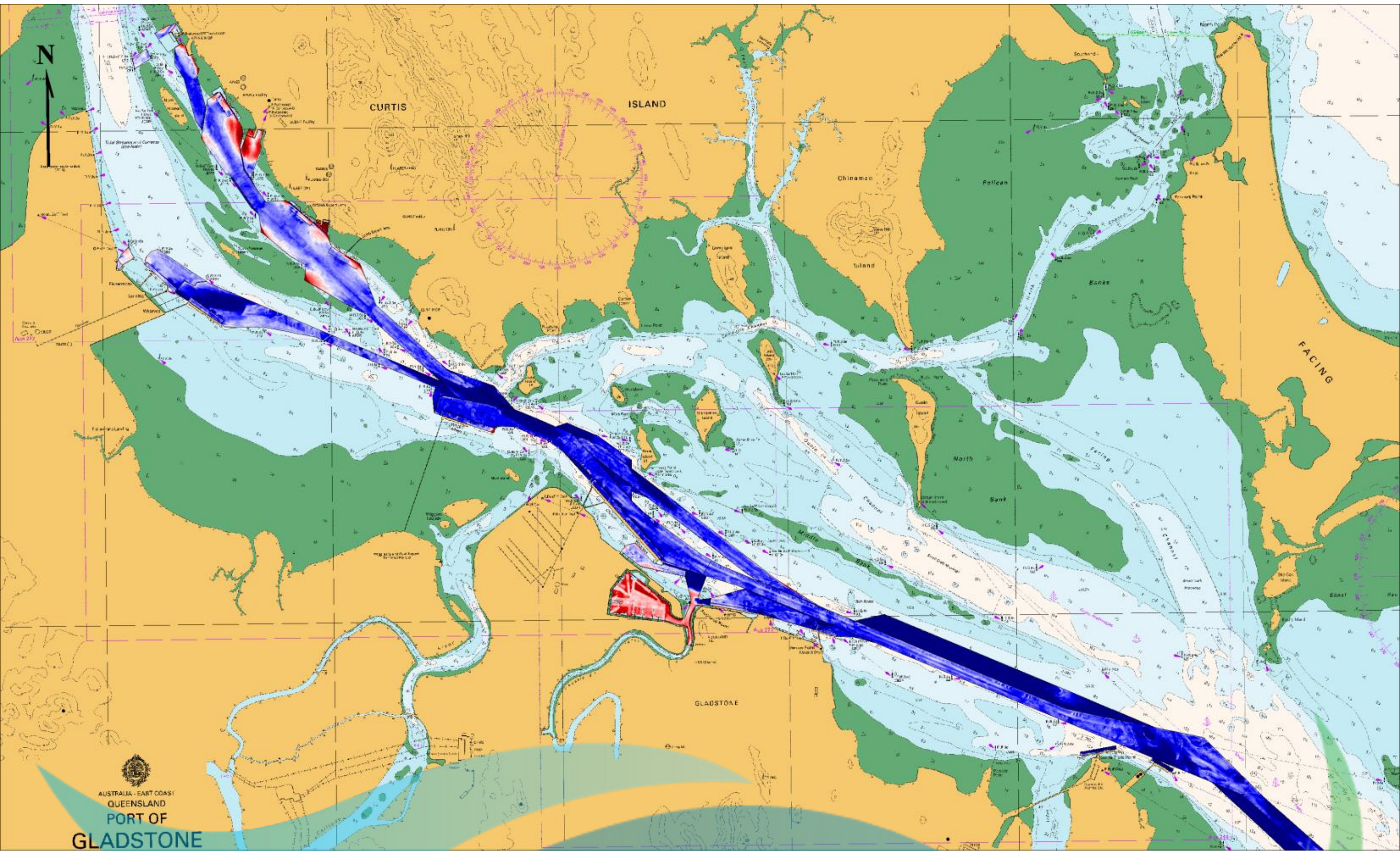
PORT & COASTAL SOLUTIONS

Sustainable Sediment Management Project

Port of Gladstone: Reduce Assessment

Final 1.0



Gladstone Ports Corporation
Technical Report
April 2020

Sustainable Sediment Management Project

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Final 1.0

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ACRONYMS

APLNG	Australia Pacific Liquified Natural Gas
BPAR	Benthic Photosynthetic Active Radiation
CSD	Cutter Suction Dredger
DES	Department of Environment and Science
DoEE	Department of Environment and Energy
DTMR	Department of Transport and Main Roads
EBSDS	East Banks Sea Disposal Site
EMS	Environmental Management System
GBRMP	Great Barrier Reef Marine Park
GBRMPA	Great Barrier Reef Marine Park Authority
GBRWHA	Great Barrier Reef World Heritage Area
GHG	Greenhouse Gas
GLNG	Gladstone Liquified Natural Gas
GPC	Gladstone Ports Corporation
LAT	Lowest Astronomical Tide
LMDMP	Long-term Maintenance Dredging Management Plan
LNG	Liquified Natural Gas
MDS	Maintenance Dredging Strategy
PCS	Port and Coastal Solutions
PoG	Port of Gladstone
QCLNG	Queensland Curtis Liquified Natural Gas
QLD	Queensland
RHM	Regional Harbour Master
RODV	Remotely Operated Dredge Vessel
SSC	Suspended Sediment Concentration
SSM	Sustainable Sediment Management
TSHD	Trailing Suction Hopper Dredger
WICT	Wiggins Island Coal Terminal

Executive Summary

Gladstone Ports Corporation (GPC) commissioned Port and Coastal Solutions (PCS) to undertake an assessment into possible approaches to reduce maintenance dredging as part of their Sustainable Sediment Management (SSM) Project for the Port of Gladstone (PoG).

Aims: The scope of the work included in this report is as follows:

- Task 1: to undertake a comprehensive Objectives Assessment of possible approaches to reduce maintenance dredging (either the volume or duration) within the PoG; and
- Task 2: to develop standardised approach synopses for each of the approaches considered to reduce maintenance dredging.

Future Sediment Management: The report has provided an overview of the existing and predicted future sediment management requirements of the PoG. It was identified that the majority (approximately 90%) of the ongoing sedimentation above declared depths in the PoG occurred in the Liquified Natural Gas (LNG) Terminal region, Marina, Outer Harbour Cuttings (Golding, Boyne and Wild Cattle Cuttings) and berths. These areas have therefore been the focus of the reduce assessment, with possible alternative approaches to maintenance dredging considered for each area.

Sustainable Practises: To allow for ongoing SSM it is important to acknowledge that sediment from maintenance dredging is an essential component of natural sediment budgets and ecosystems. Therefore, a key principle is to consider dredged material as a valuable resource to be used in the natural environment, rather than a waste material for disposal. In line with this, recent industry guidance has been promoting the approach of sustainable relocation where dredged sediment is released into the active sediment system, where it can be transported to areas which rely on an ongoing supply of sediment. This approach helps to maintain the sediment supply and therefore helps to support sediment-based habitats and shorelines which rely on an ongoing natural supply of sediment. For this assessment, this type of sustainable practise has been considered as an approach to reduce maintenance dredging, when it improves the efficiency of the dredging. This practice, therefore, has the potential to reduce the duration of maintenance dredging as well as reducing the volume of sediment placed at the East Banks Sea Disposal Site (EBSDS).

Reduce Assessment: A summary of the key findings of the PoG reduce assessment are detailed below:

- an initial feasibility assessment was undertaken with consideration to the natural processes which cause sedimentation. Reduce approaches can be considered to be based on three broad strategies, (i) to keep sediment out, (ii) keep sediment moving and (iii) keep sediment navigable. A total of eleven possible reduce approaches were identified based on information taken from global best practise guidance. Of these, seven approaches were considered to be potentially feasible based on the natural processes driving sedimentation in the PoG and were considered as part of a detailed Objectives Assessment;
- the seven approaches were assessed along with ongoing maintenance dredging as part of a comprehensive Objectives Assessment. The assessment considered objectives for twelve separate aspects. Based on the Objectives Assessment, four approaches were selected as possible approaches which could be further investigated to reduce maintenance dredging in the PoG:
  - LNG Terminal Region – Sustainable Relocation: the approach assumes that half of the annual sedimentation which requires management in the LNG Terminal region is managed through sustainable relocation using the Trailing Suction Hopper Dredger (TSHD) *Brisbane*, while the other half continues to be placed at the EBSDS by the TSHD *Brisbane*. It is recommended that the approach is discussed with the relevant regulators to confirm the legislative requirements. Following this, if the approach is

still considered feasible, then detailed numerical modelling should be undertaken. The modelling should be aimed at understanding how much sediment is likely to be redeposited in the dredged areas of the PoG, identifying potential impacts to sensitive receptors and optimising the approach relative to the metocean conditions. A trial could then be adopted with a small volume of sediment placed at the proposed sustainable relocation site (e.g. full hoppers at varying stages of the tide over a day), with monitoring used to confirm the fate and impact of the sediment. Based on the assumptions made as part of this assessment (that half of the ongoing sedimentation in the region could be managed through sustainable relocation), the approach would reduce the maintenance dredging duration by 5 days per year and could reduce the volume of sediment placed at EBSDS by up to 75,000 m^3/yr (in-situ).

– Marina – Sustainable Relocation: the approach assumes that all of the annual sedimentation which requires management in the Marina (40,000 m^3/yr) is managed through sustainable relocation through a pipeline to the edge of Clinton Channel. The approach requires the sedimentation to be moved to a corner of the Marina by drag barring, dredging by a remotely operated dredge vessel (RODV) in the corner of the Marina and pumping of low concentration dredged sediment to the edge of the Clinton Channel. The RODV would be capable of pumping approximately 60 m^3/hr (*in-situ volume*) of sediment and based on this it has been assumed that 640 hours of dredging would be required per year. Similar to the sustainable relocation approach for the LNG Terminal region, it is recommended that the approach is discussed with the relevant regulators to confirm the legislative requirements. Following this, if the approach is still considered feasible, then detailed numerical modelling should be undertaken to understand how much sediment is likely to be redeposited in the dredged areas of the PoG, as well as any potential impacts to sensitive receptors. Following this the approach could be implemented with monitoring used to confirm the fate and impact of the sediment. The approach could reduce the volume of sediment placed at EBSDS by approximately 40,000 m^3/yr (in-situ).
– Berths – Jet Array: The jet array approach is only expected to be feasible in berths with high rates of sedimentation such as the berths at the LNG Terminals, although in some other berths where high rates of sedimentation occur over a small region of the berth (e.g. at Fisherman's Landing Berth 5 and Auckland Point Berth 1 where sedimentation occurs at one end) this approach could also be feasible with only one or two jets required. Due to the configuration of the berths at the LNG Terminals, there is the potential that some sedimentation could occur in the corners of the berths and so ongoing drag barring is likely to be required in conjunction with the jet array. If the approach is adopted at a single berth in the LNG Terminal region, then it could reduce maintenance dredging by between 4,500 and 12,000 m^3/yr (variable rates depending on the berth). If adopted at all berths in the LNG Terminal region then it could reduce maintenance dredging and the subsequent placement of sediment at sea by around 23,600 m^3/yr (in-situ) on average which equates to approximately four days of maintenance dredging.
– Berths – Nautical Depth Navigation / Drag Barring: This approach is only considered to be potentially feasible in berths where the adjacent apron is at a similar depth to the berths, such as the berths at the LNG Terminals. It is recommended that sediment testing and a dual frequency bathymetric survey are undertaken between annual maintenance dredging campaigns to better understand the sediment properties and determine if the nautical depth navigation aspect would be applicable. In addition, test case drag barring could be undertaken in the berths between annual maintenance dredging campaigns to better understand the production rates and therefore the number of days required per year. If the approach is adopted at a single berth in the LNG Terminal region then it is estimated to be able to reduce maintenance dredging by between 9,000 and 24,000 m^3 (in-situ) (variable rates depending on the berth) and if it was adopted at all berths in the LNG Terminal region then it could reduce maintenance dredging by 47,200 m^3 (in-situ) every three years on average. It is important to note that this approach would need to be combined with a suitable sediment management approach for the adjacent apron area (e.g.

drag barring combined with annual maintenance dredging) to prevent a build-up of sediment in the apron directly adjacent to the berth.

- Outer Harbour Cuttings: no realistic approaches were identified to reduce maintenance dredging in the Outer Harbour Cuttings (Golding, Boyne and Wild Cattle Cuttings).

Future Implications: If the jet array approach is implemented at the three LNG Terminal berths and the sustainable relocation approaches are adopted at the LNG Terminal region and the Marina, then there could be a reduction in maintenance dredging of 23,600 m^3/yr (in-situ) and a reduction in sediment placed at the EBSDS of approximately 138,600 m^3/yr (in-situ) (inclusive of the 23,600 m^3/yr reduction in maintenance dredging). This represents a 9% reduction in maintenance dredging per year and a 50-60% reduction in the volume of sediment placed at the EBSDS per year.

1. Introduction

Gladstone Ports Corporation (GPC) commissioned Port and Coastal Solutions (PCS) to undertake a number of tasks as part of their Sustainable Sediment Management (SSM) Project for the Port of Gladstone (PoG). The scope of the work included in this report is as follows:

- Task 1: to undertake a comprehensive Objectives Assessment of possible approaches to reduce maintenance dredging (either the volume or duration) within the PoG; and
- Task 2: to develop standardised approach synopses for each of the approaches considered to reduce maintenance dredging.

1.1. Project Overview

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

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

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

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

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

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

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

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

The SSM Project will therefore help to fulfil the requirements of the Deed and will also provide input to the LMDMP. The SSM Project has been developed to build on the information collected to date within Port Curtis, to develop a sediment budget and associated model to better understand the contribution of GPC's activities to the overall sediment system and to investigate possibilities to avoid or reduce the need for further placement of sediment into the marine environment.

As part of the Avoid component of the SSM Project, it was concluded that there were no realistic options available to completely avoid maintenance dredging and the placement of dredged material at sea and for the PoG to remain operational. This assessment follows on from the Avoid assessment and is aimed at understanding the potential options for and implications of reducing sedimentation, maintenance dredging and the placement of dredged material at sea.

1.2. Port of Gladstone

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

In the 2018/19, financial year the PoG handled approximately 124.8 million tonnes of commodities. This was predominantly made up of coal, alumina/aluminium related products and Liquified Natural Gas (LNG), although other products including cement, petroleum, industrial chemicals, grain and containers were also handled (GPC, 2019).

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

1. RG Tanna Coal Terminal: four (4) wharves;
2. Barney Point Terminal: one (1) wharf;
3. Auckland Point Terminal: four (4) wharves;
4. Fisherman's Landing: four (4) wharves;

5. South Trees: two (2) wharves;
6. Boyne Wharf: one (1) wharf;
7. Curtis Island LNG Precinct, Australia Pacific LNG (APLNG): one (1) wharf;
8. Curtis Island LNG Precinct, Queensland Curtis LNG (QCLNG): one (1) wharf;
9. Curtis Island LNG Precinct, Gladstone LNG (GLNG): one (1) wharf; and
10. Wiggins Island Coal Terminal (WICT): one (1) wharf.

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

The PoG consists of approximately 50 km of shipping channels to ensure safe navigation from the entrance to Port Curtis to the wharves (Figure 2). Sediment management practises are undertaken to ensure that the depths of the channels and berths are maintained at their original declared depths (Table 1). The sediment management practises include maintenance dredging, bed levelling and drag barring[1]. Annual maintenance dredging and bed levelling/drag barring practises are undertaken in the PoG, with some areas requiring sediment management at least annually while others require less frequent management.

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

Channel	Declared Depth (m LAT)
Outer Harbour	
Wild Cattle Cutting	-16.1
Boyne Cutting	-16.1
Golding Cutting	-16.1
South Bypass Channel	-7.3
Gatcombe Channel	-16.3
Gatcombe Bypass	-12.5
Inner Harbour	
Auckland Channel	-15.8
Auckland Bypass	-6.8
Clinton Channel	-16.0
Clinton Bypass	-13.0

[1] in this report these are defined as follows: bed levelling is aimed at the removal of high spots to level the seabed immediately after dredging; and drag barring is aimed at resuspending and redistributing bed sediment between dredging campaigns to help maintain depths.

Channel	Declared Depth (m LAT)
Targinnie Channel	-10.6
Jacobs Channel	-13.0
Marina	-4.5
WICT departure channel	-16.0

Capital dredging has historically been undertaken in the PoG as the port has grown. Most recently, between 2011 and 2013, capital dredging associated with the construction of three LNG terminals was undertaken. Table 2 provides details of the maintenance and capital dredging, which has been undertaken at the PoG when sediment has been placed at the EBSDS over the last 10 years. It is important to note that the table does not include the volume of sediment removed from the Marina and a number of other areas of the PoG (e.g. Boyne River) as to date the sediment from these areas has been placed on land. Historic maintenance dredging of the Marina has included the removal of 352,000 m^3 (in-situ volume) in 2009 and 305,000 m^3 (in-situ volume) in 2015.

Table 2. PoG dredging volumes where sediment was placed at the EBSDS over the last 10 years.

Year	Maintenance Dredging (in-situ m^3)	Capital Dredging (in-situ m^3)
2007	160,972	
2008	17,995	
2009	282,000	
2010	0 (dredging was at start of 2011)	
2011	309,000	
2012	150,000	5,113,475
2013	0 (dredging was at start of 2014)	
2014	550,366	
2015	68,000	
2016	455,000	
2017	209,456	
2018	211,102	
Total (2007-2017)	**2,413,891**	**5,113,475**

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

Capital dredging has been reported as in-situ cubic metres, taken from contract documentation as calculated between pre-dredge hydrographic surveys and the contract design dredge depth. This calculation is typically indicative of the amount delivered to EBSDS since capital material is of a denser nature than maintenance.

A breakdown of the volumes of sediment dredged throughout the different areas of the PoG during the 2018 annual maintenance dredging[2] is shown in Figure 3. The plot shows that just

[2] Use of the term 'annual maintenance dredging' in this report refers to the maintenance dredging of the main channels, basins and berths of the PoG by the TSHD *Brisbane* each year and the subsequent placement of the sediment at EBSDS. This does not include the maintenance dredging of other areas where the sediment is currently placed on land (e.g. the Marina).

over 60,000 m^3 was removed from the Golding, Boyne and Wild Cattle Cuttings, approximately 115,000 m^3 was removed from the areas to the north of the RG Tanna Wharves (north of Clinton Channel, WICT berths, Targinnie Channel and Jacobs Channel region) and the remaining volume was removed from the area between the RG Tanna Wharves and the eastern end of the Gatcombe Channel. As the PoG Sea Dumping Permit requires GPC to report the in-situ cubic metres that are delivered by the dredger to EBSDS, the reported dredge volumes and sedimentation (measured as the in-situ change in volume based on bathymetric data) will not correlate directly. This is because the dredge volumes placed at EBSDS do not include the volume of sediment which is removed from the seabed by the dredger and subsequently lost during overflowing when the dredger is filling its hopper. Based on monitoring during previous maintenance dredging and advice from expert dredging consultants, the efficiency of the TSHD *Brisbane* ranges from 50% to 70% when undertaking maintenance dredging at the PoG (BMT, 2017). This means that between 30% and 50% of the sediment which is dredged from the seabed is lost during overflowing and of this amount it has been estimated that approximately 15% remains in suspension as a plume and the remainder is locally deposited back into the channel (BMT, 2017). The sediment which is locally redeposited in the channel might subsequently be re-dredged, redistributed by bed levelling or settle into naturally deeper areas which don't require dredging.

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

1.3. Report Structure

The report herein is set out as follows:

- details of the existing sediment management in the PoG and the expected future requirements is given in **Section 2**;
- the reduce assessment which includes an objectives assessment is provided 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). Volumes presented throughout are in-situ cubic metres calculated from surveyed bathymetry. The ongoing sedimentation volumes assumed to require sediment management were based on the volumes predicted as part of the Avoid Assessment (PCS, 2018a), these were typically the sedimentation above design depth.

Figure 2. PoG declared channels and sea disposal site.

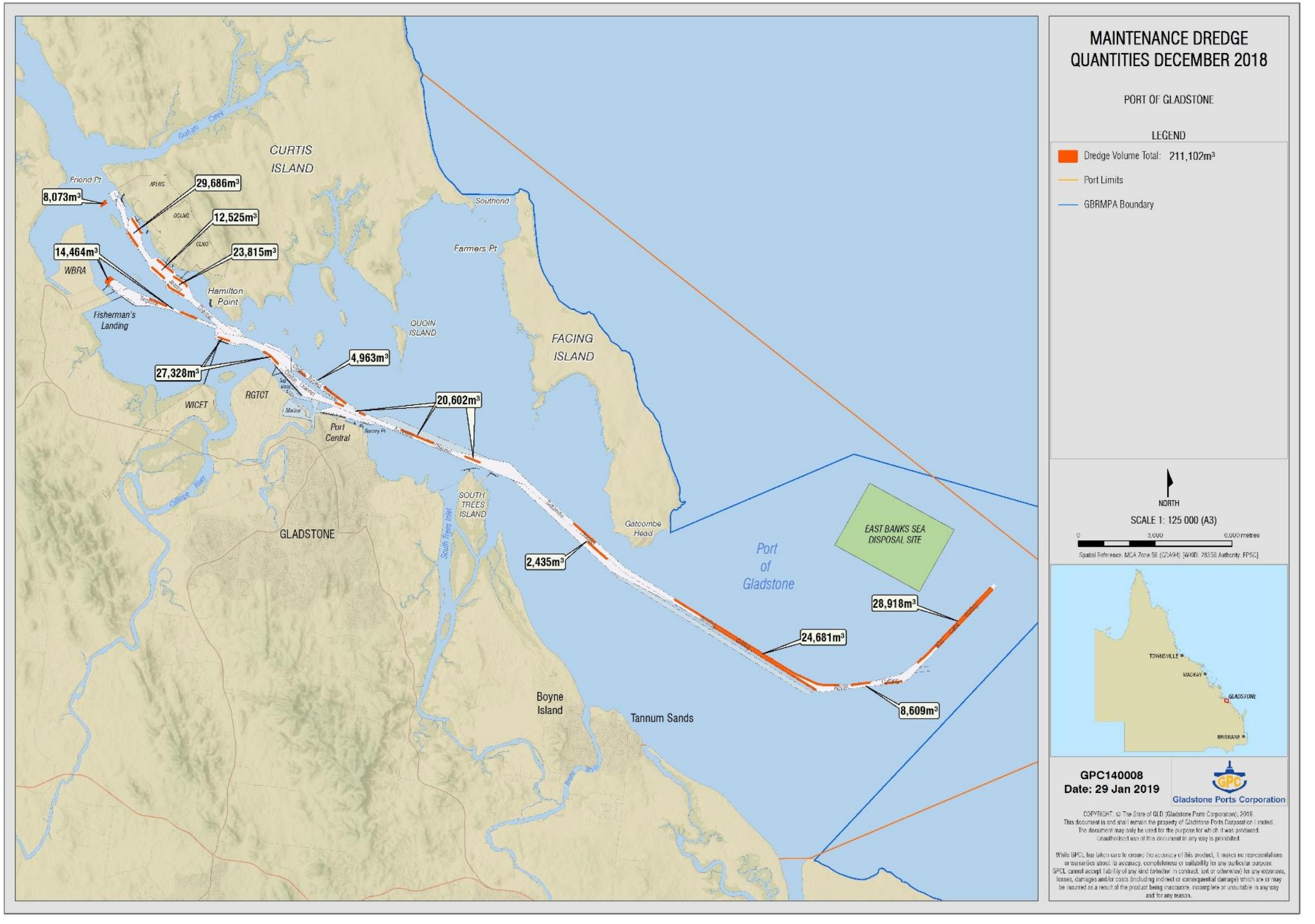

Figure 3. PoG annual maintenance dredging volumes from 2018.

2. Sediment Management

2.1. Introduction

To better understand how the historic sedimentation which has been observed in the PoG could potentially influence maintenance dredging and navigation in the future, a detailed analysis of the bathymetric changes relative to the declared depths in the PoG was undertaken as part of the Avoid assessment (PCS, 2018a).

The declared depth is the depth nominated by the Regional Harbour Master (RHM) and shown on navigational charts to represent the maximum legal and safe vessel draft for an area (Figure 4). Channels and berths can also have a design depth which is below the declared depth and includes an insurance depth to allow for natural sedimentation over the period between maintenance dredging campaigns to allow safe navigation to continue. In addition, as dredgers are not able to dredge to an exact level, it is common for the dredger to over-dredge by a small amount (e.g. 0.3 m) to ensure that the design levels have been achieved throughout. In the PoG the declared depth and the design depth are typically the same. For this assessment we have adopted the declared depth as the depth for any sedimentation calculations, assuming the original declared depth rather than any subsequent changes to this by the RHM due to sedimentation or erosion.

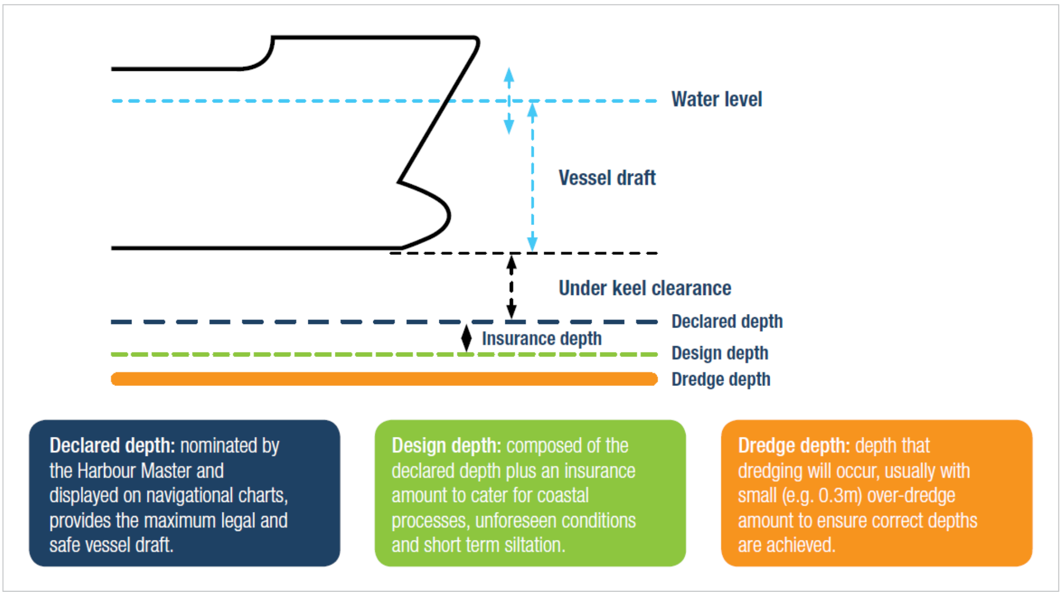

Figure 4. Schematic of depths for navigation and dredging purposes (Ports Australia, 2016).

2.2. Future Requirements

The areas where the bathymetry in the PoG was above the declared depths in the October 2017 pre-maintenance dredging survey are shown by the pink and red areas in Figure 5 and Figure 6. The plots show the following:

- the bathymetry in October 2017 was below the declared depths for the majority of the PoG;
- the main areas where the bathymetry was above the declared depth were the aprons and berths of the LNG Terminals in the Jacobs Channel region and in the Marina;
- some localised areas adjacent to the channel edge were above the declared depth in the Golding, Boyne and Wild Cattle Cuttings and in the Clinton Channel; and
- areas of some of the other berths were above the declared depths, these were typically either along the wharf side of the berth or at the ends of the berth.

Further analysis of bathymetric data from 2007 to 2017 showed that between 2015 and 2017 approximately 70% of the sedimentation above the declared depths in the PoG occurred in the berths and aprons of the LNG Terminals in the Jacobs Channel region. The other areas where regular sedimentation above the declared depths occurred include the northern apron adjacent to Fisherman's Landing Berth 5, Clinton Channel directly north of the Clinton Wharf berths, the Tug Base, Marina, Golding Cutting, Boyne and Wild Cattle Cuttings and some of the berths.

Estimates of the future sediment management requirements were made by PCS (2018a). Typical and worst case estimates were calculated by using the annual mean/median volume (typical) and the annual maximum volume (worst case) of sedimentation above the declared depths based on 10 years of data. The future sediment management requirements were estimated to be 213,000 m^3 during a typical year and 317,000 m^3 during a worst case year. The areas where the largest sediment management requirements have been predicted are:

- LNG Terminals berths and aprons: 155,000 - 195,000 m^3/yr (with 17,000 – 34,000 m^3/yr of the sedimentation being in the berths);
- Marina: 39,000 - 43,000 m^3/yr;
- Golding, Boyne and Wild Cattle Cuttings (Outer Harbour Cuttings): 4,000 - 25,000 m^3/yr; and
- Other Berths (Fisherman's Landing Berth 5, Clinton Wharf Berth, Auckland Point Berth 1 and South Trees West Berth): 2,000 – 21,000 m^3/yr.

These areas represent the majority of the sediment management requirement within the PoG (approximately 90%). Therefore, the reduce assessment will focus on the sedimentation in these areas to assess potential alternatives to maintenance dredging. The sedimentation requiring ongoing management adopted for the reduce assessment has been defined based on the sedimentation volumes detailed above as well as the historic maintenance dredging requirements for the area, this is further detailed in Section 3.5.

2.3. Existing Sediment Management

Based on historic campaigns between 2007 and 2017, the average annual maintenance dredging campaign undertaken by the Trailing Suction Hopper Dredge (TSHD) *Brisbane* in the PoG has been 200,000 m^3 (Table 2). This volume relates to approximately 30 days of dredging using the TSHD *Brisbane*. In addition to the dredging by the TSHD *Brisbane*, approximately 21 days of bed levelling are undertaken[3] each year during the maintenance dredging activity. An additional 15 days of drag barring[2] are also undertaken to help manage sedimentation in the APLNG service facilities which are not part of the existing TSHD *Brisbane* campaign for the TSHD *Brisbane* to operate. Evidence from previous drag barring campaigns in the PoG has found that the production rate is variable depending on the sediment characteristics and site conditions. An average rate of 1,000 m^3/day has been assumed for this assessment to allow the duration of drag barring required for approaches to be defined (T Ware, pers. comm., 2018).

There is some variability in the dredging methods and frequency currently adopted to manage the sedimentation in the PoG in the areas identified as having the largest sediment management requirements:

- LNG Terminals: the aprons of the LNG Terminals adjacent to Jacobs Channel have required at least annual maintenance dredging (a second maintenance dredging campaign was undertaken the year after the capital dredging was completed) by the TSHD *Brisbane*. The sediment from the maintenance dredging has been placed at the EBSDS. Bed levelling has routinely been undertaken following maintenance dredging to redistribute sediment on the bed and remove any high spots;

[3] generally by the Pacific Conquest.

- Marina: maintenance dredging campaigns have historically been undertaken every five years. The ongoing sedimentation causes the bed elevation in the Marina to gradually increase over the five years above the original declared depth. Due to the size of the Marina and associated manoeuvrability safety within the Marina it is not possible for the TSHD *Brisbane* to dredge the area. Instead, a small cutter suction dredger (CSD) has undertaken the dredging, with the sediment being pumped directly to a nearby onshore placement area. However, there is limited capacity in the onshore placement area and no other nearby onshore placement sites and so after the next maintenance dredging campaign (planned for 2020) an alternative approach will be required. For this assessment the alternative maintenance dredging approach which has been adopted is for a small TSHD (hopper capacity of 500 to 1,000 m^3) to dredge the Marina every five years and the sediment to be placed at the EBSDS. A similar alternative approach, which has not been assessed, is that the dredging continues to be undertaken by a small CSD and the sediment is transported on a barge and placed at the EBSDS;
- Outer Harbour Cuttings: maintenance dredging is undertaken in these Outer Harbour channels every year as part of the TSHD *Brisbane* dredging campaign. The sediment from the maintenance dredging has been placed at the EBSDS. The volume removed has been variable depending on the sedimentation which has occurred since the previous dredging campaign and the volume of sediment removed during the previous campaign. Bed levelling has typically been undertaken following maintenance dredging to redistribute sediment on the bed and remove any high spots; and
- Berths (LNG Terminals, Fisherman’s Landing Berth 5, Clinton Wharf Berth, Auckland Point Berth 1 and South Trees West Berth): maintenance dredging is undertaken in most of these berths annually as part of the TSHD *Brisbane* dredging campaign. The sediment from the maintenance dredging has been placed at the EBSDS. Bed levelling has routinely been undertaken following maintenance dredging to redistribute sediment on the bed and remove any high spots. The highest sedimentation rates have occurred in the LNG Terminal berths and the area required a mid-year maintenance dredging campaign following the capital dredging and immediately prior to the terminals becoming operational.

The Reduce assessment will consider these existing sediment management practises along with alternative options as part of an Objectives Assessment detailed in the following section.

PORT & COASTAL
SOLUTIONS

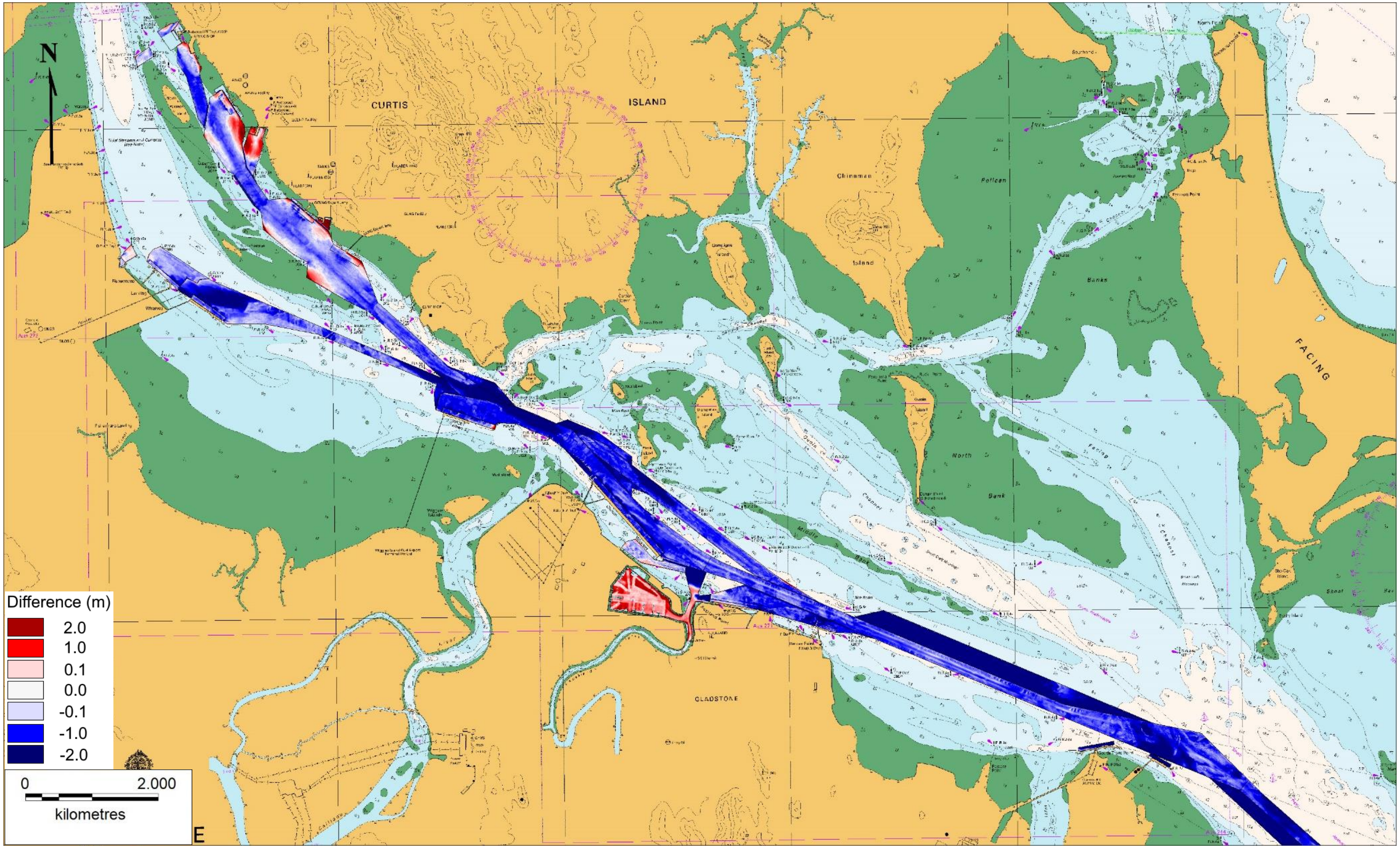

Figure 5. Inner Harbour depth above (red) and below (blue) declared depth in October 2017, pre-maintenance dredging (PCS, 2018a).

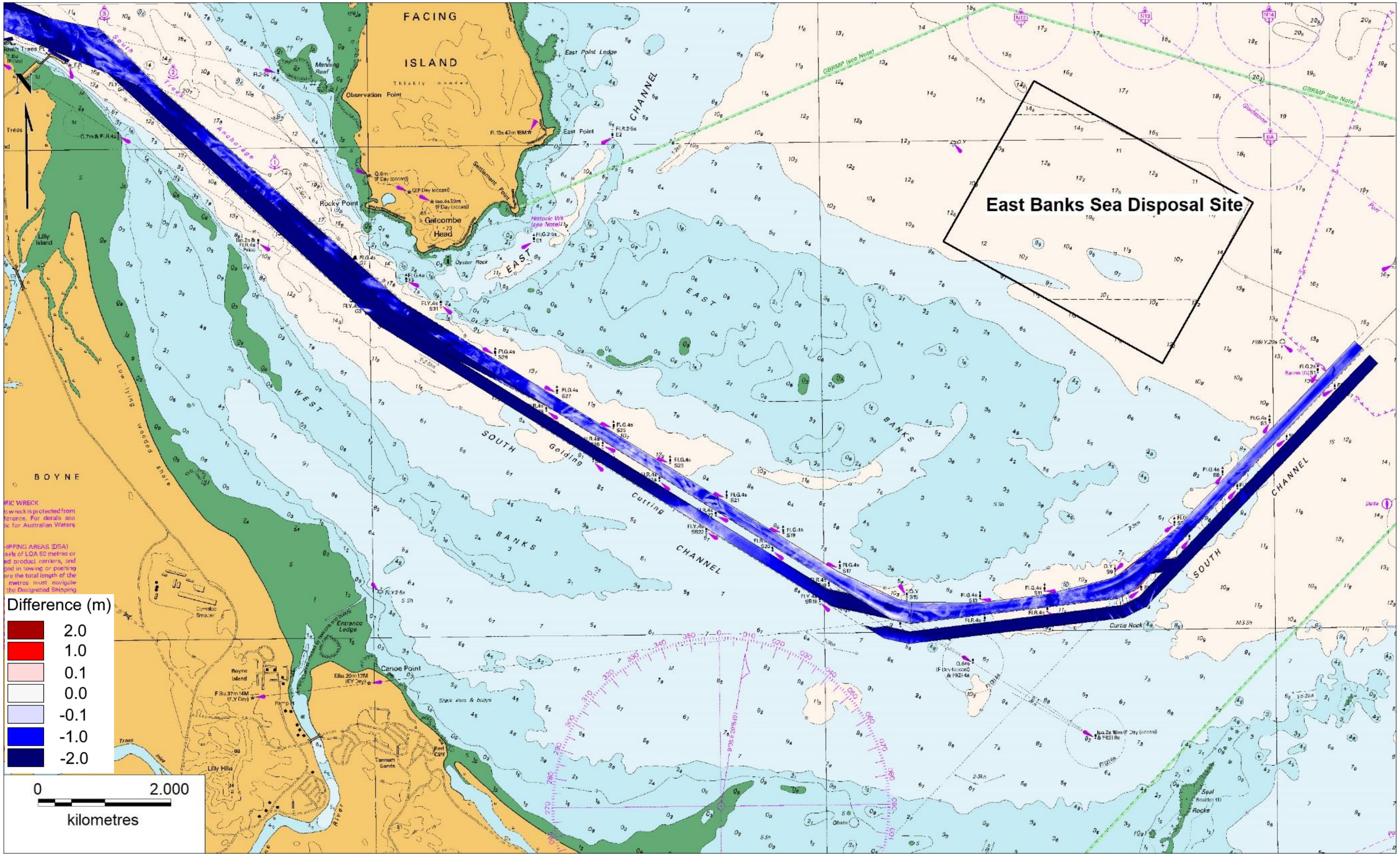

Figure 6. Outer Harbour depth above (red) and below (blue) declared depth in October 2017, pre-maintenance dredging (PCS, 2018a).

3. Reduce Assessment

A requirement of the Deed associated with the Sea Dumping Permit for maintenance dredging between GPC and DoEE, as well as the LMDMP in accordance with the MDS framework, is the analysis of options of avoiding or reducing the need for further placement of maintenance dredged sediment into the marine environment (see Section 1.1). A previous assessment considered the possibility of avoiding further placement of dredged material into the marine environment and found that it was not a feasible solution (PCS, 2018a). This assessment is considering the possibility of reducing maintenance dredging and the subsequent placement of maintenance dredged material into the marine environment.

To understand the potential options for reducing maintenance dredging and reducing the placement of dredged material at sea, it is necessary to undertake an Objectives Assessment. This section details the approaches for reducing maintenance dredging and the placement of dredged material at sea.

3.1. Sustainable Practises

To allow for ongoing SSM it is important to acknowledge that sediment from maintenance dredging is an essential component of natural sediment budgets and ecosystems (Laboyrie et al, 2018). Therefore, a key principle which should be adopted is to consider dredged material as a valuable resource to be used in the natural environment, rather than a waste material for disposal.

Recent industry guidance has been promoting the approach of sustainable relocation where the dredged sediment is retained within the marine environment and within the natural sediment system (CEDA, 2009; RHDHV, 2016). This approach involves the dredging of recently deposited sediment and the subsequent release of it into the active sediment system, where it can be transported to areas which rely on an ongoing supply of sediment. The natural response of many intertidal habitats, such as mudflats and mangroves, to sea-level rise is to accrete to ensure that the elevation of the habitat relative to the tidal levels remains the same. As such, if natural sediment which has recently deposited in dredged areas is consistently removed from the system and placed offshore in a retentive placement area, there is a risk that the habitats cannot accrete as quickly as sea level rise, which could result in a change in both the flora and fauna in the area.

For this assessment, this type of sustainable practise has been considered as a possible approach to reduce maintenance dredging when it improves the efficiency of the dredging. Therefore, the approach could reduce the risk of habitats not accreting as quickly as sea level rise, as well as having the potential to reduce the duration of dredging and reducing the volume of sediment placed at the EBSDS.

3.2. Natural Sedimentation Processes

To assess the suitability of reduce approaches it is necessary to understand the natural processes which are causing sedimentation and the physical characteristics of the sediment which is accreting. The future sedimentation predictions in Section 2.2 show that although the majority of the recent sedimentation above declared depths has occurred in the Inner Harbour region, some sedimentation has also occurred in the Outer Harbour region of the PoG. It is noted by PCS (2018b) that the majority of the sediment which has been deposited in the Inner Harbour region has been fine-grained silt and clay, while in the Outer Harbour region the sediment has been more variable with approximately equal proportions of sand to silt/clay in the Golding Cutting and predominantly sand in the Wild Cattle Cutting. A summary of the processes which result in sedimentation in the Inner and Outer Harbour regions of the PoG has been detailed by PCS (2018b).

3.2.1. Inner Harbour

Resuspension and sediment transport in the Inner Harbour region is dominated by the tidal currents. The strong tidal currents are the dominant process for resuspending sediment in the Inner Harbour, although small locally generated wind waves and wind induced currents can also result in resuspension in shallow areas where fine-grained sediment is present. The fine-grained sediment which is deposited on intertidal mudflats within the Inner Harbour remains undisturbed during neap tides, but during larger spring tides which inundate all the intertidal mudflats (referred to as 'over-bank tides') this sediment can be resuspended resulting in increased sediment mobilisation during large spring tides. Based on the above, the bed sediment throughout much of the Inner Harbour is regularly mobilised, transported and redeposited until it is either transported to a sheltered location where ongoing sedimentation occurs (e.g. the Marina), or out of the region by the ebb tidal currents. The Inner Harbour region can be considered a sediment sink, with extensive sources of fine-grained and coarser sands and gravels already present due to deposition over geological timeframes.

In addition to the available sediment already present in the Inner Harbour, new sediment is added to the region by the suspended sediment being discharged from the Calliope River, South Trees Inlet and from fluxes of suspended sediment being transported through the three entrances to the Inner Harbour during the flooding tide. Although it is likely that the gross flux of suspended sediment through the main entrance of the Inner Harbour will be high during a spring tide, the net flux is likely to be comparatively small compared to the mass of sediment resuspended within the Inner Harbour. The relatively high tidal current speeds which occur throughout much of the Inner Harbour limit the build-up of fine-grained sediment in the main channels. However, in sheltered areas at the sides of the channels, within berths and aprons, closed-end channels (e.g. Jacobs and Targinnie Channels) and vegetated areas (e.g. areas with seagrass or mangroves which promote deposition) regular sedimentation of fine-grained sediment can occur.

3.2.2. Outer Harbour

The Outer Harbour is influenced by a combination of offshore waves and tidal currents. The wave action is the dominant process for resuspending sediment in the Outer Harbour, while tidal currents are the dominant process for transporting the suspended sediment. The majority of the Outer Harbour region is an ebb tidal delta which has developed over time at the mouth of the Port Curtis estuary. Therefore, the region is a natural sediment sink, which is further highlighted by the presence of the East and West Banks (located to the north and south of the Golding Cutting) and is expected to continue to act as a sink over time. Due to the influence of offshore wave action the majority of the sediment which has accumulated in the area is sand.

In addition to the available sediment already present in the Outer Harbour, sediment is added to the region by the net northerly longshore transport of sediment (sand and fine-grained silt/clay) along the coastline, the suspended sediment being discharged from the Boyne River and from fluxes of suspended sediment being transported out of the Inner Harbour through the two entrances. The relatively high tidal current speeds which occur close to the southern entrance to the Inner Harbour limit sedimentation of fine-grained sediment in this area. As the current speeds reduce and the trapping efficiency of the channels increase (i.e. depth of channel below adjacent seabed), some deposition of sand and silt/clay sized sediment occurs.

Along the sides of the Golding Cutting a combination of sand, silt and clay has built-up, while in the Wild Cattle Cutting the sediment is predominantly made up of sand. The reason for this difference is thought to be a combination of the trapping efficiency of the channels (Wild Cattle Cutting has a lower trapping efficiency due to the naturally deeper adjacent bathymetry), the exposure to wave action (Wild Cattle Cutting is more exposed as East Bank will provide some shelter to the Golding Cutting) and the configuration of the channel (the bend at the Boyne Cutting will also influence the trapping efficiency and local conditions).

In both channels the sedimentation which has occurred has been predominantly along the edges of the channels, this is due to the natural current speeds being lowest along the edges of the channels and the propeller wash from vessels sailing along the centreline of the channel resulting in increased disturbance along the centre of the channel and therefore preventing sediment from building up here.

3.3. Overview of Reduce Solutions

Significant research has been undertaken globally into solutions to reduce sedimentation and maintenance dredging in Ports and Harbours due to the 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 and maintenance dredging based on port specific experiences (USACE, 2003; PIANC, 2008). Both guidelines note that port specific investigations, such as this, are required to assess the applicability of the approaches on a case by case basis, as the suitability is dependent on 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 be deposited;
- 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 and insurance trenches.
	Blocking sediment entry	Pneumatic barrier, silt screen, barrier curtain.
	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.
	Devices to increase bed shear stresses	Hydraulic jets, vortex foil arrays, mechanical agitators (e.g. spider dredging system).

Strategy	Approach	Example
	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.

3.4. Initial Feasibility

To ensure that the approaches considered as part of the Objectives Assessment are realistic based on the natural sedimentation processes which occur in the PoG it is necessary to undertake an initial feasibility assessment. Therefore, the potential of the approaches to reduce sedimentation or maintenance dredging in the four areas of the PoG (LNG Terminals, Marina, Outer Harbour Cuttings and Berths) where the largest sediment management requirements are has been considered and is detailed in Table 4.

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

Approach	Potential Reduction in Sedimentation or Dredging
Stabilise sediment sources	No
Diverting sediment-laden flows	No
Trapping sediment	Yes
Blocking sediment entry	Yes
Habitat creation	No
Channel realignment to train natural flows	Yes
Devices to increase bed shear stresses	Yes
Methods to reduce sediment flocculation	No
Sustainable relocation	Yes
Adopt a 'nautical depth' navigation approach which includes fluid mud	Yes
Keep sediment navigable by adopting minimum channel width	Yes

A summary of the initial feasibility of the approaches is provided 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. Due to the limited sediment supply to the PoG from rivers combined with the high natural reworking which occurs in the PoG due to the strong tidal currents, this approach is not considered to be feasible for the PoG;

- 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 PoG combined with the processes which control the resuspension and transport of suspended sediment in the PoG this approach is not considered to be feasible;
- Trapping sediment: sediment traps can be created to either prevent sediment from reaching dredged areas, or to provide additional capacity in the dredged areas where sedimentation can be moved (by drag barring or similar) and then stored between maintenance dredging campaigns. The first type of sediment trap is most effective in areas where bedload transport dominates, while the second approach can be adopted in any locations where ongoing sedimentation occurs. The approach acts to ensure that the declared depths are maintained for a longer period of time and also that ongoing sedimentation can be focused in one localised area, which would also act to promote consolidation of any fine-grained sediment. As a result, the frequency and in-situ volume (due to consolidation) for maintenance dredging would be reduced, the dredging would be more efficient and the dredge duration could also be shorter as the majority of the sediment would be in one location. This approach is therefore considered to be feasible for the berths in the PoG and will be considered as part of the Objectives Assessment detailed in the next section;
- Blocking sediment entry: for harbours or marinas with single entrances it can be possible to block sediment from entering the harbour/marina. As such, this approach would only be feasible for the 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. This approach has very high capital and maintenance costs as well as operational issues and so is not considered to be feasible. An alternative approach is creating a shallow sill at the entrance to the harbour/marina to block any bedload and suspended sediment from being transported close to the seabed. GPC has observed that suspended sediment is present throughout the water column in the Marina and as a result a shallow sill at the entrance is not expected to be effective and so is not considered a feasible approach. In some locations air-bubble screens have been adopted with the air bubbles forming a screen at the entrance to the harbour/marina. The aim of the air bubbles is to promote the generation of currents away from the bubbles, thereby reducing the input of water with high Suspended Sediment Concentration (SSC) from the adjacent water body. However, research has found that the air-bubbles are typically only suitable in areas with calm conditions and low wind speeds (Cutroneo et al, 2014). Given the local metocean conditions in the PoG this approach is unlikely to be effective in reducing sedimentation in the Marina and is therefore 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 reduce sediment resuspension in the PoG, the scale of habitat creation would have to be extensive to result in any noticeable reduction in sedimentation within the dredged areas of the PoG. As such, this approach is not considered to be feasible to reduce maintenance dredging within the PoG;
- Channel realignment: in some cases it is possible to reduce the sedimentation which occurs by either changing the channel or entrance configuration. Changes to the channel or entrance configuration can increase the flow speeds or limit the formation of eddies which both have the potential to reduce sedimentation. This approach could be considered for the LNG Terminals region where increasing the depth to the north of Jacobs Channel would improve the connectivity to the natural adjacent channel, which could increase the flow through Jacobs Channel and potentially reduce sedimentation. Increasing the flow in the Marina by creating a second entrance in the north-east of the Marina would logically be expected to reduce sedimentation in the Marina. However, it is noted by PIANC (2008) that sedimentation rates are often higher in harbours/marinas

with two entrances. The reason for this is that sediment can be imported from two directions and the change in flow pattern can result in the formation of eddies which promote sedimentation. In addition, increasing flow speeds would be seen as a negative for the Marina and could result in safety and operational issues. Based on the above, this approach is not considered to be feasible for the Marina, but is considered to be feasible for the LNG Terminals aprons;

- Devices to increase bed shear stresses: there are a range of approaches which can be adopted to increase bed shear stresses, the most commonly adopted in ports are jets or propellers which can either be attached to wharves or the seabed to generate currents to resuspend sediment and mechanical activities such as bed levelling/drag barring. In the United States fixed position jet/propeller arrays have been used in berths where high rates of sedimentation occur (typically >3 m/yr). Although this type of device has not been used in Australia, the approach is considered to be feasible for berths in the PoG where high sedimentation consistently occurs (LNG Terminal berths). The approaches of bed levelling and drag barring are also considered feasible approaches for all areas of the PoG as they are already adopted in most areas of the PoG as part of the ongoing sediment management activities (see Section 2.3);
- 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. Flocculation due to turbulence from port infrastructure in the PoG is not expected to significantly influence the sedimentation and as such this approach is not considered feasible for the PoG;
- Sustainable relocation: as discussed in Section 3.1 the approach of sustainable relocation involves dredged sediment being retained within the marine environment and within the natural sediment system. This approach helps to maintain the sediment supply and therefore helps to support sediment-based habitats and shorelines which rely on an ongoing natural supply of sediment. Although this approach does not directly reduce sedimentation it can improve the efficiency of maintenance dredging and therefore has the potential to reduce the duration of dredging. Due to the extensive mudflat and mangrove regions in the Inner Harbour region of the PoG, this approach is considered to be feasible to promote future habitat development (LNG Terminal region, some berths and Marina);
- Nautical depth navigation: in locations where fluid mud is present and high sedimentation rates occur, a wet bed density of approximately 1,200 kg/m^3 has been adopted with sediment with a lower density being considered navigable. In Queensland the bathymetric surveying standards specify that the navigable seabed is defined as the trace produced by a 200 kHz transducer (MSQ, 2009), which approximately relates to a lower wet bed density than 1,200 kg/m^3. As such, it is possible that a nautical depth navigation approach could be adopted in areas of the PoG where high sedimentation rates occur. Therefore, this approach is considered feasible for berths in the LNG Terminal region; and
- Minimum channel width navigation: in areas where regular sedimentation occurs along the sides of the channel, while the central region of the channel remains at or below the declared depth, it is possible that the Harbour Master could allow a minimum channel width navigation approach to be adopted. This would mean that as long as a designated minimum width of the channel was at or below the declared depth then the channel would be considered navigable. As sedimentation in the Outer Harbour Cuttings has typically occurred along the edges of the channel, while the centre of the channel has remained at or below the declared depth, this approach is considered feasible for the Outer Harbour Cuttings.

3.5. Objectives Assessment

This section details the Objectives Assessment for the possible approaches to reduce sedimentation or maintenance dredging at the four areas of the PoG which have the largest sediment management requirements (see Sections 2.2 and 2.3). The assessment has been undertaken assuming a 10-year period to allow aspects such as resource use (e.g. quantifying GHG emissions) and cost to be calculated over a sufficient period so that approaches which require initial capital investment are not negatively biased due to it.

A series of objectives were developed by GPC and stakeholders during a workshop held on the 8th November 2018. An objective was defined as something that matters and has a desired direction of change. The objectives were developed so that possible approaches to reduce sedimentation or maintenance dredging along with the existing sediment management approaches could be assessed in a consistent manner to assessments for approaches to beneficially reuse maintenance dredge sediment. The objectives are detailed in Table 5.

A summary of the Objectives Assessment for each approach is provided in the following sections and in Appendix A, while Appendices B and C provide further details of the GHG emission and cost calculations, respectively. It is important to note that the costs do not include any allowance for additional investigations/design or offset requirements associated with approaches that require capital dredging.

Table 5. Objectives to assess potential reduce approaches.

Aspect	Objective	Description
Environment	Maintain or enhance the environment of the PoG and Protected Areas.	Biodiversity, coastal habitats or morphology that could be altered by the option, particularly concerning areas regarded as protected by legislation.
Resource use	Minimise the use of resources and release of associated emissions.	The use of resources (natural or anthropogenic) that can have an impact of the environment, such as the use of fuel, energy and water, the generation of waste and greenhouse gas emissions
Legislative requirement	Minimise the complexity of statutory processes and meet existing legal requirements.	Non-conformance with legislation significantly restricting the viability of the option. Complex statutory processes involving long time frames and extensive information requirements required to allow the assessment of options and provision of practical condition outcomes.
Health & Safety	Maintain or enhance the Health and Safety of all port users or sediment end users.	Inclusive of personal, public and maritime safety.
Cultural	Enhance the Cultural and Historical Heritage within the Port of Gladstone.	Inclusive of potential impacts to Cultural and Historical sites and values, and tools to enhance their protection.
Social	Enhance social activities and opportunities.	Inclusive of potential impacts to any coastal (water or land based) activities/opportunities and any options to enhance them.
Port operations	Maintain or enhance port operations and future development opportunities.	Ensuring that the option does not impact shipping, operations of a commercial or industrial port user, or potential future development of the port.

Aspect	Objective	Description
Cost	Enhance the cost effectiveness of the option.	Ensuring that the cost is reflective of any benefit to any of the tabulated aspects and GPC shareholders.
Economics	Enhance the economic opportunities for the region.	Inclusive of job creation, increasing the opportunities for tourism or other commercial activities. E.g. Fishing or servicing recreational activities.
Methodology	Minimise the uncertainty of the option not working.	By using techniques that have been tried and tested in similar circumstances provides certainty about the management, performance and associated outcomes.
Innovation	Enhance the use of innovative options.	To ensure that best practice is continuously improving.
Longevity	Enhance the capability for a long-term solution.	To ensure that, based on current knowledge, a long-term solution is encouraged.

3.5.1. Approaches to Assess

In addition to the existing sediment management approaches detailed in Section 2.3, the following approaches to reduce sedimentation or maintenance dredging will be considered as part of the Objectives Assessment:

- LNG Terminals Region
  - Channel Realignment: an approach to try and reduce sedimentation in the LNG Terminal region would be to attempt to increase the current speeds to limit the potential for suspended sediment to be deposited. Deepening the shallow channel north of Jacobs Channel connects it to the naturally deeper channel to the north of North Passage Island. This has the potential to increase the flow through the LNG Terminal region, which in turn could reduce sedimentation in the area. It is estimated that approximately 3 million m^3 of sediment would need to be removed from the area by capital dredging and it has been assumed that this sediment would be placed in the Western Basin Reclamation Area. The capital dredging would create a 250 m wide channel with an average depth of 10 m below LAT (Figure 7).
  - Sustainable Relocation: as detailed in Section 3.1, retaining sediment in the marine environment and within the natural sediment system should be considered as an option for sediment removed by maintenance dredging. The aim of the sustainable relocation approach is to ensure that some of the fine-grained sediment which is deposited/trapped within the dredged areas of the PoG is retained within the sediment system of Port Curtis, to feed natural habitats such as mudflats and mangroves. As such, the sustainable relocation area needs to be dispersive and located where sediment has the potential to be transported to a number of different mudflat and mangrove regions without being redeposited in the dredged areas where it had just been removed from or other dredged areas. A potential sustainable relocation area is shown in Figure 8, this location is within the designated channels and was previously used as a relocation ground for capital dredging in 1981. It is located close to mudflat and mangrove environments and is naturally deep (approximately 1 million m^3 capacity below declared depth), indicating that it is dispersive which suggests that any sediment placed there would subsequently be transported away. As the purpose of sustainable relocation is to retain sediment in the system and promote the natural transport of the sediment, it has been assumed that the dredging would be undertaken by the TSHD *Brisbane*, operating with no overflow (to limit consolidation of sediment in the hopper) to promote the dispersion of the sediment when it is relocated. For the purposes of the Objectives Assessment

it has been assumed that half of the annual sedimentation within the LNG Terminals region will be sustainably relocated each year (75,000 m^3), while the other half will continue to be placed at the EBSDS.

- Marina
  - Sustainable Relocation: the aim of the sustainable relocation approach for the Marina is to ensure that the fine-grained sediment, which is transported into the Marina in suspension during the flooding tide and is then deposited and subsequently becomes trapped in the Marina due to the calm conditions, is retained within the local sediment system of Port Curtis to feed natural habitats such as mudflats and mangroves. Due to the restricted manoeuvring and depth restrictions within the Marina it is not possible for the TSHD *Brisbane* to access the Marina and so a small remotely operated dredge vessel (RODV) has been assumed[4]. The small RODV is constrained over where it can operate, due to it having to be connected to shore by cables, and so it is proposed that it would operate in the eastern corner of the Marina and recently deposited sediment will be moved to this location by drag barring. The small RODV will regularly pump low concentration, loosely consolidated fine-grained sediment through a fixed position pipeline to the edge of the Clinton Channel (Figure 9). The relatively high tidal currents which occur in this area, combined with the low concentration of sediment in the pipeline, will promote the transport of the suspended sediment away from the pipeline. It is assumed that all the sedimentation within the Marina will be managed using this approach.
- Outer Harbour Cuttings
  - Minimum Channel Width Navigation: the main areas of the Outer Harbour Cuttings where historical sedimentation has occurred above the declared depths have been along the sides of the channels, as such a form of minimum channel width navigation is already adopted albeit only between annual maintenance dredging campaigns. This is partially because the propeller wash from vessels has limited sedimentation in the centre of the channels. At present, the straight sections of the channels are 180 m wide (toe to toe), but the RHM has advised that as long as the declared depth is achieved in the central 110 m of the channels they are still considered to be navigable. Therefore, this approach aims to ensure a central 110 m of the channels remains at or below the declared depth, while sedimentation above the declared depths can occur along the sides of the channels (the remaining 70 m). Bed levelling would be undertaken to maintain the depths in the central 110 m of the channel (Figure 10). This approach would be expected to reduce the frequency of maintenance dredging in this area and to some extent the volume. However, it is expected that some maintenance dredging would continue to be required.
- Berths
  - Sediment Trap: the sediment trap approach does not negate the requirement for maintenance dredging. It can reduce the frequency that maintenance dredging is required and also the volume of sediment to be removed (due to consolidation of fine-grained sediment and also some resuspension during drag barring). It can also improve the efficiency of the dredging, reducing the dredge duration, as the majority of the sediment is in a relatively small area. The sediment trap approach would be most effective at the LNG Terminal Berths as they experience relatively high sedimentation rates and the berth depth is the same as the adjacent swing basin depth, which would allow drag barring to move sediment from the berths to the trap. As an example, the APLNG berth has been assumed for the sediment trap approach. A sediment trap with a volume of approximately 10,000 m^3 (area of 10,000 m^2 and a depth of 1 m) has been assumed to allow sufficient capacity for the annual sedimentation at the berth (Figure 11). The capacity of the sediment trap could be

[4] the dredging could also be undertaken by a small CSD and pumped to the edge of Clinton Channel. This change would not significantly alter the Objectives Assessment, although the costs and GHG emissions would be different.

increased to also include sedimentation from the swing basin, but for this comparative analysis only the volume required for the berth has been included so the approach can be directly compared to other approaches for the berths. The sediment trap would need to be created by capital dredging, with the sediment assumed to be placed into the Western Basin Reclamation Area. It has been assumed that bed levelling would be undertaken four times each year to move sediment deposited in the berth to the sediment trap. The sediment trap would then be reinstated each year by maintenance dredging using the TSHD *Brisbane* removing the sediment from the trap.

- Jet Array: the aim of the jet array is to prevent sedimentation from occurring over a set region. An array of water jets are setup which can resuspend and transport newly deposited sediment away from the region. Typically, the jets are configured to come on for a short duration during either the flood or ebb tide (depending on the direction the sediment should be transported). The frequency of the jets can be configured based on the site specific requirements, but typically they are used regularly (i.e. during each tidal cycle). As such, the approach aims to mimic the natural process which would occur if the artificially deepened areas did not exist, whereby any recently deposited sediment would be resuspended on the subsequent tide. This approach is generally only feasible in locations with very high sedimentation rates and so will only be considered for the LNG Terminal Berths where the highest berth sedimentation rates in the PoG occur. There are a range of different jet array options available, but only the turbo scouring units are able to scour a sufficient distance for the LNG Terminal berths (approximately 75 m from the unit and rotate 180º). These units can be installed on existing wharf piles. If the APLNG berth is used as an example, the berth is 325 m in length but as the wharf is only directly adjacent to the berth along the central 100 m it would only be possible to attach three units, at either end and in the middle of this 100 m length (Figure 12). These three units should be sufficient to limit sedimentation throughout the majority of the berth (as the majority of historical sedimentation has occurred within the area covered by the units). Some ongoing sedimentation could occur in the corners of the berth where the current from the jet units is not as strong. It has been assumed that annual drag barring would be adopted to remove any sedimentation from the corners of the berths. A single hydraulic pump would also be required at the berth to power the three units, for the assessment we have assumed that this would be powered using purchased electricity[5]. The units will operate in sequence, with the first unit gradually rotating until it has covered its area and then the adjacent unit doing the same and so on. To ensure that the units are able to manage the total maintenance dredging requirement in the berth, it has been assumed that each unit will operate for one hour per tidal cycle.
- Nautical Depth Navigation: the aim of this approach is to allow an area to remain navigable with minimal maintenance dredging despite ongoing sedimentation of fine-grained sediment. It is only applicable in locations where fine-grained sediment is deposited as a low density fluid mud, typically these areas are associated with high sedimentation rates. At the LNG Terminal berths it is possible that low density fluid mud is present and so a nautical depth navigation approach could be adopted. The approach would allow vessels to operate in the berths when there is sedimentation above the declared depth as long as the density of the sediment is less than a certain value (1,200 kg/m^3 has been adopted at other Ports (PIANC, 2008)). This approach could therefore be combined with drag barring so the denser sedimentation can be removed by the drag barring leaving only fluid mud which would be navigable. It is likely that there would still be some ongoing maintenance dredging required to prevent a gradual build-up of sediment in the berth.

[5] The approach could adopt alternate sources of energy if available, such as an onsite renewable source, which would reduce the associated GHG emissions.

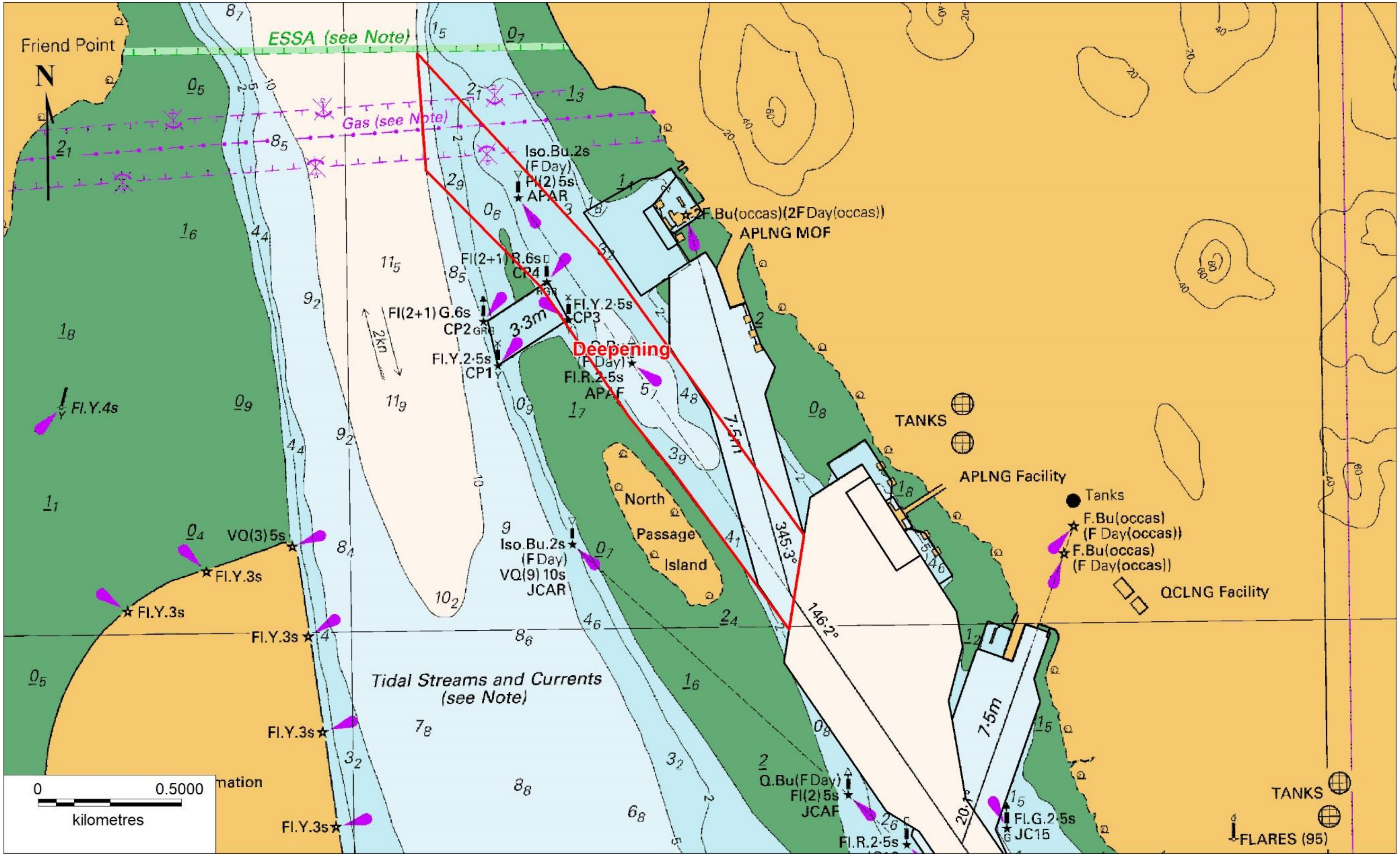

Figure 7. Schematic showing the area requiring deepening as part of the channel realignment approach.

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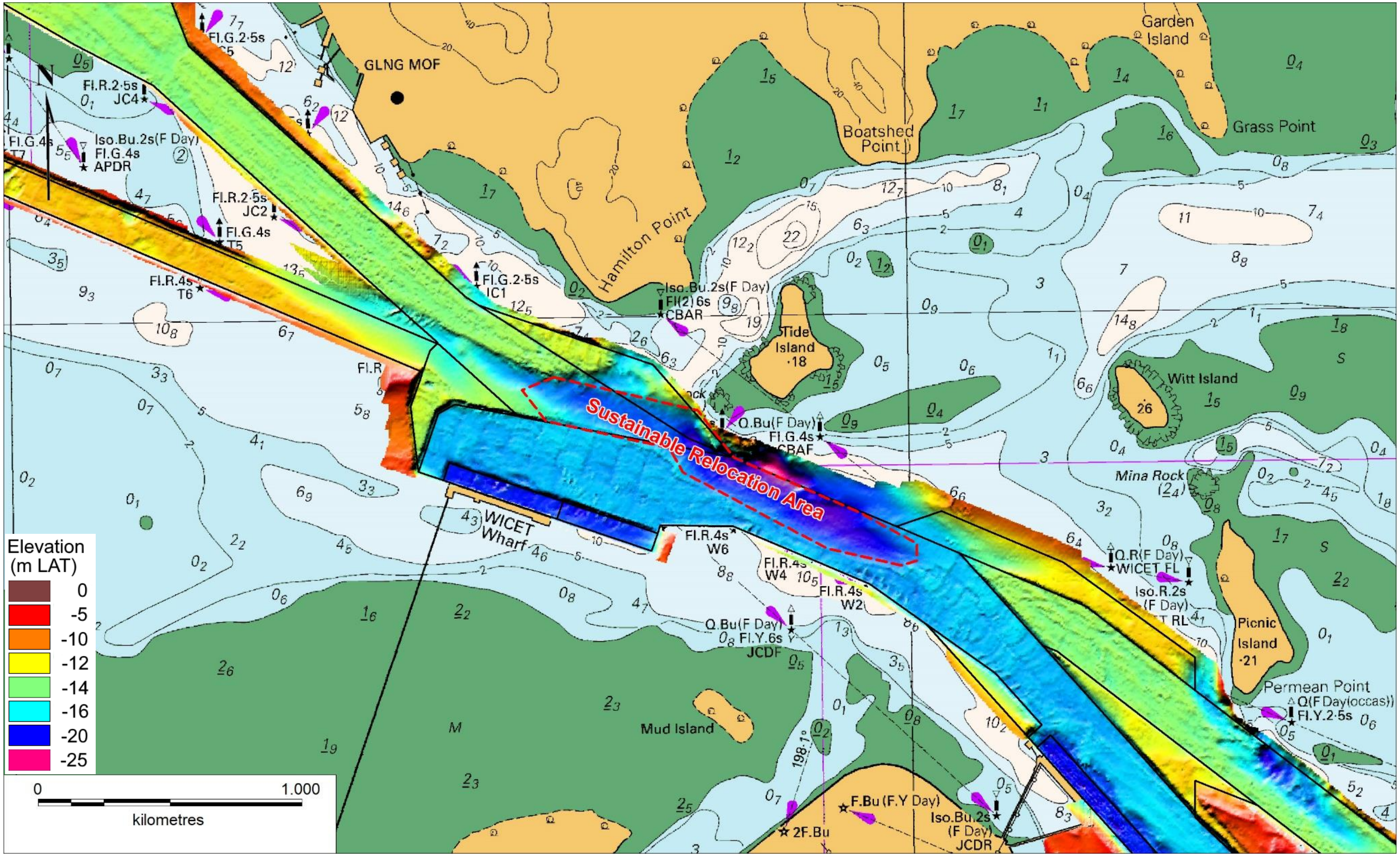

Figure 8. Schematic showing a possible sustainable relocation area.

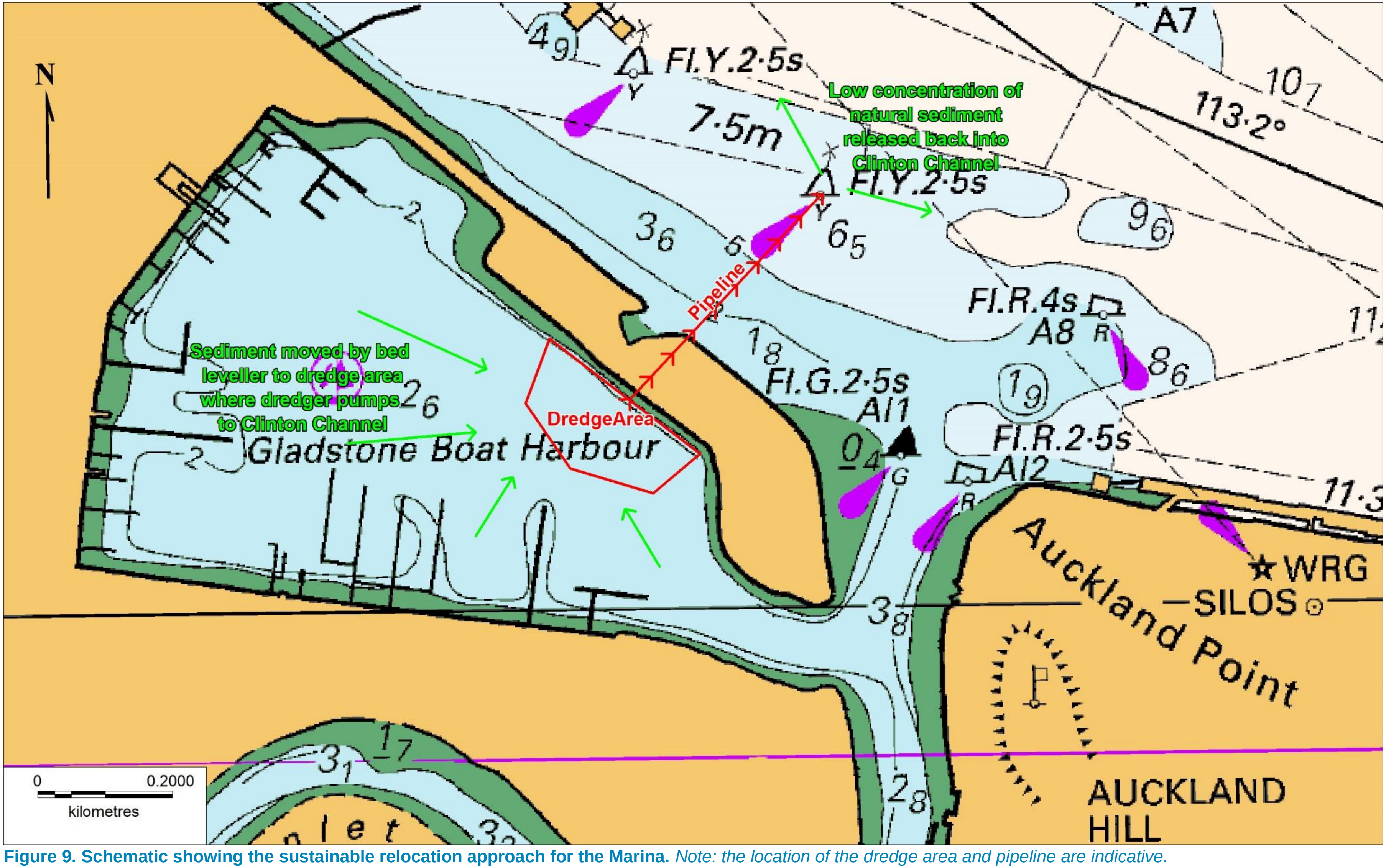

Figure 9. Schematic showing the sustainable relocation approach for the Marina. *Note: the location of the dredge area and pipeline are indicative.*

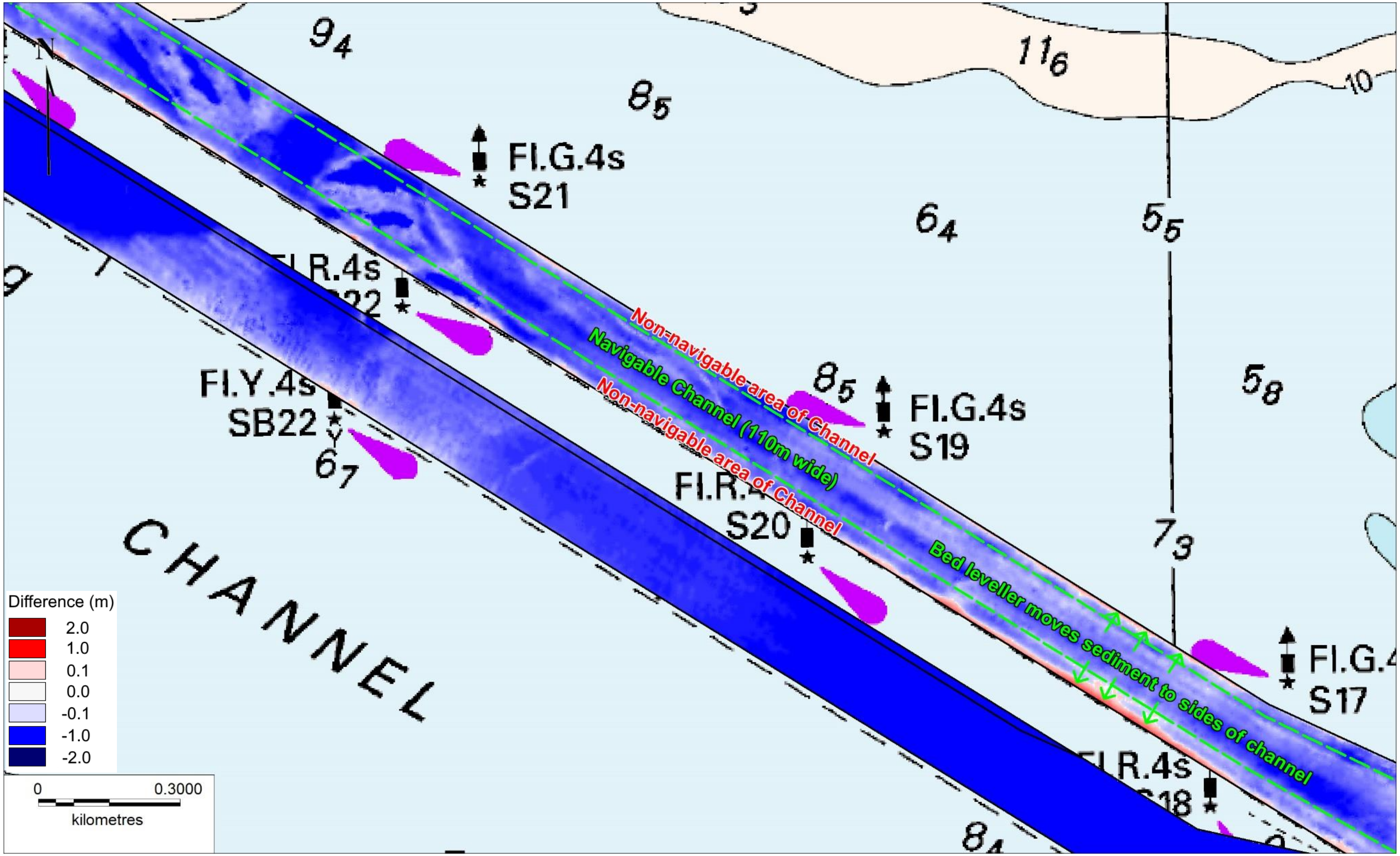

Figure 10. Schematic showing the navigable channel width approach for the Outer Harbour Cuttings.

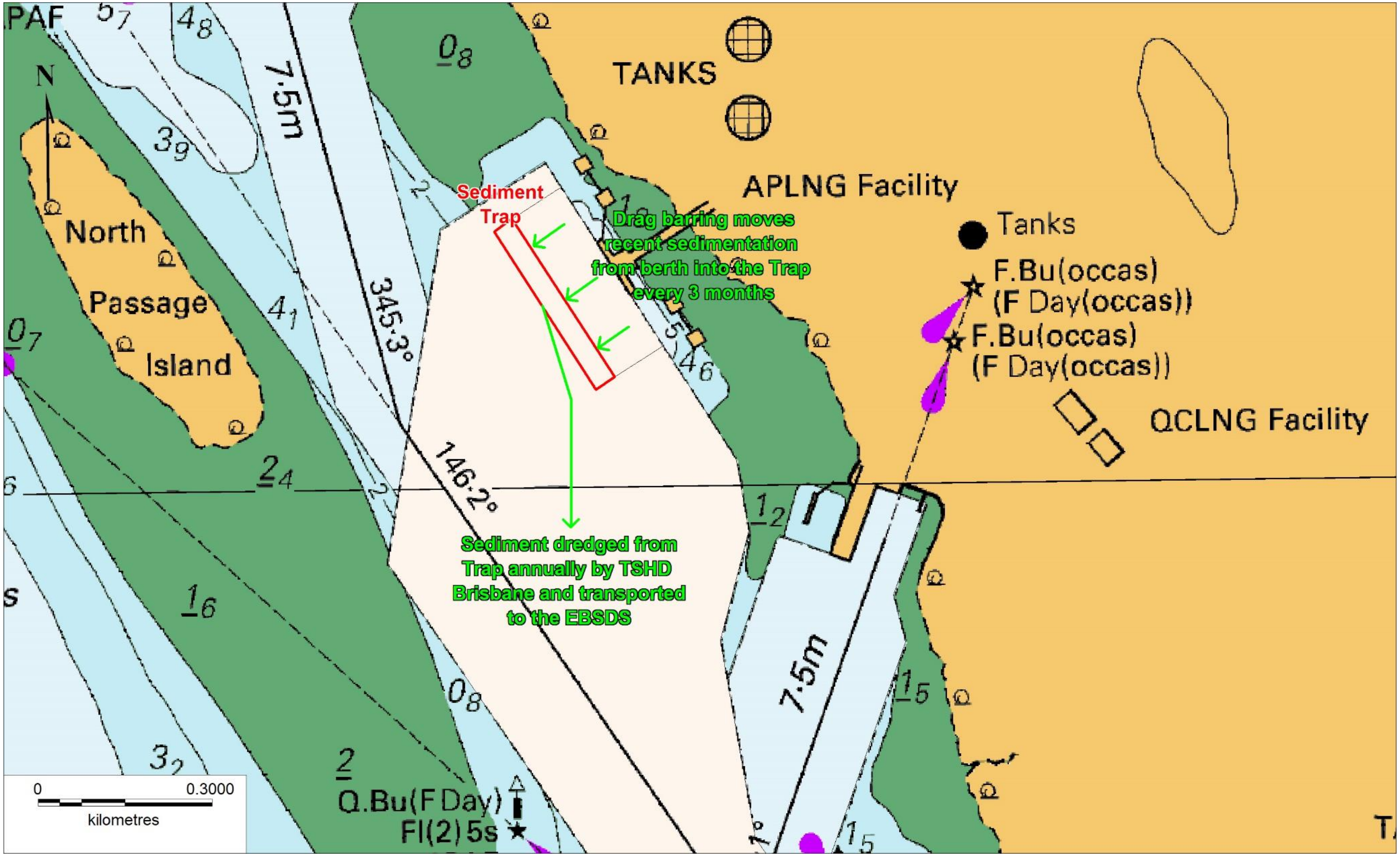

Figure 11. Schematic showing the sediment trap approach for a berth.

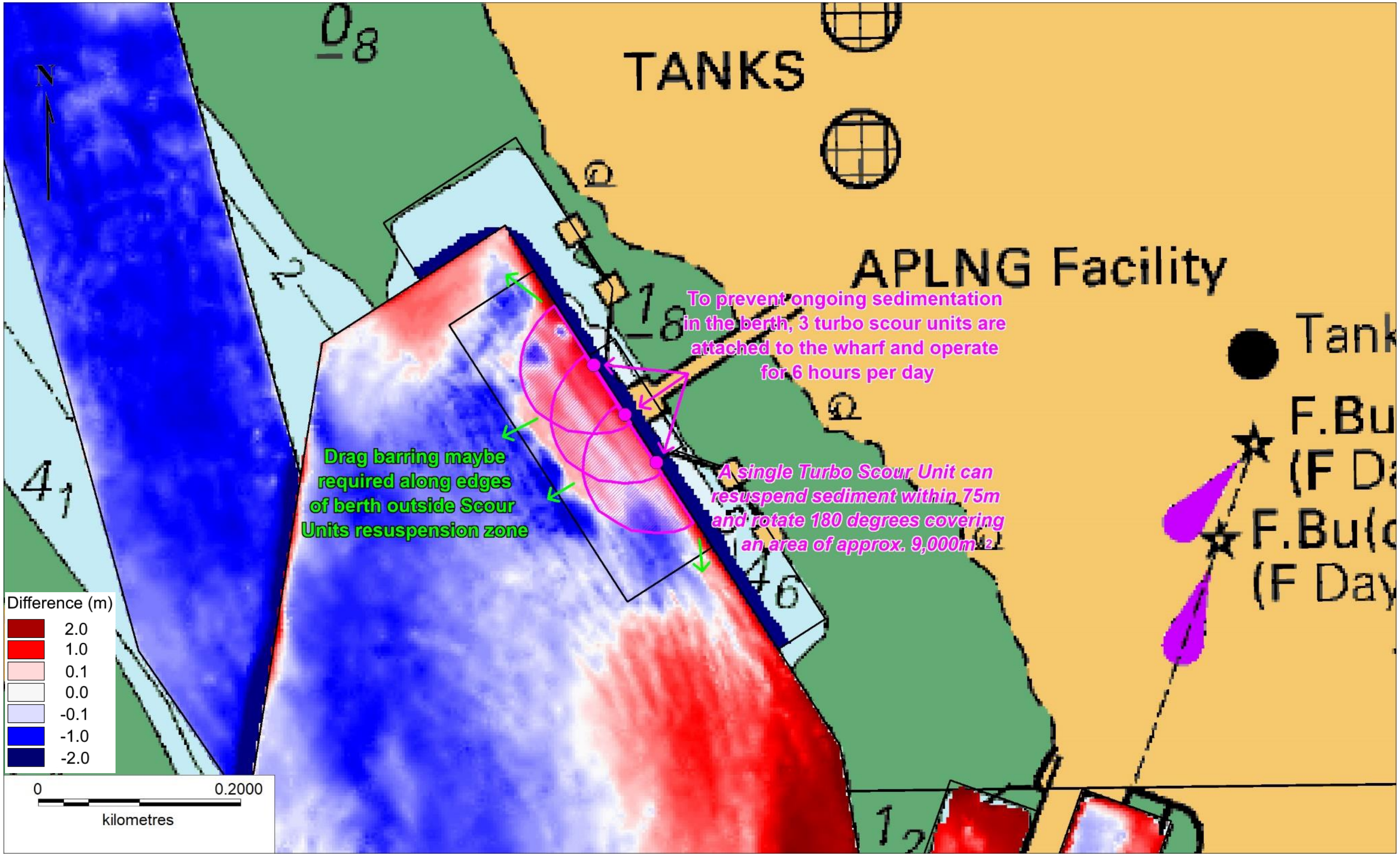

Figure 12. Schematic showing the jet array approach for a berth.

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3.5.2. LNG Terminals Region

Approximately 70% of the total sedimentation above declared depths in the PoG has occurred in the LNG Terminals, with typical and maximum sedimentation rates above design depths ranging from 155,000 to 195,000 m^3/yr. Between 80% and 90% of the sedimentation at the LNG Terminals has occurred in the aprons, with the remaining sedimentation in the three berths (20,000 to 35,000 m^3/yr). For this assessment a sediment management requirement of 150,000 m^3/yr for the apron areas has been assumed. The sedimentation in the LNG Terminal region berths are not included in this 150,000 m^3 as they are considered separately in Section 3.5.5.

3.5.2.1. Maintenance Dredging

This approach assumes that 150,000 m^3/yr of sedimentation is removed by the TSHD *Brisbane* and placed at the EBSDS over 15 days of dredging as part of an annual maintenance dredging campaign. In addition, 15 days of bed levelling is also assumed to be undertaken during the maintenance dredging. A summary of the Objectives Assessment for this approach is detailed in Table 6.

Table 6. Objectives Assessment for the Maintenance Dredging approach in the LNG Terminals region.

Aspect	Summary
Environment	Based on previous monitoring during maintenance dredging by the TSHD *Brisbane*, the dredging activity and placement of the sediment at the EBSDS only results in short duration, localised increases in turbidity. In addition, there are existing monitoring and adaptive management strategies in place. As a result, there is a high confidence that the approach is not expected to influence the biodiversity, coastal habitats or morphology in the region, except within the dredged areas of the PoG and within the EBSDS.
Resource use	The main resource use will be diesel fuel for the TSHD *Brisbane* and the Pacific Conquest. The associated GHG emissions are estimated to be 10,210 t CO_{2e} over 10 years.
Legislative requirement	Standard approval required under the *Environment Protection (Sea Dumping) Act 1981* and the Queensland *Environment Protection Act 1994.* The approval process is well known to GPC and they have experience with it.
Health & Safety	Expected to maintain health and safety in the PoG as the approach is currently undertaken annually and there have not been any health and safety issues.
Cultural	No change to cultural or historic sites and values in the PoG.
Social	No change to social activities and opportunities in the PoG.
Port operations	Will maintain Port operations as activities can be undertaken to fit in around the Port operations.
Cost	Cost over ten years is estimated to be $16.5 million. Costs associated with options for this region range from $13.0 million to $113 million over 10 years.
Economics	No change to economic opportunities for the region other than those associated with the ongoing operation of the PoG.
Methodology	High certainty of the approach being successful as it is currently undertaken annually.
Innovation	Limited innovation, although the TSHD *Brisbane* is updated regularly to incorporate the latest environmental advances in dredging technology.
Longevity	The approach is a long-term solution. Based on the existing annual maintenance dredging requirement for the PoG, the EBSDS has capacity for more than 100 years of maintenance dredging.

3.5.2.2. Channel Realignment

This approach assumes that 3 million m^3 of sediment would be removed from the shallow channel north of Jacobs Channel by capital dredging and pumped directly into the Western

Basin Reclamation Area with an estimated dredging duration of 17 weeks. It is not possible to accurately predict the future sediment management requirement for the LNG Terminal region following the channel realignment at this stage[6]. Given the high sedimentation rates which occur is the region and the trapping efficiency of the berths and sides of the aprons it is considered unlikely that the approach would result in a significant reduction in sedimentation. To allow cost and resource calculations to be made, the annual sedimentation has been assumed to be reduced by 20% due to the increased flows resulting from the channel realignment. Therefore, the ongoing annual sedimentation has been assumed to be 120,000 m^3/yr, with this sedimentation being removed by the TSHD *Brisbane* and placed at the EBSDS. In addition, 12 days of bed levelling is also assumed to be undertaken during the maintenance dredging. Based on the assumptions made the approach would result in a reduction in maintenance dredging volume and placement at EBSDS of 30,000 m^3, with a corresponding reduction in annual maintenance dredging duration of three days. A summary of the Objectives Assessment for this approach is detailed in Table 7.

Table 7. Objectives Assessment for the Channel Realignment approach in the LNG Terminals region.

Aspect	Objective
Environment	The approach is considered to have a localised negative impact on the environment as new areas of seabed will be dredged. Previous monitoring has found seagrass in the area of the proposed capital dredging, indicating a risk of direct impacts to seagrass. There is also a risk of impacts due to increased turbidity during the capital dredging, although based on the dredging approach (CSD pumping direct to the Western Basin Reclamation Area), any impacts would be expected to be localised and remain within the Port boundaries and could be mitigated through monitoring and adaptive management.
Resource use	The main resource use will be diesel fuel for the CSD, TSHD *Brisbane* and the Pacific Conquest. The associated GHG emissions are estimated to be 23,540 t CO_{2e} over 10 years.
Legislative requirement	Multiple approvals are required for both capital (*EPBC Act 1999, Sustainable Ports Development Act 2015, Fisheries Act 1994*) and ongoing maintenance dredging (*Environment Protection (Sea Dumping) Act 1981* and Queensland *Environment Protection Act 1994*). Well known approval processes which GPC have experience with.
Health & Safety	There would be an increased risk to health and safety due to the duration of dredging works in the PoG (estimated to be approximately 4 months), along with the approach requiring a pipeline to be in place throughout the duration of the dredging to allow the sediment to be directly pumped into the Western Basin Reclamation. Additional on land health and safety risks associated with the reclamation works.
Cultural	The approach is not expected to change the cultural or historic sites and values in the PoG. Based on previous impact assessments in the region there are not expected to be any sites of historic heritage significance recorded (Converge Heritage and Community, 2009), but this would need to be reviewed in more detail as part of an impact assessment.
Social	Possible negative impact to social activities and opportunities in the PoG as capital dredging could limit water based recreational activities to the north of Jacobs Channel during the dredging campaign.
Port operations	Expected to maintain Port operations, although there is a risk that increased flows in the LNG Terminal region could negatively influence vessel navigation.
Cost	Cost over ten years is estimated to be $113 million. Costs for all options for this region range from $13.0 million to $122 million over ten years. The costs do not include any allowance for offsets required as part of the capital dredging.

[6] detailed numerical modelling would be required to inform this.

Economics	No change to economic opportunities for the region other than those associated with the ongoing operation of the PoG.
Methodology	There is significant uncertainty in the effectiveness of the approach and how much it would reduce sedimentation in the Jacobs Channel region. Detailed modelling would be required to predict this, but there would still be some uncertainty.
Innovation	The approach should be considered relatively innovative as it represents a form of working with nature.
Longevity	If the approach is successful then it should result in a long term reduction in sedimentation in the LNG Terminal region. However, it is expected that annual maintenance dredging would continue to be required in the region.

3.5.2.3. Sustainable Relocation

This approach assumes that half of the annual sedimentation which requires management in the LNG Terminal region (75,000 m^3) is managed through sustainable relocation using the TSHD *Brisbane*, while the other half continues to be placed at the EBSDS by the TSHD *Brisbane*. Dredging as part of the sustainable relocation approach would be undertaken to ensure the sediment in the hopper remains unconsolidated. As with the maintenance dredging approach, 15 days of bed levelling is also assumed to be undertaken during this approach. It has been assumed that the sustainable relocation approach would be optimised (through numerical modelling) to prevent increased sedimentation within the dredged areas of the PoG. Based on the assumptions made the approach would result in an annual reduction of sediment placement at EBSDS of 75,000 m^3 and a reduction in annual maintenance dredging duration of four days. A summary of the Objectives Assessment for this approach is detailed in Table 8.

Table 8. Objectives Assessment for the Sustainable Relocation approach in the LNG Terminals region.

Aspect	Objective
Environment	The approach aims to enhance the environment of the PoG by ensuring sufficient sediment remains within the active system to feed naturally accreting areas. However, there is a risk that negative impacts could occur due to increased turbidity associated with the release of sediment to a dispersive region of the PoG. Detailed numerical modelling would be required to mitigate the risk of negative impacts.
Resource use	The main resource use will be diesel fuel for the TSHD *Brisbane* and the Pacific Conquest. The associated GHG emissions are estimated to be 8,200 t CO_{2e} over 10 years.
Legislative requirement	There is uncertainty regarding the approval process as it will involve dredged sediment being placed outside of the designated offshore placement area, but within the designated PoG channels and at a historic relocation ground. The ongoing maintenance dredging and placement at the EBSDS will require standard approval under the *Environment Protection (Sea Dumping) Act 1981* and the Queensland *Environment Protection Act 1994.*
Health & Safety	Potential for improved health and safety within the PoG due to reduced travel distance and duration for TSHD *Brisbane*.
Cultural	No change to cultural or historic sites and values in the PoG.
Social	Potential for enhancement in water based activities in the PoG due to reduced travel distance and duration for the TSHD *Brisbane*. Also potential for social benefits due to possible environmental enhancement of habitats such as mudflats and mangroves.
Port operations	Potential for enhancement in port operations due to reduced travel distance and duration for the TSHD *Brisbane*.
Cost	Cost over ten years is estimated to be $13.0 million. Costs for options for this region range from $13.0 million to $113 million over ten years.

Economics	Possible enhancement to economic opportunities in the region due to potential benefits to coastal habitats such as mudflats and mangroves. Economic opportunities could be in tourism and fishing (as habitats such as mangroves act as nurseries for many species of fish).
Methodology	There is a high degree of confidence that the approach would be successful in removing sedimentation from the LNG Terminal region. However, there is uncertainty and risk associated with potential impacts from the approach on sensitive receptors and how much of the sediment would be returned to the area after the sustainable relocation. Detailed numerical modelling and monitored trials would be required to reduce the uncertainty and mitigate the risk.
Innovation	The approach is considered to be innovative as it is not widely adopted in Australia and is sustainable and a type of working with nature.
Longevity	The approach is a long-term solution which would reduce the volume of sediment being placed at the EBSDS. However, there is uncertainty as to whether the approach would be able to completely replace the placement of sediment at the EBSDS. There could be constraints regarding when sediment could be sustainably relocated to ensure it does not impact sensitive receptors and is not subsequently deposited back into the LNG Terminal region.

3.5.3. Marina

The annual sedimentation above design depths which requires management in the Marina has been found to be between 39,000 and 43,000 m^3 (PCS, 2018a), with the sedimentation being relatively evenly distributed throughout the Marina. It has been assumed that the Marina will be at the original declared depth at the start of the 10-year period being considered for the Objectives Assessment. For the assessment the sediment management requirement has been assumed to be 40,000 m^3/yr.

3.5.3.1. Short-term Maintenance Dredging

This approach assumes that 200,000 m^3 of sedimentation is removed by a small CSD every five years and pumped directly to an adjacent onshore placement area. The dredge duration is estimated to be in the region of 40 days every five years with the sediment all placed at the adjacent onshore placement area. There is only sufficient capacity at the onshore site for a single maintenance dredging campaign, with no other suitable onshore sites available close to the Marina. A summary of the Objectives Assessment for this approach is detailed in Table 9. The costs and GHG emissions for this approach have been calculated over a 10-year period (so they are directly comparable to the other approaches) despite the approach only being able to manage the sedimentation for a single dredging campaign (i.e. over a 5-year period).

Table 9. Objectives Assessment for the short-term Maintenance Dredging approach in the Marina.

Aspect	Objective
Environment	The maintenance dredging by a small CSD will only result in localised increases in turbidity in the Marina. As a result, the approach is not expected to influence the biodiversity, coastal habitats or morphology outside of the Marina.
Resource use	The main resource use will be diesel fuel for the small CSD and the Pacific Conquest. The associated GHG emissions are estimated to be 1,290 t CO_{2e} over 10 years.
Legislative requirement	Standard approval required under the Queensland *Environment Protection Act 1994.* The approval process is well known to GPC and they have experience with it.
Health & Safety	Expected to maintain health and safety in the PoG as maintenance dredging of the Marina and placement on land has been undertaken numerous times and there have not been any health and safety issues.

Cultural	No change to cultural or historic sites and values in the PoG. The Marina and surrounding land were constructed as part of reclamation works in the 1980s and so no cultural or historic sites are expected to be present in the area.
Social	No change to social activities and opportunities in the PoG.
Port operations	Will maintain Port operations as activities will only be undertaken within the Marina. Potential for some impacts to vessel operations in the Marina during maintenance dredging campaigns (estimated to be 40 days every five years).
Cost	Cost over ten years is estimated to be $6.0 million. Costs of options for this region range from $4.1 million to $20.1 million over ten years.
Economics	No change to economic opportunities for the region other than those associated with the ongoing operation of the Marina.
Methodology	High certainty of the approach being successful as it has previously been adopted to manage the sedimentation in the Marina.
Innovation	Limited innovation, it is considered a standard dredging approach.
Longevity	The approach is only a short-term solution. There is limited capacity remaining in the onshore placement area and it is estimated that this approach can only be adopted for one more maintenance dredging campaign (i.e. 5 years of sedimentation).

3.5.3.2. Long-term Maintenance Dredging

This approach assumes that 200,000 m^3 of sedimentation is removed by a small TSHD (hopper capacity of 500 to 1,000 m^3) every five years and placed at EBSDS[7]. The dredge duration is estimated to be in the region of 125 days every five years with the sediment all placed at EBSDS. In addition, 5 days of bed levelling/drag barring is also assumed to be undertaken during each maintenance dredging campaign to move sedimentation from areas that the dredger cannot access and to level the seabed after dredging. A summary of the Objectives Assessment for this approach is detailed in Table 10.

Table 10. Objectives Assessment for the long-term Maintenance Dredging approach in the Marina.

Aspect	Objective
Environment	Based on previous monitoring during maintenance dredging by the TSHD *Brisbane*, the dredging activity and placement of sediment at the EBSDS only results in short duration, localised impacts to turbidity. This represents a volume of sediment which has not previously been placed at EBSDS as it has historically been placed on land. The volume represents an increase in sediment placed at EBSDS in the order of 20%. As a result, the use of a smaller TSHD is not expected to influence the biodiversity, coastal habitats or morphology in the region, except for within the Marina and the EBSDS.
Resource use	The main resource use will be diesel fuel for the small TSHD and the Pacific Conquest. The associated GHG emissions are estimated to be 5,360 t CO_{2e} over 10 years.
Legislative requirement	Standard approval required under the *Environment Protection (Sea Dumping) Act 1981* and the Queensland *Environment Protection Act 1994.* The approval process is well known to GPC and they have experience with it.
Health & Safety	Potential for increased risk to health and safety in the PoG due to the long duration of the maintenance dredging campaigns (estimated to be 125 days every five years), combined with the fact the vessel will regularly be sailing between the Marina and the EBSDS.

[7] if a suitable size TSHD was not available then the dredging could also be undertaken by a small CSD and then transported by barge to the EBSDS. This change would not significantly alter the Objectives Assessment, although the costs and GHG emissions would change.

Cultural	No change to cultural or historic sites and values in the PoG. The Marina and surrounding land were constructed as part of reclamation works in the 1980s and so no cultural or historic sites are expected to be present in the area.
Social	No change to social activities and opportunities in the PoG.
Port operations	There is a risk of minor impacts to Port operations due to the duration of the activity (estimated to be 125 days every five years), combined with the fact the vessel will regularly be sailing between the Marina and the EBSDS. There is also likely to be impacts to vessel operations in the Marina during the maintenance dredging campaigns.
Cost	Cost over ten years is estimated to be $20.1 million. Costs of options for this region range from $4.1 million to $20.1 million over ten years.
Economics	No change to economic opportunities for the region other than those associated with the ongoing operation of the Marina.
Methodology	High certainty of the approach being successful.
Innovation	Limited innovation, it is considered a standard dredging approach.
Longevity	The approach is a long-term solution. Based on the existing annual maintenance dredging requirement for the PoG, the EBSDS has capacity for more than 100 years of maintenance dredging.

3.5.3.3. Sustainable Relocation

This approach assumes that all of the annual sedimentation which requires management in the Marina (40,000 m^3/yr) is managed through sustainable relocation using drag barring, dredging by a RODV[8] and pumping of low concentration dredged sediment to the edge of the Clinton Channel. The RODV would be capable of pumping approximately 60 m^3/hr (*in-situ volume*) of sediment and based on this it has been assumed that 640 hours of dredging would be required per year. A total of 12 days of drag barring has also been included per year to move sediment to the eastern corner of the Marina where the RODV operates. It is estimated that the dredge duration would be between one and two months each year and none of the sediment would be placed at EBSDS. This represents a reduction in volume placed at EBSDS of 40,000 m^3/yr compared to the long-term maintenance dredging approach. A summary of the Objectives Assessment for this approach is detailed in Table 11.

Table 11. Objectives Assessment for the Sustainable Relocation approach in the Marina.

Aspect	Objective
Environment	The approach aims to enhance the environment of the PoG by ensuring sufficient sediment remains within the active system to feed naturally accreting regions. However, there is a risk that negative impacts could occur due to increased turbidity associated with the release of sediment to a dispersive region (the edge of Clinton Channel). Detailed numerical modelling would be required to mitigate the risk of negative impacts.
Resource use	The main resource use will be diesel fuel for the RODV and pump generator and the Pacific Conquest. The associated GHG emissions are estimated to be 2,240 t CO_{2e} over 10 years (with 60% of the emissions being from the drag barring).
Legislative requirement	There is uncertainty regarding the approval process as it will involve dredged sediment being placed outside of the designated offshore placement area. The permanent pipeline will require a Tidal Works approval from the Department of Environment and Science (DES).

[8] the dredging could also be undertaken by a small CSD and pumped to the edge of Clinton Channel. This change would not significantly alter the Objectives Assessment, although the costs and GHG emissions would change.

Health & Safety	Reduction to health and safety within the PoG due to maintenance dredging occurring throughout the year, the dredging including land-based infrastructure and a fixed pipeline.
Cultural	No change to cultural or historic sites and values in the PoG. The Marina and surrounding land were constructed as part of reclamation works in the 1980s and so no cultural or historic sites are expected to be present in the area.
Social	No change to social activities in the PoG. Occasional drag barring and small RODV activity are unlikely to impact vessel operations in the Marina.
Port operations	Will maintain port operations as activity will not influence any vessel operations outside of the Marina.
Cost	Cost over ten years is estimated to be $4.1 million. Costs of options for this region range from $4.1 million to $20.1 million over ten years.
Economics	This approach could result in economic benefits as it would ensure that the original declared depths in the Marina are constantly maintained which has the potential to allow a greater range of commercial (tourism or fishing) vessels to operate out of the Marina.
Methodology	There is high confidence that the approach would be successful in maintaining depths within the Marina. However, there is uncertainty and risk associated with how much of the sediment would either be returned to the area, or deposited in another dredged area of the PoG after the sustainable relocation. Detailed numerical modelling and monitored trials would be required to reduce the uncertainty and mitigate the risk.
Innovation	The approach is considered to be innovative as it is not widely adopted in Australia[9] and is sustainable and a type of working with nature.
Longevity	The approach is a long-term solution and has the potential to manage all of the ongoing sedimentation which occurs in the Marina.

3.5.4. Outer Harbour Cuttings

The annual sedimentation above design depths in the Outer Harbour Cuttings (Golding, Boyne and Wild Cattle Cuttings) has been calculated to be between 4,000 and 25,000 m^3/yr (PCS, 2018a). However, considerable sedimentation occurs in the Outer Harbour Cuttings below the design depths (calculated to range from 50,000 to 270,000 m^3/yr (PCS, 2018b)). This has meant that annual maintenance dredging of 30,000 to 60,000 m^3/yr has been required to ensure the channels remain navigable (T Ware, pers. comm., 2018). The sedimentation has been concentrated along the sides of the channels (due to vessel propeller wash limiting sedimentation along the centre of the channels). This also makes it difficult for sediment management activities to accurately target just the areas where sedimentation has occurred above the design depth. As a result of the above, it is expected that the ongoing sediment management requirement for the Outer Harbour Cuttings will be more than just the sedimentation above design depths and so for this assessment the sediment management requirement has been assumed to be 40,000 m^3/yr.

3.5.4.1. Maintenance Dredging

This approach assumes that 40,000 m^3/yr of sedimentation is removed by the TSHD *Brisbane* and placed at the EBSDS with an estimated dredge duration of three and a half days. In addition, one day of bed levelling is also assumed to be undertaken during the maintenance dredging. A summary of the Objectives Assessment for this approach is detailed in Table 12.

[9] a similar approach has been adopted at Rosslyn Bay Boat Harbour where maintenance dredging has been undertaken by a small dredger and the sediment pumped directly to an agreed disposal site located 1.1 km north-east of the Harbour entrance (Keppel Bay Marina, 2016).

Table 12. Objectives Assessment for the Maintenance Dredging approach in the Outer Harbour Cuttings.

Aspect	Objective
Environment	Based on previous monitoring during maintenance dredging by the TSHD *Brisbane*, the dredging activity and placement of the sediment at the EBSDS only results in short duration, localised impacts in turbidity. As a result, the approach is not expected to influence the biodiversity, coastal habitats or morphology in the region, except for the dredged areas of the PoG and EBSDS.
Resource use	The main resource use will be diesel fuel for the TSHD *Brisbane* and the Pacific Conquest. The associated GHG emissions are estimated to be 1,970 t CO_{2e} over 10 years.
Legislative requirement	Standard approval required under the *Environment Protection (Sea Dumping) Act 1981* and the Queensland *Environment Protection Act 1994.* The approval process is well known to GPC and they have experience with it.
Health & Safety	Expected to maintain health and safety in the PoG as approach is currently undertaken annually and there have not been any health and safety issues.
Cultural	No change to cultural or historic sites and values in the PoG.
Social	No change to social activities and opportunities in the PoG.
Port operations	Will maintain Port operations as activities can be undertaken to fit in around the port operations.
Cost	Cost over ten years is estimated to be $3.5 million. Costs for the other option of adopting a minimum channel width is estimated to be $1.7 million over ten years.
Economics	No change to economic opportunities for the region other than those associated with the ongoing operation of the PoG.
Methodology	High certainty of the approach being successful as it is currently undertaken annually.
Innovation	Limited innovation, although the TSHD *Brisbane* is updated regularly to incorporate the latest environmental advances in dredging technology.
Longevity	The approach is a long-term solution. Based on the existing annual maintenance dredging requirement for the PoG, the EBSDS has capacity for more than 100 years of maintenance dredging.

3.5.4.2. Minimum Channel Width Navigation

This approach assumes that the RHM would provide a signed statement noting that as long as a width of 110 m of the Golding, Boyne and Wild Cattle Cuttings was at or below the declared depth then the channels would be considered navigable. It is assumed that by adopting the minimum channel width approach the original declared depths can be maintained by undertaking 40 days of bed levelling and drag barring per year. The approach is expected to negate the requirement for annual or biennial maintenance dredging in the Cuttings, but some ongoing maintenance dredging (a reduced volume compared to the current requirement) is likely to be required. Due to the complex processes controlling the natural sedimentation and resuspension by propeller wash and drag barring, the ongoing maintenance dredging requirement can only be accurately defined through implementation (i.e. testing the approach). For this assessment it has been assumed that maintenance dredging of 150,000 m^3 would be required every five years (i.e. 25% of the predicted ongoing sedimentation is either resuspended by the annual drag barring and bed levelling or by regular propeller wash from the vessels). In addition, four days of bed levelling is also assumed to be undertaken during the years when maintenance dredging occurs (i.e. every five years). For years three and four it has been assumed that quarterly hydrographic surveys would be required for the channels to confirm their navigability, we have assumed that each survey would take three days to complete. Based on the assumptions made it is estimated that the approach would reduce the dredge duration by 1.5 days every five years and reduce the volume of sediment placed at EBSDS by 19,000 m^3 every five years. A summary of the Objectives Assessment for this approach is detailed in Table 13.

Table 13. Objectives Assessment for the Minimum Channel Width Navigation approach in the Outer Harbour Cuttings.

Aspect	Objective
Environment	The dredging activity and placement of the sediment at the EBSDS only results in short duration, localised impacts in turbidity. As a result, the approach is not expected to influence the biodiversity, coastal habitats or morphology in the region, except for the dredged areas of the PoG and the EBSDS.
Resource use	The main resource use will be diesel fuel for the TSHD *Brisbane* and the Pacific Conquest. The associated GHG emissions are estimated to be 5,250 t CO_{2e} over 10 years.
Legislative requirement	No approval is required for bed levelling and drag barring as it is within the footprint of the channel. Standard approval required for the ongoing maintenance dredging under the *Environment Protection (Sea Dumping) Act 1981* and the Queensland *Environment Protection Act 1994.* The approval process is well known to GPC and they have experience with it. Additional approval is also likely to be required by the Regional Harbour Master to confirm the change in navigable channel widths.
Health & Safety	There is a risk to the safety of vessels due to the reduction in channel width. Therefore, this approach has the potential to reduce the maritime safety in the PoG.
Cultural	No change to cultural or historic sites and values in the PoG.
Social	No change to social activities and opportunities in the PoG.
Port operations	There is a potential of some negative impacts to port operations due to the required annual drag barring duration, although generally these activities can be undertaken to fit in around the Port operations. However, there is an additional risk that after multiple years with no maintenance dredging and ongoing sedimentation, an extreme event (e.g. large waves resulting from a tropical cyclone) could result in high rates of sedimentation over a short period of time which could result in the channel depths having to be redeclared to a shallower depth which would significantly impact Port operations.
Cost	The cost over ten years is estimated to be $6.3 million. Costs for the other option of maintenance dredging is estimated to be $3.5 million over ten years.
Economics	No change to economic opportunities for the region other than those associated with the ongoing operation of the PoG.
Methodology	Moderate certainty of the approach being successful. Uncertainty regarding the volume and frequency that maintenance dredging will also be required.
Innovation	The approach is considered to be innovative as it is not widely adopted in Australia and it represents a sustainable approach to maintaining navigable channels.
Longevity	Although the approach can be considered long-term (i.e. it can be adopted to help manage sedimentation for > 10 years), it only provides a medium-term alternative solution to maintenance dredging. There is uncertainty in the future maintenance dredging requirements associated with the approach, but it is expected that ongoing maintenance dredging would be required.

3.5.5. Berths

The sedimentation above design depths which requires management in the berths of the PoG is highly variable between the berths. The highest rates of sedimentation occur in the berths in the LNG Terminal region, with the sedimentation at the APLNG berth being the highest, with rates ranging from 6,000 to 18,000 m^3/yr. The APLNG berth has been selected as an example berth for the Objectives Assessment, with an average sedimentation rate of 10,000 m^3/yr assumed.

3.5.5.1. Maintenance Dredging

This approach assumes that 10,000 m^3/yr of sedimentation is removed by the TSHD *Brisbane* and placed at the EBSDS with an estimated dredge duration of two days. In addition, two days of bed levelling is also assumed to be undertaken during the maintenance dredging. A summary of the Objectives Assessment for this approach is detailed in Table 14.

Table 14. Objectives Assessment for the Maintenance Dredging approach in the Berths.

Aspect	Objective
Environment	Based on previous monitoring during maintenance dredging by the TSHD *Brisbane*, the dredging activity and placement of the sediment at the EBSDS only results in short duration, localised impacts in turbidity. As a result, the approach is not expected to influence the biodiversity, coastal habitats or morphology in the region, except for the dredged areas of the PoG and the EBSDS.
Resource use	The main resource use will be diesel fuel for the TSHD *Brisbane* and the Pacific Conquest. The associated GHG emissions are estimated to be 1,210 t CO_{2e} over 10 years.
Legislative requirement	Standard approval required under the *Environment Protection (Sea Dumping) Act 1981* and the Queensland *Environment Protection Act 1994.* The approval process is well known to GPC and they have experience with it.
Health & Safety	Expected to maintain health and safety in the PoG as approach is currently undertaken annually.
Cultural	No change to cultural or historic sites and values in the PoG.
Social	No change to social activities and opportunities in the PoG.
Port operations	Will maintain Port operations as activities can be undertaken to fit in around the Port operations.
Cost	Cost over ten years is estimated to be $1.9 million. Costs for options for this region range from $1.9 million to $3.2 million over ten years.
Economics	No change to economic opportunities for the region other than those associated with the ongoing operation of the PoG.
Methodology	High certainty of the approach being successful as it is currently undertaken annually.
Innovation	Limited innovation, although the TSHD *Brisbane* is updated regularly to incorporate the latest environmental advances in dredging technology.
Longevity	The approach is a long-term solution. Based on the existing annual maintenance dredging requirement for the PoG, the EBSDS has capacity for more than 100 years of maintenance dredging.

3.5.5.2. Sediment Trap

This approach assumes that a sediment trap with a capacity of 10,000 m^3/yr[10] is created by capital dredging with the sediment pumped into the Western Basin Reclamation Area. It has been assumed that all dredging (capital and maintenance) associated with this approach is undertaken by the TSHD *Brisbane*. The ongoing maintenance associated with this approach includes 10 days of drag barring to move sediment from the berth into the sediment trap through the year, 10,000 m^3 of maintenance dredging and two days of bed levelling to reinstate the trap and maintain the berth. It is expected that the drag barring would result in some resuspension of sediment which would mean that the volume requiring annual maintenance dredging from the sediment trap and placement at EBSDS would be slightly

[10] the sediment trap could be adapted based on the requirements, for example the capacity could be increased so that it is designed to also accommodate sedimentation from the swing basin.

lower than 10,000 m^3, but it is not possible to accurately quantify the reduction at this stage. A summary of the Objectives Assessment for this approach is detailed in Table 15.

Table 15. Objectives Assessment for the Sediment Trap approach in the Berths.

Aspect	Objective
Environment	Based on previous monitoring during maintenance dredging by the TSHD *Brisbane*, the dredging activity and placement of the sediment at the EBSDS only results in short duration, localised impacts in turbidity. As a result, the approach is not expected to influence the biodiversity, coastal habitats or morphology in the region, except for the dredged areas of the PoG. Note: Due to the scale of the capital dredging and the fact it is located within the existing dredged areas of the Port, it is not expected to have any direct impact on sensitive habitats (e.g. seagrass) and it is expected to result in similar impacts during dredging as annual maintenance dredging of the berths.
Resource use	The main resource use will be diesel fuel for the TSHD *Brisbane* and the Pacific Conquest. The associated GHG emissions are estimated to be 2,860 t CO_{2e} over 10 years.
Legislative requirement	Multiple approvals are likely to be required for both capital (due to the small scale of capital dredging and associated potential impacts the approval requirements are not expected to be too onerous) and ongoing maintenance dredging (*Environment Protection (Sea Dumping) Act 1981* and Queensland *Environment Protection Act 1994*). Well known approval processes which GPC have experience with.
Health & Safety	There would be an increased risk to health and safety as the approach involves ongoing maintenance dredging, along with sediment being pumped into the Western Basin Reclamation Area. Additional on land health and safety risk associated with the reclamation works.
Cultural	No change to cultural or historic sites and values in the PoG.
Social	No change to social activities and opportunities in the PoG.
Port operations	Will maintain port operations as activities can be undertaken to fit in around the Port operations.
Cost	Cost over ten years is estimated to be $3.1 million. Costs for options for this region range from $1.9 million to $3.2 million over ten years. The costs do not include any allowance for offsets required as part of the capital dredging for the sediment trap.
Economics	No change to economic opportunities for the region other than those associated with the ongoing operation of the PoG.
Methodology	High certainty of the approach being successful as it is based on maintenance dredging and drag barring which have both been found to be effective at managing sedimentation in the LNG Terminal berths.
Innovation	Limited innovation. The approach of a sediment trap to reduce the frequency of sediment management activities has been commonly adopted both in Australia and overseas.
Longevity	Although the approach can be considered long-term (i.e. it can be adopted to help manage sedimentation for 10 years, or more), it only provides a possible alternative solution to the occasional maintenance dredging required between the annual campaigns.

3.5.5.3. Jet Array

This approach assumes that three turbo scouring unit propellers are installed on the APLNG wharf to limit ongoing sedimentation within the berth resulting in no ongoing maintenance dredging requirement. However, due to the configuration of the berth there is the potential that some sedimentation could occur in the corners of the berth. To manage this, two days of drag barring has been included each year. The approach should negate the requirement for any maintenance dredging in the berth, thereby reducing the annual maintenance dredging duration by two days and reducing the volume placed at EBSDS by 10,000 m^3/yr if the jet array is adopted at a single berth (e.g. just the APLNG berth). A summary of the Objectives Assessment for this approach is detailed in Table 16.

Table 16. Objectives Assessment for the Jet Array approach in the Berths.

Aspect	Objective
Environment	As the approach would regularly resuspend recently deposited sediment (every 12 hours around the time of peak flood/ebb currents), the approach would be replicating the natural environment. Any increase in turbidity will be small and localised. As such, the approach is not expected to influence the biodiversity, coastal habitats or morphology in the region, except for the dredged areas of the PoG.
Resource use	The main resource use will be electricity for the pump powering the jet array. The associated GHG emissions are estimated to be 1,970 t CO_{2e} over 10 years. This could be reduced if renewable or low emission sources of energy are available.
Legislative requirement	A Tidal Works permit would be required and the application for this would need to be submitted by the owners of the seabed lease (i.e. the LNG Company rather than GPC). DES would be the referral agency and based on recent applications it is likely that they will want to understand potential impacts to water quality and mega fauna.
Health & Safety	Increased health and safety risk due to additional wharf based infrastructure which will require ongoing maintenance. There would be a reduced maritime safety risk of the vessel grounding in the berth due to sedimentation.
Cultural	No change to cultural or historic sites and values in the PoG.
Social	No change to social activities and opportunities in the PoG.
Port operations	Potential to enhance Port operations as no requirement for annual maintenance dredging in the berth.
Cost	Cost over ten years is estimated to be $3.2 million, with $2.3 million of this being the initial capital cost. Costs for options for this region range from $1.9 million to $3.2 million over ten years. It is expected that after ten years major maintenance would be required which could be in the region 50% of the initial capital costs.
Economics	There could be a potential economic benefit through the ongoing maintenance of the jet array for a local company.
Methodology	Moderate to high certainty of the approach being successful as it has been successfully adopted at other Ports globally, although it has not been adopted in Australia.
Innovation	The approach is considered innovative as it replicates the natural environment (causing increased resuspension during periods of increased tidal current speed) and has not been adopted in Australia.
Longevity	The approach can be considered a long-term solution to manage the majority of sedimentation in the berth (some drag barring is also likely to be required in the corners of the berth). The approach would reduce the annual sedimentation and therefore the volume of sediment placed at EBSDS by 10,000 m^3/yr and this would result in a reduction in the dredge duration by two days.

3.5.5.4. Nautical Depth Navigation / Drag Barring

This approach assumes that any sedimentation which occurs above the declared depth in the berth can be managed by quarterly drag barring and that any sediment which remains after the drag barring or is deposited between the quarterly campaigns can be considered to be fluid mud and therefore would be navigable[11]. The approach assumes eight days of drag

[11] Additional testing and dual frequency hydrographic surveying would be required to confirm this.

barring per year, with maintenance dredging of 10,000 m^3 required every third year to prevent an ongoing build-up of sediment in the region. It is important to note that this approach would need to be combined with a suitable sediment management approach for the adjacent apron area (e.g. drag barring combined with annual maintenance dredging) to prevent a build-up of sediment in the apron directly adjacent to the berth. Due to the potential navigational risk of the approach it has been assumed that quarterly hydrographic surveys would be required (included in the cost estimate), we have assumed that each survey would take one day to complete (i.e. an additional three days of surveying is required each year). The approach reduces the volume of maintenance dredging and the volume placed at EBSDS by 20,000 m^3 every three years. A summary of the Objectives Assessment for this approach is detailed in Table 17.

Table 17. Objectives Assessment for the Nautical Depth Navigation / Drag Barring approach in the Berths.

Aspect	Objective
Environment	Based on previous monitoring during maintenance dredging by the TSHD *Brisbane*, the dredging activity and placement of the sediment at the EBSDS only results in short duration, localised impacts in turbidity. In addition, the quarterly drag barring is only expected to result in very localised increases in turbidity. As a result, the approach is not expected to influence the biodiversity, coastal habitats or morphology in the region, except for the dredged areas of the PoG and the EBSDS.
Resource use	The main resource use will be diesel fuel for the Pacific Conquest and the TSHD *Brisbane*. The associated GHG emissions are estimated to be 1,270 t CO_{2e} over 10 years.
Legislative requirement	Standard approval required for maintenance dredging under the *Environment Protection (Sea Dumping) Act 1981* and the Queensland *Environment Protection Act 1994*, this is a well known process which GPC have experience with. Additional approval would be required by the Regional Harbour Master to change the echo-sound frequency that is assumed to represent the seabed in the berths (it is currently specified as 200 kHz in Queensland (MSQ, 2009)).
Health & Safety	There is a risk to the safety of vessels resulting from the nautical depth navigation approach. Therefore, this approach has the potential to reduce the maritime safety in the PoG.
Cultural	No change to cultural or historic sites and values in the PoG.
Social	No change to social activities and opportunities in the PoG.
Port operations	Will maintain Port operations as activities can be undertaken to fit in around the Port operations.
Cost	Cost over ten years is estimated to be $2.1million. Costs for options for this region range from $1.9million to $3.2 million over ten years.
Economics	No change to economic opportunities for the region other than those associated with the ongoing operation of the PoG.
Methodology	Moderate certainty of the approach being successful, but some uncertainty due to possibility that sediment remaining after drag barring is too dense to allow the nautical depth approach.
Innovation	The approach is considered to be innovative as it is not widely adopted in Australia.
Longevity	Although the approach can be considered long-term (i.e. it can be adopted to help manage sedimentation for > 10 years), it is expected that some maintenance dredging will continue to be required.

3.6. Recommendations and Implications

Based on the Objectives Assessment detailed in the previous sections, it is suggested that the following approaches should be considered and potentially further investigated as approaches to reduce future maintenance dredging in the PoG:

- LNG Terminal Region – Sustainable Relocation: out of the approaches considered this approach resulted in the lowest GHG emissions and costs and was also identified as having the potential to provide environmental, health and safety, social, port operations and economic benefits. The approach is long-term although placement of sediment at the EBSDS is likely to continue to be required. There are uncertainties regarding the legislative requirements for the approach as well as potential impacts to sensitive receptors and there is a risk of sediment being redeposited in the dredged areas. It is recommended that the approach is discussed with the relevant regulators to confirm the legislative requirements. Following this, if the approach is still considered feasible then detailed numerical modelling should be undertaken to understand how much sediment is likely to be redeposited in the dredged areas of the PoG, the potential impacts to sensitive receptors and to optimise the approach relative to the metocean conditions. A trial could then be adopted with a small volume of sediment placed at the proposed sustainable relocation site (e.g. place 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 (that half of the ongoing sedimentation in the region could be managed through sustainable relocation), the approach would reduce the maintenance dredging duration by five days per year and would reduce the volume of sediment placed at the EBSDS by 75,000 m^3/yr.
- Marina – Sustainable Relocation: compared to maintenance dredging and placement at the EBSDS, this approach resulted in lower costs but higher GHG emissions than the short-term maintenance dredging option (due to the ongoing drag barring requirement) and lower GHG emissions than the long-term maintenance dredging option. The approach was also identified as having the potential to provide economic and Port operations benefits. The approach is long-term and would mean that no ongoing placement of sediment at the EBSDS is required. There are uncertainties regarding the legislative requirements for the approach as well as potential impacts to sensitive receptors and the potential for sediment to be redeposited in dredged areas of the PoG. Similar to the sustainable relocation approach for the LNG Terminal region, it is recommended that the approach is discussed with the relevant regulators to confirm the legislative requirements. Following this, if the approach is still considered feasible then detailed numerical modelling should be undertaken to understand how much sediment is likely to be redeposited in the dredged areas of the PoG, as well as any potential impacts to sensitive receptors. Following this, the approach could be implemented with turbidity monitoring undertaken at the start of the sustainable relocation to confirm the results of the numerical modelling. The approach would reduce the volume of sediment placed at the EBSDS by approximately 40,000 m^3/yr.
- Berths – Jet Array: out of the possible alternative approaches to maintenance dredging considered for berths in the PoG, this approach is the only one that does not require ongoing maintenance dredging. It is important to note that the jet array approach is only expected to be feasible in berths with high rates of sedimentation, such as the berths at the LNG Terminals. Although in some other berths where high rates of sedimentation occur over a small area of the berth (e.g. at one end) this approach could also be feasible with only one or two jets required. Although the approach had higher predicted GHG emissions than maintenance dredging this could be reduced if renewable or low emission sources of energy are available. Over the 10-year period considered it was the most expensive approach with it being $1.3M more than maintenance dredging. It is expected that after 10 years major maintenance would be required which would be in the order of 50% of the initial capital costs and as such over 20 years it has the potential to be only slightly more expensive than maintenance dredging ($5.3 million for the jet array over 20 years compared to $4.8 million for maintenance dredging). This approach is considered

to be innovative as it attempts to replicate the natural environment, by resuspending bed sediment during either peak flood or peak ebb and it is not expected to result in any environmental impacts. The approach also provides potential Port operational benefits, as it would mean that maintenance dredging and bed levelling/drag barring is not required for the main area of the berth. The approach would require a Tidal Works permit, which could include potentially onerous conditions relating to mega fauna impacts. Although the approach does increase the health and safety risk due to the requirement for ongoing maintenance of land based infrastructure, it does also enhance the maritime safety as the berth would not need to be maintained by a vessel. It is a long-term approach and would prevent ongoing sedimentation throughout the majority of the berth. If the approach is adopted at a single berth in the LNG Terminal region then it could reduce maintenance dredging by between 4,500 and 12,000 m^3/yr (variable rates depending on the berth) and if it was adopted at all berths in the LNG Terminal region, then it could reduce maintenance dredging by around 23,600 m^3/yr on average.

- Berths – Nautical Depth Navigation / Drag Barring: this approach is only considered to be potentially feasible for berths where the adjacent apron is at a similar depth to the berths (i.e. in the LNG Terminal region). However, it is important to note that this approach would need to be combined with a suitable sediment management approach for the adjacent apron area (e.g. drag barring combined with annual maintenance dredging) to prevent a build-up of sediment in the apron directly adjacent to the berth. Over the 10-year period considered ongoing maintenance dredging was the cheapest approach with the lowest GHG emissions, while this approach was the cheapest alternative approach being slightly more expensive and with slightly higher GHG emissions than maintenance dredging. The approach was generally similar to maintenance dredging in most aspects expect that there could be a risk to the safety of vessels due to the nautical depth navigation approach. Sediment testing and regular dual frequency bathymetric survey would be required to mitigate this risk. The approach has a moderate certainty of being successful as there remains uncertainty as to the effectiveness of a drag bar in removing sedimentation from the berth and the density of the sedimentation. Although the approach is expected to be able to manage the long-term sedimentation in the berth, some maintenance dredging will also be required, but the exact frequency and volume could only be determined by testing the approach. If the approach is adopted at a single berth in the LNG Terminal region then it is estimated to be able to reduce maintenance dredging by between 9,000 and 24,000 m^3 (variable rates depending on the berth) and if it was adopted at all berths in the LNG Terminal region then it could reduce maintenance dredging by 47,200 m^3 every three years on average.

Based on the Objectives Assessment the minimum channel width navigation approach is not considered to be a realistic alternative to maintenance dredging in the Outer Cuttings. It does not provide any significant benefits over maintenance dredging and results in an increased maritime safety risk.

If the jet array approach is implemented at the three LNG Terminal berths and the sustainable relocation approaches are adopted at the LNG Terminal region and the Marina, then there could be a reduction in maintenance dredging of 23,600 m^3/yr and a reduction in sediment placed at the EBSDS of 138,600 m^3/yr (inclusive of the 23,600 m^3/yr reduction in maintenance dredging). This represents a 9% reduction in maintenance dredging per year and a 50-60% reduction in the volume of sediment placed at the EBSDS per year.

4. Summary

This report has provided a comprehensive Objectives Assessment of the approaches to reduce sedimentation and maintenance dredging in the PoG. The report has provided an overview of the existing and predicted future sediment management requirement for the PoG. It was identified that the majority (approximately 90%) of the ongoing sedimentation above declared depths in the PoG occurred in the LNG Terminal region, Marina, Outer Harbour Cuttings and berths. These areas have therefore been the focus of the reduce assessment, with possible alternative approaches to maintenance dredging considered within each area.

To allow for ongoing SSM it is important to acknowledge that sediment from maintenance dredging is an essential component of natural sediment budgets and ecosystems. Therefore, a key principle is to consider dredged material as a valuable resource to be used in the natural environment, rather than a waste material for disposal. In line with this, recent industry guidance has been promoting the approach of sustainable relocation, where dredged sediment is released into the active sediment system where it can be transported to areas which rely on an ongoing supply of sediment. This approach helps to maintain the sediment supply and therefore helps to support sediment-based habitats and shorelines which rely on an ongoing natural supply of sediment. For this assessment, this type of sustainable practise has been considered as an approach to reduce maintenance dredging, when it improves the efficiency of the dredging and therefore has the potential to reduce the duration of dredging as well as reducing the volume of sediment placed at the EBSDS.

A summary of the key findings of the PoG reduce assessment are detailed below:

- an initial feasibility assessment was undertaken with consideration to the natural processes which cause sedimentation. Reduce approaches that have been considered are based on three broad strategies, (i) to keep sediment out, (ii) keep sediment moving and (iii) keep sediment navigable. A total of 11 possible reduce approaches were identified based on information from global best practise guidance. Of these, seven approaches were considered to be potentially feasible based on the natural processes driving sedimentation in the PoG and were considered as part of an Objectives Assessment;
- the seven approaches were assessed along with ongoing maintenance dredging as part of an Objectives Assessment. This considered objectives for 12 separate aspects which ensured a comprehensive assessment. Based on the Objectives Assessment, four approaches were selected as possible approaches which could be further investigated to reduce sedimentation and maintenance dredging in the PoG:
  - LNG Terminal Region – Sustainable Relocation: the approach assumes that half of the annual sedimentation which requires management in the LNG Terminal region (75,000 m^3), is managed through sustainable relocation using the TSHD *Brisbane*, while the other half continues to be placed at the EBSDS by the TSHD *Brisbane*. It is recommended that the approach is discussed with the relevant regulators to confirm the legislative requirements. Following this, if the approach is still considered feasible, then detailed numerical modelling should be undertaken to understand how much sediment is likely to be redeposited in the dredged areas of the PoG, any potential impacts to sensitive receptors and to optimise the approach relative to the metocean conditions. A trial could then be adopted with a small volume of sediment placed at the proposed sustainable relocation site (e.g. full hoppers 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, (that half of the ongoing sedimentation in the region could be managed through sustainable relocation), the approach would reduce the maintenance dredging duration by five days per year and would reduce the volume of sediment placed at EBSDS by 75,000 m^3/yr.
  - Marina – Sustainable Relocation: the approach assumes that all of the annual sedimentation which requires management in the Marina (40,000 m^3/yr) is managed through sustainable relocation through a pipeline to the edge of Clinton Channel.

The approach requires the sedimentation to be moved to a corner of the Marina by drag barring, dredging by a remotely operated dredge vessel (RODV) in the corner of the Marina and pumping of low concentration dredged sediment to the edge of the Clinton Channel. The RODV would be capable of pumping approximately 60 m^3/hr (*in-situ volume*) of sediment and based on this it has been assumed that 640 hours of dredging would be required per year. Similar to the sustainable relocation approach for the LNG Terminal region, it is recommended that the approach is discussed with the relevant regulators to confirm the legislative requirements. Following this, if the approach is still considered feasible, then detailed numerical modelling should be undertaken to understand how much sediment is likely to be redeposited in the dredged areas of the PoG as well as any potential impacts to sensitive receptors. Following this, the approach could be implemented with turbidity monitoring undertaken at the start to confirm the results of the numerical modelling. The approach would reduce the volume of sediment placed at the EBSDS by approximately 40,000 m^3/yr.

  – Berths – Jet Array: The jet array approach is only expected to be feasible in berths with high rates of sedimentation, such as the berths at the LNG Terminals, although in some other berths where high rates of sedimentation occur over a small region of the berth (e.g. at one end) this approach could also be feasible with only one or two jets required. Due to the configuration of the berths at the LNG Terminals, there is the potential that some sedimentation could occur in the corners of the berths and so ongoing drag barring is likely to be required. If the approach is adopted at a single berth in the LNG Terminal region, then it could reduce maintenance dredging by between 4,500 and 12,000 m^3/yr (variable rates depending on the berth) and if it was adopted at all berths in the LNG Terminal region, then it could reduce maintenance dredging by around 23,600 m^3/yr on average.
  – Berths – Nautical Depth Navigation / Drag Barring: This approach is only considered to be potentially feasible in berths where the adjacent apron is at a similar depth to the berths, such as the berths at the LNG Terminals. It is recommended that sediment testing and dual frequency bathymetric survey are undertaken between annual maintenance dredging campaigns to better understand the sediment properties and determine if the nautical depth navigation aspect would be applicable. In addition, test case drag barring could be undertaken in the berths between annual maintenance dredging campaigns to better understand the production rates and therefore the number of days required per year. If the approach is adopted at a single berth in the LNG Terminal region then it is estimated to be able to reduce maintenance dredging by between 9,000 and 24,000 m^3 (variable rates depending on the berth) and if it was adopted at all berths in the LNG Terminal region then it could reduce maintenance dredging by 47,200 m^3 every three years on average. It is important to note that this approach would need to be combined with a suitable sediment management approach for the adjacent apron area (e.g. drag barring combined with annual maintenance dredging) to prevent a build-up of sediment in the apron directly adjacent to the berth.

- if the jet array approach is implemented at the three LNG Terminal berths and the sustainable relocation approaches are adopted at the LNG Terminal region and the Marina, then there could be a reduction in maintenance dredging of 23,600 m^3/yr and a reduction in sediment placed at the EBSDS of approximately 138,600 m^3/yr (inclusive of the 23,600 m^3/yr reduction in maintenance dredging). This represents a 9% reduction in maintenance dredging per year and a 50-60% reduction in the volume of sediment placed at the EBSDS per year; and
- no realistic approaches were identified to reduce maintenance dredging in the Outer Harbour Cuttings (Golding, Boyne and Wild Cattle Cuttings).

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Appendices

Appendix A – Option Synopses

SUSTAINABLE SEDIMENT MANAGEMENT PROJECT

REDUCE DREGING OPTION 1: LNG Terminals Region – Ongoing Maintenance Dredging

Approximately 70% of the total sedimentation above declared depths in the Port of Gladstone (PoG) has occurred in the LNG Terminals region, with between 80% and 90% of the sedimentation in the aprons. For this assessment a sediment management requirement of 150,000 m^3/yr (in-situ) has been assumed.

This approach assumes that ongoing annual maintenance dredging of 150,000 m^3/yr (in-situ) of sedimentation is undertaken by the TSHD Brisbane and the sediment placed at the EBSDS. In addition, 15 days of bed levelling is also assumed to be undertaken during the maintenance dredging. The Objectives Assessment for this approach is detailed in the table below, and a schematic representation is shown overleaf.

ASPECT	SUMMARY
Environment	Based on previous monitoring during maintenance dredging by the TSHD Brisbane, the dredging activity and placement of the sediment at the EBSDS only results in short duration, localised increases in turbidity. In addition, there are existing monitoring and adaptive management strategies in place. As a result, there is a high confidence that the approach is not expected to influence the biodiversity, coastal habitats or morphology in the region, except within the dredged areas of the PoG and within the EBSDS.
Resource use	The main resource use will be diesel fuel for the TSHD Brisbane and the Pacific Conquest. The associated GHG emissions are estimated to be 10,210 t CO_{2e} over 10 years.
Legislative requirement	Standard approval required under the *Environment Protection (Sea Dumping) Act 1981* and the Queensland *Environment Protection Act 1994.* The approval process is well known to GPC and they have experience with it.
Health & Safety	Expected to maintain health and safety in the PoG as the approach is currently undertaken annually and there have not been any health and safety issues.
Cultural	No change to cultural or historic sites and values in the PoG.
Social	No change to social activities and opportunities in the PoG.
Port operations	Will maintain Port operations as activities can be undertaken to fit in around the Port operations.
Cost	Cost over ten years is estimated to be $16.5 million. Costs associated with options for this region range from $13.0 million to $113 million over 10 years.
Economics	No change to economic opportunities for the region other than those associated with the ongoing operation of the PoG.
Methodology	High certainty of the approach being successful as it is currently undertaken annually.
Innovation	Limited innovation, although the TSHD Brisbane is updated regularly to incorporate the latest environmental advances in dredging technology.
Longevity	The approach is a long-term solution. Based on the existing annual maintenance dredging requirement for the PoG, the EBSDS has capacity for more than 100 years of maintenance dredging.


150,000 m³/yr of sediment dredged from LNG Terminal Region
EBSDS
Sediment placed at EBSDS

SUSTAINABLE SEDIMENT MANAGEMENT PROJECT

REDUCE DREGING OPTION 2: LNG Terminals Region - Sustainable Relocation

Approximately 70% of the total sedimentation above declared depths in the Port of Gladstone (PoG) has occurred in the LNG Terminals region, with between 80% and 90% of the sedimentation in the aprons. For this assessment a sediment management requirement of 150,000 m^3/yr (in-situ) has been assumed.

This approach assumes that half of the annual sedimentation which requires management in the LNG Terminal region is managed through sustainable relocation using the TSHD Brisbane, while the other half continues to be placed at the EBSDS by the TSHD Brisbane. Sediment would be placed at the sustainable relocation area in the same way as it is placed at EBSDS, with the main difference being that the sediment would be less consolidated to promote transport away from the sustainable relocation site. As with the maintenance dredging approach, 15 days of bed levelling is also assumed to be undertaken each year. Based on the assumptions made the approach could result in an annual reduction of sediment placement at EBSDS of 75,000 m^3 (in-situ) and a reduction in annual maintenance dredging duration of four days. The Objectives Assessment for this approach is detailed in the table below, and a schematic representation is shown overleaf.

ASPECT	SUMMARY
Environment	The approach aims to enhance the environment of the PoG by ensuring sufficient sediment remains within the active system to feed naturally accreting areas. However, there is a risk that negative impacts could occur due to increased turbidity associated with the release of sediment to a dispersive region of the PoG. Detailed numerical modelling would be required to mitigate the risk of negative impacts.
Resource use	The main resource use will be diesel fuel for the TSHD Brisbane and the Pacific Conquest. The associated GHG emissions are estimated to be 8,200 t CO_{2e} over 10 years.
Legislative requirement	There is uncertainty regarding the approval process as it will involve dredged sediment being placed outside of the designated placement area, but within the designated PoG channels and at a historic relocation ground. The ongoing maintenance dredging and placement at the EBSDS will require standard approval under the *Environment Protection (Sea Dumping) Act 1981* and the Queensland *Environment Protection Act 1994.*
Health & Safety	Potential for improved health and safety within the PoG due to reduced travel distance and duration for TSHD Brisbane.
Cultural	No change to cultural or historic sites and values in the PoG.
Social	Potential for enhancement in water based activities in the PoG due to reduced travel distance and duration for the TSHD Brisbane. Also potential for social benefits due to possible environmental enhancement of habitats such as mudflats and mangroves.
Port operations	Potential for enhancement in port operations due to reduced travel distance and duration for the TSHD Brisbane.
Cost	Cost over ten years is estimated to be $13.0 million. Costs for options for this region range from $13.0 million to $113 million over ten years.
Economics	Possible enhancement to economic opportunities in the region due to potential benefits to coastal habitats such as mudflats and mangroves. Economic opportunities could be in tourism and fishing (as habitats such as mangroves act as nurseries for many fish species).
Methodology	There is a high degree of confidence that the approach would be successful in removing sedimentation from the LNG Terminal region. However, there is uncertainty and risk associated with potential impacts from the approach on sensitive receptors and how much sediment would be returned to the area. Detailed numerical modelling and monitored trials would be required to reduce the uncertainty and mitigate the risk.
Innovation	The approach is considered to be innovative as it is not widely adopted in Australia and is sustainable and a type of working with nature.
Longevity	The approach is a long-term solution which would reduce the volume of sediment being placed at the EBSDS. However, there is uncertainty as to whether the approach would be able to completely replace the placement of sediment at the EBSDS. There could be constraints regarding when sediment could be sustainably relocated to ensure it does not impact sensitive receptors and is not deposited back into the LNG Terminal region.

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SUSTAINABLE SEDIMENT MANAGEMENT PROJECT

REDUCE DREGING OPTION 3: LNG Terminals Region – Channel Realignment

Approximately 70% of the total sedimentation above declared depths in the Port of Gladstone (PoG) has occurred in the LNG Terminals region, with between 80% and 90% of the sedimentation in the aprons. For this assessment a sediment management requirement of 150,000 m^3/yr (in-situ) has been assumed.

This approach is aimed at increasing the flow speeds in the LNG Terminal Region by connecting the Jacobs Channel to the natural channel to the north. It is estimated that 3 million m^3 of sediment would need to be removed from the shallow channel north of Jacobs Channel by capital dredging, this would be pumped directly into the Western Basin Reclamation (dredging duration = 17 weeks). It is not possible to accurately predict the future sediment management requirement but to allow cost and resource calculations to be made, the annual sedimentation has been assumed to be reduced by 20%. The ongoing annual sedimentation has been assumed to be 120,000 m^3/yr, with the sediment being removed by the TSHD Brisbane and placed at the EBSDS. In addition, 12 days of bed levelling is assumed to be undertaken during the maintenance dredging. Based on the assumptions made the approach would result in a reduction in maintenance dredging volume and placement at EBSDS of 30,000 m^3 and a reduction in annual maintenance dredging duration of three days. The Objectives Assessment for this approach is detailed in the table below, and a schematic representation is shown overleaf.

ASPECT	SUMMARY
Environment	The approach is considered to have a localised negative impact on the environment as new areas of seabed will be dredged. Previous monitoring has found seagrass in the area of the proposed capital dredging, indicating a risk of direct impacts to seagrass. There is also a risk of impacts due to increased turbidity during the capital dredging, although based on the dredging approach (CSD pumping direct to the Western Basin Reclamation), any impacts would be expected to be localised within the Port boundaries and could be mitigated through monitoring and adaptive management.
Resource use	The main resource use will be diesel fuel for the CSD, TSHD Brisbane and the Pacific Conquest. The associated GHG emissions are estimated to be 23,540 t CO_{2e} over 10 years.
Legislative requirement	Multiple approvals are required for capital (*EPBC Act 1999, Sustainable Ports Development Act 2015, Fisheries Act 1994*) and maintenance dredging (*Environment Protection (Sea Dumping) Act 1981* and Queensland *Environment Protection Act 1994*). Well known approval processes which GPC have experience with.
Health & Safety	There would be an increased risk to health and safety due to the duration of dredging works in the PoG (estimated to be approximately 4 months), along with the approach requiring a pipeline to be in place throughout the duration of the dredging for sediment to be directly pumped into the Western Basin Reclamation. Additional on land health and safety risks associated with the reclamation works.
Cultural	The approach is not expected to change the cultural or historic sites and values in the PoG. Based on previous impact assessments in the region there are not expected to be any sites of historic heritage significance recorded (Converge Heritage and Community, 2009), but this would need to be reviewed in more detail as part of an impact assessment.
Social	Possible negative impact to social activities and opportunities in the PoG as capital dredging could limit local water based recreational activities during the capital dredging campaign.
Port operations	Expected to maintain Port operations, although there is a risk that increased flows in the LNG Terminal region could negatively influence vessel navigation.
Cost	Cost over ten years is estimated to be $113 million. Costs for all options for this region range from $13.0 million to $122 million over ten years. The costs do not include any allowance for offsets required as part of the capital dredging.
Economics	No change to economic opportunities for the region other than those associated with the ongoing operation of the PoG.
Methodology	There is significant uncertainty in the effectiveness of the approach and how much it would reduce sedimentation in the Jacobs Channel region. Detailed modelling would be required to predict this, but there would still be some uncertainty.
Innovation	The approach should be considered relatively innovative as it is a form of working with nature.
Longevity	If the approach is successful then it should result in a long term reduction in sedimentation in the LNG Terminal region. However, it is expected that annual maintenance dredging would continue to be required in the region.

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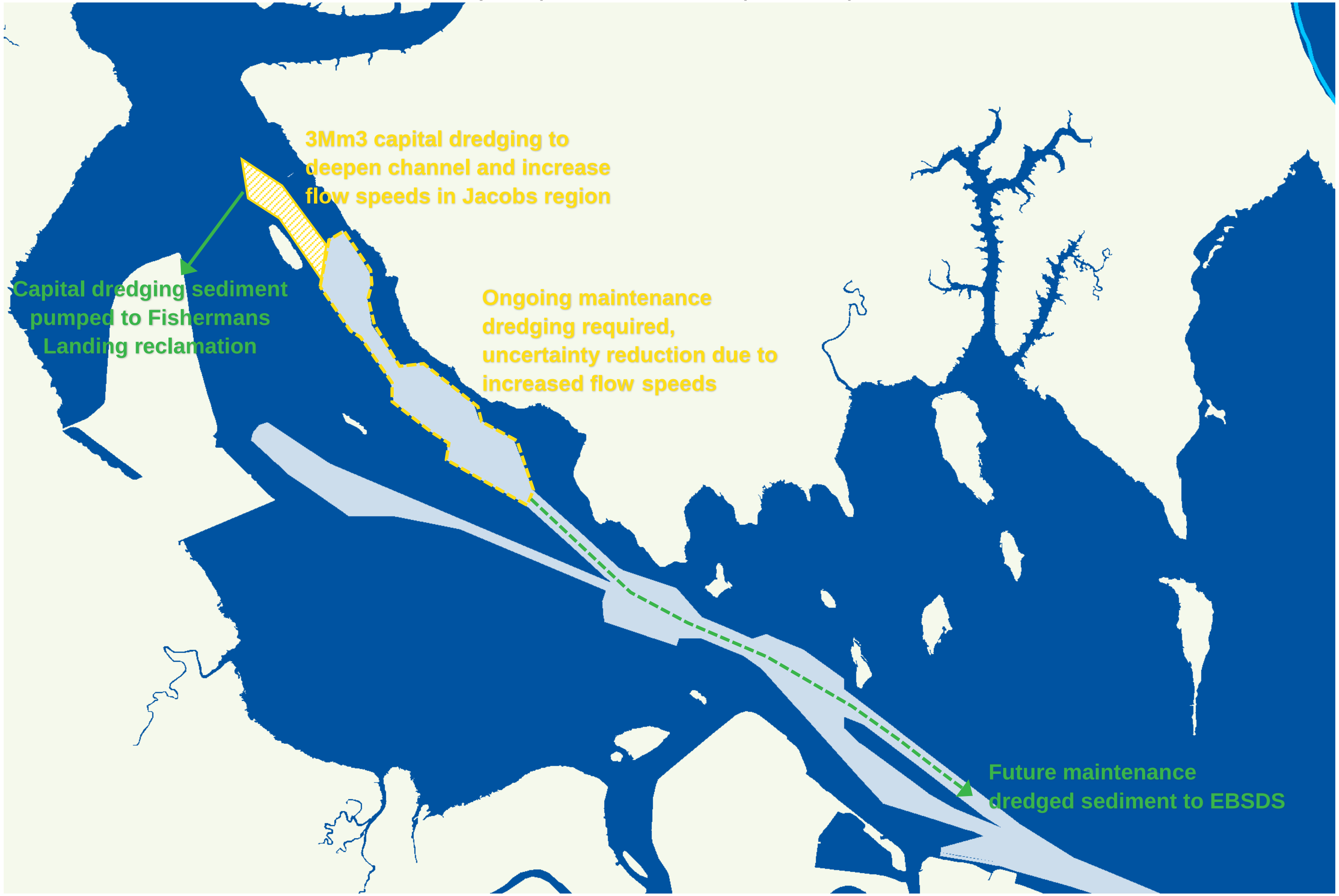

SUSTAINABLE SEDIMENT MANAGEMENT PROJECT

REDUCE DREGING OPTION 4: Marina – Short-term Maintenance Dredging

The annual sedimentation which requires management in the Marina has been between 39,000 and 43,000 m^3. For the assessment the sediment management requirement has been assumed to be 40,000 m^3/yr.

This approach assumes that 200,000 m^3 of sedimentation is removed by a small CSD every five years and pumped directly to an adjacent onshore placement area. The dredge duration is estimated to be in the region of 40 days every five years with the sediment all placed at the adjacent onshore placement area. There is only sufficient capacity at the onshore site for a single future maintenance dredging campaign, with no other suitable onshore sites available close to the Marina. The Objectives Assessment for this approach is detailed in the table below, and a schematic representation is shown overleaf. Please note that the costs and GHG emissions for this approach have been calculated over a 10-year period (so they are directly comparable to the other approaches) despite the approach only being able to manage the sedimentation for the next five years.

ASPECT	SUMMARY
Environment	The maintenance dredging by a small CSD will only result in localised increases in turbidity in the Marina. As a result, the approach is not expected to influence the biodiversity, coastal habitats or morphology outside of the Marina.
Resource use	The main resource use will be diesel fuel for the small CSD and the Pacific Conquest. The associated GHG emissions are estimated to be 1,290 t CO_{2e} over 10 years.
Legislative requirement	Standard approval required under the Queensland *Environment Protection Act 1994.* The approval process is well known to GPC and they have experience with it.
Health & Safety	Expected to maintain health and safety in the PoG as maintenance dredging of the Marina and placement on land has been undertaken numerous times and there have not been any health and safety issues.
Cultural	No change to cultural or historic sites and values in the PoG. The Marina and surrounding land were constructed as part of reclamation works in the 1980s and so no cultural or historic sites are expected to be present in the area.
Social	No change to social activities and opportunities in the PoG.
Port operations	Will maintain Port operations as activities will only be undertaken within the Marina. Potential for some impacts to vessel operations in the Marina during maintenance dredging campaigns (estimated to be 40 days every five years).
Cost	Cost over ten years is estimated to be \$6.0 million. Costs of options for this region range from \$4.1million to \$20.1 million over ten years.
Economics	No change to economic opportunities for the region other than those associated with the ongoing operation of the Marina.
Methodology	High certainty of the approach being successful as it has previously been adopted to manage the sedimentation in the Marina.
Innovation	Limited innovation, it is considered a standard dredging approach.
Longevity	The approach is only a short-term solution. There is limited capacity remaining in the onshore placement area and it is estimated that this approach can only be adopted for one more maintenance dredging campaign (i.e. 5 years of sedimentation).

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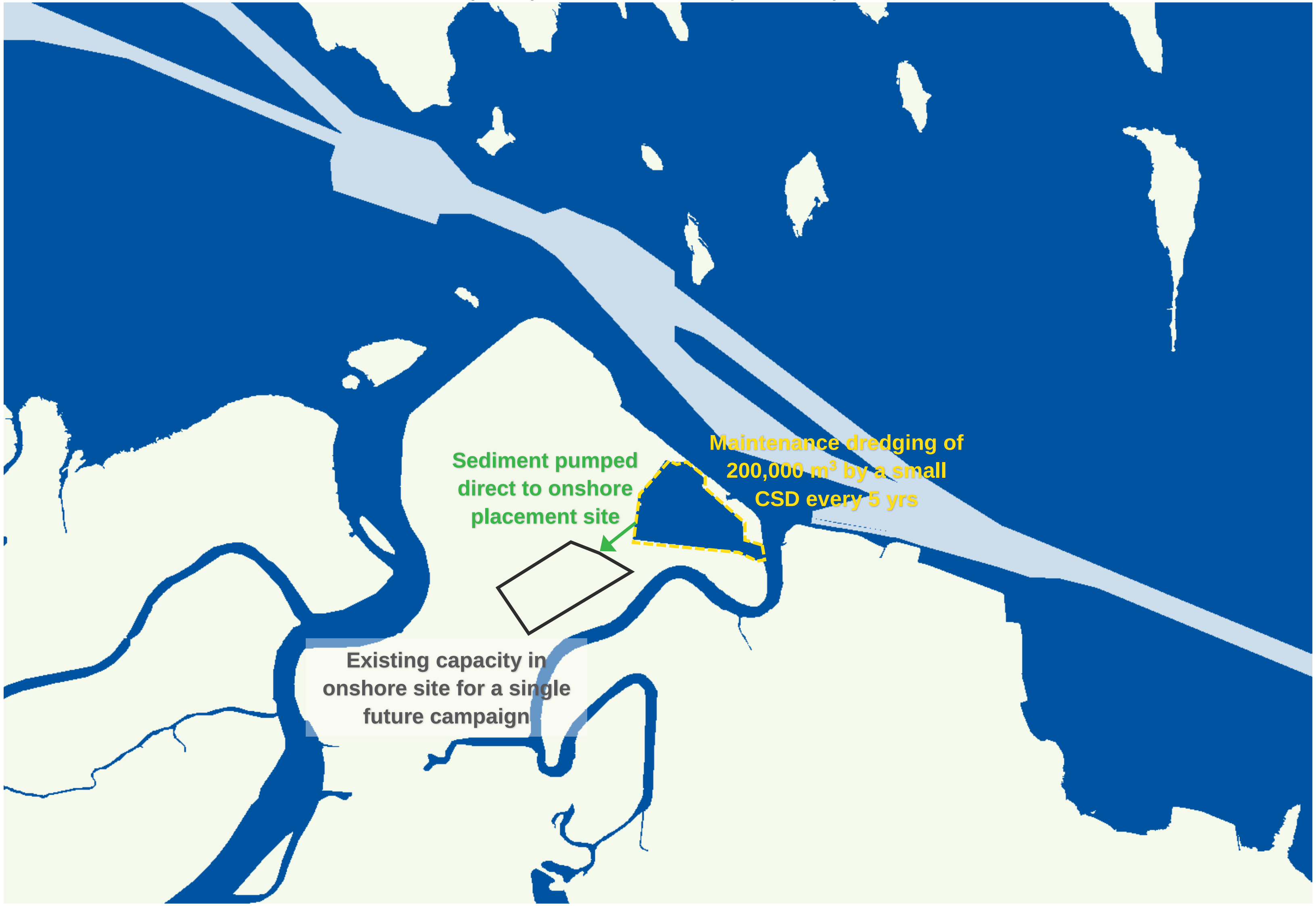

SUSTAINABLE SEDIMENT MANAGEMENT PROJECT

REDUCE DREGING OPTION 5: Marina – Long-term Maintenance Dredging

The annual sedimentation which requires management in the Marina has been between 39,000 and 43,000 m^3. For the assessment the sediment management requirement has been assumed to be 40,000 m^3/yr.

This approach assumes that 200,000 m^3 of sedimentation is removed by a small TSHD (hopper capacity of 500 to 1,000 m^3) every five years and placed at EBSDS. The dredge duration is estimated to be in the region of 125 days every five years with the sediment all placed at EBSDS. In addition, 5 days of bed levelling/drag barring is also assumed to be undertaken during each maintenance dredging campaign to move sedimentation from areas that the dredger cannot access and to level the seabed after dredging. The Objectives Assessment for this approach is detailed in the table below, and a schematic representation is shown overleaf.

ASPECT	SUMMARY
Environment	Based on previous monitoring during maintenance dredging by the TSHD Brisbane, the dredging activity and placement of sediment at the EBSDS only results in short duration, localised impacts to turbidity. This represents a volume of sediment which has not previously been placed at EBSDS as it has historically been placed on land. The volume represents an increase in sediment placed at EBSDS in the order of 20%. As a result, the use of a smaller TSHD is not expected to influence the biodiversity, coastal habitats or morphology in the region, except for within the Marina and the EBSDS.
Resource use	The main resource use will be diesel fuel for the small TSHD and the Pacific Conquest. The associated GHG emissions are estimated to be 5,360 t CO_{2e} over 10 years.
Legislative requirement	Standard approval required under the *Environment Protection (Sea Dumping) Act 1981* and the Queensland *Environment Protection Act 1994.* The approval process is well known to GPC and they have experience with it.
Health & Safety	Potential for increased risk to health and safety in the PoG due to the long duration of the maintenance dredging campaigns (estimated to be 125 days every five years), combined with the fact the vessel will regularly be sailing between the Marina and the EBSDS.
Cultural	No change to cultural or historic sites and values in the PoG. The Marina and surrounding land were constructed as part of reclamation works in the 1980s and so no cultural or historic sites are expected to be present in the area.
Social	No change to social activities and opportunities in the PoG.
Port operations	There is a risk of minor impacts to Port operations due to the duration of the activity (estimated to be 125 days every five years), combined with the fact the vessel will regularly be sailing between the Marina and the EBSDS. There is also likely to be impacts to vessel operations in the Marina during the maintenance dredging campaigns.
Cost	Cost over ten years is estimated to be $20.1 million. Costs of options for this region range from $4.1 million to $20.1 million over ten years.
Economics	No change to economic opportunities for the region other than those associated with the ongoing operation of the Marina.
Methodology	High certainty of the approach being successful.
Innovation	Limited innovation, it is considered a standard dredging approach.
Longevity	The approach is a long-term solution. Based on the existing annual maintenance dredging requirement for the PoG, the EBSDS has capacity for more than 100 years of maintenance dredging.

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SUSTAINABLE SEDIMENT MANAGEMENT PROJECT

REDUCE DREDGING OPTION 6: Marina - Sustainable Relocation

The annual sedimentation which requires management in the Marina has been between 39,000 and 43,000 m^3. For the assessment the sediment management requirement has been assumed to be 40,000 m^3/yr.

This approach assumes that all of the annual sedimentation which requires management in the Marina (40,000 m^3/yr) is managed through sustainable relocation using drag barring, dredging by a Remotely Operated Dredge Vessel (RODV) and pumping of low concentration dredged sediment to the edge of the Clinton Channel. The RODV would be capable of pumping approximately 60 m^3/hr (in-situ) of sediment and based on this it has been assumed that 640 hours of dredging would be required per year. A total of 12 days of drag barring has also been included per year to move sediment to the eastern corner of the Marina where the RODV would operate. It is estimated that the dredge duration would be between one and two months each year and none of the sediment would be placed at EBSDS. This represents a reduction in volume placed at EBSDS of 40,000 m^3/yr compared to the long-term maintenance dredging approach. The Objectives Assessment for this approach is detailed in the table below, and a schematic representation is shown overleaf.

ASPECT	SUMMARY
Environment	The approach aims to enhance the environment of the PoG by ensuring sufficient sediment remains within the active system to feed naturally accreting regions. However, there is a risk that negative impacts could occur due to increased turbidity associated with the release of sediment to a dispersive region (the edge of Clinton Channel). Detailed numerical modelling would be required to mitigate the risk of negative impacts.
Resource use	The main resource use will be diesel fuel for the RODV and pump generator and the Pacific Conquest. The associated GHG emissions are estimated to be 2,240 t CO_{2e} over 10 years (with 60% of the emissions being from the drag barring).
Legislative requirement	There is uncertainty regarding the approval process as it will involve dredged sediment being placed outside of the designated offshore placement area. The permanent pipeline will require a Tidal Works approval from the Department of Environment and Science (DES).
Health & Safety	Reduction to health and safety within the PoG due to maintenance dredging occurring throughout the year, the dredging including land-based infrastructure and a fixed pipeline.
Cultural	No change to cultural or historic sites and values in the PoG. The Marina and surrounding land were constructed as part of reclamation works in the 1980s and so no cultural or historic sites are expected to be present in the area.
Social	No change to social activities in the PoG. Occasional drag barring and small RODV activity are unlikely to impact vessel operations in the Marina.
Port operations	Will maintain port operations as activity will not influence any vessel operations outside of the Marina.
Cost	Cost over ten years is estimated to be $4.1 million. Costs of options for this region range from $4.1 million to $20.1 million over ten years.
Economics	This approach could result in economic benefits as it would ensure that the original declared depths in the Marina are constantly maintained which has the potential to allow a greater range of commercial (tourism or fishing) vessels to operate out of the Marina.
Methodology	There is high confidence that the approach would be successful in maintaining depths within the Marina. However, there is uncertainty and risk associated with how much of the sediment would either be returned to the area, or deposited in another dredged area of the PoG after the sustainable relocation. Detailed numerical modelling and monitored trials would be required to reduce the uncertainty and mitigate the risk.
Innovation	The approach is considered to be innovative as it is not widely adopted in Australia (although a similar approach has been adopted at Rosslyn Bay Boat Harbour) and is sustainable and a type of working with nature.
Longevity	The approach is a long-term solution and has the potential to manage all of the ongoing sedimentation which occurs in the Marina.

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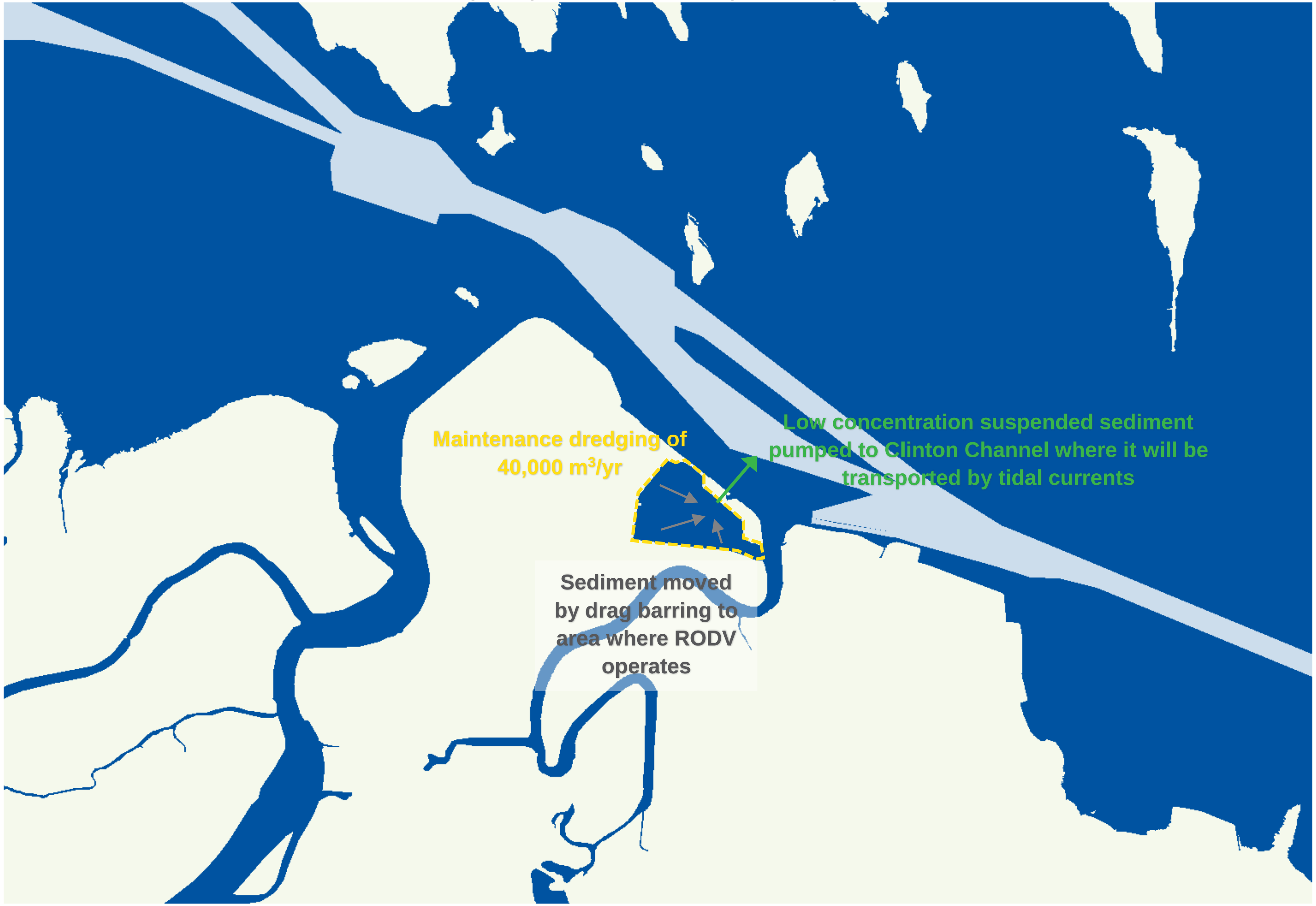

SUSTAINABLE SEDIMENT MANAGEMENT PROJECT

REDUCE DREGING OPTION 7: Outer Harbour Cuttings – Maintenance Dredging

For this assessment the ongoing sediment management requirement for the Outer Harbour Cuttings (Golding, Boyne and Wild Cattle Cuttings) has been assumed to be 40,000 m^3/yr. Historic sedimentation has been concentrated along the sides of the channels partially due to vessel propeller wash limiting sedimentation along the centre of the channels and partially due to the sedimentation being due to the bedload transport of natural sediment from the adjacent to the channels.

This approach assumes that 40,000 m^3/yr of sedimentation is removed by the TSHD Brisbane and placed at the EBSDS with an estimated dredge duration of three and a half days. In addition, one day of bed levelling is also assumed to be undertaken during the maintenance dredging. The Objectives Assessment for this approach is detailed in the table below, and a schematic representation is shown overleaf.

ASPECT	SUMMARY
Environment	Based on previous monitoring during maintenance dredging by the TSHD Brisbane, the dredging activity and placement of the sediment at the EBSDS only results in short duration, localised impacts in turbidity. As a result, the approach is not expected to influence the biodiversity, coastal habitats or morphology in the region, except for the dredged areas of the PoG and EBSDS.
Resource use	The main resource use will be diesel fuel for the TSHD Brisbane and the Pacific Conquest. The associated GHG emissions are estimated to be 1,970 t CO_{2e} over 10 years.
Legislative requirement	Standard approval required under the *Environment Protection (Sea Dumping) Act 1981* and the Queensland *Environment Protection Act 1994.* The approval process is well known to GPC and they have experience with it.
Health & Safety	Expected to maintain health and safety in the PoG as approach is currently undertaken annually and there have not been any health and safety issues.
Cultural	No change to cultural or historic sites and values in the PoG.
Social	No change to social activities and opportunities in the PoG.
Port operations	Will maintain Port operations as activities can be undertaken to fit in around the port operations.
Cost	Cost over ten years is estimated to be $3.5 million. Costs for the other option of adopting a minimum channel width is estimated to be $1.7 million over ten years.
Economics	No change to economic opportunities for the region other than those associated with the ongoing operation of the PoG.
Methodology	High certainty of the approach being successful as it is currently undertaken annually.
Innovation	Limited innovation, although the TSHD Brisbane is updated regularly to incorporate the latest environmental advances in dredging technology.
Longevity	The approach is a long-term solution. Based on the existing annual maintenance dredging requirement for the PoG, the EBSDS has capacity for more than 100 years of maintenance dredging.

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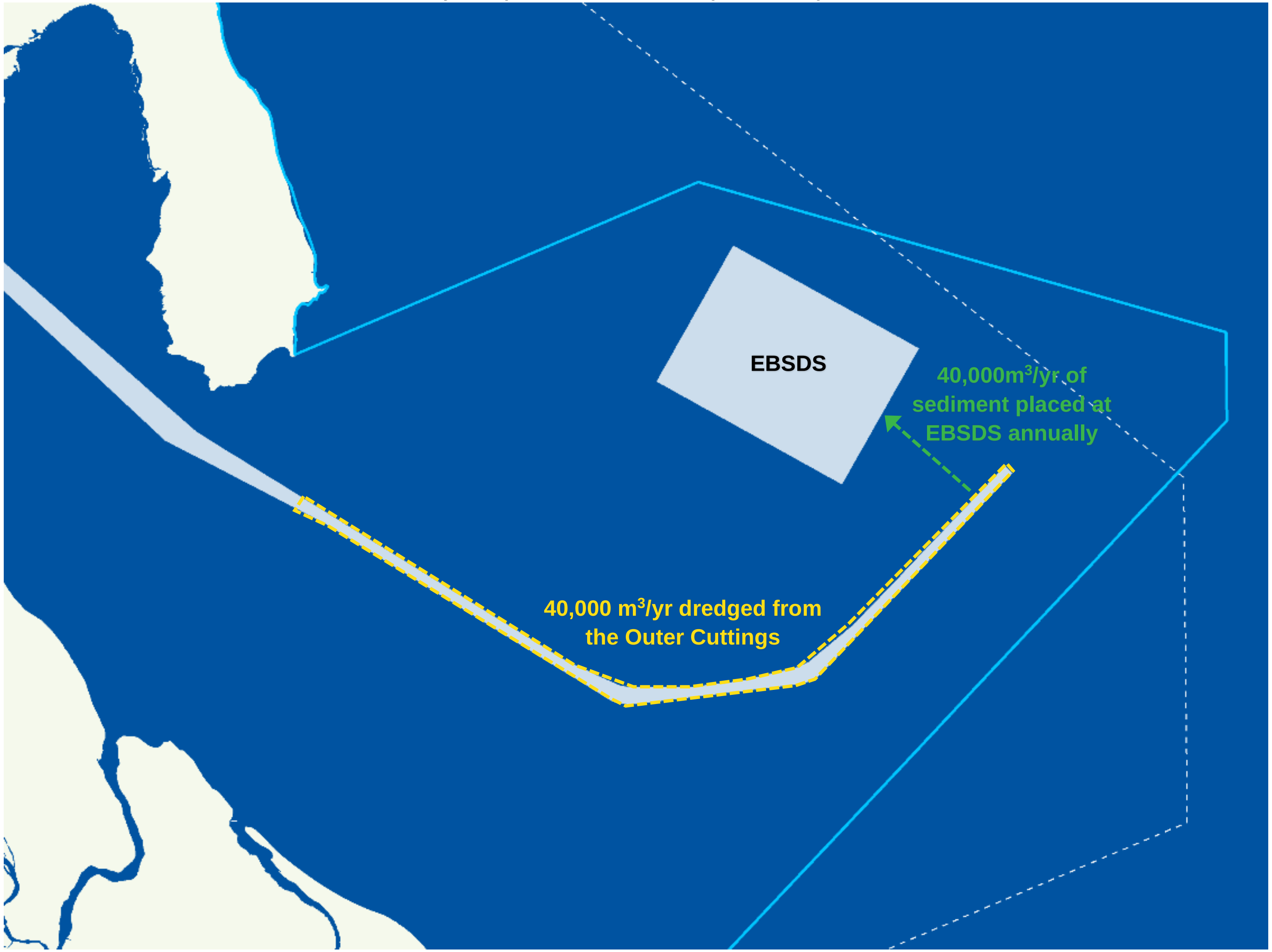

SUSTAINABLE SEDIMENT MANAGEMENT PROJECT

REDUCE DREGING OPTION 8: Outer Cuttings Region – Minimum Channel Width Navigation

For this assessment the ongoing sediment management requirement for the Outer Harbour Cuttings (Golding, Boyne and Wild Cattle Cuttings) has been assumed to be 40,000 m^3/yr. Historic sedimentation has been concentrated along the sides of the channels partially due to vessel propeller wash limiting sedimentation along the centre of the channels and partially due to the sedimentation being due to the bedload transport of natural sediment from the adjacent to the channels.

This approach assumes that the Regional Harbour Master would accept that as long as a width of 110 m of the Golding, Boyne and Wild Cattle Cuttings was at or below the declared depth then the channels would be considered navigable. It is assumed this can be achieved by undertaking 40 days of bed levelling and drag barring per year. Due to the complex processes controlling the natural sedimentation and resuspension by propeller wash and drag barring, the ongoing maintenance dredging requirement can only be accurately defined through implementation (i.e. testing the approach). For this assessment it has been assumed that maintenance dredging of 150,000 m^3 would be required every five years (i.e. reduction of 25%). In addition, four days of bed levelling will be undertaken during years when maintenance dredging occurs. For years three and four quarterly hydrographic surveys would be required to confirm the channels navigability. Based on the assumptions made it is estimated that the approach would reduce the dredge duration by 1.5 days every five years and reduce the volume of sediment placed at EBSDS by 19,000 m^3 every five years. The Objectives Assessment for this approach is detailed in the table below, and a schematic representation is shown overleaf.

ASPECT	SUMMARY
Environment	The dredging activity and placement of the sediment at the EBSDS only results in short duration, localised impacts in turbidity. As a result, the approach is not expected to influence the biodiversity, coastal habitats or morphology in the region, except for the dredged areas of the PoG and the EBSDS.
Resource use	The main resource use will be diesel fuel for the TSHD Brisbane and the Pacific Conquest. The associated GHG emissions are estimated to be 5,250 t CO_{2e} over 10 years.
Legislative requirement	No approval is required for bed levelling and drag barring as it is within the footprint of the channel. Standard approval required for the ongoing maintenance dredging under the *Environment Protection (Sea Dumping) Act 1981* and the Queensland *Environment Protection Act 1994.* The approval process is well known to GPC and they have experience with it. Additional approval is also likely to be required by the Regional Harbour Master to confirm the change in navigable channel widths.
Health & Safety	There is a risk to the safety of vessels due to the reduction in channel width. Therefore, this approach has the potential to reduce the maritime safety in the PoG.
Cultural	No change to cultural or historic sites and values in the PoG.
Social	No change to social activities and opportunities in the PoG.
Port operations	There is a potential for negative impacts to port operations due to the required annual drag barring duration, although generally these activities can be undertaken to fit in around the Port operations. However, there is an additional risk that after multiple years with no maintenance dredging and ongoing sedimentation, an extreme event (e.g. very large waves) could result in high rates of sedimentation over a short period of time which could result in the channel depths having to be redeclared to a shallower depth which could significantly impact Port operations.
Cost	The cost over ten years is estimated to be \$6.3 million. Costs for the other option of maintenance dredging is estimated to be \$3.5 million over ten years.
Economics	No change to economic opportunities for the region other than those associated with the ongoing operation of the PoG.
Methodology	Moderate certainty of the approach being successful. Uncertainty regarding the volume and frequency that maintenance dredging will also be required.
Innovation	The approach is considered to be innovative as it is not widely adopted in Australia and it represents a sustainable approach to maintaining navigable channels.
Longevity	Although the approach can be considered long-term (i.e. it can be adopted to help manage sedimentation for > 10 years), it only provides a medium-term alternative solution to maintenance dredging. There is uncertainty in the future maintenance dredging requirements associated with the approach, but it is expected that ongoing maintenance dredging would be required.

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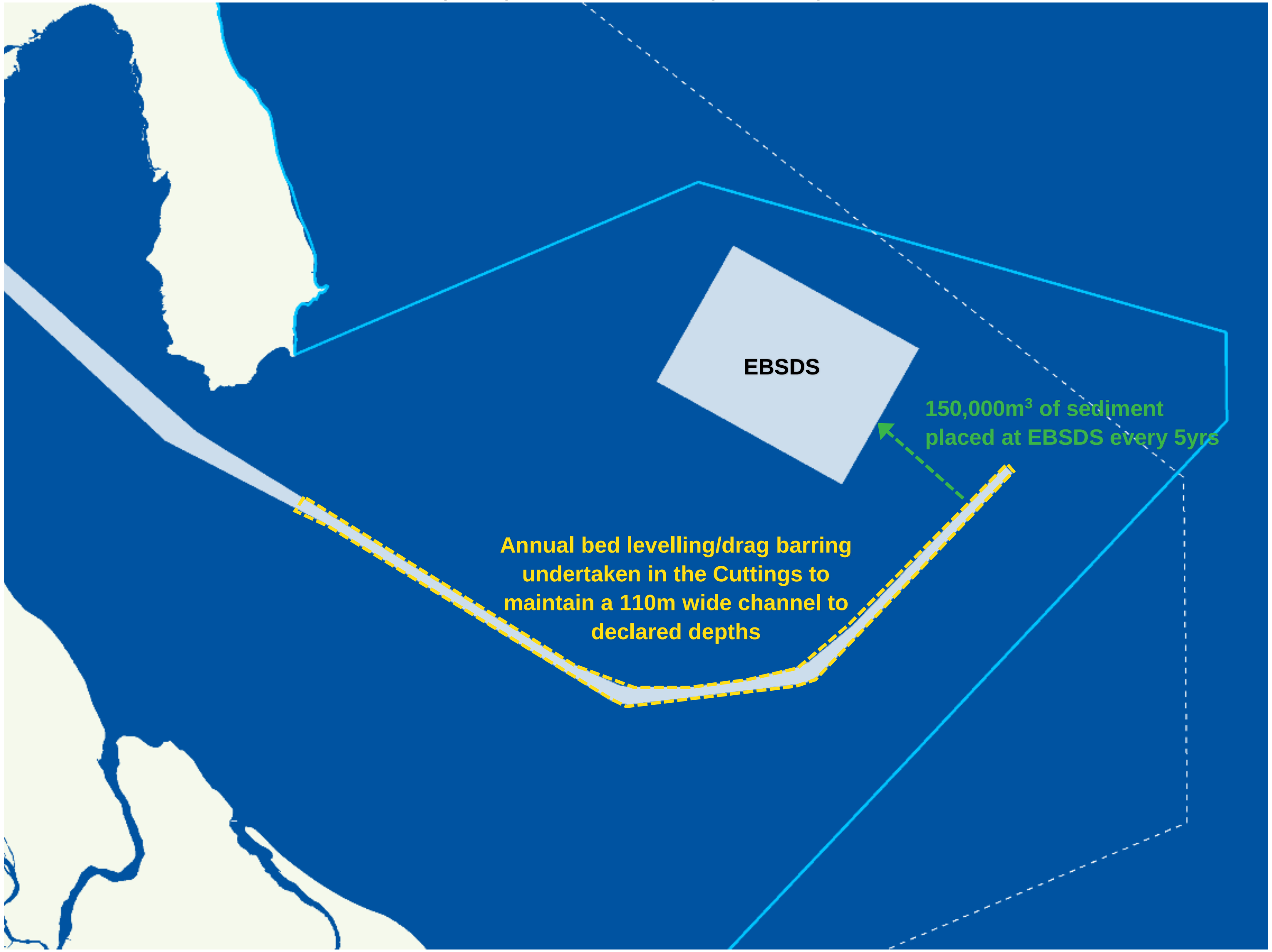

SUSTAINABLE SEDIMENT MANAGEMENT PROJECT

REDUCE DREGING OPTION 9: Berths – Maintenance Dredging

The sedimentation above design depths which requires management in the berths of the PoG is highly variable between the berths. The highest rates of sedimentation occur in the berths in the LNG Terminal region, with an average sedimentation rate of 10,000 m^3/yr.

This approach assumes that 10,000 m^3/yr of sedimentation is removed by the TSHD Brisbane and placed at the EBSDS with an estimated dredge duration of two days. In addition, two days of bed levelling is also assumed to be undertaken during the maintenance dredging. The Objectives Assessment for this approach is detailed in the table below, and a schematic representation is shown overleaf.

ASPECT	SUMMARY
Environment	Based on previous monitoring during maintenance dredging by the TSHD Brisbane, the dredging activity and placement of the sediment at the EBSDS only results in short duration, localised impacts in turbidity. As a result, the approach is not expected to influence the biodiversity, coastal habitats or morphology in the region, except for the dredged areas of the PoG and the EBSDS.
Resource use	The main resource use will be diesel fuel for the TSHD Brisbane and the Pacific Conquest. The associated GHG emissions are estimated to be 1,210 t CO_{2e} over 10 years.
Legislative requirement	Standard approval required under the *Environment Protection (Sea Dumping) Act 1981* and the Queensland *Environment Protection Act 1994.* The approval process is well known to GPC and they have experience with it.
Health & Safety	Expected to maintain health and safety in the PoG as approach is currently undertaken annually.
Cultural	No change to cultural or historic sites and values in the PoG.
Social	No change to social activities and opportunities in the PoG.
Port operations	Will maintain Port operations as activities can be undertaken to fit in around the Port operations.
Cost	Cost over ten years is estimated to be $1.9 million. Costs for options for this region range from $1.9 million to $3.2 million over ten years.
Economics	No change to economic opportunities for the region other than those associated with the ongoing operation of the PoG.
Methodology	High certainty of the approach being successful as it is currently undertaken annually.
Innovation	Limited innovation, although the TSHD Brisbane is updated regularly to incorporate the latest environmental advances in dredging technology.
Longevity	The approach is a long-term solution. Based on the existing annual maintenance dredging requirement for the PoG, the EBSDS has capacity for more than 100 years of maintenance dredging.

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SUSTAINABLE SEDIMENT MANAGEMENT PROJECT

REDUCE DREGING OPTION 10: Berths – Sediment Trap

The sedimentation above design depths which requires management in the berths of the PoG is highly variable between the berths. The highest rates of sedimentation occur in the berths in the LNG Terminal region, with an average sedimentation rate of 10,000 m^3/yr.

This approach assumes that a sediment trap with a capacity of 10,000 m^3/yr is created by capital dredging with the sediment pumped into the Western Basin Reclamation. It has been assumed that all dredging (capital and maintenance) associated with this approach is undertaken by the TSHD Brisbane. The ongoing maintenance associated with this approach includes 10 days of drag barring to move sediment from the berth into the sediment trap through the year, 10,000 m^3 of maintenance dredging and two days of bed levelling to reinstate the trap and maintain the berth. It is expected that the drag barring would result in some resuspension of sediment which would mean that the volume requiring annual maintenance dredging from the sediment trap and placement at EBSDS would be slightly lower than 10,000 m^3, but it is not possible to accurately quantify the reduction at this stage. The Objectives Assessment for this approach is detailed in the table below, and a schematic representation is shown overleaf.

ASPECT	SUMMARY
Environment	Based on previous monitoring during maintenance dredging by the TSHD Brisbane, the dredging activity and placement of the sediment at the EBSDS only results in short duration, localised impacts in turbidity. As a result, the approach is not expected to influence the biodiversity, coastal habitats or morphology in the region, except for the dredged areas of the PoG. Note: Due to the scale of the capital dredging and the fact it is located within the existing dredged areas of the Port, it is not expected to have any direct impact on sensitive habitats (e.g. seagrass) and it is expected to result in similar impacts during dredging as annual maintenance dredging of the berths.
Resource use	The main resource use will be diesel fuel for the TSHD Brisbane and the Pacific Conquest. The associated GHG emissions are estimated to be 2,860 t CO_{2e} over 10 years.
Legislative requirement	Multiple approvals are likely to be required for both capital (due to the small scale of capital dredging and associated potential impacts the approval requirements are not expected to be too onerous) and ongoing maintenance dredging (*Environment Protection (Sea Dumping) Act 1981* and Queensland *Environment Protection Act 1994*). Well known approval processes which GPC have experience with.
Health & Safety	There would be an increased risk to health and safety as the approach involves ongoing maintenance dredging, along with sediment being pumped into the Western Basin Reclamation. Additional on land health and safety risk associated with the reclamation works.
Cultural	No change to cultural or historic sites and values in the PoG.
Social	No change to social activities and opportunities in the PoG.
Port operations	Will maintain port operations as activities can be undertaken to fit in around the Port operations.
Cost	Cost over ten years is estimated to be $3.1 million. Costs for options for this region range from $1.9 million to $3.2 million over ten years. The costs do not include any allowance for offsets required as part of the capital dredging for the sediment trap.
Economics	No change to economic opportunities for the region other than those associated with the ongoing operation of the PoG.
Methodology	High certainty of the approach being successful as it is based on maintenance dredging and drag barring which have both been found to be effective at managing sedimentation in the LNG Terminal berths.
Innovation	Limited innovation. The approach of a sediment trap to reduce the frequency of sediment management activities has been commonly adopted both in Australia and overseas.
Longevity	Although the approach can be considered long-term (i.e. it can be adopted to help manage sedimentation for > 10 years), it only provides a possible alternative solution to the occasional maintenance dredging required between the annual campaigns.

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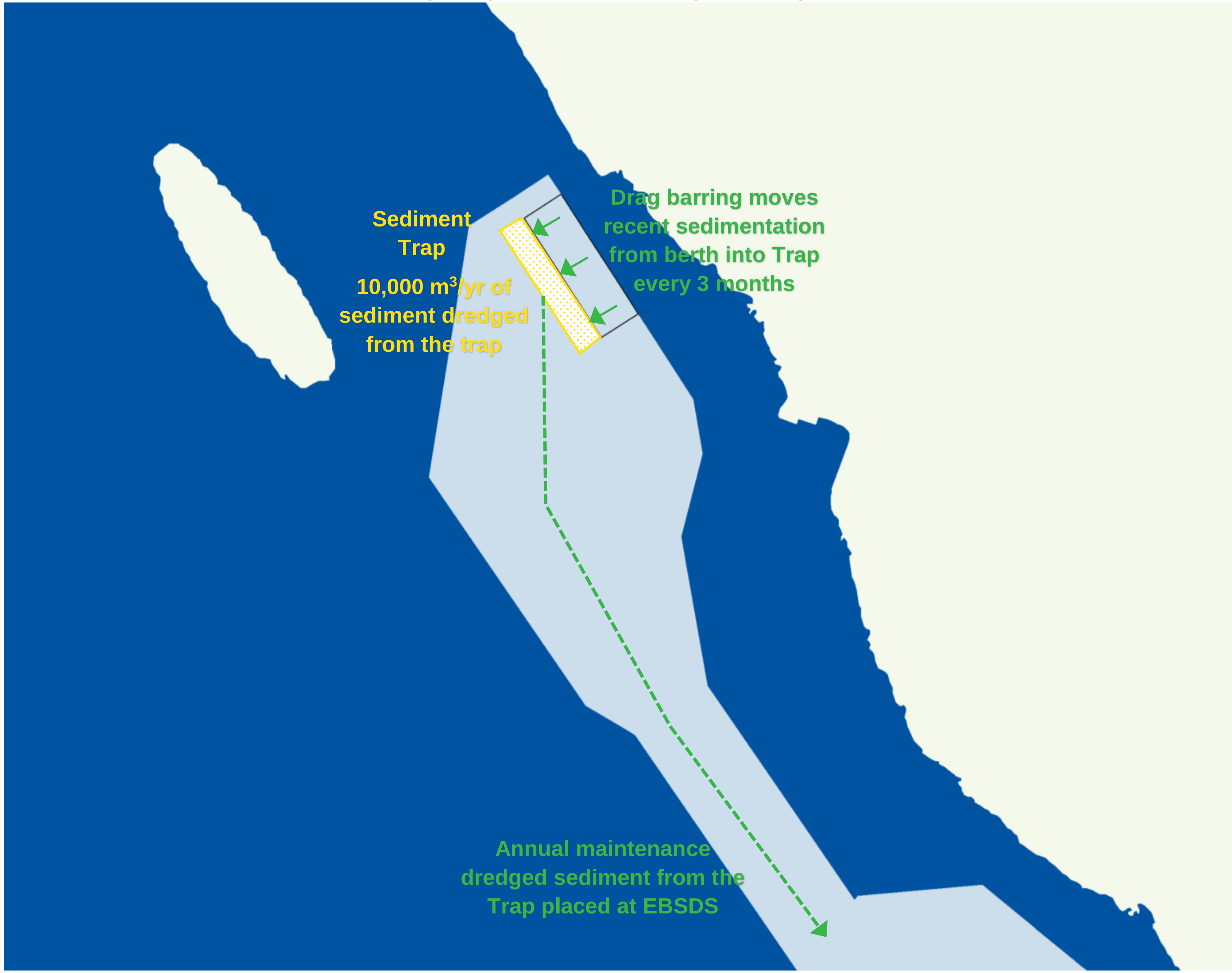

SUSTAINABLE SEDIMENT MANAGEMENT PROJECT

REDUCE DREGING OPTION 11: Berths – Jet Array

The sedimentation above design depths which requires management in the berths of the PoG is highly variable between the berths. The highest rates of sedimentation occur in the berths in the LNG Terminal region, with an average sedimentation rate of 10,000 m^3/yr.

This approach assumes that three turbo scouring unit propellers are installed on the APLNG wharf to limit ongoing sedimentation within the berth resulting in no ongoing maintenance dredging requirement. However, due to the configuration of the berth there is the potential that some sedimentation could occur in the corners of the berth. To manage this, two days of drag barring has been included each year. The approach should negate the requirement for any maintenance dredging in the berth, thereby reducing the annual maintenance dredging duration by two days and reducing the volume placed at EBSDS by 10,000 m^3/yr if the jet array is adopted at a single berth (e.g. just the APLNG berth). The Objectives Assessment for this approach is detailed in the table below, and a schematic representation is shown overleaf.

ASPECT	SUMMARY
Environment	As the approach would regularly resuspend recently deposited sediment (every 12 hours around the time of peak flood/ebb currents), the approach would be replicating the natural environment. Any increase in turbidity will be small and localised. As such, the approach is not expected to influence the biodiversity, coastal habitats or morphology in the region, except for the dredged areas of the PoG.
Resource use	The main resource use will be electricity for the pump powering the jet array. The associated GHG emissions are estimated to be 1,970 t CO_{2e} over 10 years. This could be reduced if renewable or low emission sources of energy are available.
Legislative requirement	A Tidal Works permit would be required and the application for this would need to be submitted by the owners of the seabed lease (i.e. the LNG Company rather than GPC). DES would be the referral agency and based on recent applications it is likely that they will want to understand potential impacts to water quality and mega fauna.
Health & Safety	Increased health and safety risk due to additional wharf based infrastructure which will require ongoing maintenance. There would be a reduced maritime safety risk of the vessel grounding in the berth due to sedimentation.
Cultural	No change to cultural or historic sites and values in the PoG.
Social	No change to social activities and opportunities in the PoG.
Port operations	Potential to enhance Port operations as no requirement for annual maintenance dredging in the berth.
Cost	Cost over ten years is estimated to be $3.2 million, with $2.3 million of this being the initial capital cost. Costs for options for this region range from $1.9 million to $3.2 million over ten years. It is expected that after ten years major maintenance would be required which could be in the region 50% of the initial capital costs.
Economics	There could be a potential economic benefit through the ongoing maintenance of the jet array for a local company.
Methodology	Moderate to high certainty of the approach being successful as it has been successfully adopted at other Ports globally, although it has not been adopted in Australia.
Innovation	The approach is considered innovative as it replicates the natural environment (causing increased resuspension during periods of increased tidal current speed) and has not been adopted in Australia.
Longevity	The approach can be considered a long-term solution to manage the majority of sedimentation in the berth (some drag barring is also likely to be required in the corners of the berth). The approach would reduce the annual sedimentation and therefore the volume of sediment placed at EBSDS by 10,000 m^3/yr and this would result in a reduction in the dredge duration by two days.

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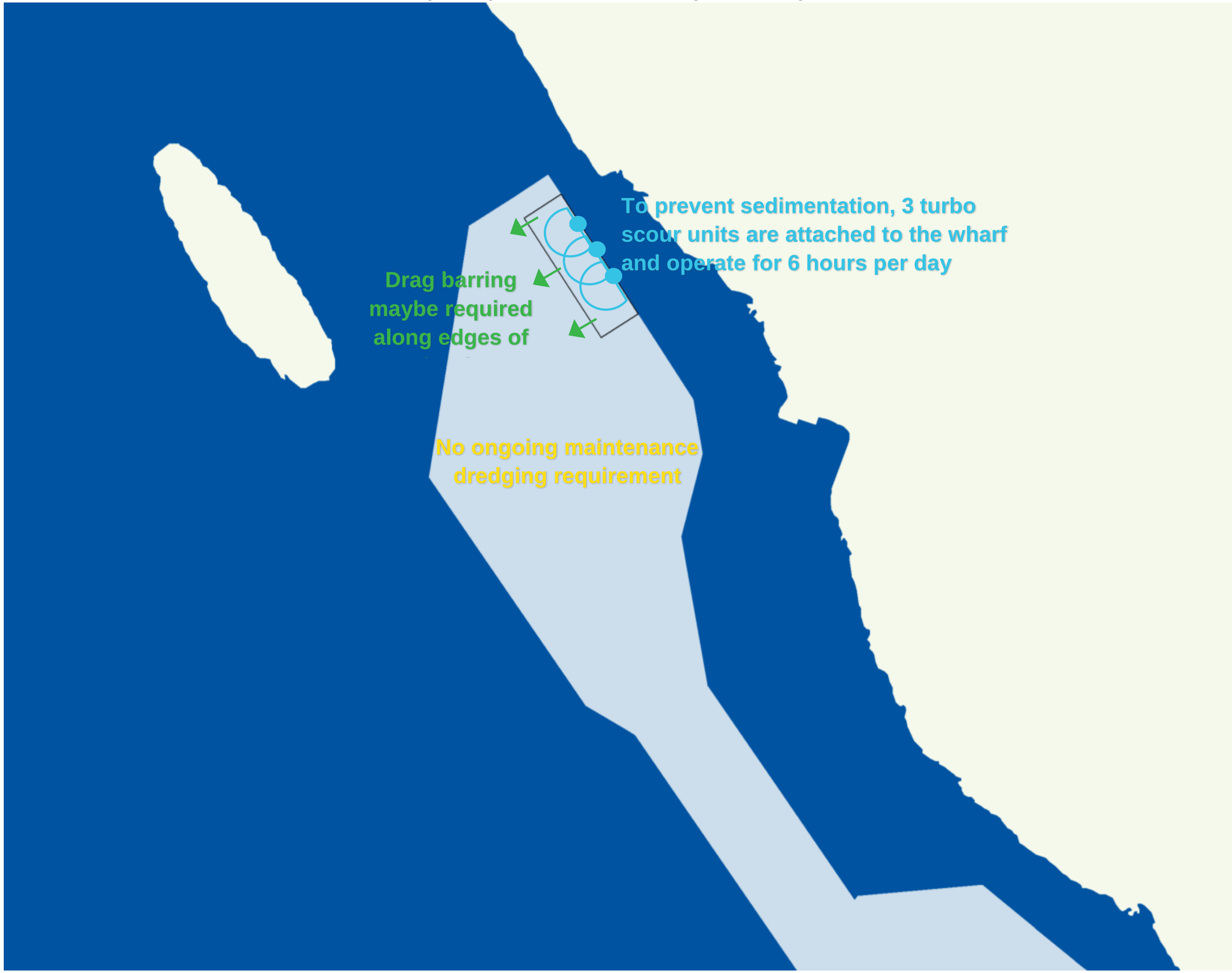

SUSTAINABLE SEDIMENT MANAGEMENT PROJECT

REDUCE DREGING OPTION 12: Berths – Nautical Depth Navigation \ Drag Barring

The sedimentation above design depths which requires management in the berths of the PoG is highly variable between the berths. The highest rates of sedimentation occur in the berths in the LNG Terminal region, with an average sedimentation rate of 10,000 m^3/yr.

This approach assumes that any sedimentation which occurs above the declared depth in the berth can be managed by quarterly drag barring and that any sediment which remains after the drag barring or is deposited between the quarterly campaigns can be considered to be fluid mud and therefore would be navigable. The approach assumes 8 days of drag barring per year, with maintenance dredging of 10,000 m^3 required every third year to prevent an ongoing build-up of sediment in the region. It is important to note that this approach would need to be combined with a suitable sediment management approach for the adjacent apron area (e.g. drag barring) to prevent a build-up of sediment in the apron directly adjacent to the berth. Due to the potential navigational risk of the approach it has been assumed that quarterly hydrographic surveys would be required, we have assumed that each survey would take one day to complete (i.e. an additional three more days of surveying is required). The approach reduces the volume of maintenance dredging and the volume placed at EBSDS by 20,000 m^3 every three years. The Objectives Assessment for this approach is detailed in the table below, and a schematic representation is shown overleaf.

ASPECT	SUMMARY
Environment	Based on previous monitoring during maintenance dredging by the TSHD Brisbane, the dredging activity and placement of the sediment at the EBSDS only results in short duration, localised impacts in turbidity. In addition, the quarterly drag barring is only expected to result in very localised increases in turbidity. As a result, the approach is not expected to influence the biodiversity, coastal habitats or morphology in the region, except for the dredged areas of the PoG and the EBSDS.
Resource use	The main resource use will be diesel fuel for the Pacific Conquest and the TSHD Brisbane. The associated GHG emissions are estimated to be 1,270 t CO_{2e} over 10 years.
Legislative requirement	Standard approval required for maintenance dredging under the *Environment Protection (Sea Dumping) Act 1981* and the Queensland *Environment Protection Act 1994*, this is a well known process which GPC have experience with. Additional approval would be required by the Regional Harbour Master to change the echo-sound frequency that is assumed to represent the seabed in the berths (it is currently specified as 200 kHz in Queensland (MSQ, 2009)).
Health & Safety	There is a risk to the safety of vessels resulting from the nautical depth navigation approach. Therefore, this approach has the potential to reduce the maritime safety in the PoG.
Cultural	No change to cultural or historic sites and values in the PoG.
Social	No change to social activities and opportunities in the PoG.
Port operations	Will maintain Port operations as activities can be undertaken to fit in around the Port operations.
Cost	Cost over ten years is estimated to be $2.1million. Costs for options for this region range from $1.9million to $3.2 million over ten years.
Economics	No change to economic opportunities for the region other than those associated with the ongoing operation of the PoG.
Methodology	Moderate certainty of the approach being successful, but some uncertainty due to possibility that sediment remaining after drag barring is too dense to allow the nautical depth approach.
Innovation	The approach is considered to be innovative as it is not widely adopted in Australia.
Longevity	Although the approach can be considered long-term (i.e. it can be adopted to help manage sedimentation for > 10 years), it is expected that some maintenance dredging will continue to be required.

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Appendix B – GHG Emission Calculations

B 1 GHG Assessment Approach

The aim of this Greenhouse Gas (GHG) emissions assessment is to estimate GHG emissions, to allow a comparative assessment between ongoing maintenance dredging and alternative sediment management approaches proposed for the PoG to be undertaken. The assessment has been undertaken in accordance with the internationally recognised methodology outlined in the GHG Protocol[12]. 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 approaches, 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 approaches; 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 approaches. 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 has considered Scope 1 and Scope 2 emissions from maintenance dredging and alternative sediment management approaches. The calculations have been undertaken assuming that they have been adopted to manage sedimentation over a 10 year period.

B 1.1 Approaches

Based on an initial feasibility assessment which considered the natural sedimentation processes, seven alternative approaches to ongoing maintenance dredging were identified as being realistic and so were taken forward to the Objectives Assessment. The approaches have been separated by the region of the PoG where they could be adopted to allow a direct comparison to maintenance dredging for just that area. In cases where the approach only relates to a portion of a larger campaign, (e.g. the maintenance dredging only relates to the dredging of a region of the PoG and not dredging to entire PoG), the GHG emissions for the mobilisation and demobilisation of any vessels have not been included.

A summary of the relevant assumptions adopted for each approach is provided in the following sections. Further details of the approaches are provided in Sections 3.5.1 to 3.5.5 in the main report.

B 1.1.1 LNG Terminals - Maintenance Dredging

It has been assumed that the trailing suction hopper dredger (TSHD) *Brisbane* would be used to undertake the maintenance dredging in the LNG Terminals region of the PoG. It has been assumed that the dredger would be working for 15 days every year to relocate sediment from the LNG Terminals aprons to EBSDS and that the Pacific Conquest would also be undertaking 15 days of bed levelling every year. An average downtime for the vessels of 10% has been assumed. During this maintenance dredging campaign, the following assumptions were made:

- 20% of the time the vessel is dredging, 80% of the time the vessel is transiting between the LNG Terminals region and EBSDS;

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

- during cruising periods the TSHD *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.

B 1.1.2 LNG Terminals – Channel Realignment

For the capital dredging it has been assumed that a medium cutter suction dredger (CSD) will be used and the sediment will be pumped directly from the dredger into the Western Basin Reclamation Area. It has been assumed that the dredge duration would be approximately 17 weeks and that over this period the dredger would be operating for 70% of the time. For the ongoing annual maintenance dredging (assumed to be 80% of the existing sedimentation rate) it has been assumed that the dredger would be working for 12 days every year to relocate sediment from the LNG Terminals aprons to EBSDS and that the Pacific Conquest would also be undertaking 12 days of bed levelling every year. An average downtime for the vessels of 10% has been assumed. The same assumptions regarding the TSHD *Brisbane* as detailed in Section B 1.1.1 were adopted.

B 1.1.3 LNG Terminals – Sustainable Relocation

To manage the half of the annual maintenance dredging requirement at the LNG Terminals aprons, four days of sustainable relocation to a site approximately 4 km away has been assumed using the TSHD *Brisbane.* The other half of the annual maintenance dredging required has been assumed to be managed by the TSHD *Brisbane* and placed at the EBSDS (approximately 40 km from the region), requiring seven and a half days of dredging activity. A total of 15 days of bed levelling by the Pacific Conquest has also been assumed to be required as part of the approach. An average downtime for the vessels of 10% has been assumed. The same assumptions regarding the TSHD *Brisbane* as detailed in Section B 1.1.1 were adopted.

B 1.1.4 Marina – Maintenance Dredging (short-term)

A small cutter suction dredger (CSD) has been assumed to undertake the maintenance dredging in the PoG Marina. It has been assumed that the dredger would be working for 40 days every five years to relocate sediment from the Marina to the EBSDS. An average downtime for the vessels of 10% has been assumed. During the maintenance dredging campaign, the following assumptions were made:

- for all operational time the dredger is dredging and pumping sediment to the on land placement site; and
- during dredging the dredge pumps are operating at full capacity.

B 1.1.5 Marina – Maintenance Dredging (long-term)

A small trailing suction hopper dredger (TSHD) has been assumed to undertake the maintenance dredging in the PoG Marina. It has been assumed that the dredger would be working for 125 days every five years to relocate sediment from the Marina to EBSDS and that the Pacific Conquest would also be undertaking five days of bed levelling/drag barring during each dredging campaign. An average downtime for the vessels of 10% has been assumed. During the maintenance dredging campaign, the following assumptions were made:

- 25% of the time the vessel is dredging, 75% of the time the vessel is transiting between the Marina and the EBSDS;
- during cruising periods the dredger 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.

B 1.1.6 Marina – Sustainable Relocation

For the sustainable relocation approach at the PoG Marina, it has been assumed that a small remotely operated dredge vessel (RODV) would undertake the dredging and would pump the sediment directly to a sustainable relocation area on the edge of the Clinton Channel. The dredging has been estimated to take 640 hours using the small RODV and an additional 12 days of drag barring using the Pacific Conquest has been included. The small RODV and the pump would be powered by a diesel fuel generator.

B 1.1.7 Outer Harbour Cuttings – Maintenance Dredging

It has been assumed that the TSHD *Brisbane* would be used to undertake the maintenance dredging in the Outer Harbour Cuttings of the PoG. It has been assumed that the dredger would be working for 3.5 days every year to relocate sediment from the Outer Harbour Cuttings to the EBSDS and that the Pacific Conquest would also be undertaking one day of bed levelling every year. An average downtime for the vessels of 10% has been assumed. During this maintenance dredging campaign, the following assumptions were made:

- 45% of the time the vessel is dredging, 55% of the time the vessel is transiting between the LNG Terminals region and the EBSDS;
- during cruising periods 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.

B 1.1.8 Outer Harbour Cuttings – Minimum Channel Width Navigation

It has been assumed that the frequency and volume of maintenance dredging could be reduced by adopting a minimum channel width navigation approach. It has been assumed that the TSHD *Brisbane* would be used to undertake the maintenance dredging and that the dredger would be working for 12.5 days every five years to relocate sediment from the Outer Harbour Cuttings to the EBSDS. In addition, it has been assumed that the Pacific Conquest would be undertaking forty days of drag barring every year (reducing to four days for the years when maintenance dredging is undertaken) to ensure the central 110 m of the channels remain at or below the declared depth. An average downtime for the vessels of 10% has been assumed. The same assumptions regarding the TSHD *Brisbane* as detailed in Section B 1.1.7 were adopted.

B 1.1.9 Berths – Maintenance Dredging

For the assessment of sedimentation in the berths, the APLNG berth located in the LNG Terminals region has been adopted as an example case as it represents the berth with the highest sedimentation rates in the PoG. It has been assumed that the TSHD *Brisbane* would be used to undertake the maintenance dredging in the berths of the PoG. It has been assumed that the dredger would be working for just under two days every year to relocate sediment from the APLNG berth to the EBSDS and that the Pacific Conquest would also be undertaking two days of bed levelling during the maintenance dredging every year. An average downtime for the vessels of 10% has been assumed. During this maintenance dredging campaign, the following assumptions were made:

- 20% of the time the vessel is dredging, 80% of the time the vessel is transiting between the LNG Terminals region and the EBSDS;
- during cruising periods 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.

B 1.1.10 Berths – Sediment Trap

For both the establishment dredging and ongoing maintenance dredging required for the sediment trap option, it has been assumed that the TSHD *Brisbane* would be used. It has been assumed that one and a half days of establishment dredging would be required to create the sediment trap and that the sediment from it would be pumped into the Western Basin Reclamation. To move sediment from the berth to the sediment trap 10 days of drag barring by the Pacific Conquest has been assumed each year, as well as two days of bed levelling following the annual maintenance dredging. It has been assumed that the annual maintenance dredging will be undertaken by the TSHD *Brisbane* and the sediment would be placed at the EBSDS. The same assumptions regarding the TSHD *Brisbane* dredging as detailed in Section B 1.1.8 were adopted.

B 1.1.11 Berths – Jet Array

A series of three turbo scouring propellers would be installed on the APLNG wharf to create high bed currents to resuspend any recently deposited bed sediment. The propellers would be powered by a single hydraulic pump which has been assumed o use purchased electricity with a predicted consumption of 600 kWh per day. This is based on the operation of the system for three hours per tide, and two tides per day.

B 1.1.12 Berths – Nautical Depth Navigation

This approach assumes that eight days of drag barring would be undertaken by the Pacific Conquest each year. In addition, every third year the TSHD *Brisbane* would undertake maintenance dredging of just under two days with the sediment placed at EBSDS. The same assumptions regarding the TSHD *Brisbane* as detailed in Section B 1.1.9 were adopted.

B 1.2 Assumptions

The following assumptions were used in 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 PoG, 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 each marine vessel it was assumed that one generator with a total power of 800 kW for the TSHD *Brisbane*, 180 kW for the Pacific Conquest and 240 kW for the small TSHD which was operated at full capacity to supply power for the onboard facilities; and
- GHG emissions were calculated over a 10 year operating period for each approach in the GHG assessment. It was assumed that the same equipment, available today, is used with no technology improvements.

B 1.3 Emission Factors and Calculations

B 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*'.[13] 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 were determined from Equation 1:

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

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

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 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 approach.

The marine vessel parameters and emission factors utilised to calculate GHG emissions are detailed in Table B1**.**

Table B1: Marine Vessel Emission Parameters & Factors Utilised in the GHG Assessment.

Details	Marine Vessel	Engine Power (kW)	Dredge/ Water Pumps (kW)	Generator (kW)	CO_2 + CH_4 + N_2O Emission Factor[1] (g/kWh)
Maintenance Dredging	TSHD *Brisbane*	3,700	2,120	800	690.1
Drag Barring / Bed Levelling	*Pacific Conquest*	672	0	180	690.1
Marina short-term Maintenance Dredging	Small CSD	0	1400	180	690.1
Marina long-term Maintenance Dredging	Small TSHD	3,600	875	240	690.1
Capital Dredging for Channel Realignment	Medium CSD	0	7,426	240	690.1

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

B 1.3.2 Scope 2 GHG Emissions Calculations

Indirect GHG emissions from the consumption of purchased electricity to power the jet array system for the berth approach were calculated using EFs from the Department of the Environment[14]. The Australian National Greenhouse Accounts provides a list of EFs for the consumption of electricity applicable for each state in Australia. As the PoG does not control the energy provider for the LNG Terminals, the most representative EF used in the assessment was an average figure for purchased electricity in Queensland, which in 2015 was 0.79 kg CO_2e/kWh.

GHG emissions from the embodied GHGs during construction of the jet array system were not included in the assessment as construction activities and materials were not available at the time of assessment.

[14] Australia Government, Department of the Environment, Australian National Greenhouse Accounts, 2015

B 2 Results

The predicted comparative GHG emissions associated with each approach over a representative 10-year period are detailed in Table B2. As expected the results show that the predicted GHG emissions vary significantly between the different regions of the PoG due to the variation in the sediment management requirement (i.e. approximately 150,000 m^3/yr of sediment requires management in the LNG Terminals aprons, while only 40,000 m^3/yr requires management in the Outer Harbour Cuttings).

The results show that in some regions maintenance dredging would produce a lower quantity of GHG emissions over the 10 years compared to the alternative approaches (Marina and Outer Harbour Cuttings), while at other regions some of the alternative approaches are predicted to result in lower GHG emissions. The only Scope 2 emissions are from the Jet Array approach due to the assumption that the hydraulic pump powering the propellers will be powered using purchased electricity. If the pump could be powered using a renewable or low GHG emission form of energy, then the GHG emissions for the Jet Array approach could be significantly reduced and potentially the lowest out of the approaches considered for the berths.

Table B2. Predicted GHG emissions from the sediment management approaches considered.

Approach	Scope 1 CO_2e Emissions over 10 Years (Tonnes)	Scope 2 CO_2e Emissions over 10 Years (Tonnes)
LNG Terminals		
Maintenance Dredging	*10,210*	
Channel Realignment	23,540	
Sustainable Relocation	8,200	
Marina		
Maintenance Dredging (Short-term)	*1,290*	
Maintenance Dredging (Long-term)	*5,360*	
Sustainable Relocation	2,240	
Outer Harbour Cuttings		
Maintenance Dredging	*1,970*	
Minimum Channel Width	5,250	
Berths		
Maintenance Dredging	*1,210*	
Sediment Trap	2,860	
Jet Array	240	1,730
Nautical Depth	1,270	

Appendix C – Cost Estimates

C 1 Cost Estimation Approach

The aim of this assessment is to estimate costs associated with a range of sediment management approaches (detailed in Sections 3.5.1 to 3.5.5 in the main report) to allow a comparative assessment to be undertaken. The cost estimates have been developed based on available information, calculations of dredge durations, estimations of the bed levelling/drag barring requirements (assuming an average rate of 1,000 m^3/day) and a range of additional assumptions which are detailed in the following section.

C 1.1 Assumptions

To calculate high level comparative cost estimates, the following assumptions were made:

- the daily cost for the TSHD *Brisbane* (including hydrographic survey, monitoring and other GPC costs) is $100,000;
- costs for a small TSHD (hopper capacity of 500 to 1,000 m^3) will be in the order of \$50/m^3. This estimate was provided by GPC based on quotes received for previous dredging campaigns;
- the daily cost for the *Pacific Conquest* is $10,000. An increased daily rate of $15,000 has been assumed for the drag barring for the berth nautical depth / drag barring approach as a larger drag bar (20 m width) would be required;
- the daily cost for the Maritime Safety Queensland hydrographic survey vessel is $12,500. The cost for hydrographic survey has only been included for approaches which require additional survey without maintenance dredging;
- the cost to undertake maintenance dredging of the Marina every five years using a small CSD and pumping to the adjacent on land placement site is $2 million, plus an additional $1 million for the on land works. This estimate is provided by GPC based on costs for previous similar campaigns;
- the cost to purchase a small remotely operated dredge vessel (RODV), pump and generator is $450,000. This was based on costs provided by Fitt Resources;
- to manage and operate the small RODV an allowance of $150,000/yr was included for GPC personnel;
- the costs to undertake capital dredging of 3,000,000 m^3 using a medium CSD and pumping into the Western Basin Reclamation Area, including environmental monitoring and the landside operations is in the order of $100 million. This estimate was provided by GPC based on experience from previous capital dredging undertaken as part of the Western Basin Dredging and Disposal Project; and
- costs for the jet array approach (both capital and ongoing operation and maintenance) have been based on the costs detailed by Bryant (2007)[15] and scaled according to the requirements of this project.

C 1.2 Results

Based on the assumptions detailed in the previous section, along with the dredging and bed levelling/drag barring durations detailed in Appendix B, comparative cost estimates were calculated for maintenance dredging and the seven alternative approaches. The cost estimates are detailed in Table C1.

The results show that the estimated costs of the different approaches for each area are typically within ±50% of each other. The only exceptions to this are the long-term maintenance dredging approach for the Marina and the channel realignment approach for the LNG Terminals. The long-term maintenance dredging approach for the Marina is the only

[15] Bryant, J.T., 2007. A potential alternative to berth maintenance dredging. Ports 2007, American Society of Civil Engineers.

approach which considers transporting the sediment to the EBSDS which, combined with the fact the dredging cannot be undertaken by the TSHD *Brisbane* due to insufficient depths[16], results in a significant increase in the cost of the approach. The channel realignment approach for the LNG Terminals is predicted to cost almost $100,000,000 more than the costs for the other approaches to manage sedimentation in the region due to the capital dredging required. Based on this, it is likely that this approach will be unfeasible due to the costs.

Table C1. Cost estimation for the sediment management approaches considered for the PoG.

Approach	Capital Costs	Operation and Maintenance Costs (over 10 years)	Total Costs (over 10 years)
LNG Terminals			
Maintenance Dredging	-	*$16,475,000*	***$16,475,000***
Channel Realignment	$100,000,000	$13,180,000	**$113,180,000**
Sustainable Relocation	-	$12,990,000	**$12,990,000**
Marina			
Maintenance Dredging (Short-term)	-	*$6,000,000*	***$6,000,000***
Maintenance Dredging (Long-term)	-	*$20,100,000*	***$20,100,000***
Sustainable Relocation	$450,000	$3,600,000	**$4,050,000**
Outer Harbour Cuttings			
Maintenance Dredging	-	*$3,470,000*	***$3,470,000***
Minimum Channel Width	-	$6,255,000	**$6,255,000**
Berths			
Maintenance Dredging	-	*$1,930,000*	***$1,930,000***
Sediment Trap	$135,000	$2,930,000	**$3,065,000**
Jet Array	$2,340,000	$890,000	**$3,230,000**
Nautical Depth	-	$2,095,000	**$2,095,000**

[16] due to the combined dredging of the Queensland Ports and the existing contract that GPC have in place with the Port of Brisbane Pty Ltd the rate for the TSHD *Brisbane* is lower than for other TSHD.