PORT OF **WEIPA**

APPENDIX D

Engineering and technical solutions

Port of Weipa: Sustainable Sediment Management Assessment

Engineered and Technical Solutions

Report No. P007_R05F1

Technical Report
May 2019

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North Queensland Bulk Ports Corporation Ltd

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PORT & COASTAL SOLUTIONS

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North Queensland Bulk Ports Corporation (NQBP) and Rio Tinto Alcan (RTA) commissioned Port and Coastal Solutions (PCS) who, along with its sub-consultants Water Modelling Solutions and DAMCO Consulting, are undertaking a series of studies to understand whether sedimentation can be managed at the Port of Weipa and at Amrun Port, to avoid or reduce the need for maintenance dredging. The studies form part of NQBP/RTA's Sustainable Sediment Management (SSM) assessment at the Ports, which is aimed at answering the questions regulators have regarding ongoing maintenance dredging.

Aim: The aim of this study is to assess the availability, practicality and feasibility of engineered or technical solutions that could be implemented to reduce sedimentation in the dredged areas of the Port of Weipa. The results from this study will then be used to determine whether there are feasible solutions to avoid or reduce the need for maintenance dredging at the Port of Weipa.

Sediment Management Requirements: Analysis of historic bathymetric data has shown that the majority of the sedimentation has historically occurred in the South Channel, with on average 95% of the annual sedimentation occurring in this region, with limited sedimentation occurring within the Inner Harbour.

Initial Feasibility: Due to differences in the sedimentation rates and processes between the South Channel and Inner Harbour, these regions have been considered separately in the assessment. Following the initial feasibility assessment, a number of potentially feasible alternative solutions to maintenance dredging were identified. These included: optimising the sediment trap in the South Channel, drag barring in the Inner Harbour, and sustainable relocation of sediment in both the South Channel and the Inner Harbour.

Constraints Analysis: Due to the processes which control the sedimentation and the configuration of the dredged areas of the Port of Weipa, the assessment has not been able to identify any feasible engineered or technical solutions which could significantly reduce the natural sedimentation and therefore maintenance dredging at the Port of Weipa. However, a number of alternative approaches have been identified which could reduce the volume of sediment placed at the Albatross Bay DMPA and the maintenance dredging duration. The constraints analysis showed that maintenance dredging is the most effective approach and has a low legislative requirement, while the sustainable relocation solutions have the lowest cost and lowest GHG emissions. None of the alternative solutions are clearly preferable over ongoing maintenance dredging, but some of the solutions could be considered further. It is suggested that the overall sustainable relocation approach be discussed with the relevant regulators to confirm the legislative requirements. Following this, if the approach is still considered feasible then numerical modelling could be undertaken to better understand how much sediment is likely to be redeposited in the dredged areas of the Port of Weipa and to optimise the potential solutions relative to the metocean conditions. A trial could then be adopted as part of an annual maintenance dredging campaign with a small volume of sediment placed at the proposed sustainable relocation sites (e.g. a single or multiple hopper loads at varying stages of the tide over a day) with monitoring used to confirm the fate of the sediment. Based on the assumptions made as part of this assessment, the approach could potentially reduce the maintenance dredging duration by four days per year and would reduce the average annual volume of sediment placed at the Albatross Bay DMPA by approximately 115,000 m^3.

Future Requirements: The predicted dredge volumes and frequencies for ongoing maintenance dredging and assuming both the sustainable relocation solutions in the South Channel and Inner Harbour are as follows:

- Maintenance Dredging: annual maintenance dredging and bed levelling with 425,000 m^3 relocated each year to the existing Albatross Bay DMPA (total volume over 20 years = 8.5 million m^3).
- Sustainable Relocation: annual maintenance dredging and bed levelling with 310,000 m^3 relocated each year to the existing Albatross Bay DMPA (total volume over 20 years = 6.2 million m^3) and sustainable relocation of 115,000 m^3 each year within Albatross Bay and the Inner Harbour (total volume over 20 years = 2.3 million m^3).

Further Investigations: Two additional solutions, which were not considered as part of the initial constraints analysis - as additional detailed investigations would be required to confirm the effectiveness of those solutions - could also be further investigated. The first solution would involve optimising the depths in the South Channel to achieve the right balance between an ongoing capacity for sedimentation and reducing the trapping efficiency to try and reduce overall sedimentation. The second solution would involve varying the departure path of laden vessels across the full width of the South Channel as a passive approach towards reducing the long-term sedimentation in the channel through vessel propeller wash erosion. Field testing along with bathymetric surveying and analysis would be required to inform the effectiveness of this approach.

1. Introduction

North Queensland Bulk Ports Corporation (NQBP) and Rio Tinto Alcan (RTA) commissioned Port and Coastal Solutions (PCS) who, along with its sub-consultants Water Modelling Solutions and DAMCO Consulting, are undertaking a series of studies to understand whether sedimentation can be managed at the Port of Weipa and at Amrun Port, to avoid or reduce the need for maintenance dredging. These studies form part of NQBP/RTA's long-term Sustainable Sediment Management (SSM) assessment at the Ports, which aims to answer the questions regulators have regarding ongoing maintenance dredging. The various studies being undertaken by PCS as part of the SSM assessment are as follows:

- Bathymetric Analysis: the aim of this study is to analyse historic bathymetric data, quantify previous bathymetric changes at the ports and define the natural processes which have caused the changes;
- Sediment Budget: the aim of this study is to understand the sediment transport processes which naturally occur at the Ports. This includes understanding the source of the sediment, sediment transport pathways, processes controlling the sediment transport and the development of a quantitative sediment budget;
- Bathymetric Model: the aim of this study is to develop interactive predictive sedimentation models for the two Ports. These models will allow future sedimentation predictions to be made for the dredged areas of the Ports which will allow NQBP/RTA to understand future maintenance dredging requirements at the Ports; and
- Engineered and Technical Solutions: the aim of this study is to assess the availability, practicality and feasibility of engineered or technical solutions that could be implemented to reduce sedimentation in the dredged areas of the Ports. The results from this study will then be used to determine whether there are feasible solutions to avoid or reduce the need for maintenance dredging at the Ports.

1.1. Project Background

NQBP undertakes regular maintenance dredging of the channels and berths at the Port of Weipa to ensure there is sufficient depth for vessels to safely travel to and from the berths (further detail of the historic maintenance dredging is provided in Section 1.2). The sediment that has historically been removed by maintenance dredging, has been relocated to an offshore dredge material placement area (DMPA) located in Albatross Bay (Figure 2).

NQBP has current State and Commonwealth approvals to support maintenance dredging and at-sea placement of the dredged sediment at the Port of Weipa. The current 10-year permit was issued in 2010. Since then, the process to obtain new long-term sea dumping permits in Queensland has become more onerous.

A Maintenance Dredging Strategy (MDS) has been developed for the ports that are situated within the Great Barrier Reef World Heritage Area (GBRWHA) (DTMR, 2016). The MDS provides a framework for the sustainable, leading practise management of maintenance dredging (Figure 1). It is a requirement of the MDS that each Port within the GBRWHA develop Long-term Maintenance Dredging Management Plans (LMDMPs). The LMDMPs are aimed at creating a framework for continual improvement in environmental performance. DTMR have provided guidelines to assist in the development of the LMDMPs (DTMR, 2018). The guidelines note that they 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.

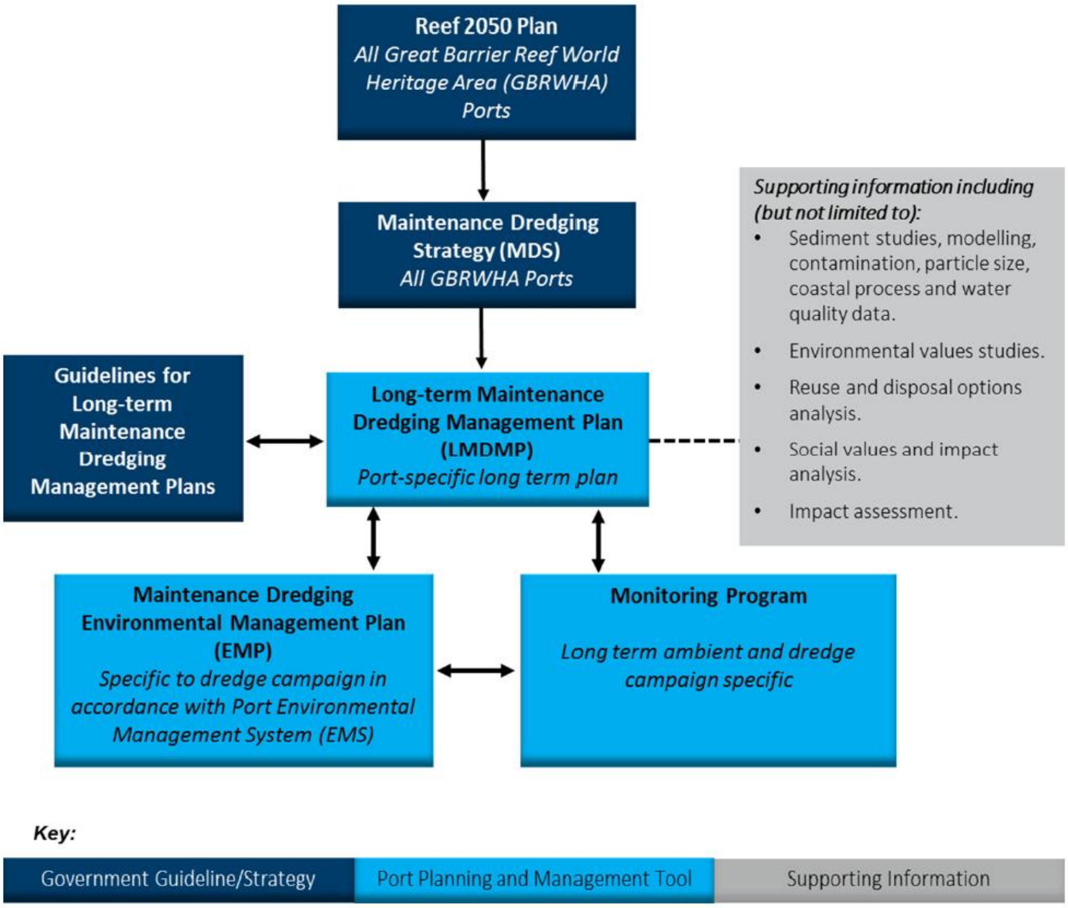

Figure 1. Planning and implementation mechanisms for maintenance dredging of ports Queensland wide (DTMR, 2018).

The requirement to investigate whether sedimentation at ports can be managed to avoid or reduce the need for maintenance dredging is derived from the London Protocol, which forms the basis for Australia's Sea Dumping Act 1981. Based on this, the environmental regulators are particularly focused on the following questions:

1. Can sedimentation be managed at the Port to avoid or reduce the need for maintenance dredging?
   - Where do sediments accumulate in the Port and at what volumes and rates?
   - What causes sedimentation in the Port?
   - Does sedimentation at the Port pose a risk to port operations and safety?
   - Why does the Port need to undertake maintenance dredging?
2. If maintenance dredging must occur has there been a comprehensive assessment of whether the material can be beneficially reused?
3. If no beneficial reuse options are available, what would be the most suitable and feasible disposal or placement options?
4. Has a comparative analysis of options been undertaken, which considers human health, social values, environmental impacts and disproportionate costs?

To answer these questions, NQBP developed a framework as part of the SSM assessment at the Port of Hay Point. This framework was subsequently used to inform the framework which has been adopted at the Port of Weipa and Amrun Port as well as the framework developed for the MDS, demonstrating that NQBP have been proactive at developing sound long-term maintenance dredging strategies. The studies included as part of the work currently being undertaken by PCS are aimed at answering the questions posed under point 1. Separate studies will be undertaken by NQBP/RTA to answer the other three questions. The findings from all these SSM studies will feed into the development of new LMDMPs at the Ports of Weipa and Amrun.

1.2. Port of Weipa

The Port of Weipa is located in the Gulf of Carpentaria, on the north-west coast of the Cape York Peninsula in Northern Queensland. The Port is within Albatross Bay, a large embayment, with the wharves and berths located in the Embley River (Figure 2 and Figure 3).

In the 2016/17 financial year, the Port of Weipa handled approximately 36 million tonnes of commodities, including bauxite (>95%), fuel, cattle and general cargo. Rio Tinto Alcan (RTA) currently operates most of the port facilities for the export of bauxite (aluminium ore) from the nearby RTA mine.

The Port of Weipa consists of:

- a main shipping channel in Albatross Bay called South Channel (Figure 2); and
- an Inner Harbour which is within the Embley River and consists of four shipping berths (Lorim Point East and West, Humbug Wharf and Evans Landing) and the Approach and Departure Channels (Figure 3).

Several capital dredging campaigns have been undertaken at the Port of Weipa since the early 1960's, with the most recent capital works undertaken in 2012:

- 1961-63: the South Channel was first dredged across the inner half of Albatross Bay, with the natural South Channel being deepened to a depth of 8.2 m below Low Water Datum (approximately equivalent to the Lowest Astronomical Tide (LAT));
- 1980's: the South Channel was deepened and extended to a length of 14.5 km;
- 2006: the South Channel was widened and deepened (GHD, 2005). Due to variable sedimentation within the South Channel the design depth[1] was increased from the uniform depth of -12.2 m LAT in some areas (see Figure 4 for depths following capital dredging) and due to the deepening, the channel also had to be widened to ensure the batter slopes were stable; and
- 2012: the South Channel was extended by 2.4 km with a design depth of -12.2 m LAT (PaCE, 2011).

The Port has approximately 622 hectares of channels, swing basins and berths where depths are maintained by maintenance dredging. NQBP currently has a 10-year Sea Dumping Permit for the Port of Weipa which allows for an average of 1,200,000 m^3 of sediment to be removed by maintenance dredging per annum, although this includes a contingency for events such as cyclones and so this maximum volume is not normally realised on an annual basis. Since 2002 maintenance dredging at the Port has been undertaken annually by the Trailing Suction Hopper Dredger (TSHD) Brisbane, with volumes ranging from approximately 300,000 m^3 to 980,000 m^3 (the high volume of 980,000 m^3 dredged in 2002 was due to the fact that dredging had not been undertaken in 2001). Prior to 2002, maintenance dredging was typically undertaken every two years. The majority of the historic maintenance dredging at the Port of Weipa has been undertaken towards the western end of the South Channel,

[1] the design or dredge depth is the depth that engineers have selected as suitable for the safe and efficient operation of the Port at all tidal levels with natural sedimentation also factored in. The declared depth is the depth designated by the harbour master and reflects the shallowest depth within the area.

with limited maintenance dredging occurring in the Inner Harbour. A summary of the historic dredging works is provided in Table 1 and the average volumes removed (2012 to 2016) are detailed in Table 2.

The fact that the Port requires annual maintenance dredging indicates that regular sedimentation occurs. In addition to the regular sedimentation, it has also been observed that extreme events such as tropical cyclones (TCs) can result in significant increases in the sedimentation and therefore increased maintenance dredging requirements at the Port. TCs occur in the Gulf of Carpentaria most years and based on historical TCs the Weipa region is influenced by them on average every other year, although the magnitude of the influence varies significantly. To reduce the risk of increased sedimentation from a TC resulting in operational or safety issues at the Port, the maintenance dredging has typically been scheduled immediately after the wet season (when TCs occur) and the design depths have been adjusted over time based on the variable sedimentation which occurs in the Port (Figure 4 and Figure 5). In addition, the Dynamic Under Keel Clearance (DUKC®) system developed by OMC International is in operation at the Port of Weipa to provide real-time navigational aid to ensure safe vessel navigation and to help optimise port operations.

Table 1. Historic in-situ dredging volumes at the Port of Weipa (Advisian, 2018).

Year	Type of Dredging	Volume of in-situ Material removed (m^3)
2002	Maintenance	976,585
2003	Maintenance	463,513
2004	Maintenance	621,650
2005	Maintenance	803,098
2006	Capital and Maintenance	2,976,868
2007	Maintenance	711,000
2008	Maintenance	774,100
2009	Maintenance	553,457
2010	Maintenance	832,779
2011	Maintenance	470,820
2012	Capital and Maintenance	927,057
2013	Maintenance	644,525
2014	Maintenance	394,523
2015	Maintenance	368,384
2016	Maintenance	504,071
2017	Maintenance	297,301
2018	Maintenance	591,875

Table 2. Typical maintenance dredging volume estimate, declared depth, design depth and footprint for the dredged areas at the Port of Weipa (Advisian, 2018).

Port Area	Volume Estimate (m^3)	Declared Depth (m below LAT)	Design Depth[1] (m below LAT)	Footprint (ha)
South Channel	465,000	11.1	12.1 to 14.1	256
Approach Channel	24,000	7.3	7.3	272.5
Departure Channel	12,000	11.1	11.1 to 11.8	138.3
Evans Landing	500	9.4	9.4	0.5
Humbug	500	9.5	9.5	0.86
Lorim Point	500	12.3	12.3	2.45
Tug Berth	500	9.0	9.0[2]	2.12

[1] in some areas the design depth is variable due to natural variability in the sedimentation which occurs. The design depths are shown in Figure 4 and Figure 5.

[2] although the design depth at the Lorim Point Tug Berths is -9 m LAT it has not been dredged to that depth (currently around -5 m LAT) and due to the existing depths the TSHD Brisbane is not able to dredge the area and so bed levelling has been used to maintain the depths to -5 m LAT.

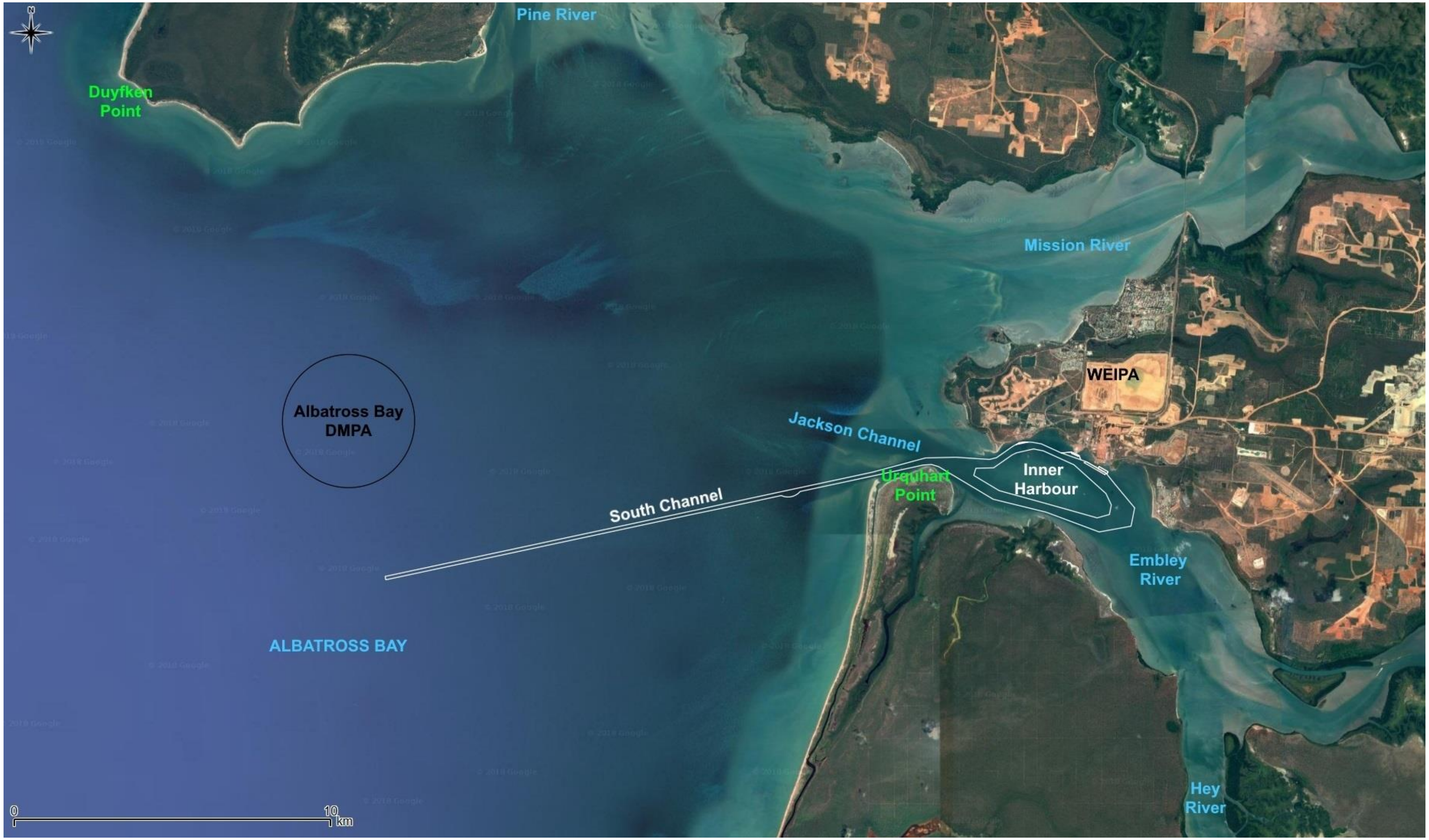

Figure 2. Location of the Port of Weipa.

Figure 3. Close up of the Port of Weipa Inner Harbour area.

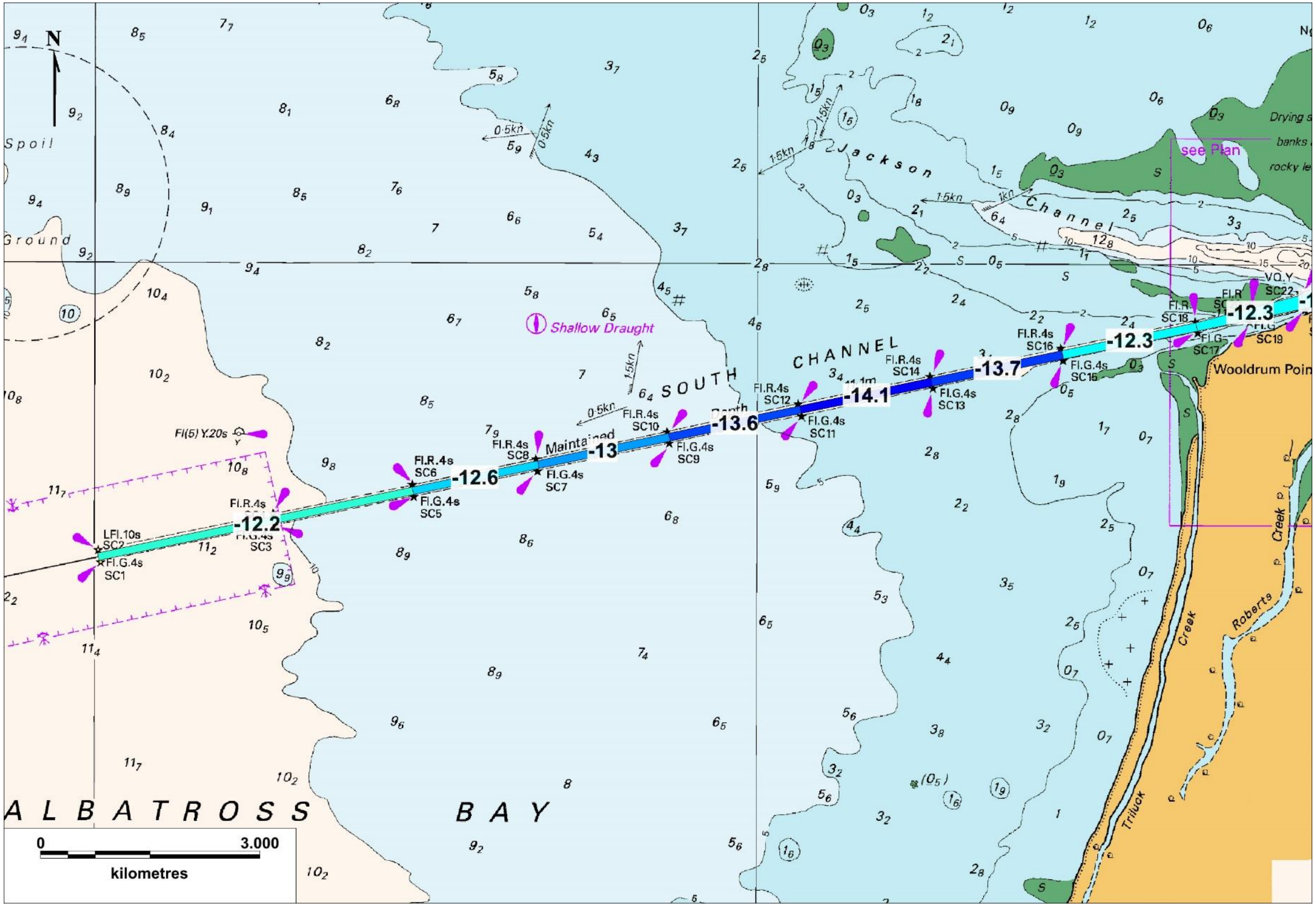

Figure 4. Variable design depths (m LAT) in the Port of Weipa South Channel.

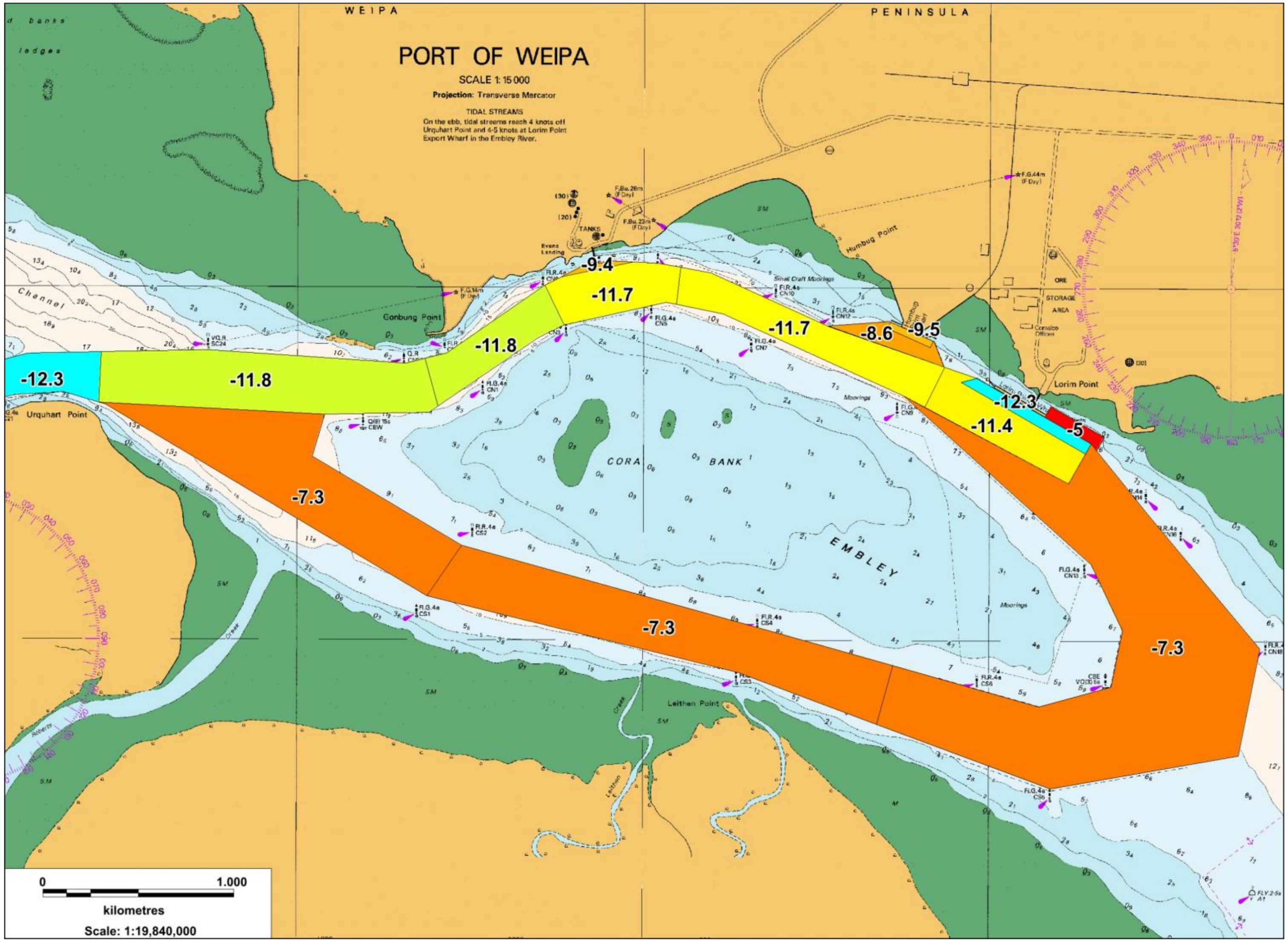

Figure 5. Variable design depths (m LAT) in the Port of Weipa Inner Harbour.

1.3. Report Structure

Each study is being undertaken for both Ports, with separate reports prepared for each of them. **The present report is for the Engineered and Technical Solutions to avoid or reduce sedimentation at the Port of Weipa.**

This report is set out as follows:

- an introduction and background to the study is provided in Section 1;
- description of the existing environment and dominant sediment transport processes at the Port of Weipa is given in Section 2;
- the sedimentation reduction assessment is detailed in Section 3; and
- a summary of the findings is detailed in Section 4.

Unless stated otherwise, levels are reported to Lowest Astronomical Tide (LAT). Zero metres LAT is equal to Chart Datum (CD) at the Port of Weipa. Volumes presented throughout are *in-situ* cubic metres.

2. Understanding of the Existing Environment

In order to determine realistic and feasible options to manage and reduce siltation, it is imperative to have a good understanding of natural environment and the processes driving sediment transport and siltation. The recent investigations by PCS (2018a and 2018b) provide a good understanding of the existing environment. As such, based on the findings of these reports the following sections provide a summary of the key processes in the resuspension, transport and deposition of sediment at the Port of Weipa.

2.1. Regional Natural Processes

The sediment in the Weipa and Amrun region is made up of a combination of fine-grained cohesive sediment (silt and clay) and coarser grained sands and gravels. The sediment composition was summarised by PCS (2018b) as follows:

- the majority of Albatross Bay is made up of sandy/clayey silt;
- the ebb tidal deltas and some upstream areas of the main channels in the Pine, Mission and Embley Rivers are predominantly composed of silty sand;
- the main channels of the Pine, Mission and Embley Rivers close to the river mouths are predominantly made up of sand, with some sandy gravel present in the Embley River where the current speeds are highest, (it is likely that sandy gravel will be present in the other rivers, but there are no samples available to confirm this);
- the nearshore areas along the open coast and the southern side of Albatross Bay are predominantly sandy sediment; and
- the offshore region (deeper than 15 to 20 m) is predominantly made up of silty sand.

The quantitative sediment budget provides a good overview of the regional sediment transport in the Weipa and Amrun region (PCS, 2018b). Relevant findings from the quantitative sediment budget are summarised below:

- the majority of sediment which is suspended at the Weipa and Amrun regional scale is from the local resuspension of existing fine-grained sediment. Wave action drives the resuspension of existing fine-grained sediment within Albatross Bay and along the open coast to the north and south, while tidal currents transport the suspended sediment. Within the estuaries a combination of tidal currents and locally generated wind waves drive resuspension, while tidal currents transport the suspended sediment;
- the region can be considered as being a relatively turbid environment, with approximately 45 Mt/yr of sediment resuspended during a typical year and 70 Mt/yr during a cyclonic year (covering 10,000 km^2, approximately 130 km along the coast and 80 km offshore);
- there is limited input of new sediment to the sediment budget in the Weipa and Amrun region (less than 1% of the total annual resuspension mass), with the main sources of new fine-grained sediment being from cliff erosion and river discharges/overland flow; and
- there is limited net residual transport of sediment (less than 10% of the gross sediment transport) and as such the sediment budget is generally balanced. The suspended sediment is typically either transported north and south along the open coastline, or offshore (west) and onshore (east) in Albatross Bay and the adjoining estuaries.

Analysis of historical bathymetric data found that the majority of the sedimentation has historically occurred in the South Channel, with on average 95% of the annual sedimentation occurring in this region and of limited sedimentation occurring within the Inner Harbour (PCS, 2018a). The sediment transport in the South Channel and Inner Harbour are discussed in more detail in the following sections.

It is also worth noting that the analysis of bathymetric data found that the Albatross Bay DMPA is partially retentive with approximately 60% of the sediment placed there has been retained (PCS, 2018a). In addition, sediment transport modelling undertaken as part of the sediment budget study found that of the sediment transported from the Albatross Bay DMPA less than 5% of it was subsequently deposited in the South Channel, with the majority of the sediment being thinly distributed within Albatross Bay (PCS, 2018b).

2.2. South Channel Sediment Transport

The majority of the sedimentation which occurs within the South Channel is a result of a combination of wave and tidal current processes. Wave action resuspends natural fine-grained sediment from the seabed in Albatross Bay. The spatial distribution of tidal currents around the South Channel, along with the trapping efficiency of the channel (i.e. depth of channel below adjacent seabed), control where in the South Channel the fine-grained sediment is deposited. High tidal current speeds occur in the South Channel within 4 km of the mouth of the Embley River, limiting the build-up of fine-grained sediment in this region. As the currents reduce with distance away from the mouth of the Embley River the potential for the build-up of fine-grained sediment increases. The elevation of the adjacent seabed typically remains between 2 and 6 m below LAT. As the depth of the adjacent seabed increases, sedimentation in the South Channel reduces, due to resuspension occurring less regularly as larger waves are required to resuspend the fine-grained sediment.

The quantitative sediment budget found that there is limited net residual transport of sediment (less than 10% of the gross sediment transport in the local Port of Weipa region) and as such the sediment budget is generally balanced. The suspended sediment in Albatross Bay is typically transported offshore (west) and onshore (east) by the tidal currents. Significant sedimentation occurs in the South Channel of the Port of Weipa, which is mainly due to the resuspension of existing fine-grained sediment within Albatross Bay due to wave action. The suspended sediment is then repeatedly transported backwards and forwards past the channel with 2 – 3% of the total (gross) suspended sediment becoming trapped. Sedimentation occurs predominantly during the wet season due to the increased SSC resulting from larger waves, with limited sedimentation during the dry season when wave conditions are calm and there is little resuspension of sediment from the seabed.

The sediment budget has shown that as a result of the regular reworking of existing fine-grained sediment within Albatross Bay, due to wave conditions in the wet season, there is expected to be regular annual sedimentation in the South Channel. As long as the South Channel remains deeper than the adjacent natural seabed (i.e. remains as a navigable channel), it will act as a sediment sink with sedimentation expected to continue. It can therefore be concluded that, if no maintenance dredging is undertaken, ongoing sedimentation in the South Channel is likely to pose a significant risk to Port operations and safety, as the sedimentation will result in the South Channel becoming shallower than the declared depth of 11.1 m below LAT.

2.3. Inner Harbour Sediment Transport

There are only localised areas of sedimentation in the Inner Harbour, with the sediment that is typically deposited being predominantly composed of sand. The relatively high tidal current speeds limit deposition of fine-grained sediment in most areas. In general, sedimentation is due to the existing shallow sand banks (e.g. Cora Bank and the shallow banks near Wooldrum Point) encroaching on the channels, as a result of bedload transport being driven by tidal currents. Propeller wash from vessels operating in the Port results in some localised erosion in the Approach and Departure Channels, as well as at the Lorim Point berths and adjacent tug berths. Adjacent to the areas of erosion in the berths there is also localised deposition in the areas which are sheltered from vessel propeller wash, typically directly adjacent to the wharf and at the ends of the berths.

At the entrance to the Inner Harbour, where the South Channel meets the Jackson Channel strong tidal currents has resulted in erosion. In addition, strong tidal currents have also caused a natural deepening along the western half of the Departure Channel within Embley River.

3. Sedimentation Reduction

This section investigates possible engineered or technical solutions to avoid or reduce sediment accumulation and/or maintenance dredging within the Port of Weipa. The overall approach adopted for the assessment of available options for reducing sedimentation has been based on the practise guidelines developed by PIANC (PIANC, 2008) and the United States Army Corps of Engineers (USACE, 2003).

This study includes an assessment of the feasibility of solutions based on the local environment and Port configuration, a constraints analysis of potentially feasible solutions relative to maintenance dredging and consideration of the impact of any feasible solutions to future maintenance dredging volumes.

3.1. Ongoing Sedimentation Management

The following two sediment management approaches have historically been used and are expected to continue to be adopted at the Port of Weipa:

- Maintenance Dredging: this has been the main approach to remove sediment and maintain declared depths in the Port of Weipa. Since 2002, annual maintenance dredging has been undertaken at the Port, with volumes ranging from approximately 300,000 m^3 to over 800,000 m^3 per year. Over this period the TSHD Brisbane has undertaken the majority of the maintenance dredging. This type of vessel has a high production rate (approximately 15,000 m^3/day for the Port of Weipa), can operate in offshore areas and heavily trafficked areas, has a hopper allowing offshore placement and is well suited to dredging soft unconsolidated sediment typically associated with maintenance material (it was built specifically for undertaking maintenance dredging at the Queensland Ports); and
- Bed levelling: bed levelling has routinely been undertaken following maintenance dredging to redistribute the sediment on the bed and remove any high spots.

The capital dredging which was undertaken in 2006 to implement variable design depths (ranging from 14.1 to 12.2 m below LAT, see Figure 4) within the South Channel due to the different sedimentation rates which occur, can be considered a form of sediment management. The deepening was adopted to reduce the risk of sedimentation occurring above the declared depths and therefore negate the requirement for sediment management between the annual maintenance dredging programs. The deepening is a form of sediment trap designed to increase the sedimentation capacity of the channel prior to the declared depths being affected. This approach can be considered a success in terms of sedimentation, as the depths in the South Channel have consistently remained below the declared depths since 2006. Although there is insufficient bathymetric data available to quantify this, it is likely that the deepening of the South Channel resulted in an increase in the annual maintenance dredging, due to the increased trapping efficiency of the channel increasing sedimentation. The trapping efficiency of a channel is related to the dimensions of the channel as well as the relative difference in depth between the channel bed and the adjacent natural seabed (i.e. the greater the depth difference the higher the trapping efficiency and the higher the sedimentation).

Future sedimentation rates were predicted based on the results of the historic analysis of bathymetric data (PCS, 2018a):

- South Channel: annual sedimentation typically ranges from 200,000 to 600,000 m^3, with the majority of this being above the design depths but below the declared depth. The majority of the sediment is deposited in the middle 8 km of the 17 km long channel and on the sides of the channel (approximately 70 m of the 100 m wide channel). The sedimentation pattern is not uniform and so the annual depths of sedimentation could range from 0.7 to 2.1 m. Based on these maximum sedimentation depths and the current design depths (average of -13.5 m LAT for the region where the most sedimentation occurs), the South Channel is likely to require annual maintenance dredging to ensure that none of the channel exceeds the declared depth of -11.1 m LAT. The only scenarios which would allow less frequent maintenance dredging would be either if multiple years of low wave energy occurred, or if a low wave energy year was followed by a typical wave energy year. However, there would be significant risk to Port operations if maintenance dredging was not undertaken annually in case the subsequent year was a high wave energy year. As such, this assessment will assume that maintenance dredging is required annually; and

- Inner Harbour: the annual average volume of sediment above the design depths in the Inner Harbour is approximately 25,000 m^3 with an annual minimum of 3,500 m^3 and an annual maximum of 105,000 m^3. Of the average sedimentation of approximately 25,000 m^3/yr, around 15,000 m^3 is in the Departure Channel, 7,000 m^3 in the Approach Channel and 2,000 m^3 in the berths. As much of the sediment that is above the design depths is not in a location that is considered an issue for vessel navigation and operation (i.e. directly adjacent to the sides of the channel or adjacent to the wharves) the historic maintenance dredging hasn't always removed the sediment immediately. Due to the relatively low sedimentation rates in the Inner Harbour region, along with the location of the sedimentation, a maintenance dredging frequency of every 2-5 years is estimated. As such, this assessment will assume that maintenance dredging of the Inner Harbour is required every two years.

3.2. Overview of Solutions

Significant research has been undertaken globally into solutions to reduce sedimentation in ports and harbours due to its ongoing economic and operational impacts. Best practise guidelines have been developed by PIANC and the United States Army Corps of Engineers (USACE) for approaches to minimise harbour and channel sedimentation based on port specific experience (USACE, 2003; PIANC, 2008). Both guidelines note that port specific investigations, such as the present study, are required to assess the applicability of the approaches on a case by case basis, as the suitability is dependent on a range of factors, such as the port configuration, sediment type, natural environment and processes. These guidelines are summarised in the Maintenance Dredging Strategy, Technical Supporting Document (RHDHV, 2016), where it is noted that three broad strategies can be implemented to reduce sedimentation:

- Keep Sediment Out: keeping sediment out of the Port that might otherwise enter and deposit;
- Keep Sediment Moving: increase current speeds in quiescent areas to prevent sediment from settling as it passes through the Port; and,
- Keep Sediment Navigable: applicable to sites characterised by high turbidity near-bottom sediment regimes where navigability of fluid mud zones is permitted, thereby reducing the required dredged depth.

An overview of the various approaches available for each strategy is provided in Table 3.

Table 3. Summary of strategies to reduce future sedimentation (RHDHV, 2016).

Strategy	Approach	Example
Keep Sediment Out	Stabilise sediment sources	Reduce sediment input through better catchment management.
	Diverting sediment-laden flows	Diverting river sediment inputs away from port.
	Trapping sediment before it enters port	Sediment traps, insurance trenches and sediment bypass systems.
	Blocking sediment entry	Pneumatic barrier, silt screen, barrier curtain.

Strategy	Approach	Example
	Habitat creation	Seagrass, saltmarsh, mangroves to stabilise sediment and promote accretion.
Keep Sediment Moving	Structural solutions to train natural flows	Training walls/dikes to divert flow and prevent local deposition of sediment (e.g. Current Deflecting Wall (CDW)).
	Devices to increase bed shear stresses	Hydraulic jets, vortex foil arrays, mechanical agitators (e.g. spider dredging system).
	Methods to reduce sediment flocculation	Adopting designs which reduce turbulence and therefore flocculation (e.g. solid wharf walls instead of piling supported wharfs).
Keep Sediment Navigable	Adopt a 'nautical depth' navigation approach which includes fluid mud	Nautical depth is the distance from the water surface to a given wet density, typically in the range of 1100 to 1300 kg/m^3.

In addition to the strategies to reduce sedimentation summarised in Table 4, the guidelines for the preparation of Long-term Maintenance Dredging Management Plans (DTMR, 2018) note that consideration should also be given to actions to reduce the volume and frequency of maintenance dredging and placement at sea. The example actions noted include the side casting of dredge material which involves dredging sediment from the seabed and releasing it at the water surface adjacent to the dredge vessel, although this type of dredging doesn't specifically reduce the volume or frequency of dredging it would reduce the duration of dredging. As such, this assessment will consider approaches which can reduce the volume, frequency and duration of maintenance dredging.

3.3. Initial Feasibility

To ensure that the approaches considered as part of the Constraints Analysis are realistic based on the natural sedimentation processes which occur in the Weipa region, it is necessary to undertake an initial feasibility assessment. For a solution to be considered as potentially feasible it must firstly have the potential to reduce sedimentation or maintenance dredging (duration or volume) (based on the natural sedimentation processes) and secondly have a medium to high probability of being effective. A summary of the feasibility of the broad approaches detailed in Table 3 are shown in Table 4 and have been based on its potential to reduce sedimentation/dredging and its probability of being effective.

Table 4. Initial feasibility assessment of approaches to reduce future maintenance dredging volumes.

Approach	Potential Reduction in Sedimentation / Dredging	Probability of Effectiveness	Potentially Feasible
Stabilise sediment sources	No	Low	No
Diverting sediment-laden flows	No	Low	No
Trapping/Bypassing sediment	Yes	Medium/Low	**Yes**
Blocking sediment entry	No	Low	No
Habitat creation	No	Low	No

Approach	Potential Reduction in Sedimentation / Dredging	Probability of Effectiveness	Potentially Feasible
Structural solutions to train natural flows	Yes	Low	No
Devices to increase bed shear stresses	Yes	High	**Yes**
Methods to reduce sediment flocculation	No	Low	No
Sustainable relocation	Yes	Medium	**Yes**
Adopt a 'nautical depth' navigation approach which includes fluid mud	Yes	Low	No

The feasibility of all the possible approaches to reduce sedimentation at the Port of Weipa are discussed in more detail below:

- Stabilise sediment sources: this approach involves implementing measures to stabilise sediment sources before they are eroded and subsequently transported into dredged areas and deposited. This approach is generally most effective in non-tidal areas with a high sediment supply from rivers. As the majority of the sedimentation which occurs in the Port of Weipa occurs in the South Channel due to the natural reworking of fine-grained sediment in Albatross Bay, the approach of stabilising sediment sources is not considered feasible;
- Diverting sediment-laden flows: in environments where high turbidity flows occur (e.g. due to river flood events) modifying the channel configuration can help to divert the high turbidity water from the dredged areas. Due to the configuration of the Port of Weipa, combined with the processes which control the resuspension and transport of suspended sediment in the Port, this approach is not considered to be feasible;
- Trapping/Bypassing sediment: as noted in Section 3.1 the 2006 capital dredging of the South Channel is a form of sediment trap designed to increase the sedimentation capacity of the channel prior to the declared depths being affected. Based on analysis of historic bathymetric data since the capital dredging, the annual sedimentation has never exceeded the declared depths in the South Channel, with the highest bed elevation being between 1 and 1.5 m below the declared depth. As a result, the annual maintenance dredging has not continued to reduce depths down to the original design depths, which has allowed some natural sedimentation to occur. It is possible that further optimisation of the design depths could be achieved which could have both short-term and long-term reductions in sedimentation in the South Channel. The deeper a channel relative to the adjacent natural seabed the higher its trapping efficiency and therefore the higher the sedimentation rate within the channel. Based on predictions by Van Rijn (2013), if a channel depth is increased by 50% (from 10 m to 15 m) the sedimentation rate within the channel could increase by up to 30%. Therefore, if the depth that the maintenance dredging maintained within the South Channel was reduced, then the trapping efficiency of the channel would be reduced and the sedimentation rate would also be expected to reduce. Optimisation would be aimed at achieving the right balance between an ongoing capacity in the South Channel for sedimentation and reducing the trapping efficiency to try and reduce overall sedimentation. Detailed empirical and numerical modelling investigations would be required to assess the solution further and determine whether it would be effective in reducing sedimentation in the South Channel. The solution has not been included in the constraints analysis as a separate solution as it would be identical to ongoing maintenance dredging except that the volume could be slightly reduced (this could range from 0 to 10% depending on how effective the approach is);

- Blocking sediment entry: for harbours or marinas with single entrances it can be possible to block sediment from entering the harbour/marina. The most successful solution for this approach is a pneumatic barrier at the entrance, which is closed during periods when high turbidity is present in the adjacent water body. As the Port of Weipa does not have a single entrance harbour/marina the approach is not considered to be feasible;
- Habitat creation: this approach is aimed at promoting increased natural vegetation cover (subtidal, intertidal or supratidal) to help stabilise sediment and therefore reduce the amount of sediment potentially available for resuspension. Although this approach could result in some minor reductions in sediment resuspension in areas of the Inner Harbour, due to the huge source of fine-grained sediment from Albatross Bay combined with the relatively low sedimentation within the Inner Harbour, it is unlikely to result in any noticeable reduction in sedimentation within the dredged areas of the Port of Weipa. As such, this approach is not considered to be feasible to reduce sedimentation or maintenance dredging;
- Structural solutions to train natural flows: this approach includes a number of possible solutions including training walls and Current Deflector Walls (CDW). Parallel training walls along a channel can be used to not only train the flow in the channel, but also to keep suspended sediment from the adjacent waters from entering the channel. Training walls have been widely adopted globally to help maintain the location and navigability of channels and river entrances. They are a form of hard engineering which were commonly adopted in the 19th and 20th centuries but are less commonly adopted now, as softer engineering solutions which are more sustainable and easier/cheaper to modify or reverse are preferred (Kirby, 2015). Training walls can be effective in maintaining the location of channels in areas where natural channel migration occurs, but they are not always successful in reducing sedimentation within the channel. In some cases, training walls have been found to result in increased sedimentation as they can increase the trapping efficiency of the channel (USACE, 2003). They can also result in impacts to the hydrodynamics and sediment transport on a regional scale which in turn can impact the ecology (SGS, 2011). The numerical model developed as part of the sediment budget (see PCS (2018b) for further details of the model) was used to test the effectiveness of training walls along either side of the South Channel in reducing sedimentation. The modelling predicted that the natural sedimentation within the South Channel would be reduced by approximately 30% due to the training walls, but that the sedimentation within the Inner Harbour would be increased (Figure 6). Due to the uncertainties associated with the effectiveness of training walls, combined with the extensive infrastructure required, the high capital costs (cost is likely to be in the order of $20,000 to $50,000 per metre (SGS, 2011) meaning the proposed configuration shown in Figure 6 would cost between $500 million and $1 billion), training walls are not considered to be a feasible approach to reduce sedimentation in the Port of Weipa. In some cases eddy currents can form at entrances to harbours or basins or around port structures and these can result in increased sedimentation in the centre of the eddy. An approach which has been successfully adopted to eliminate the eddy currents is a CDW. The CDW is a fixed vertical walled structure with a curved wall that extends throughout the water column and is positioned so that it changes the flow pathways of the tidal currents. Due to the configuration of the Port of Weipa (i.e. no harbour or basins with single entrances) there are no suitable locations where a CDW would be effective at reducing sedimentation in the Port and as a result the solution is not feasible.
- Devices to increase bed shear stresses: this approach can include a wide range of possible solutions including both mechanical and hydraulic systems which can be fixed or attached to vessels. For the Port of Weipa, the solutions of **bed levelling/drag barring** and **propeller wash** in the South Channel are considered as potentially feasible solutions. Both of these solutions are currently adopted in some way in the Port of Weipa and so are known to reduce or limit sedimentation. The use of drag barring in place of maintenance dredging is only likely to be possible in the Inner Harbour region where sediment deposited above design depths can be moved to an adjacent area that is below

design depths. Less sedimentation occurs in the central 50 m of the South Channel due to increased near-bed currents from propeller wash of the bulk carriers limiting sedimentation, which demonstrates that propeller wash from these vessels could be used to try and limit sedimentation in the South Channel. However, the effectiveness of this approach would only be known by field testing and so the solution has not been included in the constraints analysis as a separate solution as it would be identical to ongoing maintenance dredging except that the volume could be slightly reduced. Hydraulic approaches such as **jet arrays**, which use propellers or jets to locally increase near-bed currents, can be very effective at preventing ongoing sedimentation in berths. However, due to the high capital cost of purchases and installing these (likely to be more than $5 million (based on Bryant (2007))), they have only be implemented in berths with very high sedimentation rates and as the berths in the Port of Weipa have annual average sedimentation rates of less than 100 m^3/yr (PCS, 2018a), they are not considered to be a feasible solution;

- Reduce sediment flocculation: in some cases port infrastructure can result in localised turbulence which in turn can act to increase the flocculation of fine-grained cohesive sediment. The process of flocculation causes fine-grained sediment particles to join together to forms flocs which settle to the seabed faster than individual grains. As a result, increased flocculation has the potential to result in increased sedimentation. Flocculation can be reduced by adopting designs which reduce turbulence such as solid wharf walls instead of piling supported wharfs. As the sedimentation rates in the berths are low it is considered unlikely that flocculation due to turbulence from port infrastructure in the Port of Weipa significantly influences the sedimentation and as such this approach is not considered feasible;
- Sustainable relocation: the approach of sustainable relocation involves retaining sediment in the marine environment and within the natural sediment system. The aim of the sustainable relocation approach is to ensure that some sediment which is deposited/trapped within the dredged areas of the Port of Weipa is retained within the sediment system, to feed natural habitats such as mudflats (fine-grained sediment), mangroves (fine-grained sediment) and beaches (sand sized sediment). The sustainable relocation could be achieved by a number of different ways, including side-casting and placing sediment in a suitable location to keep it within the active sediment system. Side-casting of the sediment involves dredging it from the seabed and then pumping it to the water surface within 50 m of the side of the vessel. As such, there is a high chance of at least some of the sediment being directly deposited back into the dredged areas. As such, for this assessment the sustainable relocation approach will consider a suitable location to keep it within the active sediment system; and
- Nautical Depth: this approach can be feasible in areas with high sedimentation of fine-grained sediment where the density of the sediment is sufficiently low for it to be considered navigable (i.e. it is a fluid mud). The approach could result in a reduction in maintenance dredging in the South Channel, but it is considered unlikely to be effective in this location. The reason for this is that the sedimentation in the South Channel occurs over a large area and the sediment is predominantly silt sized rather than clay sized. Consequently, it is considered unlikely that the density of sediment would be sufficiently low to allow the approach to be adopted and there would also be significant safety concerns adopting this type of approach in a navigation channel.

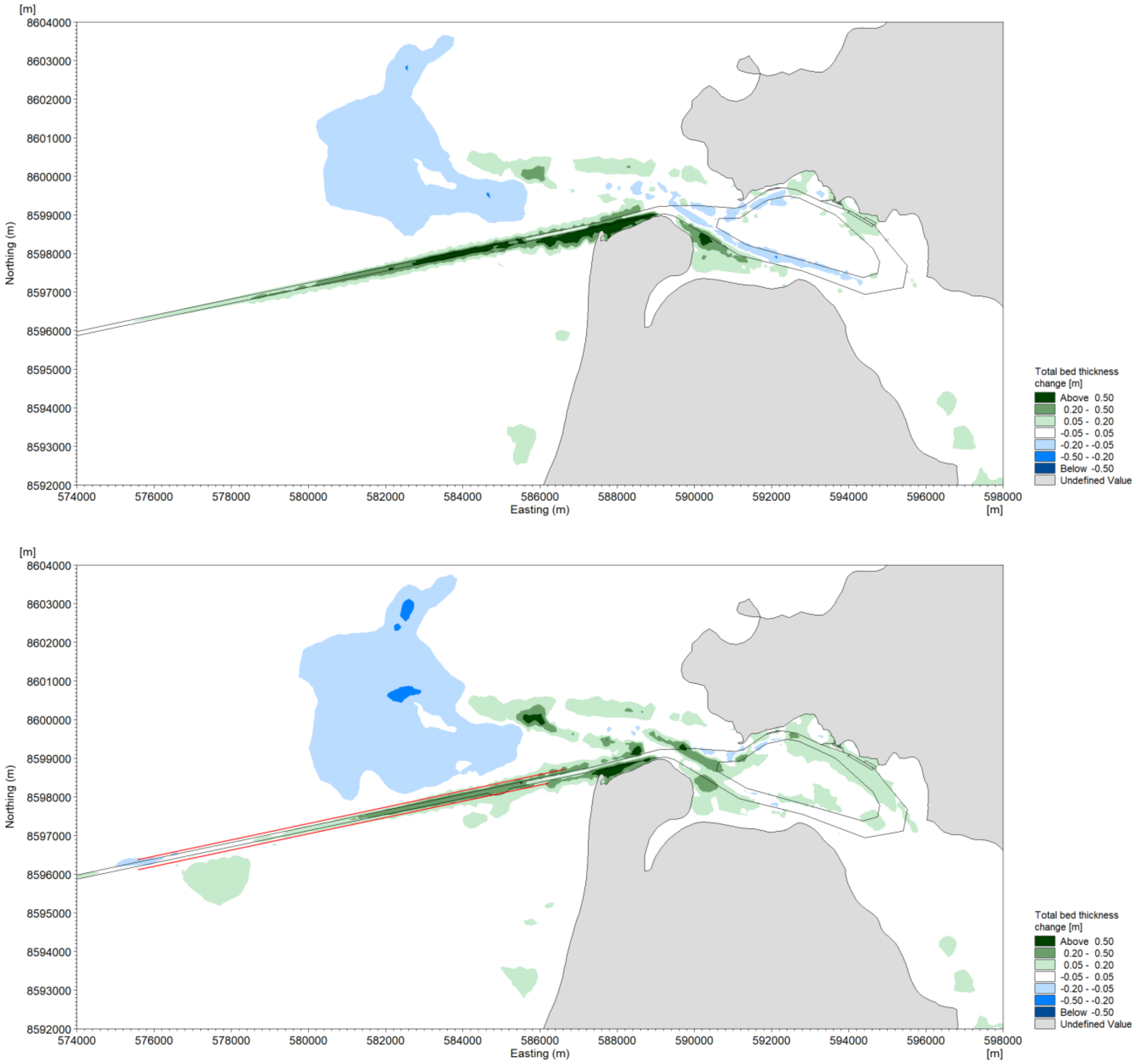

Figure 6. Modelled sedimentation depth over a wet season in the South Channel for the existing conditions (top) and with a training walls (bottom). Note: the training walls are shown by the red lines.

3.4. Constraints Analysis

As the processes driving sedimentation and the resultant sedimentation rates differ between the South Channel and the Inner Harbour, the possible solutions to reduce sedimentation or maintenance dredging for the two areas are discussed separately. Comparative constraints analyses of the possible solutions for these two areas relative to ongoing maintenance dredging are provided in the following sections. Costs and greenhouse gas emissions have been calculated assuming a representative duration of 20 years.

3.4.1. Option Details

Based on the findings of the bathymetric analysis, the average sedimentation rate in the South Channel is approximately 400,000 m^3/yr and in the Inner Harbour it is approximately

25,000 m³/yr (PCS, 2018a). These sedimentation rates have been assumed for the constraints assessment. It is important to note that depending on the metocean conditions over the year the rates are variable; in the South Channel they can range from 200,000 to 600,000 m³/yr and in the Inner Harbour they can range from 3,500 to 105,000 m³/yr. Of the average sedimentation of 25,000 m³/yr assumed for the Inner Harbour, 15,000 m³/yr is within the Approach Channel, 8,000 m³/yr is in the Departure Channel and 2,000 m³/yr is within the berths.

Based on the findings of the initial feasibility assessment detailed in the previous section, the following approaches for ongoing sediment management in the South Channel and in the Inner Harbour of the Port of Weipa will be assessed as part of the constraints analysis:

- South Channel - Maintenance Dredging: this solution assumes that the TSHD Brisbane (or a similar vessel) dredges 400,000 m³/yr of sediment from the South Channel and places the sediment at the Albatross Bay DMPA. Based on the specifications and historic production rates of the TSHD Brisbane it has been calculated that the dredging will take approximately 35 days to complete. A total of 35 days of bed levelling by the Pacific Conquest has been assumed immediately after the maintenance dredging to remove any high spots in the dredged areas. It has been assumed that annual maintenance dredging will be required to ensure the declared depths are maintained over the 20-year period;
- South Channel - Sustainable Relocation: this solution also assumes that the TSHD Brisbane (or a similar vessel) dredges 400,000 m³/yr of sediment from the South Channel. However, it is assumed that 300,000 m³/yr of the sediment is placed at the existing Albatross Bay DMPA while the remaining 100,000 m³/yr is placed at a sustainable relocation area located approximately 1 km to the south of channel marker SC7 (Figure 7)[2]. It is assumed that sediment would only be released at the sustainable relocation site when the tidal current is ebbing to ensure the sediment is not immediately redeposited in the South Channel. Further investigation would be required to estimate the volume of sediment which could be placed in this region and when it could be placed to prevent it being immediately redeposited in the South Channel. Based on the specifications and historic production rates of the TSHD Brisbane it has been calculated that the dredging will take approximately 32 days to complete, this represents a reduction in dredge duration of three days compared to placement at the Albatross Bay DMPA. A total of 35 days of bed levelling by the Pacific Conquest has been assumed immediately after the maintenance dredging to remove any high spots in the dredged areas. It has been assumed that annual maintenance dredging will be required to ensure the declared depths are maintained over the 20-year period;
- Inner Harbour – Maintenance Dredging: this solution assumes that the TSHD Brisbane (or a similar vessel) dredges 50,000 m³ of sediment from the Inner Harbour and places the sediment at the Albatross Bay DMPA every two years. Based on the specifications and historic production rates of the TSHD Brisbane it has been calculated that the dredging will take approximately six days to complete. Six days of bed levelling by the Pacific Conquest has been assumed immediately after the maintenance dredging to remove any high spots in the dredged areas. It has been assumed that biennial maintenance dredging will be required to ensure the declared depths are maintained over the 20-year period;
- Inner Harbour – Sustainable Relocation: this solution also assumes that the TSHD Brisbane (or a similar vessel) dredges 50,000 m³ of sediment from the Inner Harbour every two years. However, it is assumed that the 30,000 m³ of sediment dredged from the Approach Channel is placed at a sustainable relocation site located adjacent to the

[2] the sustainable relocation site has been selected based on the local bathymetry and numerical modelling results to provide a location close to where the most sedimentation occurs in the South Channel, while also being a location where minimal sediment would be expected to be transported back to the channel and in sufficiently shallow water for the sediment to still be regularly transported. The location should be considered as preliminary and would need to be confirmed following further detailed investigations.

eastern corner of the Approach Channel (Figure 8)[3] while the remaining 20,000 m^3 of sediment continues to be placed at the existing Albatross Bay DMPA. As the sediment which deposits in the Approach Channel is predominantly sand it is assumed that sediment could be released throughout the tide without any significant risk of the material being transported back into the Approach Channel, although further investigation would be required to confirm this. Based on the specifications and historic production rates of the TSHD Brisbane it has been calculated that the dredging will take approximately four days to complete, this represents a reduction in dredge duration of two days compared to placement of the entire volume at the Albatross Bay DMPA. Six days of bed levelling by the Pacific Conquest has been assumed immediately after the maintenance dredging to remove any high spots in the dredged areas. It has been assumed that biennial maintenance dredging will be required to ensure the declared depths are maintained over the 20-year period; and

- Inner Harbour – Drag Barring: this solution assumes that the 10,000 m^3/yr of sedimentation which occurs in the Departure Channel and berths of the Inner Harbour is managed by annual drag barring. Sedimentation above the design depths in these regions typically occurs adjacent to areas which are below the design depths and so the solution assumes that the sediment is moved into these deeper areas by drag barring. Drag barring is not a realistic solution to manage the sedimentation of 15,000 m^3/yr in the Approach Channel as there are no adjacent areas which are consistently below the design depth. As such, ongoing biennial maintenance dredging by the TSHD Brisbane (or a similar vessel) and placement of the sediment at the existing Albatross Bay DMPA is assumed to manage this volume of sedimentation. The approach therefore assumes that four days of maintenance dredging will be required every two years (this represents a reduction in dredge duration of two days compared to placement at the Albatross Bay DMPA) along with 10 days of drag barring and bed levelling (assuming a production rate of 1,000 m^3/day for the activity) every year. It has been assumed that biennial maintenance dredging and annual drag barring will be required to ensure the declared depths are maintained over the 20-year period.

None of these solutions are able to completely avoid sedimentation in the dredged areas of the Port of Weipa, demonstrating that due to the natural conditions and ongoing natural sedimentation processes it is not possible to avoid sedimentation. However, the drag barring solution is able to avoid the requirement for maintenance dredging for part of the Inner Harbour (the Departure Channel and berths), but maintenance dredging would still be required to maintain depths in the Approach and South Channels.

[3] the sustainable relocation site has been selected based on the local bathymetry and numerical modelling results. The site is in relatively deep water where sand transport rates would be low and so sediment transport back into the dredged channel would be low. In addition, the site is located adjacent to Jessica Point where there are sandy beaches and so the sediment could over time act as a source for the beach. The location should be considered as preliminary and other sites in the Inner Harbour region could also be considered. The site would need to be confirmed following further detailed investigations.

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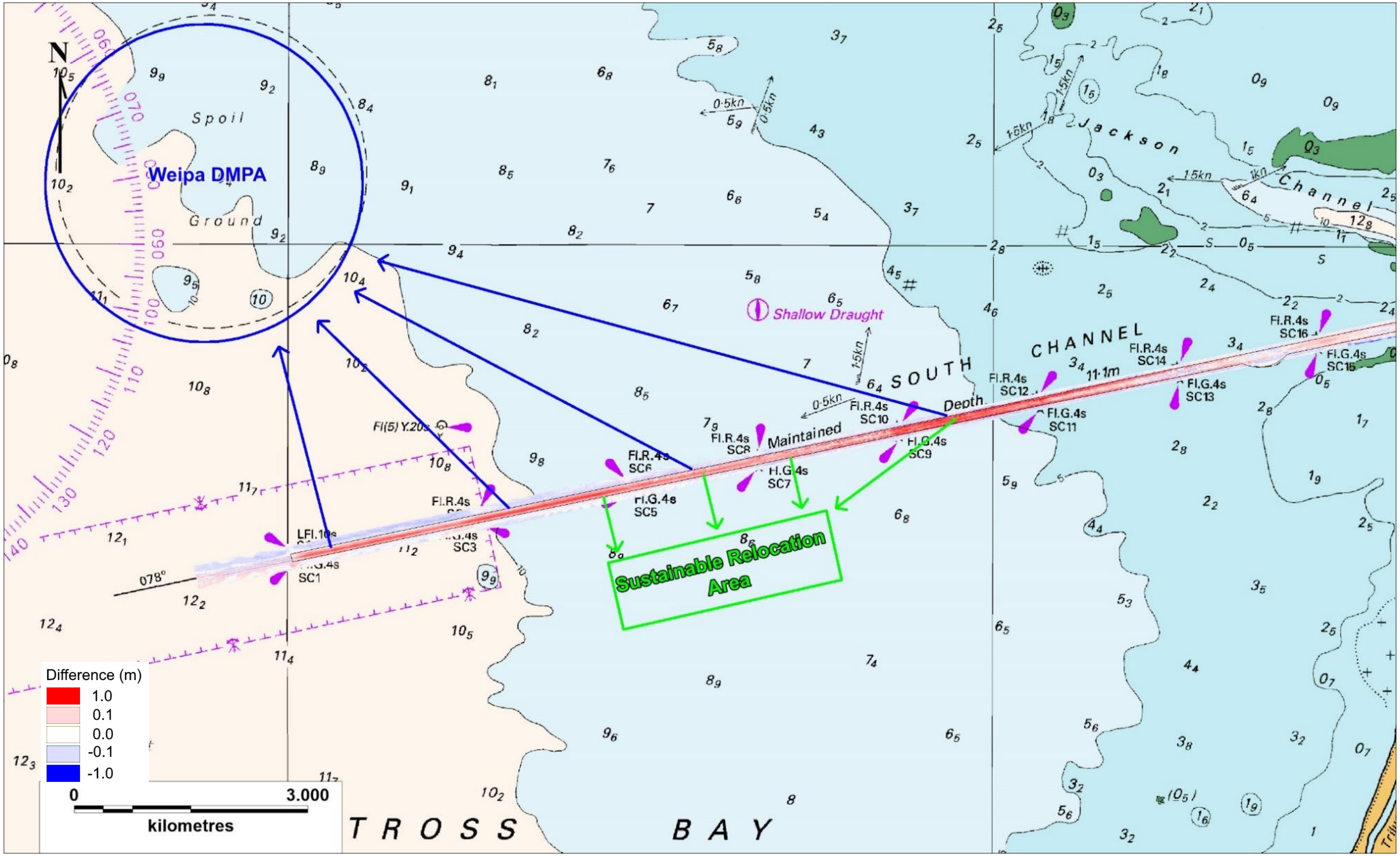

Figure 7. Schematic representation of the sustainable relocation solution for the South Channel.

Note: green box and arrows = sustainable relocation, blue box and arrows = maintenance dredging

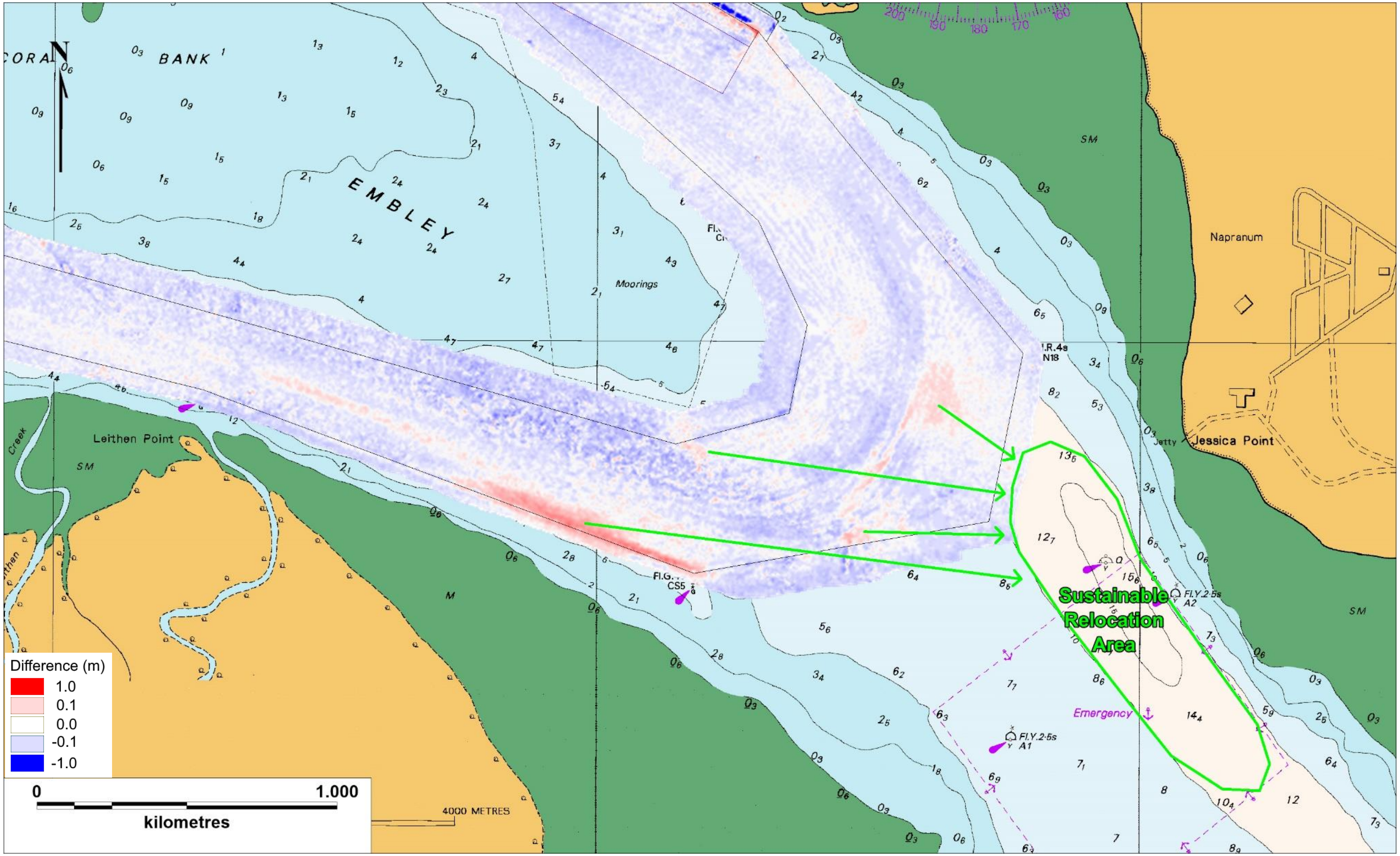

Figure 8. Schematic representation of the sustainable relocation solution for the Approach Channel in the Inner Harbour.

3.4.1.1. Environmental Impacts

Based on the solutions being considered, potential environmental impacts would be indirect resulting from changes to the turbidity, light availability and deposition due to the solutions. All of the solutions would result in the potential for (short-term) indirect impacts due to sediment suspended during any dredging, placement and bed disturbance activity.

Based on previous monitoring of the TSHD Brisbane during maintenance dredging the impacts are expected to be low, short-term and localised (BMT WBM, 2013).

The impacts from bed agitation by drag barring or bed levelling are typically less than by dredging as the production rate is lower (typically an order of magnitude less sediment is moved by drag barring compared to dredging by the TSHD Brisbane) and the majority of sediment remains in front of the bar and close to the bed (Bray, 2008).

Bed agitation by propeller wash has been shown to have the potential to result in suspended sediment concentrations in excess of 1,000 mg/l when large vessels are manoeuvring (Stoschek et al., 2014). However, it is also noted that much of the eroded sediment is expected to be rapidly redeposited, meaning any impacts to water quality remain localised to where the vessel is operating and are short in duration (Hayes et al., 2010).

Based on the above, the potential environmental impacts of all the solutions are considered to be low.

3.4.1.2. Operational Impacts

The operational impacts of all the solutions are similar, with the solutions all requiring the TSHD Brisbane and the Pacific Conquest to be operating. The duration of time the vessels are required to be working varies slightly between the solutions, with the sustainable relocation and drag barring solutions reducing the duration of the maintenance dredging by between one and three days. The duration of drag barring/bed levelling is similar for the comparable solutions except for the drag barring which requires an additional eight days. The two vessels currently operate in the Port of Weipa for approximately 30 days per year without negatively impacting Port operations and as a result the possible operational impacts of all the solutions are considered to be low.

3.4.1.3. Ongoing Maintenance

The ongoing maintenance associated with the equipment required for the solutions is similar in all cases. All solutions require the ongoing maintenance of the vessels, in all cases the vessel contractor is responsible for the ongoing maintenance and so there would be no maintenance requirement for NQBP.

3.4.1.4. Effectiveness

The effectiveness of the solutions in managing the sedimentation is detailed below:

- South Channel and Inner Harbour - Maintenance Dredging: based on previous experience at the Port of Weipa, there is a high level of confidence that this approach would be successful. Numerical modelling has estimated that less than 2% of the sediment placed at the Albatross Bay DMPA is subsequently redeposited in the South Channel (PCS, 2018b).
- South Channel – Sustainable Relocation: the sustainable relocation approach is a similar approach to maintenance dredging and so there is a high level of confidence that the approach would be successful in removing sediment from the South Channel. However, there is a risk that some of the sediment placed at the sustainable relocation area could be transported back to the South Channel and redeposited. Numerical modelling would be required to better understand and quantify the risk of this and to assist in optimising

the approach to mitigate the risk. Based on this, there is a moderate to high confidence that the approach would be successful.

- Inner Harbour – Sustainable Relocation: the sustainable relocation approach is a similar approach to maintenance dredging and so there is a high level of confidence that the approach would be successful in removing sediment from the Approach Channel. However, there is a risk that some of the sediment placed at the sustainable relocation area could be transported to the dredged areas of the Inner Harbour and redeposited. Numerical modelling would be required to better understand the risk of this and to assist in optimising the approach to mitigate the risk and promote the transport of the sediment to the beaches around Jessica Point. Based on this, there is a moderate to high confidence that the approach would be successful.
- Inner Harbour - Drag Barring: this solution has typically only been adopted in the Port of Weipa to remove small volumes of sedimentation in areas that are too shallow for the TSHD Brisbane to access. Although it is likely that the approach will be able to successfully move the sediment to adjacent deeper areas, there is uncertainty as to how many days would be required to move the sediment and how many years this approach could be adopted before maintenance dredging would be required. Therefore, there is a moderate risk that drag barring would not be able to manage the long-term sedimentation in the Departure Channel and berths of the Inner Harbour.

3.4.1.5. Legislative Requirements

The legislative requirements, such as approvals and permits, that need to be considered and potentially sought for the solutions in managing the sedimentation are expected to be as follows:

- South Channel and Inner Harbour - Maintenance Dredging: there are ongoing approval requirements for maintenance dredging, but they are considered standard approval requirements under the *Environment Protection (Sea Dumping) Act 1981* and the Queensland *Environment Protection Act 1994.* The approval process is well known to NQBP and they have experience with it. The risk implications of the approval requirements are therefore considered to be low.
- South Channel and Inner Harbour – Sustainable Relocation: there is uncertainty regarding the approval process as it will involve some of the dredged sediment being placed outside of the designated offshore placement area. The ongoing maintenance dredging and placement at the existing Albatross Bay DMPA will require standard approval under the *Environment Protection (Sea Dumping) Act 1981* and the Queensland *Environment Protection Act 1994.* The risk implications of the approval requirements are considered to be medium to high due to the uncertainty regarding the approval process.
- Inner Harbour - Drag Barring: no approval is required for the drag barring activity. The ongoing maintenance dredging and placement at the existing Albatross Bay DMPA will require standard approval under the *Environment Protection (Sea Dumping) Act 1981* and the Queensland *Environment Protection Act 1994.* The risk implications of the approval requirements are therefore considered to be low.

3.4.1.6. Comparative Costs

In order to develop comparative costs for the solutions a number of assumptions have had to be made:

- a daily rate of $80,000 has been assumed for the TSHD Brisbane, along with a combined mobilisation and demobilisation cost of $400,000 per visit (the mobilisation and demobilisation costs have only been included in the South Channel costs); and
- a daily rate of $12,500 has been assumed for the Maritime Safety Queensland (MSQ) survey vessel. It has been assumed that hydrographic survey would be required

annually with the vessel being required for a total of 30 days per year for the South Channel and 10 days per year for the Inner Harbour; and

- a daily rate of $10,000 has been assumed for bed levelling and drag barring (based on the Pacific Conquest rate), along with a combined mobilisation and demobilisation cost of $40,000 per visit (the mobilisation and demobilisation costs have only been included in the South Channel costs).

Based on these assumptions comparative cost estimates have been made for the solutions assuming a 20-year period:

- South Channel – Maintenance Dredging: the estimated cost is $79.7 million over 20 years. The costs allow for annual maintenance dredging of 400,000 m^3 from the South Channel and placement at the Albatross Bay DMPA. In addition, 35 days of bed levelling along with 30 days of bathymetric survey is included each year.
- South Channel – Sustainable Relocation: the estimated cost is $74.7 million over 20 years. The costs allow for annual sustainable relocation of 100,000 m^3 as well as annual maintenance dredging of 300,000 m^3 which is placed at the Albatross Bay DMPA. In addition, 35 days of bed levelling along with 30 days of bathymetric survey is included each year.
- Inner Harbour – Maintenance Dredging: the estimated cost is $8.1 million over 20 years. The costs allow for biennial maintenance dredging of 50,000 m^3 from the Inner Harbour and placement at the Albatross Bay DMPA. In addition, six days of bed levelling is included every two years along with 10 days of bathymetric survey every year.
- Inner Harbour – Sustainable Relocation: the estimated cost is $6.3 million over 20 years. The costs allow for biennial sustainable relocation of 30,000 m^3 as well as biennial maintenance dredging of 20,000 m^3 which is placed at the Albatross Bay DMPA. In addition, six days of bed levelling is also included every two years along with 10 days of bathymetric survey every year.
- Inner Harbour – Drag Barring: the estimated cost is $6.5 million over 20 years. The costs allow for annual drag barring of 10,000 m^3 (10 days per year) as well as biennial maintenance dredging of 30,000 m^3 which is placed at the Albatross Bay DMPA. No additional days of bed levelling are included as it is assumed this could be incorporated by the 10 days of drag barring every year. An allowance of 10 days of bathymetric survey every year has also been included.

3.4.1.7. Greenhouse Gas Emissions

An estimate of the Greenhouse Gas (GHG) emissions from the operation of the vessels associated with the solutions has been made. Details of the approach adopted are provided in Appendix A. For all solutions the GHG emissions are due to Scope 1 emissions which are direct emissions associated with fossil fuel consumption by vessels during movement and operation. The estimates have included the GHG emissions with the travel of the vessels (TSHD Brisbane and Pacific Conquest) to the Port of Weipa and the dredging/bed levelling activity. As with the cost estimates, the GHG estimates have been made over a 20-year period:

- South Channel – Maintenance Dredging: The total GHG emissions over 20 years is estimated to be 52,000 tonnes CO_2 equivalent (CO_{2e}).
- South Channel – Sustainable Relocation: The total GHG emissions over 20 years is estimated to be 48,410 tonnes CO_2 equivalent (CO_{2e}).
- Inner Harbour – Maintenance Dredging: The total GHG emissions over 20 years is estimated to be 4,210 tonnes CO_2 equivalent (CO_{2e}).
- Inner Harbour – Sustainable Relocation: The total GHG emissions over 20 years is estimated to be 2,910 tonnes CO_2 equivalent (CO_{2e}).

- Inner Harbour – Drag Barring: The total GHG emissions over 20 years is estimated to be 4,460 tonnes CO_2 equivalent (CO_{2e}).

3.5. Summary and Implications

A summary of the comparative constraints analysis for the potentially feasible solutions for the Port of Weipa is provided in Table 5. The table shows that although maintenance dredging is the most effective at managing the future sedimentation and has a low legislative requirement, the sustainable relocation solutions have the lowest cost and lowest GHG emissions. As a result, none of the alternative solutions are clearly preferable over ongoing maintenance dredging.

Table 5. Summary of the constraints analysis for the Port of Weipa.

Approach	Environmental Impacts	Operational Impacts	Ongoing Maintenance	Effectiveness	Legislative Requirement	Cost	GHG (tonnes CO_{2e})
South Channel							
Maintenance Dredging	Low	Low	No	High	Low	$79.7M	52,000
Sustainable Relocation	Low	Low	No	Moderate/High	Medium/High	$74.7M	48,410
Inner Harbour							
Maintenance Dredging	Low	Low	No	High	Low	$8.1M	4,210
Sustainable Relocation	Low	Low	No	Moderate/High	Medium/High	$6.3M	2,910
Drag Barring	Low	Low	No	Low/Moderate	Low	$6.5M	4,460

Based on the results of the constraints analysis it is suggested that the sustainable relocation solutions are considered further and the overall sustainable relocation approach should be discussed with the relevant regulators to confirm the legislative requirements. Following this, if the approach is still considered feasible then detailed numerical modelling could be undertaken to understand how much sediment is likely to be redeposited in the dredged areas of the Port of Weipa and to optimise the solutions relative to the metocean conditions. A trial/pilot program could then be adopted as part of an annual maintenance dredging campaign with a small volume of sediment placed at the proposed sustainable relocation sites (e.g. a single or multiple hopper loads at varying stages of the tide over a day) with monitoring used to confirm the fate of the sediment. The Long-term Maintenance Dredging Management Plan guidelines note that in some cases trial or pilot programs may be required (DTMR, 2018). Based on the assumptions made as part of this assessment, the approach could reduce the maintenance dredging duration on average by four days per year and would reduce the average annual volume of sediment placed at the Albatross Bay DMPA by 115,000 m^3.

The predicted dredge volumes and frequencies for ongoing maintenance dredging and assuming both the sustainable relocation solutions in the South Channel and Inner Harbour:

- Maintenance Dredging: annual maintenance dredging and bed levelling with 425,000 m^3 relocated each year to the existing Albatross Bay DMPA (total volume over 20 years = 8.5 million m^3).
- Sustainable Relocation: annual maintenance dredging and bed levelling with 310,000 m^3 relocated each year to the existing Albatross Bay DMPA (total volume over 20 years = 6.2 million m^3). Annual sustainable relocation of 115,000 m^3 each year within Albatross Bay and the Inner Harbour (total volume over 20 years = 2.3 million m^3).

It is also important to consider the solution of optimising the depths in the South Channel to achieve the right balance between an ongoing capacity in the South Channel for sedimentation and reducing the trapping efficiency to try and reduce overall sedimentation. As previously noted, detailed investigations would be required to assess this solution further and determine whether it could be effective in reducing the long-term sedimentation in the South Channel (it is anticipated that this could result in a possible reduction of 0 to 10% of the annual sedimentation in South Channel). In addition, varying the departure path of laden vessels across the full width of the South Channel could also be considered as a passive approach towards reducing the long-term sedimentation in the channel. Field testing along with bathymetric surveying and analysis would be required to inform the effectiveness of this alternative approach.

4. Conclusions

This report has assessed the feasibility of engineered or technical solutions to avoid or reduce sedimentation and maintenance dredging at the Port of Weipa. The assessment has included an initial feasibility assessment of potential solutions based on the predicted ongoing sedimentation at the Port and the processes driving the sedimentation. The potentially feasible solutions were then assessed along with maintenance dredging as part of a constraints analysis which considered the following:

- environmental impacts of the solutions;
- operational impacts of the solutions;
- ongoing maintenance requirement for NQBP of the solutions;
- the effectiveness of the solutions in managing long-term sedimentation;
- any legislative considerations associated with the solutions;
- comparative cost estimates of the solutions over a 20-year period; and
- estimated GHG emissions for the solutions over a 20-year period.

Due to differences in the sedimentation rates and processes between the South Channel and Inner Harbour, these regions have been considered separately in the assessment. Following the initial feasibility assessment a number of potentially feasible alternative solutions to maintenance dredging were identified, these included optimising the sediment trap in the South Channel, drag barring in the Inner Harbour and the sustainable relocation of sediment in both the South Channel and the Inner Harbour.

Due to the processes which control the sedimentation and the configuration of the dredged areas of the Port of Weipa, the assessment has not been able to identify any feasible engineered and technical solutions which could significantly reduce the natural sedimentation and therefore maintenance dredging at the Port of Weipa. However, a number of alternative approaches have been identified which could reduce the volume of sediment placed at the Albatross Bay DMPA and the maintenance dredging duration. The constraints analysis showed that although maintenance dredging is the most effective and has a low legislative requirement, the **sustainable relocation solutions** have the lowest cost and lowest GHG emissions. As a result, none of the alternative solutions are clearly preferable over ongoing maintenance dredging, but some of the solutions could be worth considering further. It is suggested that the overall sustainable relocation approach should be discussed with the relevant regulators to confirm the legislative requirements. Following this, if the approach is still considered feasible then detailed numerical modelling could be undertaken to understand how much sediment is likely to be redeposited in the dredged areas of the Port of Weipa and to optimise the solutions relative to the metocean conditions. A trial could then be adopted as part of an annual maintenance dredging campaign with a small volume of sediment placed at the proposed sustainable relocation sites (e.g. a single or multiple hopper loads at varying stages of the tide over a day) with monitoring used to confirm the fate of the sediment. Based on the assumptions made as part of this assessment, the approach could reduce the maintenance dredging duration by four days per year and would reduce the average annual volume of sediment placed at the Albatross Bay DMPA by 115,000 m^3.

The predicted dredge volumes and frequencies for ongoing maintenance dredging and assuming both the sustainable relocation solutions in the South Channel and Inner Harbour are detailed below:

- Maintenance Dredging: annual maintenance dredging and bed levelling with 425,000 m^3 relocated each year to the existing Albatross Bay DMPA (total volume over 20 years = 8.5 million m^3).

- Sustainable Relocation: annual maintenance dredging and bed levelling with 310,000 m^3 relocated each year to the existing Albatross Bay DMPA (total volume over 20 years = 6.2 million m^3). Annual sustainable relocation of 115,000 m^3 each year within Albatross Bay and the Inner Harbour (total volume over 20 years = 2.3 million m^3).

Two additional solutions, which were not considered as part of the constraints analysis as additional detailed investigations would be required to confirm the effectiveness of the solutions, could also be further investigated. The first solution involves optimising the depths in the South Channel to achieve the right balance between an ongoing capacity in the South Channel for sedimentation and reducing the trapping efficiency to try and reduce overall sedimentation. The second solution involves varying the departure path of laden vessels across the full width of the South Channel as a passive approach towards reducing the long-term sedimentation in the channel by vessel propeller wash erosion. Field testing along with bathymetric surveying and analysis would be required to inform the effectiveness of this approach.

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Appendices

Appendix A – GHG Calculations

A 1 GHG Assessment Approach

The aim of this Greenhouse Gas (GHG) emissions assessment is to estimate GHG emissions, to allow a comparative assessment between the four sediment management options to be undertaken. The assessment has been undertaken in accordance with the internationally recognised methodology outlined in the GHG Protocol[4]. The GHG Protocol defines three groups of GHG emissions that arise from an organisation's operational entity:

- **Scope 1 emissions**: "direct" GHG emissions arising from each of the options, such as those associated with fossil fuel consumption by marine vessels in movements and dredging activity;
- **Scope 2 emissions**: account for "indirect" GHG emissions from the production of electricity and gas (i.e. off site and usually by third parties) consumed by plant and equipment as part of the options; and
- **Scope 3 emissions**: are indirect emissions arising from supporting activities (e.g. work upstream and/or downstream, the activities of sub-contractors and ancillary travel associated with a project) associated with the options. Scope 3 emissions are voluntary, and an organisation can take a decision on the materiality of such activities before deciding to spend effort on calculating them for inclusion in a GHG footprint, or excluding them.

This GHG assessment considered only Scope 1 emissions for the options to manage ongoing sedimentation at the Port of Weipa over a 20-year period. As noted in the main report the sedimentation rates and driving processes are different between the South Channel and the Inner Harbour of the Port of Weipa and due to this these areas have been considered separately. This assessment considers two options for the South Channel and three options for the Inner Harbour, these are detailed in the following sections.

A 1.1 Options

For all the options it has been assumed that any dredging would be undertaken by the trailing suction hopper dredger (TSHD) Brisbane (or a similar vessel) and any bed levelling/drag barring would be undertaken by the Pacific Conquest (or a similar vessel). It has also been assumed that these vessels would be travelling from the Port of Cairns to the Port of Weipa and then either onto Amrun Port (every other year) or to the Port of Townsville for each visit, with this travel distance included in the GHG emission calculations for the South Channel region. The mobilisation and demobilisation of the vessels has only been included in the South Channel region calculations as this represents the vast majority of the maintenance dredging requirement and dredging or bed levelling in the Inner Harbour would only be expected to occur when the vessels are already in Weipa for the South Channel.

A 1.1.1 South Channel - Maintenance Dredging

It has been estimated that the dredger would be working for 35 days every year to relocate sediment from the South Channel to the Albatross Bay DMPA and that the Pacific Conquest would also be undertaking 35 days of bed levelling every year to support the maintenance dredging. During this maintenance dredging program, the following assumptions were made:

- based on the average distance from the area of the South Channel where the highest sedimentation occurs and the Albatross Bay DMPA it has been assumed that approximately 45% of the time the vessel will be dredging and 55% of the time the vessel will be transiting to and from the Albatross Bay DMPA;
- during cruising periods, including travelling to the Port of Weipa and to the DMPA, the THSD Brisbane was assumed to operate engines at 80% power;

[4] World Resources Institute and World Business Council on Sustainable Development (2015), Greenhouse Gas Protocol, available at URL: http://www.ghgprotocol.org/

- when dredging it was assumed that the engines operated at 50% power and the pumps operate at full capacity; and
- when the Pacific Conquest is sailing it is assumed that the vessel engines would operate at 80% power. During the bed levelling/drag barring activity, the Pacific Conquest engines would operate at full power.

A 1.1.2 South Channel – Sustainable Relocation

It has been assumed that the TSHD Brisbane would undertake both the sustainable relocation and ongoing placement of sediment to the Albatross Bay DMPA as part of the same annual program. It has been estimated that the dredger would be working for 5.5 days every year to relocate sediment from the South Channel to the sustainable relocation site, and 26.5 days every year to relocate sediment from the South Channel to the Albatross Bay DMPA. In addition, it has been assumed that the Pacific Conquest would also be undertaking 35 days of bed levelling every year to support the maintenance dredging. The following additional assumptions have been made:

- Sustainable relocation site: based on the average distance from the area of the South Channel where the highest sedimentation occurs and the proposed sustainable relocation area it has been assumed that approximately 65% of the time the vessel will be dredging and 35% of the time the vessel will be transiting to and from the sustainable relocation area;
- Albatross Bay DMPA: based on the average distance from the area of the South Channel where the highest sedimentation occurs and the Albatross Bay DMPA it has been assumed that approximately 45% of the time the vessel will be dredging and 55% of the time the vessel will be transiting to and from the Albatross Bay DMPA;
- during cruising periods, including travelling to the Port of Weipa and to the DMPA, the THSD Brisbane was assumed to operate engines at 80% power;
- when dredging it was assumed that the engines operated at 50% power and the pumps operate at full capacity; and
- when the Pacific Conquest is sailing it is assumed that the vessel engines would operate at 80% power. During the bed levelling/drag barring activity, the Pacific Conquest engines would operate at full power.

A 1.1.3 Inner Harbour – Maintenance Dredging

It has been estimated that the dredger would be working for 6.5 days every two years to relocate sediment from the Inner Harbour to the Albatross Bay DMPA and that the Pacific Conquest would also be undertaking 6 days of bed levelling every two years to support the maintenance dredging. During this maintenance dredging program, the following assumptions were made:

- based on the average distance from the Inner Harbour to the Albatross Bay DMPA it has been assumed that approximately 30% of the time the vessel will be dredging and 70% of the time the vessel will be transiting to and from the Albatross Bay DMPA;
- during cruising periods, including travelling to the Port of Weipa and to the DMPA, the THSD Brisbane was assumed to operate engines at 80% power;
- when dredging it was assumed that the engines operated at 50% power and the pumps operate at full capacity; and
- when the Pacific Conquest is sailing it is assumed that the vessel engines would operate at 80% power. During the bed levelling/drag barring activity, the Pacific Conquest engines would operate at full power.

A 1.1.4 Inner Harbour – Sustainable Relocation

It has been assumed that the TSHD Brisbane would undertake both the sustainable relocation and ongoing placement of sediment to the Albatross Bay DMPA as part of the same biennial program. It has been estimated that the dredger would be working for 1.5 days every two years to relocate sediment from the Approach Channel of the Inner Harbour to the sustainable relocation site, and 2.5 days every year to relocate sediment from the Departure Channel and berths of the Inner Harbour to the Albatross Bay DMPA. In addition, it has been assumed that the Pacific Conquest would also be undertaking 6 days of bed levelling every two years to support the dredging. The following additional assumptions have been made:

- Sustainable relocation site: based on the average distance from the area of the Approach Channel of the Inner Harbour where regular sedimentation occurs and the proposed sustainable relocation area it has been assumed that approximately 80% of the time the vessel will be dredging and 20% of the time the vessel will be transiting to and from the sustainable relocation area;
- Albatross Bay DMPA: based on the average distance from the Inner Harbour to the Albatross Bay DMPA it has been assumed that approximately 30% of the time the vessel will be dredging and 70% of the time the vessel will be transiting to and from the Albatross Bay DMPA;
- during cruising periods, including travelling to the Port of Weipa and to the DMPA, the THSD Brisbane was assumed to operate engines at 80% power;
- when dredging it was assumed that the engines operated at 50% power and the pumps operate at full capacity; and
- when the Pacific Conquest is sailing it is assumed that the vessel engines would operate at 80% power. During the bed levelling/drag barring activity, the Pacific Conquest engines would operate at full power.

A 1.1.5 Inner Harbour – Drag Barring

It has been estimated that the Pacific Conquest would be undertaking 10 days of drag barring every year to manage the ongoing sedimentation in the Departure Channel and berths of the Inner Harbour. In addition, 4 days of dredging by the TSHD Brisbane will be required every two years to relocate sediment from the Approach Channel of the Inner Harbour to the Albatross Bay DMPA. For this option the following assumptions were made:

- when the Pacific Conquest is sailing it is assumed that the vessel engines would operate at 80% power. During the bed levelling/drag barring activity, the Pacific Conquest engines would operate at full power;
- based on the average distance from the Inner Harbour to the Albatross Bay DMPA it has been assumed that approximately 30% of the time the vessel will be dredging and 70% of the time the vessel will be transiting to and from the Albatross Bay DMPA;
- during cruising periods, including travelling to the Port of Weipa and to the DMPA, the THSD Brisbane was assumed to operate engines at 80% power; and
- when dredging it was assumed that the engines operated at 50% power and the pumps operate at full capacity.

A 1.2 Assumptions

The following additional assumptions were adopted for the assessment of GHG emissions:

- low sulphur diesel fuel is used in all of the marine vessels;

- fuel for the vessels should be considered to be supplied by the Port of Weipa, as they would be commissioning the vessel and therefore they were considered to be Scope 1 direct GHG emissions in line with the GHG Protocol;
- for both vessels it was assumed that their generator was operated at full capacity to supply power for the onboard facilities throughout (TSHD Brisbane generator total power = 800 kW, Pacific Conquest generator total power = 180 kW); and
- GHG emissions were calculated over a 20-year operating period for each option in the GHG assessment. It was assumed that the same equipment, available today, is used with no technology improvements.

A 1.3 Emission Factors and Calculations

A 1.3.1 Scope 1 GHG Emissions Calculations

GHG emissions from the consumption of bunker fuel during the operation of marine vessels were calculated using guidance from the Environmental Protection Agency (USEPA) methodology '*Current Methodologies in Preparing Mobile Source Port-Related Emission Inventories*'.[5] The emission parameters and emission rates used were derived using the USEPA methodology. The vessel parameters were determined from the marine vessel specifications to be used in each option.

Emissions per ship call and mode can be determined from Equation 1:

$$E = P \times LF \times A \times EF \quad [1]$$

where:

E = Emissions (grams (g))
P = Engine Power (kilowatts (kW))
LF = Load Factor (percent of vessel's total power)
A = Activity (hours (h))
EF = Emission Factor (grams per kilowatt-hour (g/kWh)).

GHG emissions were calculated based on fuel consumption associated with the travel of the vessels to the Port of Weipa, and throughout the duration of the activity. Emissions of carbon dioxide (CO_2), methane (CH_4) and Nitrous Oxide (N_2O) were determined for each option.

The marine vessel parameters and emission factors utilised to calculate GHG emissions are detailed in Table 6.

Table 6. Marine Vessel Emission Parameters & Factors Utilised in the GHG Assessment

Option	Marine Vessel	Engine Power (kW)	Load Factor[1]	CO_2 Emission Factor[1] (g/kWh)	CH_4 Emission Factor[1] (g/kWh)	N_2O Emission Factor[1] (g/kWh)
Maintenance Dredging	THSD Brisbane	3,700	0.69	690	0.09	0.02
Drag Barring / Bed Levelling	Pacific Conquest	1,322	0.69	690	0.09	0.02

[1] Obtained from (USEPA) methodology '*Current Methodologies in Preparing Mobile Source Port-Related Emission Inventories*'.

[5] USEPA (2009); Current Methodologies in Preparing Mobile Source Port-Related Emission Inventories, Final Report, April 2009

A 2 Results

The predicted comparative GHG emissions associated with each option over a 20-year period are detailed in Table 7. The results show that the sustainable relocation solutions result in a reduction in GHG emissions compared to maintenance dredging due to the reduction in distance the TSHD Brisbane is required to travel.

Table 7. Predicted GHG Emissions from the solutions considered.

Solution	Scope 1 $CO_{2}e$ Emissions over 20 Year Operational Period (Tonnes CO_{2e})
South Channel – Maintenance Dredging	52,000
South Channel – Sustainable Relocation	48,410
Inner Harbour – Maintenance Dredging	4,210
Inner Harbour – Sustainable Relocation	2,910
Inner Harbour – Drag Barring	4,460