Brisbane to be able to undertake the dredging and placement.

5.3.2. Monitoring

In order to determine the success of the option, monitoring will be required as part of the pilot study. The monitoring would have the following key aims:

- to determine whether the Marina DMPA acts as a dispersive placement site when fine-grained sediment in placed there;
- to determine where sediment transported away from the placement area is transported and deposited around Port Curtis; and
- to identify whether the placement of sediment has the potential to result in any negative impacts to sensitive receptors in Port Curtis.

To achieve these aims, a monitoring campaign will be required, this is detailed in the following sub-sections. It has been assumed that ongoing monitoring of the key sensitive receptors within Port Curtis (seagrass and coral reefs) will continue to be undertaken by GPC including samples which can be analysed for sediment tracers released and will not therefore require specific focused monitoring as part of this pilot study.

The cost of the detailed monitoring proposed as part of the pilot study are expected to be in the order of $400,000 to $500,000 and so is important to consider as it could influence the feasibility of the approach for GPC. The detailed monitoring outlined in the following sections would only be required for the initial pilot study. It is not expected that any subsequent dredge campaigns when placement occurs at the Marina DMPA would require such detailed monitoring. The scale of ongoing monitoring required would be dependent on the results of the pilot study monitoring, but it is possible that an ongoing monitoring site in the area would be required with monitoring costs likely to be in the order of thousands to tens of thousands of dollars per year.If following the results from the monitoring the pilot study is deemed to have been a success, and the fate of the dredged sediment is understood, then there is the potential that the approach could subsequently be adopted as an annual maintenance dredging approach. With ongoing monitoring it could potentially be adapted so that it becomes a less frequent and larger volume maintenance dredging approach.

5.3.2.1. Tracer Investigation

An optimal way to provide evidence on the fate of the dredged sediment released at the Marina DMPA and also build a better understanding of sediment transport processes is using sediment tracers to label and track the material spatially and temporally. Sediment tracers assimilate all of the hydrodynamics and sediment transport processes including tidal currents, waves, wind-driven circulation, bedform, erosion-resuspension, transport and settling-deposition. In addition, sediment tracers can be introduced directly into a dredge hopper load to mimic the initial mixing and dispersal during dredge discharge and entrainment allowing both the near-field and mid- to far-field transport to be monitored.

Sediment tracers provide a direct, quantitative and unequivocal way of measuring whether movement of the sediment takes place (or not), how fast it is transported, where the material ends up over time and how long it remains in the target area, in this case within the wider area of Port Curtis including the navigation channel, berths, sensitive receptors and the wider environment.

Accurately modelling sediment transport, in particular fine-grained sediment (silt and clay), is extremely difficult within nearshore embayments and tidal estuaries especially deep-water ports where rapid changes in water depth, circulation and current velocities can occur along with natural intertidal and shallow subtidal environments. Models assume that fine-grained sediment are permanently in suspension once eroded or discharged into the marine environment. However, accurately predicting initial mixing and dispersal correctly during the near-field mixing from a pipeline and subsequent secondary transport are extremely difficult. Erosion-resuspension of fine-grained sediment from the bed in deeper navigation channels versus adjacent shallow intertidal/subtidal areas requires very different approaches particularly with regard to turbulence functions. This is also the case for dredge plumes where models have to assume and balance horizontal and vertical dispersion coefficients as dredge plumes dilute and disperse with assumptions on flocculation, settling and deposition parameters. Flocculation processes, and as a result settling and deposition, are affected by turbidity (along with turbulence) meaning that spatial or temporal changes in both can lead to further variations. Therefore, subtle changes in the model for turbulence, turbidity, dispersion coefficients, erosion-resuspension, flocculation and settling-deposition functions can make a significant difference to the predictions made.

To assess both whether the Marina DMPA acts as a dispersive release site as well as where sediment which is transported away from the release area is deposited, the use of sediment tracers is proposed. The tracers would have comparable properties to the sediment being placed, with silt/clay sized tracers being used. The tracers would be manually added to the hopper of the TSHD Brisbane when it has a full load of sediment from the LNG Terminals region which is going to be pumped out at the Marina DMPA. It is proposed that two (2) separate tracer colours should be used, one (1) for sediment placed during the flood tide and one (1) for sediment placed during the ebb tide. The tracer would then be pumped through the dredger suction arm along with all the sediment in the hopper at the Marina DMPA, followed by a thorough washdown of the hopper before transit from the site and the next hopper load.

It is recommended that on the day when the sediment tracers are released, vessel-mounted ADCP data (current velocity and backscatter), vertical profiling of salinity, temperature and depth and turbidity is carried out to obtain background information on the water movement and circulation in the water column during release. These data may help to determine the optimum depth to discharge the dredge material. In addition, it is proposed to carry out gated water sampling at set distances downstream of the dredge discharge, to calibrate the turbidity logger and ADCP backscatter data and convert it to SSC and also measure tracer concentrations in the water column. These data can be used to determine the horizontal and vertical mixing coefficients or dilution based on the source term concentration and that measured in the water-column downstream. These measurements will provide data to calibrate the sediment transport model and allow a comparison between model predictions and measured field data along with an initial dispersal and dilution of the dredge discharge plume. The latter may also help to streamline any sampling for subsequent monitoring.

Ongoing sediment sampling and analysis after the placement activity would be required to assess the transport and fate of the placed sediment. It is expected that this would involve the following:

- collection of background samples from the study area to determine if any coloured or fluorescent material is present that may interfere with the sediment tracers to be used. Approximately 100 sediment samples from the area will be collected and analysed; ideally this would be done in advance of deciding on which sediment tracers and colours will be used;
- once the two (2) different coloured sediment tracers are released, it is proposed to collect approximately 350-400 sediment grab samples per single sampling campaign from the Marina DMPA, adjacent areas to the placement site, navigation channels and berths including inside Marina itself, sensitive receptor sites both upstream and downstream of the DMPA and other areas where the modelling predicted high sedimentation;
- four (4) or five (5) separate sediment sampling campaigns will be undertaken 2, 4, 8 and 16 and 26 weeks after the completion of the placement activity (and completion of the annual maintenance dredging campaign) subject to the initial results;
- laboratory analysis of the background, dredge plume and seabed grab samples to determine the amount of tracer present for each release; and
- interpretation of the tracer results to estimate the retention of placed sediment at the site and the fate of any of the placed sediment which was transported away from the site.

There are a number of different sediment tracers that could be adopted for the monitoring, these are detailed below:

- artificial fluorescent silt and sand tracers, EcoTrace particles[3], that can be adjusted in terms of size and density to match the ambient sediment. EcoTrace particles have been used in the vast majority of tracer studies to date (including all previous projects in Australia) with material being tracked from multiple sources using different fluorescent colours for up to five (5) years in very high energy environments. Scientifically, EcoTrace particles represent the optimal sediment tracer in terms of being robust for tracking over months/years, minimal product needed per release and highest detectability. In the case of EcoTrace silt tracer particles, they form as part of natural fine sediment flocs and therefore move, settle and deposit mixed in with natural fine sediment. This is critical to

[3] It should be noted that EcoTrace particles contain polymer as part of the manufacturing process and even though the polymer content can be reduced to <15%, with the remaining >85% comprising all-natural occurring materials, use of polymer in some cases is less acceptable in the marine environment. Use of both recycled polymer and biopolymer (made solely from plant-based material) have been actively researched, however some parties/groups feel that anything ‘polymer’ even recycled polymer or plant-based should not be used. In addition to reducing the percentage of polymer used, detection limits have been improved for the EcoTrace particles by 150-200% which in turn has reduced the quantity of tracer needed to be released into the environment for each study or site. In terms of sediment tracers, EcoTrace offer by far the most cost-effective, accurate and tried and tested sediment tracer option and represents significant research and development carried out over 20 years to successfully manufacture, test and analyse the particles. However, non-polymer options are becoming available. However, these require a greater volume of particles to be released versus EcoTrace particles (increasing manufacturing, shipping, handling and release requirements) and have a lower detection limit.

ensure the same behaviour, processes and fate and has been studied, tried and tested over more than 30 years including more than 75 silt particle tracing studies and related laboratory analysis;

- stained or marked natural silt and sand grains, GeoTrace particles, that use material from the study site. However, these particles are only suitable for studies of a few days due to the marker being abraded and washing off the particles making them very difficult to detect over time. Therefore, this type of tracer is not considered suitable in this case; and
- non-polymer coloured silt and sand tracers, that have a fixed density of 2,650 kg/m^3 and available in a limited number of colours. Given they are not fluorescent, the detection limits are lower than the EcoTrace fluorescent particles requiring more material to be released and lower detection limits. To date, the non-polymer tracers have only had lab-scale trials, however they are proposed to be used in small-scale field studies during 2020.

6. Summary

This assessment has considered the feasibility of an alternative option to manage sediment from maintenance dredging for the Gladstone Marina. The option is the sustainable in-channel relocation of sediment from the Marina. It involves pumping low concentration fine-grained sediment from the Marina to the edge of the Clinton Channel, with the aim of the sediment subsequently being transported within the Inner Harbour and providing additional sediment input to intertidal regions whilst not resulting in an increase in sedimentation in any dredged areas. The option was identified as part of the SSM project reduce assessment and subsequently assessed by stakeholders and based on this it was considered a preferred option and considered in a feasibility assessment.

An option development was undertaken and as part of this a number of possible pipe discharge locations were considered, with a site with depths approximately 10 m below LAT adjacent to Clinton Channel being preferred as it has higher current speeds the risk of any sediment which is not immediately transported away causing any issues to navigation are low. A medium CSD is proposed for the dredging, with the dredger pumping between 40,000 and 50,000 m^3/yr of fine-grained sediment from the Marina to the edge of the Clinton Channel each year. Numerical modelling was undertaken as part of the feasibility assessment and the results predicted that any increases in SSC and deposition to sensitive receptors within Port Curtis resulting from placement at the Marina DMPA are generally small relative to natural conditions. Based on these results, the risk of any impacts to nearby sensitive receptors is considered to be low.

When the dredge duration and cost of placement at the Marina DMPA are compared to ongoing onshore placement at the ponds adjacent to the Marina (despite the fact there will not sufficient future capacity in the ponds), placement at the Marina DMPA results in a 30% increase in cost and a 65% increase in time over a five (5) year period. This assumes that the onshore placement would be undertaken once every five (5) years, while the pumping to the Marina DMPA would be undertaken annually to ensure the sediment remained loosely consolidated.

Based on the findings of this feasibility assessment the approach of sustainable in-channel relocation of sediment from the Marina to the Marina DMPA is considered feasible. Based on the results from the numerical modelling the Marina DMPA appears to be dispersive meaning that it has the potential to be used as a long-term placement option. The numerical modelling results indicate that placing sediment at the Marina DMPA results in low SSC and deposition compared to the natural conditions at the nearby sensitive receptors. However, there remains uncertainty due to the complexity of the processes being modelled and so it is proposed that an initial pilot study be undertaken as well as ongoing monitoring to confirm that there is no significant build-up of sediment at the Marina DMPA and that the approach does not result in impacts to any sensitive receptors. Details of the pilot study, which proposes that at least two (2) loads of sediment from the TSHD Brisbane is placed at the Marina DMPA, and the associated monitoring are provided.

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