APPENDIX H

Assessment for navigational maintenance

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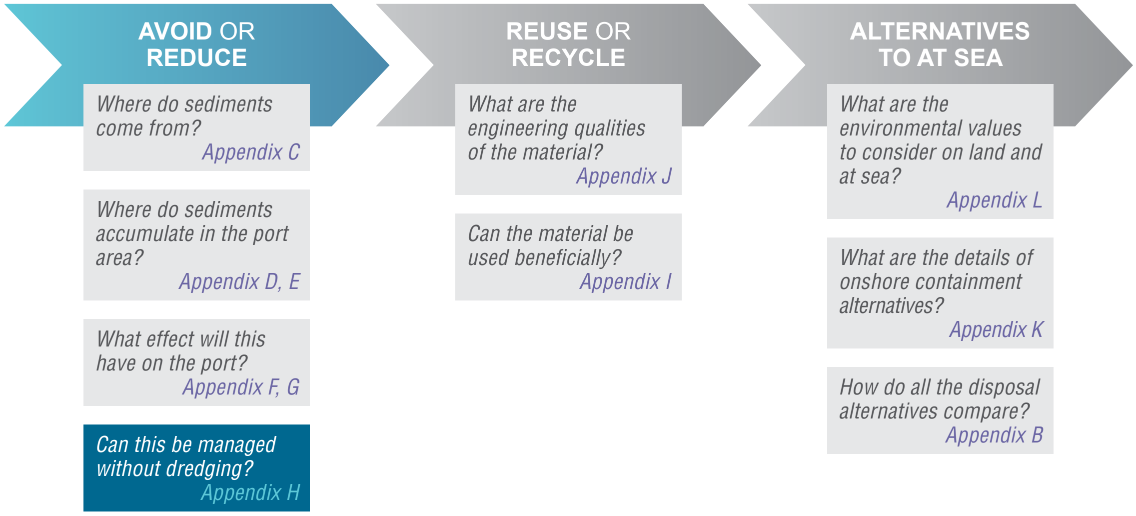
SYNOPSIS

Independent technical specialist
Royal Haskoning DHV
19 August 2016

Hay Point sustainable sediment management assessment approach



Purpose of study:

To identify realistic and feasible alternatives to traditional maintenance dredging and disposal at the Port of Hay Point.

Broad study approach:

Building on an understanding of the sediment and hydrodynamic environment at the Port of Hay Point, a range of feasible engineered and technological solutions to managing and reducing siltation at the Port of Hay Point – in the context of the three scenarios i) Keep Sediment Out, ii) Keep Sediment Moving and iii) Keep Sediment Navigable – were identified. These solutions were then analysed against key environmental, operational and engineering constraints in order that a preferred option/s could be identified.

Methodology:

An initial understanding of site conditions and existing maintenance dredging requirements and methods was established (refer Appendices C, D, E and L).

A range of siltation management and reduction solutions were then considered using both PIANC and US Army Corps of Engineers guidance for best practice approaches to minimising harbour and channel siltation (noting both recommend assessing applicability on a case-by-case basis as suitability is dependent upon port configuration, sediment type, natural environment and processes).

Solutions were considered against 3 broad strategies:

1. **Keep Sediment Out**
   - Stabilise sediment sources
   - Divert sediment-laden flows
   - Trapping sediment before it enters the port
   - Blocking sediment entry using silt curtains, sills, entrance closure
   - Habitat creation

2. Keep Sediment Moving

- Training walls
- Breakwaters
- Dikes and sills
- Current deflector walls
- Hydraulic jets
- Propeller wash
- Vortex foil arrays
- Mechanical agitators

3. Keep Sediment Navigable

- Passive nautical depth

A feasibility and comparative assessment of solutions was then undertaken using a range of performance measures including environmental, operational, ongoing maintenance, confidence, legal, cost and GHG emissions criteria.

Key findings:

Of all the options assessed, only five were found to significantly alter siltation patterns at the port and provide a level of certainty around ongoing effectiveness. These included traditional maintenance dredging, constructed sediment trap, jet array system, drag barring and propeller wash agitation.

In terms of how these solutions compare, a summary table is provided below:

	Environmental effects	Operational effects	Maintenance needs	Confidence of effectiveness	Regulatory requirements	Costs (20yrs)	GHG (20yrs)
Traditional Maintenance Dredging	Low	Low	No	High	Yes	$4.9M	6,369
Constructed Sediment Trap	Medium	Low	Low	Medium	Yes	$6.6M	8,860
Jet Array System	Low	Low	High	Low	Yes	$70.9M	242,214
Drag Barring	Medium	Medium	No	High	No	$6.8M	21,454
Propeller Wash Agitation	Medium	Low	No	Low / Medium	No	$13.2M	23,640

More specifically, key findings regarding the above options indicated:

- Maintenance dredging provides the most cost effective and lowest GHG emissions solution, with low environmental and operational effects and high effectiveness.
- Deepening the north apron to act as a sediment trap is possible and would reduce maintenance dredging volumes in the short-term. However this option requires additional capital dredging and over the long-term (20 years) will actually increase the maintenance dredging requirements at the Port by 160,000m^3.
- The jet array solution is not considered feasible as it results in the highest emissions, ongoing maintenance needs and costs. Furthermore, there is low confidence that it would be effective at reducing siltation.
- Drag barring in berths is feasible and will reduce ongoing siltation, but not completely eliminate it. Although more expensive and generates greater GHG emissions, used in conjunction with traditional maintenance dredging, this option is expected to reduce ongoing maintenance dredging requirements considerably.
- The propeller wash agitation solution using a tug vessel is not considered feasible due to its relatively high cost and GHG emissions and only low to medium effectiveness.

REPORT

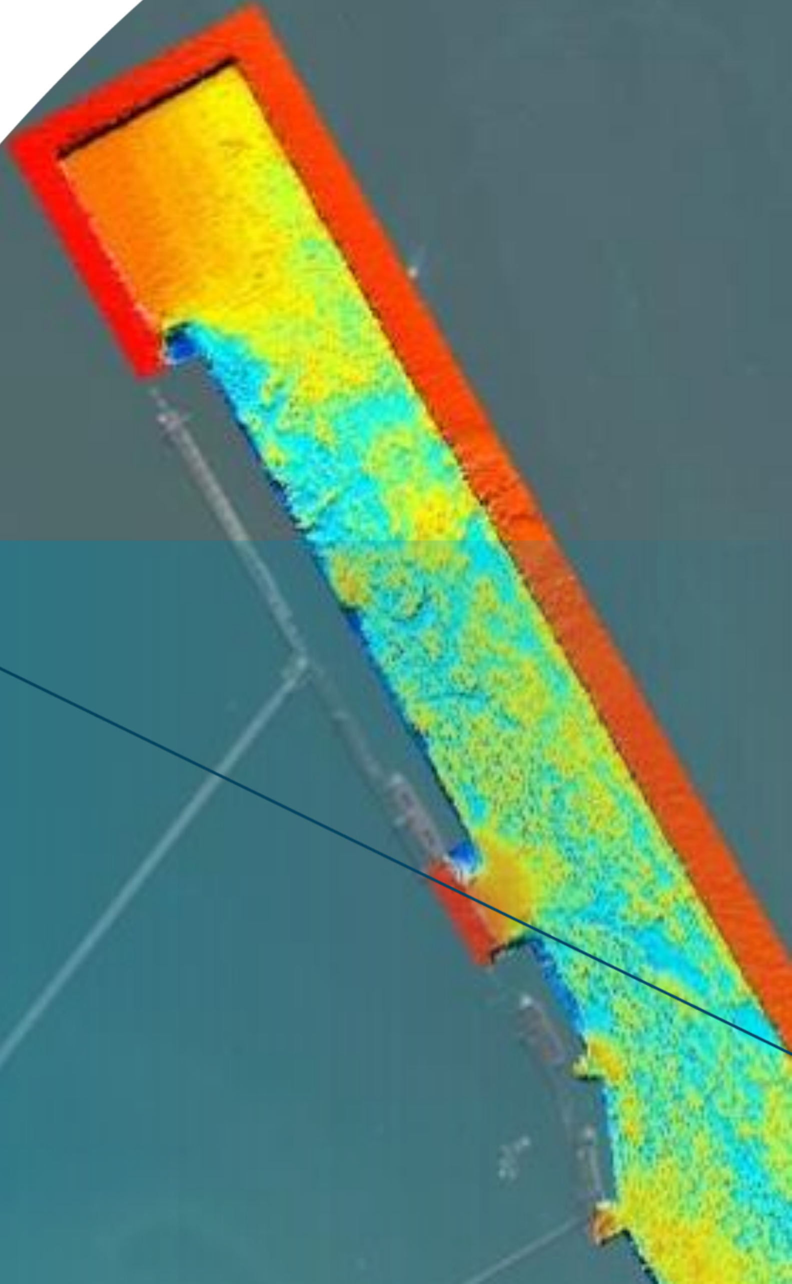
Port of Hay Point - Assessment for Navigational Maintenance

Client: North Queensland Bulk Ports Corporation

Reference: M&APA1163R001F01

Revision: 01/Final

Date: 19 August 2016



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Document title:	Port of Hay Point - Assessment for Navigational Maintenance
Document short title:	Hay Point Navigational Maintenance
Reference:	M&APA1163R001F01
Revision:	01/Final
Date:	19 August 2016
Project name:	Hay Point Navigational Maintenance
Project number:	PA1163
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Date / initials:	18/08/2016 DM
Approved by:	Dan Messiter
Date / initials:	18/08/2019 DM

Classification
Project related

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Executive Summary

North Queensland Bulk Ports Corporation (NQBP) commissioned Royal HaskoningDHV (RHDHV) to undertake an investigation into possible solutions to avoid or minimise future need for maintenance dredging at the Port of Hay Point. This study forms part of a larger investigation being undertaken by NQBP which focuses on the sustainable sediment management at the port.

This report addresses the following aims:

1. to describe the sediment and hydrodynamic environment at the Port of Hay Point in the context of possible solutions to 'keep sediment out' or 'keep sediment moving' from the Port infrastructure areas;
2. to identify both engineered and technological solutions to avoid or minimise future maintenance dredging and consider their feasibility based on the Hay Point environment, port layout and infrastructure design;
3. to undertake a constraints analysis of the solutions, including cost and greenhouse gas emission estimates for any feasible options; and,
4. to estimate the potential impact of any feasible solutions to existing and future maintenance dredging at the Port of Hay Point.

Based on recent sediment sampling undertaken by Advisian (2016) as part of the Sustainable Sediment Management Project the surficial sediment in the DBCT berths and North Apron areas where regular ongoing siltation have been identified are predominantly mud (based on Folk (1954)), with less than 10% sand. In adjacent areas of the apron the sediment was found to be sandy mud with approximately equal amounts of clay, silt and sand. These results suggest that deposition within the North Apron and DBCT berths occurs due to suspended sediment being transported due to natural background conditions, erosion from the berths by drag barring and erosion from propeller wash in the berths and apron. Due to the high trapping efficiency of the berths, resulting from their depth relative to the adjacent bed elevations, these areas are able to trap more fine grained silts and clays than the apron.

The potential applicability of approaches to reduce siltation must be considered on a case by case basis as the suitability is dependent on the port configuration, sediment type, natural environment and processes. Three broad strategies that can be implemented to reduce siltation at ports and harbours were identified:

- **Keep Sediment Out** – keeping sediment out of the area of interest that might otherwise enter and deposit;
- **Keep Sediment Moving** – raising flow velocities in quiescent areas to prevent sediment from settling as it passes through the area of interest; 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.

Based on an initial feasibility assessment considering the site specific conditions at the Port of Hay Point, the following siltation reduction approaches were identified as potentially feasible:

- Sediment trap; and

- Increasing bed shear stresses (including fixed position jet arrays, drag barring and propeller wash agitation).

These approaches were considered in terms of the existing maintenance dredging requirement and it was found that maintenance dredging is the only feasible solution. The possible solutions which could be adopted to manage future siltation along with ongoing maintenance dredging were compared based on constraints, costs and greenhouse gas emissions. Based on the findings of the comparative assessment, the following conclusions can be made as to the future maintenance dredging requirements at the Port of Hay Point:

- maintenance dredging provides the most cost effective and lowest GHG emission solution, although there are cost and risk implications with the approval requirements. The maintenance dredging required over a 20 year period is estimated to be 1.02 million m^3;

- drag barring in the berths is a feasible solution to prevent an ongoing maintenance requirement in these areas. However, this solution is likely to be more expensive and result in higher GHG emissions than maintenance dredging. This solution would reduce the ongoing maintenance dredging requirement over a 20 year period by 750,000 m^3. As such, the maintenance dredging required over a 20 year period is estimated to be 265,000 m^3;

- the study has demonstrated that propeller wash agitation by tugs is not a feasible solution for managing the siltation in the North Apron. However, it is recommended that this approach be further investigated through the port operational procedures to promote some tugs and bulk carriers transiting the North Apron. Following an optimisation study to define proposed changes to the port operational procedures a trial period with regular hydrographic survey (e.g. every 3-6 months) could be adopted to determine the long term feasibility of the approach. This approach is also recommended to manage the small ongoing siltation in the departure channel. This port operational procedure approach would have little to no cost or increased GHG emissions;

- it is possible to reduce the frequency of dredging required in the North Apron by deepening this area to act as a sediment trap. The solution reduces the frequency of the required maintenance dredging from every four years to every 10 years. However, it results in an increase in the maintenance dredge volumes of 160,000 m^3 over a 20 year period due to the initial establishment dredging required. As such, the maintenance dredging required over a 20 year period is estimated to be 1.18 million m^3;

- excluding the North Apron from the declared depth definition for the remainder of the Apron and Departure Channel is likely to prevent the requirement for future maintenance dredging of this area over a 20 year period and reduce maintenance dredging by 260,000 m^3. As such, the maintenance dredging required over a 20 year period is estimated to be 750,000 m^3. Further investigation is required to assess the actual usage of this area and to discuss the possibility with the Harbour Master to determine if this approach is realistic; and

- combining the drag barring with the exclusion approach or possibly the vessel agitation through operational procedures approach could result in no ongoing maintenance dredging requirement over a 20 year period. However, the assessment has indicated that the drag barring is more expensive and results in higher GHG emissions than the maintenance dredging of all the areas. In addition, there is some uncertainty as to the effectiveness of the vessel agitation through operational procedures approach. A trial period would be required to assess its effectiveness.

1 Introduction

North Queensland Bulk Ports Corporation (NQBP) commissioned Royal HaskoningDHV (RHDHV) to undertake an investigation into possible solutions to avoid or minimise future need for maintenance dredging at the Port of Hay Point. This study forms part of a larger investigation being undertaken by NQBP which focuses on the sustainable sediment management at the port.

The aims of this investigation are:

1. to describe the sediment and hydrodynamic environment at the Port of Hay Point in the context of possible solutions to 'keep sediment out' or 'keep sediment moving' from the Port infrastructure areas;
2. to identify both engineered and technological solutions to avoid or minimise future maintenance dredging and consider their feasibility based on the Hay Point environment, port layout and infrastructure design;
3. to undertake a constraints analysis of the solutions, including cost and greenhouse gas emission estimates for any feasible options; and,
4. to estimate the potential impact of any feasible solutions to existing and future maintenance dredging at the Port of Hay Point.

1.1 Project Background

In October 2006 NQBP completed the development of a departure channel and apron area for shipping at the Port of Hay Point. The capital works involved dredging sediment from the seabed in the order of 9 million m^3, and included:

- a ship manoeuvring apron area approximately 500 m wide adjacent to the existing berths (labelled Apron in **Figure 1**); and,
- a departure channel from the apron to the sea approximately 9,500 m long. The first 500 m is 500 m wide, after which it tapers to a width of 300 m (labelled Departure Channel in **Figure 1**).

Over the last 10 years there has also been capital dredging for new berths at both the Dalrymple Bay Coal Terminal (DBCT) and Hay Point Coal Terminal (HPCT) facilities (**Table 1** and **Figure 2**) consisting of:

- December 2005: 400,000 m^3 was removed for the DBCT Berth 4; and
- end of 2011: 275,000 m^3 was removed for the HPCT Berth 3.

Maintenance dredging has been undertaken periodically at the Port of Hay Point, with two campaigns since the 2006 capital dredging (**Table 1**). The maintenance volume dredged in 2004 approximately represents the biannual maintenance dredging requirement prior to the capital dredging. Based on historical dredged volumes, the maintenance requirement increased significantly since the capital dredging in 2006, (volumes in 2008 and 2010 were approximately double the volume in 2004).

It is also important to note that these post 2006 maintenance campaigns did not return all areas to the design depth. The 2008 campaign was an opportunistic campaign focused on a specific area, while the 2010 campaign was planned to be a full maintenance campaign to return all areas to their design depths but due to industrial action by the dredge crew the campaign was stopped early and never completed. Since 2012 it has not been possible to undertake maintenance dredging due to a two year delay in the approval of the dredging permit and a subsequent appeal lodged on the approval. Due to the timescales associated with the legal proceedings and the permit durations, the permits were revoked at the request of NQBP in July 2015.

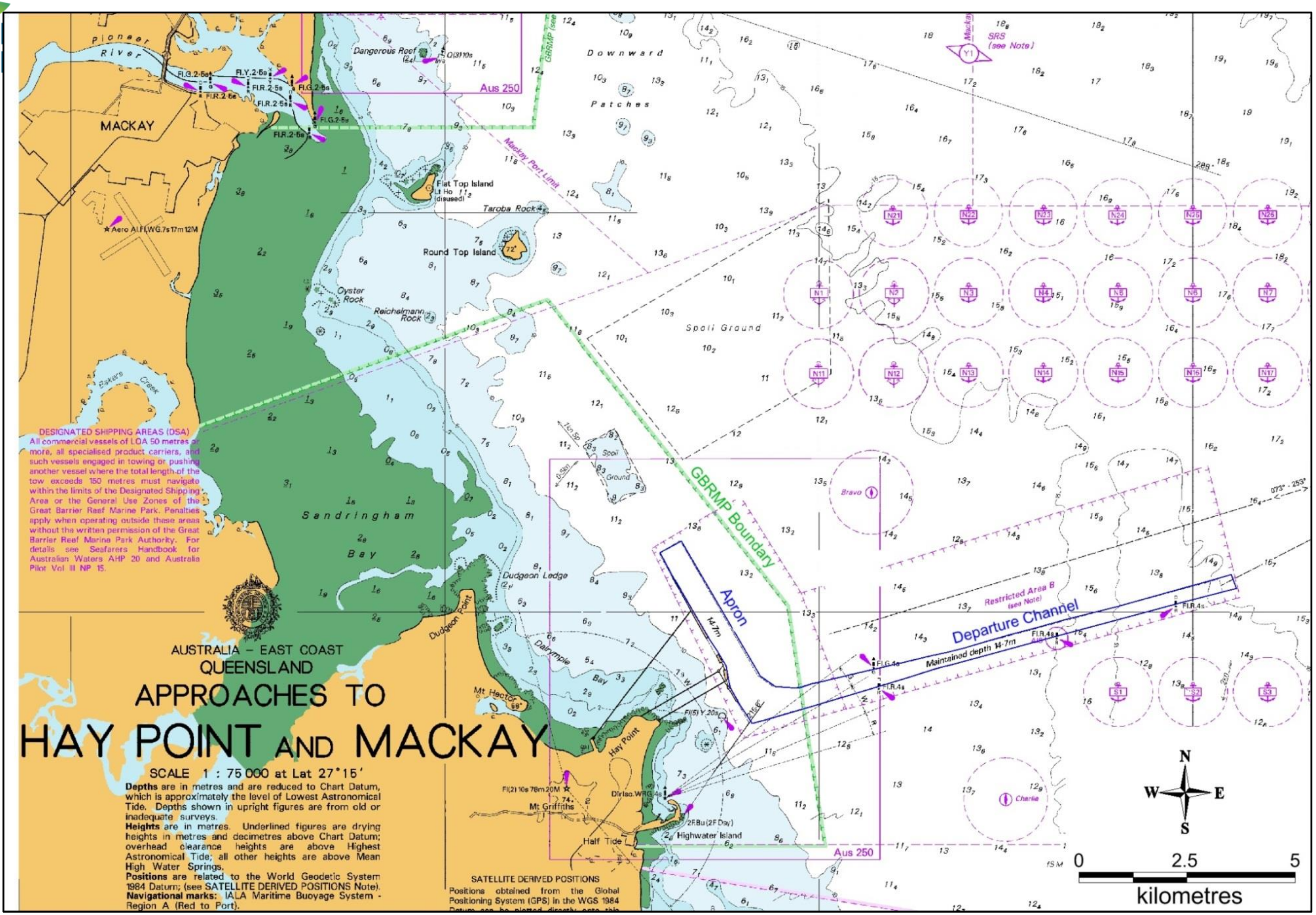

Figure 1: Location of Hay Point Port relative to the GBRMP. Note: the dredged areas are represented by the blue outline.

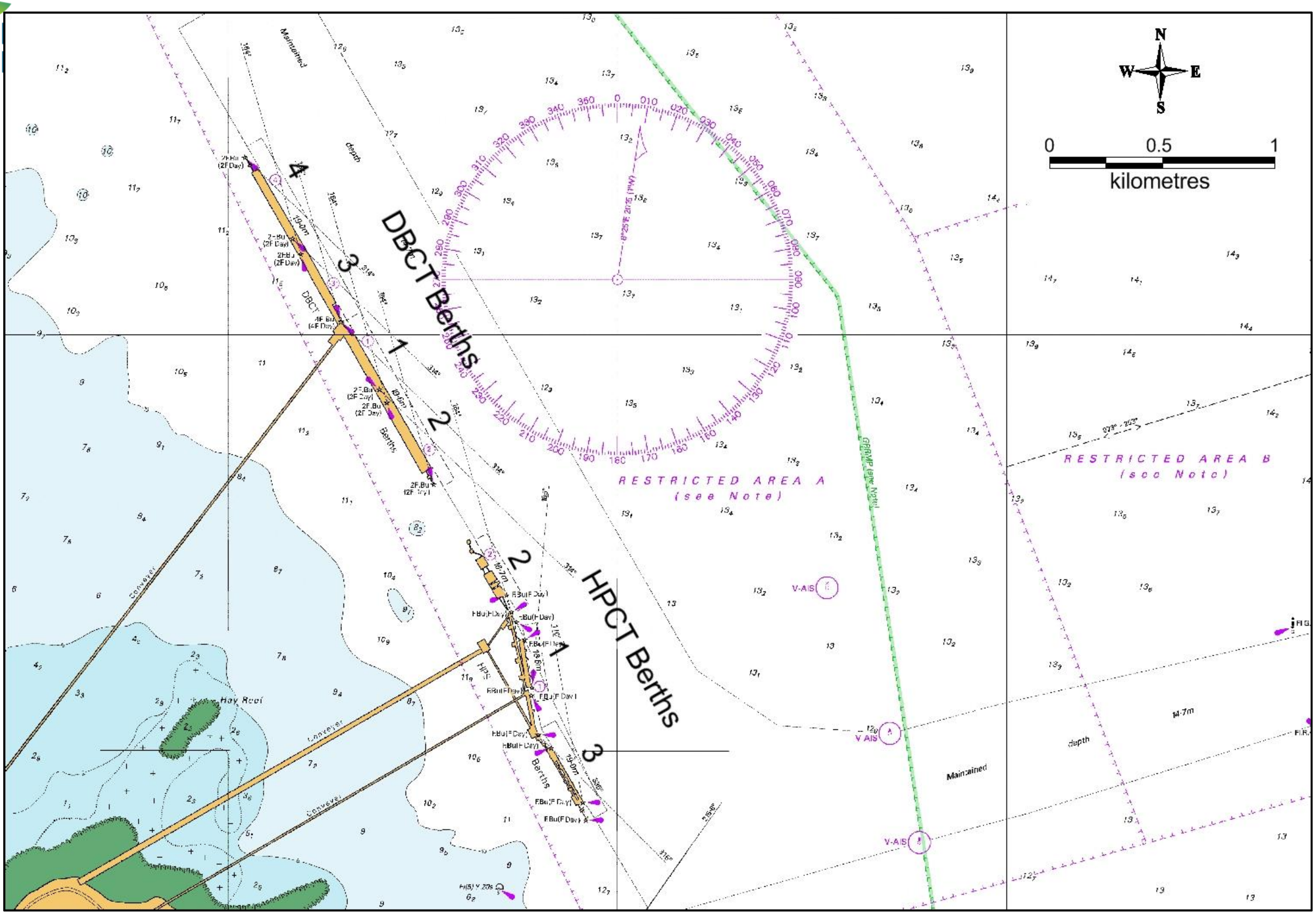

Figure 2: Configuration of the berths, apron and channel at Hay Point Port.

Siltation has been ongoing in areas of the apron, channel and berths at Hay Point since the 2010 maintenance dredging resulting in areas of shallowing. As a result, the declared depths at some areas of the port have been reduced by the Harbour Master (**Table 2**) and specific navigational requirements have been adopted at the Port for safety reasons. For example; the vessels at all berths have to be loaded during the rising tide, and sail prior to high tide with the aim of being halfway along the channel at high tide to prevent the risk of a fully laden vessel having insufficient under keel clearance and grounding. This has resulted in operational inefficiencies with significant economic ramifications, and has the potential to jeopardise safety (i.e. if a fully laden vessel breaks down in the berth or channel and there isn't sufficient time for tug vessels to move the vessel to deeper water prior to low water).

A recent bathymetric investigation undertaken by RHDHV (2016a) calculated that the existing maintenance dredging requirement, based on the most recent bathymetric survey carried out in October 2015, was 205,800 m^3. The areas where the majority of siltation had occurred were the north area of the apron and the berths. Future increases in the maintenance dredging requirement have been predicted by RHDHV (2016b), with an increase in the requirement of 41,500 m^3 predicted after 1 year and if no maintenance dredging occurs after that then an increased requirement of 440,000 m^3 to 540,000 m^3 (range due to uncertainty associated with the occurrence and impact of tropical cyclones) is predicted after 10 years.

Table 1: Historic in-situ dredging volumes (m^3) at the Port of Hay Point since 2004.

Year	Maintenance Dredging Volumes (m^3)	Capital Dredging Volumes (m^3)
2004	98,900	0
2005	0	400,000
2006	0	9,000,000
2007	0	0
2008	192,294	0
2009	0	0
2010	216,070	0
2011	0	275,000
2012	0[1]	0
2013	0[1]	0
2014	0[1]	0
2015	0[1]	0

[1] Since the last maintenance dredging approval for the Port of Hay Point expired at the end of 2011, further maintenance dredging has not been possible due to delays and complications with a new permit.

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Table 2: Details of dredged areas in the Port of Hay Point (MSQ, 2013 and 2015).

Location	Design Depth (m below LAT)	2016 Declared Depth (m below LAT)	Length (m)	Width (m)
Departure Channel	14.9	14.7	10,000	500 – 300
Apron	14.9	14.7	4,500	500
HPCT Berth 1	16.6	16.4	343	61
HPCT Berth 2	16.7	16.8	366	61
HPCT Berth 3	19.0	18.6	460	70
DBCT Berth 1	19.6	18.1	425	71
DBCT Berth 2	19.6	18.0	425	71
DBCT Berth 3	19.0	17.9	450	71
DBCT Berth 4	19.0	18.0	450	71

1.2 Port of Hay Point

The Port of Hay Point is located on the central east coast of Queensland, approximately 15 km south of Mackay, and it is one of the largest coal export ports in the world. It is located close to the neighbouring communities of Louisa Creek, Salonika Beach and Half Tide Beach, and is comprised of two separate export terminals, DBCT and HPCT which service mines in the Central Bowen Basin of Queensland. The limits of the port extend 1.75 km offshore of the berths, 3.75 km to the south of HPCT Berth 3 and 7.5 km to the north-west of DBCT Berth 4 (**Figure 1** and **Figure 2**). The port lies within the Great Barrier Reef World Heritage Area (GBRWHA) but is excluded from the Great Barrier Reef Marine Park (GBRMP).

The port has a dredged departure channel, apron and seven berths; these are shown in hydrographic charts AUS249 and AUS250 in **Figure 1** and **Figure 2**, respectively. Details of the initial design depths and the existing declared depths, as well as the dimensions of the dredged areas of the port, are provided in **Table 2**.

1.3 Report Structure

The report herein is set out as follows:

- a description of the site conditions is given in **Section 2**;
- details of the maintenance dredging methods and existing requirements is provided in **Section 3**;
- review of siltation reduction solutions is described in **Section 4**;
- a feasibility and comparative assessment of the solutions is presented in **Section 5**;
- implications of the feasible solutions on existing and future maintenance dredging is detailed in **Section 6**; and
- a summary of the findings is provided in **Section 7**.

Unless stated otherwise, levels are reported to Lowest Astronomical Tide (LAT). Zero metres LAT is equal to Chart Datum (CD) at Hay Point. Any volumes quoted are in-situ cubic metres.

2 Existing Environment

2.1 Preamble

In order to determine realistic and feasible options to manage and reduce siltation it is imperative to have a good understanding of the processes driving sediment transport and siltation. The recent investigations by RHDHV (2016a) and AECOM (2016) provide a good understanding of the existing environment. As such, based on the findings of these reports the following section provides a summary of the key processes in the transport and deposition of sediment at the Port of Hay Point.

A review of the findings of a recent sediment sampling campaign, which has been undertaken subsequent to the previous studies by RHDHV (2016a) and AECOM (2016), is also provided and discussed in terms of the areas where regular siltation occurs.

Based on the findings of the previous investigations along with the recent sediment data, an updated understanding of the existing sediment transport and siltation at the Port of Hay Point is provided. This updated understanding will be used in the subsequent section to assess possible solutions to reduce siltation and allow a first pass high level review of possible solutions to either ‘keep sediments out’ or ‘keep sediments moving’.

2.2 Summary of Existing Understanding

Based on the available information, the natural morphology in the areas adjacent to the berths, apron and channel at the Port of Hay Point appear to be relatively stable, with little natural erosion or deposition occurring. Data from the ambient water quality monitoring suggests that there is a thin mobile bed layer of sediment which is regularly reworked (resuspended, transported and then deposited) by waves and at times strong tidal flows (resuspending the material) and currents (transporting the material).

AECOM (2016) assessed coastal and shelf sediment dynamics in the Hay Point area, and produced a conceptual sediment transport model and budget for Hay Point which included the following key elements/pathways:

- an active littoral transport of coarser sediment (littoral drift pathway);
- fine suspended sediments in the nearshore zone (nearshore turbidity pathway);
- non-extreme wave and tidal action that is able to re-suspend coarser fractions in depths beyond the littoral zone (inner shelf bedload pathway); and
- substantial sediment movement across the Great Barrier Reef lagoon during cyclonic events (mid-shelf cyclone pathway).

AECOM (2016) determined that the dominant source of sediments to the navigational channel and berth pockets were large stores of available sediments on the inner shelf. This is partly a result of the fact that the inner boundary of the dredged area lies largely offshore of much of the nearshore sediment movements of coarser sediments from littoral drift and the nearshore turbidity region.

Historic siltation in the channel, apron and berths at the Port of Hay Point was recently investigated as described in RHDHV (2016a). The study found that the apron, channel and berths at the Port of Hay Point have all been subject to siltation due to the increased ‘trapping’ potential of the artificially deepened areas. However, the siltation has been limited to a few, primarily inshore areas. The key areas subject to siltation at the Port of Hay Point are as follows:

- North Apron: this is the only area of the apron and departure channel which has been consistently subject to siltation since capital dredging was completed in October 2006. The North Apron has been subject to siltation in excess of 130,000 m^3 over an eight and a half year period, and as some maintenance dredging was undertaken in 2010, the actual siltation is higher. The siltation is a result of natural resuspension of bed material initiated by wave and tidal action and potentially also propeller wash and berth drag barring induced resuspension and subsequent transport by tidal currents. Sediment accumulates in this area due to the natural residual northerly current, the high trapping efficiency of this area of the apron (it has the largest difference between the design depth and the adjacent natural bed level within the apron and departure channel) and the fact that the area is subject to limited vessel traffic. Vessel traffic in other areas of the apron and channel acts to resuspend the bed material such that it can be transported away by tidal currents.

- Inner and Outer Channel: ingress of low volumes of sediment in localised areas adjacent to the southern side of the channel have resulted in siltation. This is thought to be a result of both natural bedload transport in a net northerly direction (due to the angle at which waves reach the departure channel) along the adjacent seabed which deposits in the deeper departure channel as well as some localised slumping of the channel bank. The gradual siltation is slowly impinging on the channel, narrowing the channel in these areas.

- Mid Outer Channel: there has been net siltation in the naturally deep channel which crosses the departure channel at the Mid Outer Channel region. This has occurred on either side of the channel, with the centre of the channel having been subject to erosion due to propeller wash from the vessels. The natural bathymetry in this area is approximately 1 m below the design depth and so the siltation is not an immediate concern for future maintenance dredging.

- DBCT Berths: these areas have been subject to consistent, ongoing siltation over the last 10 years. As the composition of the sediment which has been deposited in the berths has a relatively high percentage of fine grained sediment (silt and clay) it is thought that transport has been mainly from suspended load. If the siltation had been mainly from bedload transport a higher percentage of sand sized sediment would have been expected. Due to the high trapping efficiency of the berths, resulting from their depth relative to the adjacent bed elevations, they are able to trap more suspended fine grained silts and clays than the apron and departure channel. The source of sediment is likely to be a combination of sediment transport initiated by tidal flows and waves and sediment transport initiated by propeller wash, similar to the processes detailed for the North Apron area. Approximately 200,000 m^3 has deposited in the DBCT berths over the last 10 years.

- HPCT Berths: there has only been limited siltation in these berths over the last 10 years. Although similar deposition processes to the DBCT berths would be expected (likely to be lower rates due to the natural setting and shallower depth of Berths 1 and 2), drag barring and bed levelling has proved to be a successful sediment agitation approach to limit siltation and has prevented significant reduction in depth from occurring.

RHDHV (2016a) found that wave action was the dominant natural driver responsible for the resuspension and entrainment of bed material as suspended load around the Port of Hay Point. It is also expected that wave action is the dominant driver for the entrainment of sediment as bed load. In addition, tidal currents are expected to help mobilise sediment during spring tides due to the higher bed shear stress from the currents combining with the wave induced bed shear stresses. There is broad agreement between the observations made in both RHDHV (2016a) and AECOM (2016) with regard to the sediment transport processes that influence siltation at the port.

Resuspension of bed material within the dredged areas of the port has been found to occur due to propeller wash from the bulk cargo vessels. Net erosion of approximately 500,000 m^3 of the apron and departure channel has occurred since the capital dredging was completed in 2006. The erosion has been focused along the centre line of the departure channel and apron corner as well as the area of the apron directly adjacent to the berths. This erosion has occurred as a result of high bed currents resulting from the propeller wash of vessels, specifically as the vessels leave the berths fully laden when the vessel draft is at its greatest (and the propeller is closest to the bed). The erosion of material from the bed of the apron due to propeller wash could have resulted in an increase in deposition at other locations in the apron and berths, as some of the sediment could be retained within the deeper dredged areas.

It was found by RHDHV (2016a) that extreme events which result in strong winds and large waves, such as tropical cyclones, have the potential to result in relatively large changes in the dredged areas over a short period of time. TC Dylan resulted in erosion of between 300,000 and 725,000 m^3 of the apron and departure channel, with average erosion depths of between 0.1 and 0.2 m. In the four months after TC Dylan increased siltation occurred. This is thought to be due to the cyclone resulting in widespread erosion of the natural consolidated bed and following the event the layer of potentially mobile bed sediment was increased and this material remained loosely consolidated and was subject to regular transport by waves and currents. Some of this sediment was subsequently deposited in the dredged areas of the Port of Hay Point.

2.3 Sediment Data

As part of the beneficial reuse investigation a detailed sediment sampling campaign was undertaken in March 2016 as described by Advisian (2016). Sediment sampling locations are indicated on **Figure 3**.

The sediment properties correlate well with the areas where RHDHV (2016a) observed regular ongoing deposition:

- North Apron: regular deposition has occurred in this area since the 2006 capital dredging. The highest rates of deposition have been experienced along its western side. Sample G-1 was collected from the western side of the North Apron and can be classified as mud (based on Folk (1954)) with 43% clay, 50% percent silt and 7% sand, while Sample G-2 was collected from the eastern side and can be classified as sandy mud with 33% clay, 36% silt and 31% sand. This shows that the sediment accumulating at a higher rate on the western side of the North Apron has a higher proportion of silts and clays compared to the sediment on the eastern side; and

- DBCT Berths: regular deposition has been occurring in all four of the DBCT berths, although since 2014 drag barring activities have been undertaken, resulting in erosion of approximately 26,000 m^3 of sediment from June 2014 to October 2015. The sediment samples in the berths can be classified as predominantly mud, although some sandy mud was also present at the northern end of the berths (where the stern of the vessel sits and therefore the area where any propeller wash erosion will be greatest). This shows that the same type of material is depositing in the berths and the North Apron, but that local agitation of the bed (by both drag barring and propeller wash) can winnow out the finer material and leave the coarser sands in some areas.

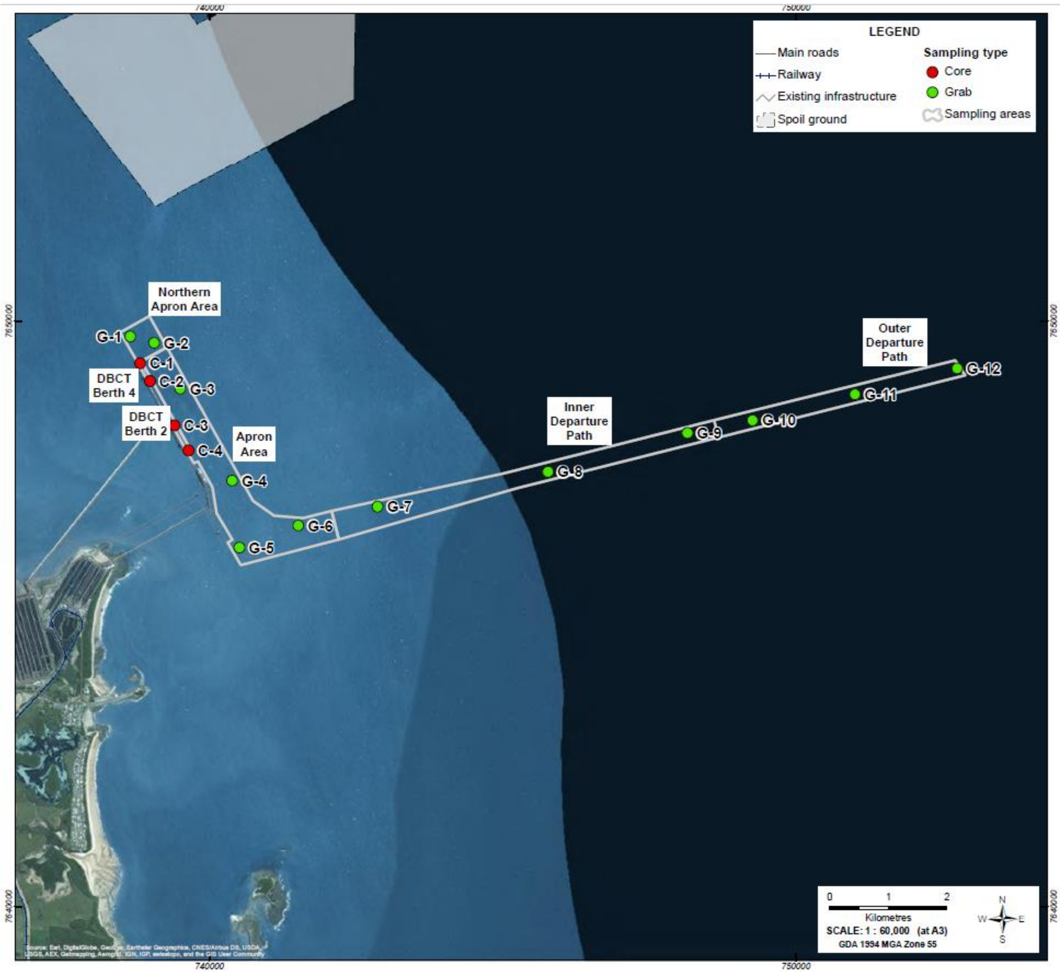

Figure 3: Sediment sampling locations at Port of Hay Point, March 2016. Source: Advisian (2016)

In the other areas of the apron, where no ongoing deposition has been observed, the sediment was predominantly made up of sandy mud and muddy sand, although some gravelly muddy sand was also found at G-6 (this coarser material is thought to be due to propeller wash erosion winnowing out the finer sediment in this area). Along the departure channel the amount of silt and clay in the samples gradually reduces, with samples G-11 and G-12 being classified as sand.

Based on the sediment sampling results, the following conclusions can be made:

- The sediment depositing in the berths and North Apron is mud with typically less than 10% sand. This suggests that the observed siltation occurs due to the deposition of natural background suspended sediment and the deposition of sediment suspended by propeller wash erosion and drag barring, with little input from shelf bedload transport;
- The natural sediment in the apron area is sandy mud, but erosion from propeller wash has removed some of the finer sediment in some areas resulting in some areas being composed of muddy sand and gravelly muddy sand; and
- The amount of fine grained silts and clay in the surface bed sediment reduces in an offshore direction along the departure channel, with the outer part of the channel being more than 90% sand.

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2.4 Sediment Sources

The sediment property data collected from Hay Point (Advisian, 2016), detailed in the previous section, identified that samples C-2 and G-1, located on the inshore side of DBCT Berth 4 and the inshore side of the North Apron, had silt and clay components of 90% and 93%, suggesting that these sediments originated from fluvial source, although the organic matter of the samples analyses were less than 2%.

RHDHV (2016a) also identified that this berth pocket area and the North Apron region traps more sediments than the majority of other areas in the dredged navigational area. Hence, it is worthwhile considering the source of this particular small area of finer sediments.

The Port is located between the Pioneer River to the North and the Plane Creek catchment to the South. Kroon et al. (2012) estimate that on average the Pioneer and Plane Creek catchments discharge 52 and 550 ktonnes of fine sediment respectively per year. This is compared to an estimated discharge of 4,700 ktonnes per year from the Burdekin River to the north. Using a conversion ratio of 1.0 (Carter et al., 1999), the average annual discharges from the Pioneer and Plane catchments become 52,000 m^3 $year^{-1}$ and 550,000 m^3 $year^{-1}$ respectively.

Lewis et al. (2014) identify that almost all sediments discharged from the Burdekin are deposited within 50 km of the river mouth. If we pro-rata this area according to the relative discharges of the Pioneer and Plane catchments then it can be estimated that almost all of the sediments discharged from these catchments will be deposited within 1.1% and 12% of the equivalent area of the Burdekin discharge zone. This is equivalent to depositional areas of 43 km^2 and 470 km^2, or radial distances from the river/creek mouth of 3.7 km and 12 km respectively. If deposition was uniform over these areas, it would be equivalent to an average annual deposition of 52,000 m^3 deposited over an area of 43 km^2 for the Pioneer deposition zone, and 550,000 m^3 deposited over an area of 470 km^2 for the Plane. This is equivalent to an average annual deposition rate of approximately 1 mm per year for both deposition zones.

RHDHV (2016b) identified an average volumetric deposition rate of 43 m^3 day^{-1} over approximately a third of the North Apron area (0.115 km^2) of the Port. This is equivalent to 0.4 mm per day, or 0.14 m per year. This can be compared to 1 mm per year from the local fluvial sources. Therefore, the immediate deposition from wet season flood events from local catchments can only account for less than 1% of the observed sediment accumulation.

Littoral drift and shelf bedload transport processes can act to redistribute the sediment stores deposited off the mouth of local fluvial sources northwards (AECOM, 2016). However these sediments transported by littoral drift are likely to mostly pass between the coast and the berth pockets (AECOM, 2016) and in terms of shelf bedload transport, the vast sediment stores updrift of the berth pockets mean that the system is essentially not supply-limited, implying that additional newly deposited mineral sediments from closer small fluvial sources are not a major contributor.

2.5 Sediment Transport and Siltation Understanding

The recent bathymetric analysis study found that there were only three areas within the dredged areas of the Port of Hay Point where regular ongoing siltation occurs, or is expected. These being:

- North Apron;
- DBCT Berths; and
- HPCT Berths (although the berths have not been subject to significant siltation this is a result of ongoing bed agitation measures and so alternative approaches will be considered).

The assessment found that the siltation rates in the North Apron and DBCT berths were relatively constant over time, as shown in **Table 3**. Historical drag barring has been undertaken at the HPCT berths and without this process it is thought that regular siltation, similar to that experienced in the DBCT Berths 1&2 (scaled relative to the plan area of the berths), would occur.

Siltation management options will be considered for the above three areas to assess if there are feasible options to reduce siltation and therefore maintenance dredging requirements.

Table 3: Estimated siltation rates North Apron and DBCT Berths

Area	Siltation Rate (m^3/day)	r^2 Value
North Apron	43.1	0.88
DBCT Berths 1&2	32.4	0.89
DBCT Berths 3&4	38.8	0.95

The conceptual sediment transport model of the accretion and erosion processes at the Port of Hay Point developed by RHDHV (2016a) has been confirmed based on the recent sediment sampling results (**Figure 4**). These results suggest that deposition within the North Apron and DBCT berths occurs due to suspended sediment being transported due to natural background conditions, erosion from the berths by drag barring and erosion from propeller wash in the berths and apron. Due to the high trapping efficiency of the berths, resulting from their depth relative to the adjacent bed elevations, these areas are able to trap more fine grained silts and clays than the apron.

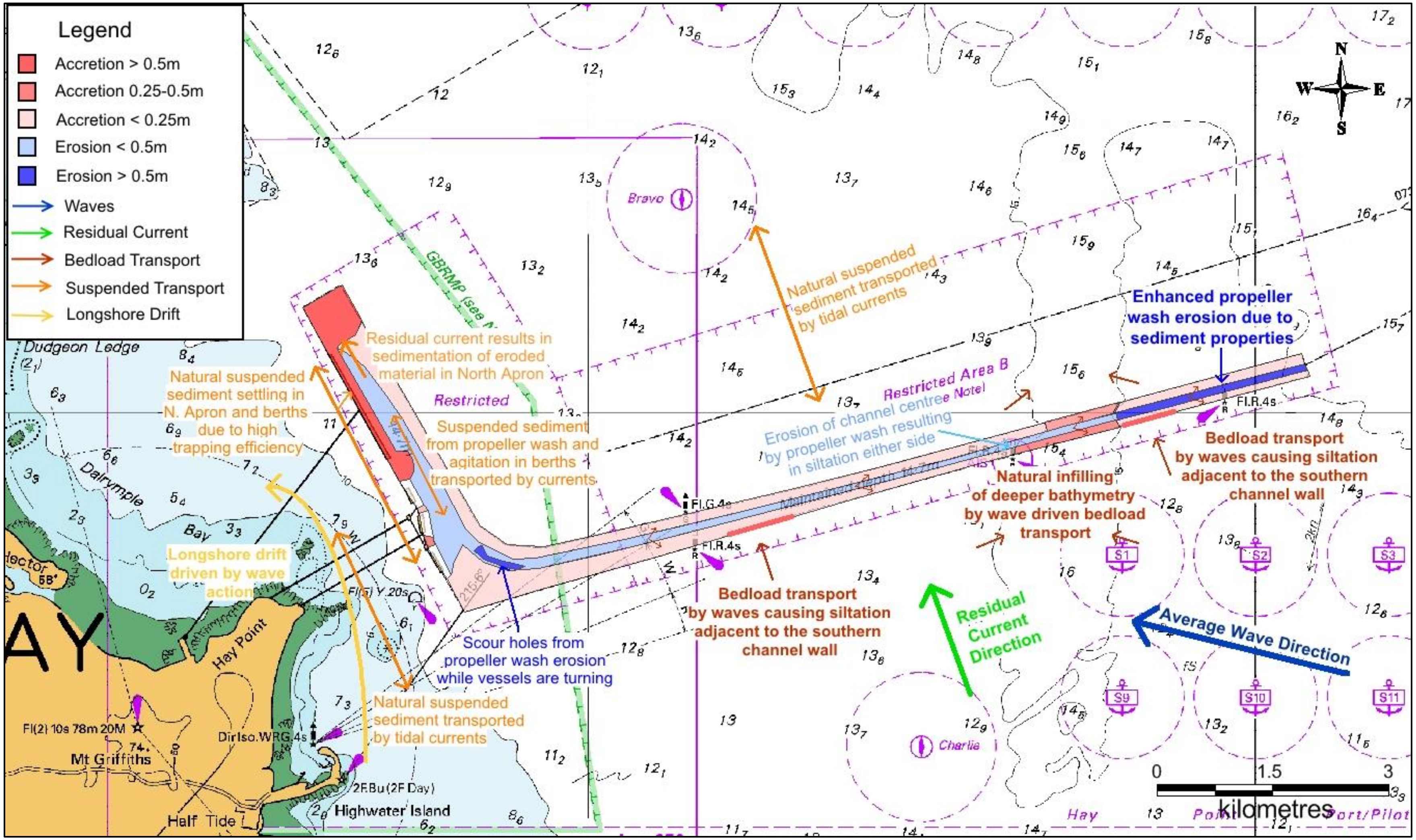

Figure 4: Updated conceptual sediment transport model at the Port of Hay Point.

3 Maintenance Dredging Options and Requirements

Siltation within the berths, apron and departure channel at the Port of Hay Point has historically been addressed by a combination of traditional maintenance dredging and drag barring. The maintenance dredging has been employed to remove sediment from the DBCT berths, apron and departure channel, while drag barring has prevented significant siltation in the HPCT berths.

Various approaches to maintenance dredging are detailed in this section along with the existing and future maintenance dredging requirements.

3.1 Traditional Maintenance Dredging

The majority of maintenance dredging at the Port of Hay Point has historically been undertaken by a trailing suction hopper dredge (TSHD). This type of vessel has a high production rate, can operate in offshore areas and heavily trafficked areas, has a hopper allowing offshore placement and is well suited to dredging soft unconsolidated sediment typically associated with maintenance material. Since 2000, the TSHD Brisbane has typically undertaken the maintenance dredging at the Port of Hay Point. The vessel was specifically designed for the maintenance dredging of Queensland Ports. The vessel has an inbuilt hopper with a capacity of 2,900 m^3 and dredge material can be pumped ashore or disposed at sea through bottom dump valves.

3.1.1 Side Casting

Side-cast disposal of dredge material involves depositing dredged sediment through a pipe on one or both sides of the dredged area from where it may be subsequently advected away from the area of interest by ambient currents (USACE, 2003a). This approach is most effective for sites where the dredging quantity is small, currents are parallel to the channel, and fine sediments are predominant. Depending on the type of sediment dredged, substantial quantities of material could deposit back into the channel.

3.1.2 Fixed Location Pipeline

In some cases where regular maintenance dredging is required and the material is pumped to shore either for onshore beneficial reuse or onshore disposal, a fixed location pipeline with a flange can be installed. The flange allows a dredger to easily connect to the pipeline, therefore allowing the onshore placement of the material to be regularly undertaken. However, the feasibility of this approach would need to be assessed based on the dredging requirements, distance to shore and disposal options.

3.2 Water Injection Dredging

Water injection dredging involves the low pressure injection of water into near-surface seabed deposits. This reduces the in-situ density of the sediment to the point where it behaves like a liquid and can be induced to flow. Although some sediment can be suspended during the process, the majority of the sediment remains relatively close to the bed in a fluid mud layer. The approach relies on the horizontal transport of the fluid mud by the combined forces of a pressure difference with the water and gravitational forces. If the seabed slopes then large masses of sediment may be induced to flow at high rates. However, in areas such as enclosed berths with no bed slope the approach would not be effective.

3.3 Bed Levelling / Drag Barring

This approach can also be known as a form of agitation dredging. It is typically used to redistribute sediment away from channels and berths so that it can be dredged during subsequent maintenance campaigns. It can also act to resuspend fine grained sediment into the water column and with the presence of sufficient current this can act to remove the sediment from the area. This approach has historically been adopted at the DBCT berths and has limited siltation at the berths. The approach is highly sensitive to weather conditions. Based on historic drag barring activities at the HPCT and DBCT berths, the downtime at Hay Point has been estimated to be approximately 55% of the time.

3.4 Vessel Agitation

This approach uses the propeller wash from a vessel to resuspend bed material so that it can be transported away by currents. This is another form of agitation dredging which has been adopted in some locations. For example, the Dart Harbour Navigation Authority commissioned the construction of a custom-built agitation dredger which they estimate moves 150 to 1,000 wet tonnes of silt and clay per year (Sullivan, 2000). Typically, this approach is more effective the closer the vessel propeller is to the seabed, so either in shallow waters or with deep draft vessels.

3.5 Existing and Future Requirements

As detailed by RHDHV (2016a; 2016b) the existing and predicted future maintenance dredging requirements at the Port of Hay Point are as follows:

- Existing requirement- 205,800 m^3. This is spilt as follows:
  - DBCT Berths- 139,800 m^3;
  - HPCT Berths- 6,700 m^3;
  - North Apron- 19,800 m^3;
  - Departure Channel- 10,600 m^3; and
  - Apron- 28,900 m^3 (noting that most of this volume is not from siltation rather it was never dredged to design depth during the 2006 capital works).

- Future requirement (assuming no drag barring in any berths and no allowance for increased siltation due to tropical cyclones) - 45,000 m^3/yr. This is split as follows:
  - DBCT Berths - 25,000 m^3/yr;
  - HPCT Berths - 12,000 m^3/yr;
  - North Apron - 7,000 m^3/yr until the 50,000m^3 volume available below the design depth fills up (this is predicted to occur after approximately 6 years), then the requirement is predicted to increase to 16,000 m^3/yr; and
  - Departure Channel: <1,000 m^3/yr.

4 Siltation Reduction Solutions

Both PIANC and the USACE have produced documents providing guidelines for the best practice approaches to minimising harbour and channel siltation (USACE, 2003b; 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.

There are three broad strategies that can be implemented to reduce siltation at ports and harbours, including:

- **Keep Sediment Out** – keeping sediment out of the area of interest that might otherwise enter and deposit;
- **Keep Sediment Moving** – raising flow velocities in quiescent areas to prevent sediment from settling as it passes through the area of interest; 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 4**. A detailed description of each approach is provided in **Appendix A**, including relevant examples of sites where these approaches have been implemented.

Table 4: Outline of strategies to reduce future maintenance dredging requirements.

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).
	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.

4.1 Relevance to Hay Point

To assess the potential feasibility of possible siltation reduction solutions at the Port of Hay Point the options have initially been considered based on the following criteria:

1. Potential to result in a significant alteration to the siltation.
2. Probability of effectiveness of the approach.

A summary of the feasibility of the broad approaches detailed in **Table 4** based on these criteria is shown in **Table 5**. Further discussion of the initial feasibility assessment for each approach is provided in the following sections.

Table 5: Initial feasibility assessment of approaches to reduce future maintenance dredging volumes.

Approach	Potential Significant Alteration to Siltation	Probability of Effectiveness	Potentially Feasible
Stabilise sediment sources	No	Low	No
Diverting sediment-laden flows	No	Low	No
Trapping sediment before it enters port	Yes	Medium	Yes
Blocking sediment entry	No	Low	No
Habitat creation	Yes	Low	No
Structural solutions to train natural flows	No	Low	No
Devices to increase bed shear stresses	Yes	High	Yes
Methods to reduce sediment flocculation	No	Low	No
Adopt a ‘nautical depth’ navigation approach which includes fluid mud	No	Low	No

4.1.1 Stabilise Sediment Sources/Diverting Sediment-laden Flows

The coastal setting and limited fluvial input of sediment to the area (as discussed in **Section 2.4**) signify that no approaches which rely on diverting or reducing sediment input from rivers will be effective at the Port of Hay Point.

4.1.2 Trapping Sediment Before it Enters Port

Sediment traps and insurance trenches are typically adopted in areas where sand transport dominates. However, the localised nature of the siltation at the Port of Hay Point means that despite the fine grained nature of the sediment deposited in the inshore dredged areas sediment traps have the potential to be effective. However, this approach will not reduce the overall siltation, rather change where it builds up and how frequently it needs to be removed.

4.1.3 Blocking Sediment Entry

This approach aims to create a physical barrier to prevent sediment (either in suspension or through bed load) from entering an area and is typically only adopted in semi-enclosed berthing areas such as harbours. It may be hypothesised that constructing a large rock wall to the south of the apron and departure channel could reduce the siltation in these areas. However, this would not be expected to reduce siltation as it would not reduce the suspended sediment concentration within the apron and departure channel which is the primary contributor to siltation. Therefore this approach is deemed not feasible.

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4.1.4 Habitat Creation

The creation of marine habitat, either intertidal such as mangroves or subtidal such as seagrass meadows, has the potential to stabilise bed sediment and therefore reduce the potential resuspension of sediment. As the Port of Hay Point is located on an open coast setting, any intertidal habitat creation would not directly influence the siltation in the port.

The creation of up drift subtidal habitat such as seagrass meadows could potentially reduce the siltation in the Port of Hay Point. However, there is limited direct evidence to provide a quantitative prediction of the potential effectiveness of the approach and it is expected that the scale of seagrass required to result in a noticeable reduction in siltation in the dredged areas of the port would be significant.

In addition, the natural bed adjacent to the dredged areas at the Port of Hay Point is relatively deep, with water depths greater than 10 m, limiting the potential species of seagrass which could survive. The native seagrass is ephemeral in nature with the potential for entire beds to die off during the senescence period. As such, habitat creation is considered not a feasible approach to reduce the ongoing siltation at the Port of Hay Point.

4.1.5 Structural Solutions to Train Natural Flows

Structures can be specifically designed to deflect currents and improve circulation and therefore reduce siltation. Historically, these have been successfully adopted in harbour and estuarine environments where the current flow is already constricted. Due to the coastal setting of the Port of Hay Point, with the wharf extending approximately 2 km offshore from the shoreline, a structural solution to change the hydrodynamic flows is considered not a feasible solution.

4.1.6 Devices to Increase Bed Shear Stress

There are a number of solutions which could be adopted to increase the bed shear stress and therefore encourage resuspension of bed material and limit the build-up of sediment. Due to the regular ongoing nature of the siltation at the Port of Hay Point this approach is considered feasible.

4.1.7 Methods to Reduce Sediment Flocculation

Research has shown that increased turbulence from jetty piles could result in increased flocculation which causes increased siltation and that by reducing turbulence from these structures siltation rates can be reduced. There is limited practical evidence of the potential success of this approach, with most evidence being theoretical. In addition, as siltation of similar sediment types occur both in the berths (adjacent to jetty piles) and the North Apron (not adjacent to jetty piles) it would appear that increased flocculation due to the jetty piles is not having a significant impact in this case. Therefore it is expected that trying to adopt methods to reduce flocculation (e.g. installing a solid wharf wall) would not result in a significant reduction in siltation in the berths.

4.1.8 Adopt a 'Nautical Depth' Navigation Approach

In some locations where fluid mud is present and high siltation 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. As the siltation rates at the Port of Hay Point are relatively low (typically less than 1 m per year) the ongoing consolidation of the sediment means that this approach is not considered feasible.

5 Feasibility and Comparative Assessment

Based on the initial feasibility assessment detailed in **Section 4.1**, the following siltation reduction approaches have been identified as potentially feasible:

- Trapping sediment; and
- Increasing bed shear stresses.

Possible solutions which could be adopted for these approaches along with ongoing maintenance dredging are further discussed in this section and compared based on constraints, costs and greenhouse gas emissions. The costs and greenhouse gas emissions have been calculated assuming a representative duration of 20 years.

The suitability of the solutions to manage the existing maintenance dredging requirement, as detailed in **Section 3.5**, is also discussed.

5.1 Approach Details

5.1.1 Ongoing Maintenance Dredging

To allow comparison of the proposed solutions with the existing approach of maintenance dredging, details of the estimated maintenance dredging requirement over the next 20 years is provided. An indication of the expected ongoing siltation volumes are detailed in **Section 3.5**. The dredging has been assumed to be undertaken by the TSHD Brisbane or a similar vessel. If it is also assumed that as part of the existing maintenance dredging required, over dredging of approximately 0.3 m would be undertaken, then the following ongoing maintenance dredging regime is expected to maintain design depths for ambient conditions (i.e. no inclusion for increased siltation due to tropical cyclones):

- dredging of 75,000 m^3 from the DBCT and HPCT berths every two years; and
- dredging of the North Apron every four years. As the eastern side of the North Apron currently has approximately 50,000 m^3 of capacity below the design depth, siltation above the design depth (and therefore the required maintenance dredging volume) is predicted to gradually increase until this capacity is filled. As such, the future maintenance dredging volumes of the North Apron are predicted to be as follows:
    - after four years, dredging of 25,000 m^3;
    - after eight years, dredging of 45,000 m^3; and
    - from 12 years and onwards dredging of 65,000 m^3.

The Departure Channel has been found to have a siltation rate of less than 1,000 m^3/yr, occurring at two locations along the southern bank of the channel. Due to the relatively low rate of siltation no maintenance dredging has been included for this area in forward estimations.

It is important to note that the historical sedimentation rates are also partly a function of the propeller wash eroding sediment from some of the dredged areas. Therefore it is not possible to identify ‘natural’ background sedimentation and the forward estimates are at least partly based on the assumption that the same level of traffic continues into the future. It is conceivable that the siltation rates may be reduced if traffic increases in the future due to increased propeller wash erosion from the vessels.

5.1.2 Trapping Sediment

Based on the natural sediment transport and siltation processes at the Port of Hay Point, a conventional sediment trap designed to trap sediment before it reaches the port area is expected not to be successful. However, as the North Apron already acts as an unintentional form of sediment trap, a realistic option would be to increase the capacity of this area through establishment dredging to allow it to act as a sediment trap containing sediment within the port area. The trap could be designed to either deepen or extend the North Apron to the north. However, deepening the existing area is thought to result in less potential direct environmental impacts as the dredging remains within the existing port area. Accordingly, this deepening option has been assumed for the sediment trap configuration.

As the North Apron area has been shown to be subject to ongoing siltation, the approach adopted will be working with the natural processes to allow ongoing siltation without influencing the design depths. However, as with all sediment traps, the solution would not actually reduce the ongoing total maintenance dredging volume for the North Apron area, rather it would reduce the frequency that the maintenance dredging would be required and potentially reduce the spatial area requiring maintenance dredging.

The sediment trap has been assumed to have a 10 year capacity. Details of the proposed solution are as follows:

- The sediment trap approach is not able to remove the existing siltation in the North Apron and as such maintenance dredging has been assumed to remove existing siltation from the North Apron;
- Establishment dredging of 160,000 m^3 of sediment from the North Apron in the form of deepening the area. It has been assumed that this dredging would be undertaken by the TSHD Brisbane (or similar vessel) and coincide with any maintenance dredging undertaken to reinstate design depths in the North Apron;
- Bed levelling every five years by the Pacific Conquest (or similar vessel) to redistribute any concentrated siltation in the trap, preventing a build-up of sediment on the western side of the trap as currently occurs in the North Apron. A bed levelling duration of 14 days has been assumed every five years; and
- Maintenance dredging every 10 years to re-establish the sediment trap capacity. The volumes assumed over a 20 year period are the same as detailed for the North Apron in **Section 5.1.1**.

5.1.3 Increasing Bed Shear Stress

Bed shear stresses can be increased by either installing a fixed position system or by regular manual agitation such as drag barring. The approach aims to replicate the regular natural resuspension of recently deposited bed sediment to prevent ongoing siltation. For the approach to be successful a relatively strong natural current is required to transport the agitated material away from the siltation area after it becomes resuspended. Historical drag barring of the HPCT berths has been successful in limiting long term siltation in the berths demonstrating that sufficient natural currents are present for this approach to be successful. Further details of possible solutions are provided in the following sections.

Fixed Position Jet Arrays

This solution aims to configure an array of water jets which can transport newly settled sediments away from the area covered by the nozzles. The shear stress required from the jet must be large enough to not only resuspend any newly settled sediment but also to transport it into the path of current which will transport the sediment away from the area. Typically the jets are configured to come on for a short duration during either the flood or ebb tide. The frequency of the jets can be configured based on the site specific requirements but typically they are used 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.

Experiments into jet arrays have previously been undertaken by the US Navy in a saline environment in San Francisco Bay with very high siltation rates (> 3.5 m/yr) (Velasco, 2000). The experiments considered the following range of different jet arrays:

- Spatial jet array: the array was distributed along the seafloor with a series of 2 cm diameter nozzles. The approach was found to result in small mounds of siltation between the individual jets, therefore not preventing all siltation in the area.

- Linear jet array: the array was distributed along a section of quay wall, with equally spaced 7.3 cm diameter jets facing away from the quay wall. The jets were located 2.5 m above the design depth and orientated to point downward 20° from horizontal. The results found that the approach prevented siltation out to a distance of 21 m from the face of the quay wall. However, maintenance issues were observed highlighting the complexity of the system and the potential issues.

- Turbo scouring units: this approach is similar to the linear jet array with it being mounted to a quay wall/wharf and facing towards the berth. It differs from the linear array as it uses larger nozzles with greater flow rates and the units have the ability to rotate 180°, providing greater scouring capability and reducing the number of units required. The units have a diameter up to 1.1 m with a scouring distance of up to 75 m. The units have been found to successfully maintain design depths in high siltation environments.

The experiments found that the scouring patterns vary according to the distance between the nozzle and the bottom, the size of the nozzle and the discharge velocity. As a result of the HPCT and DBCT berth widths varying from 60 to 70 m it is only the turbo scouring units which would be capable of preventing siltation. Based on this the following proposed solution has been assumed:

- Four to five turbo scouring units installed on the wharf piles per berth (one turbo scouring unit per 100 m length of berth);

- Two hydraulic pumping units at each berth to power the scouring units;

- Each unit at a berth will operate in sequence, gradually rotating until it has covered its area and then the adjacent unit doing the same. It has been assumed that each unit will operate for 30 minutes per tidal cycle.

This solution is not able to remove the existing siltation in the berths as it requires them to be returned to their design depths prior to installation.

Drag Barring

Drag barring, bed levelling or ploughing is typically adopted to redistribute sediment and thereby reduce the frequency that maintenance dredging is required. The process also acts to resuspend some of the bed sediment which is being redistributed, with more sediment being resuspended when the bed material is predominantly fine grained relative to coarser grained. As such, it can be adopted as a method to resuspend recently deposited fine grained sediment from the bed. Similar to the jet array approach, this approach aims to replicate the natural process of resuspension of recently deposited material, except that the frequency of resuspension is not as regular. As drag barring has historically been shown to limit siltation at the HPCT berths a similar approach in terms of method and frequency has been adopted for the future requirements:

- the Pacific Conquest (or similar vessel) will carry out four consecutive days of drag barring in the berths (approximately fourteen hours per berth). This will be repeated six times each year, giving a total of 24 days of drag barring in the berths per year in total.

Although this approach could be adopted to remove existing siltation from the berths and North Apron, it is not expected to be effective in removing any coarser material. Compared to maintenance dredging it would not be as efficient, particularly considering the partial consolidation of the bed sediment which will have occurred since 2010.

Propeller Wash Agitation

Propeller wash from a slow moving vessel can result in the effective resuspension of bed material. Deflectors can also be adopted to aim the propeller wash downward, increasing the near bed current speed and therefore the erosion rate. For this assessment it has been assumed that a local tug would be used to undertake propeller wash agitation in the North Apron, although a combination of bulk carriers and tugs could also be used with little to no cost or GHG emission implications by incorporating transit through this area into port operational procedures.

The near bed current speed resulting from the tug vessels propeller wash was predicted using an empirical model and based on this an erosion rate of 1 kg/s was estimated. As such, an estimated 20 days of propeller wash erosion from a tug would be required per year to resuspend sediment deposited as part of the ongoing siltation within the North Apron. Specifics with regard to the propeller wash agitation schedule would need to be defined as part of a more detailed investigation and validated through monitoring. However, it is suggested that the propeller wash agitation should be undertaken close to low water on a regular basis (e.g. three hours at a time, three times a week), and also when there is sufficient tidal current speed to transport the suspended sediment away from the North Apron.

As with drag barring, this approach could be adopted to remove existing siltation from the berths and the North Apron. However, it is also expected to not be effective in removing any coarser material. Similarly, compared to maintenance dredging it would not be as efficient, particularly considering the consolidation of the bed sediment which will have occurred since 2010.

The small ongoing siltation volumes which have been observed in the departure channel could be managed by propeller wash agitation. The vessels would need to be redirected along the southern side of the channel (when there is sufficient depth available) to allow this. This option has not been directly assessed in the constraints analysis due to the relatively small volume of material and the fact that this would be an operational change rather than a specific targeted solution resulting in cost and GHG emission benefits.

5.2 Constraints Analysis

The aim of the constraints analysis is to identify any aspects of the potentially feasible solutions which need to be further considered to help differentiate the solutions for a more detailed assessment of their relative potential feasibility. In this case the key constraints are considered to be environmental impacts, operational impacts, ongoing maintenance requirements, confidence, legal considerations, cost and greenhouse gas (GHG) emissions. These aspects are discussed in the following sections.

5.2.1 Environmental Impacts

Potential environmental impacts from the siltation reduction solutions could be either direct or indirect, these are described below:

- Direct impacts occur through direct interaction of an activity with the environment. For example, during dredging there will be a direct impact to the area dredged as surface sediment is removed; and

- Indirect impacts are those which are not a direct result of the project, and are often produced away from the area of direct impact or as a result of a complex impact pathway. For example, the release of sediment into suspension during dredging has the potential to result in indirect impacts due to changes in light attenuation and subsequent increased deposition in adjacent areas.

The following environmental impacts are expected for the various solutions:

- **Maintenance Dredging:**

    - direct impacts from the removal of surficial sediment which has deposited since the last maintenance dredging campaign and the placement of the sediment in the material placement site. As these areas have been subject to previous dredging and disposal campaigns these impacts are expected to be low.

    - indirect impacts due to the sediment suspended during the dredging and placement activity. Based on previous monitoring of the TSHD Brisbane during maintenance dredging activity these impacts are expected to be low (BMT WBM, 2013).

- **Sediment Trap:**

    direct impacts from the removal of surficial sediment and the placement of the sediment in the material placement site. As these areas have been subject to previous dredging and disposal campaigns these impacts are expected to be low.
    - indirect impacts due to the sediment suspended during the dredging and placement activity. Based on previous monitoring of the TSHD Brisbane during maintenance dredging activity these impacts are expected to be low (BMT WBM, 2013).

- **Fixed Position Jet Array:**

    - indirect impacts due to the regular resuspension of surficial sediment in the berths. As the jet array is proposed to operate during each tide the resuspension will be similar to the natural resuspension occurring due to the waves and currents. As such, the impacts are expected to be low.

- **Drag Barring:**

    - indirect impacts due to the resuspension of surficial sediment in the berths. As the drag barring will only occur intermittently the potential impact will be greater than for the jet array. However, the potential impact is likely to be relatively insignificant and localised.

- **Propeller Wash Agitation:**
    - indirect impacts due to the resuspension of surficial sediment in the North Apron. As the activity will be relatively regular (three times per week) the resuspension is expected to be similar to the natural resuspension which would occur due to the waves and currents. As such, the impacts are expected to be low.

5.2.2 Operational Impacts

- **Maintenance Dredging:** assuming an average weekly production rate of approximately 110,000 m^3 for the TSHD Brisbane[1], a maintenance dredging duration ranging from 5 days (just the berths every other two years) to 9 days (the berths and North Apron once the capacity below design depth has filled). As such, there is limited impact to the port operations.

- **Sediment Trap:** the establishment dredging of the North Apron is expected to take approximately 10 days to complete initially, with some subsequent bed levelling required and maintenance dredging every 10 years to remove deposited material and re-establish the trap. As the North Apron is not frequently transited by vessels this activity is expected not to impact on port operations.

- **Fixed Position Jet Array:** installation of the units would require retrofitting to the wharf which could take in the order of weeks to months to complete and would have an impact on port operations. In addition, quarterly maintenance which could take a day per unit would be required which would also impact on port operations.

- **Drag Barring:** the frequency of the drag barring required to prevent siltation in the berths would need to be defined based on ongoing trials. However, the activity is limited by weather conditions, with historical downtime for drag barring at the port in the order of 55%. As such, it is likely that the drag barring will have some impact to the port operations as the operation cannot be undertaken at any time and would have to occur when the vessel is available and the conditions are suitable.

- **Propeller Wash Agitation:** it is assumed that a local tug vessel could undertake the propeller wash agitation at the North Apron on a regular basis following operational work at the port. As the North Apron is not frequently transited by vessels this activity is expected not to impact on port operations.

5.2.3 Ongoing Maintenance

The impact of vessel movements required to manage the ongoing siltation is discussed in the Operational Impacts section above. This section deals with the ongoing maintenance associated with any equipment required for the solution.

- **Maintenance Dredging:** the Port of Brisbane are responsible for the ongoing maintenance of the TSHD Brisbane and as such there is no ongoing maintenance implications for the equipment.

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[1] This assumes the hopper will hold approximately 1,500m^3 of in-situ volume of sediment (total hopper capacity = 2,860m^3), with a two hour dredge cycle period (assuming offshore placement at the existing site) and a 10% downtime over the duration of the dredging. The rate also agrees with the latest maintenance campaign at Hay Point in 2010 where 216,070m^3 of material was dredged over 14 days, giving a rate of 108,035m^3/wk.

- **Sediment Trap:** there would be no ongoing maintenance implications for the equipment associated with the dredging. Bed levelling would be required to maintain the effectiveness of the sediment trap between re-establishment campaigns to prevent increased build-up of sediment in certain locations within the North Apron.

- **Fixed Position Jet Array:** the units would require regular maintenance, this is expected to be quarterly. The ongoing maintenance would have both cost and operational implications, as detailed in the relevant sections.

- **Drag Barring:** there would be no ongoing maintenance implications for the equipment associated with the drag barring as the vessel contractor would be responsible for this. This solution does require regular hydrographic survey to monitor progress through the course of the activity.

- **Propeller Wash Agitation:** there would be no ongoing maintenance implications for the equipment associated with the propeller wash agitation as the tug vessel contractor would be responsible for this. This solution would require regular hydrographic survey to monitor progress through the course of the activity.

5.2.4 Confidence

- **Maintenance Dredging:** there is a high level of confidence that this approach would be successful.

- **Sediment Trap:** there is a moderate to high level of confidence that this approach would be successful. There is some uncertainty as to the extent of bed levelling required to ensure roughly uniform siltation throughout the area.

- **Fixed Position Jet Array:** to date these systems have been installed at relatively sheltered estuarine environments, so there is some uncertainty as to their effectiveness in open coastal environments. The system is also untested in cyclonic conditions and so could require significant maintenance following an event.

- **Drag Barring:** this approach has successfully been adopted in the HPCT berths for the last 10 years and so there is a high level of confidence that this approach would be successful.

- **Propeller Wash Agitation:** this approach is relatively untested at Hay Point, but the analysis of historic bathymetric data has demonstrated that the sediment in the area is prone to potential erosion by propeller wash (RHDHV, 2016a). Therefore, there is a low to medium level of confidence that this approach would be successful. Field testing would be required to raise confidence levels and demonstrate that the approach is realistic. It would also allow a more accurate estimate of the frequency and duration required.

5.2.5 Legal Considerations

- **Maintenance Dredging:** ongoing approval will be required for any maintenance dredging, the nature of the approval is dependent on whether the dredged material is placed offshore or onshore. There are cost and risk implications associated with the approval requirements.

- **Sediment Trap:** approval will be required for the dredging associated with the sediment trap establishment and its ongoing maintenance. There are cost and risk implications associated with the approval requirements.

- **Fixed Position Jet Array:** it is expected that approval for the operational works associated with the jet array will be required.

- **Drag Barring:** no approval will be required for the drag barring.

- **Propeller Wash Agitation:** no approval will be required for the propeller wash agitation.

5.2.6 Comparative Costs

Comparative capital and operational cost estimates for the various solutions identified have been developed over a 20 year period. Note that net present value principals have not been applied for this initial feasibility assessment. As noted in the **Section 5.1**, maintenance dredging is the most suitable solution for managing the existing siltation at the port. As such, the cost estimates have been developed assuming that any existing maintenance dredging requirement is removed prior to the start of the 20 year period. The cost estimates are based on available information, with the specific basis of the cost estimates for each solution detailed in the following sections.

The total estimated costs provided for each solution also include any required maintenance dredging costs for other areas not maintained by the solution, allowing a direct comparison between the total costs for maintaining design depths at the Port of Hay Point over a 20 year period. It is important to note that these costs are for comparative purposes only and the confidence in the cost estimate varies between the solutions based on the information available. The costs do not include any allowance for obtaining necessary approvals, the associated cost implications of delays to approvals or any contingencies.

Maintenance Dredging

To develop cost estimates for the maintenance dredging an hourly cost for the TSHD Brisbane of $3,200 has been assumed. Based on the hourly cost and the assumed weekly production rate of 110,000 m^3 a cost of $4.89 per m^3 of maintenance material dredged has been calculated. As such, the cost of maintenance dredging for the existing requirement of approximately 200,000 m^3 would be around $1 million (not including for any over-dredging). No cost has been included for the mobilisation or de-mobilisation of the dredger as it is assumed that the TSHD Brisbane would undertake the works as part of its annual maintenance dredging trip to the Queensland Ports.

The ongoing cost of maintenance dredging is estimated to be as follows:

- Maintenance dredging of berths every two years = $365,000 per visit;
- Maintenance dredging of North Apron year four = $128,000;
- Maintenance dredging of North Apron year eight = $218,000; and
- Maintenance dredging of North Apron year 12 and onwards = $308,000 per visit.

The total estimated cost for the maintenance dredging required to maintain the design depths at the Port of Hay Point over 20 years is **$4.9 million**.

Sediment Trap

The establishment dredging required for the sediment trap is expected to have a lower weekly production rate relative to the maintenance dredging rate as the sediment will be more consolidated. As such it has been assumed that the production rate would be approximately 73,000 m^3/week, giving a cost of $7.30 per m^3 dredged. For the ongoing maintenance dredging required following the establishment dredging, a cost of 4.89 per m^3 has been assumed. A daily rate of $9,000 for the Pacific Conquest (or similar vessel) for bed levelling has been assumed for the costings along with a combined mobilisation and demobilisation cost of $10,000 per visit.

The cost of the sediment trap solution along with the required ongoing maintenance dredging of the berths is estimated to be as follows:

- Establishment dredging of the sediment trap = $1.17 million;
- Bed levelling for 14 consecutive days every five years over 20 years = $544,000;
- Ongoing maintenance dredging of the North Apron silt trap = $1.27 million;
- Maintenance dredging of berths every two years over 20 years = $3.65 million; and
- Total estimated cost for sediment trap solution over 20 years = **$6.6 million**.

Fixed Position Jet Array

As there are no existing fixed position jet array systems operational in Australia it is difficult to accurately ascertain costs. The costs have been developed based on the costs for a similar system detailed by Bryant and Moseley (2007) and scaled according to the requirements for the berths at the Port of Hay Point.

The cost of the fixed position jet array solution along with the required ongoing maintenance dredging of the North Apron is estimated to be as follows:

- Capital expenditure and installation of the system = $45.36 million;
- Estimated annual maintenance cost = $270,000 per year;
- Estimated annual electrical power costs = $380,000 per year;
- Estimated capital costs for maintenance after 10 years = $11.34 million;
- Maintenance dredging of the North Apron over 20 years = $1.27 million; and
- Total estimated cost for fixed position jet array solution over 20 years = **$70.9 million**

Drag Barring

The drag barring would utilise a similar vessel to the bed levelling detailed in the Sediment Trap Section and the costs have been assumed to be the same. Therefore, the cost of the drag barring solution along with the required ongoing maintenance dredging of the North Apron is estimated to be as follows:

- Annual cost for 24 days of drag barring and mobilisation/demobilisation = $276,000 per year;
- Total cost for drag barring of the berths over 20 years = $5.52 million;
- Maintenance dredging of the North Apron over 20 years = $1.27 million; and
- Total estimated cost for drag barring solution over 20 years = **$6.8 million**.

Propeller Wash Agitation

The cost for a tug vessel has been estimated to be $1,000 per hour, although it is possible that a reduced rate would be available to NQBP. Based on this assumption the cost of the propeller wash agitation along with the required ongoing maintenance dredging of the berths is estimated to be as follows:

- Annual cost of 20 days of tug usage for propeller wash agitation = $480,000 per year;
- Total cost for propeller wash agitation over 20 years = $9.6 million;
- Maintenance dredging of the berths over 20 years = $3.65 million; and
- Total estimated cost for propeller wash agitation option = **$13.2 million**.

The relatively high cost of the propeller wash agitation solution reflects the relatively high charge rate of the tug compared to a dredger relative to its production rate. A significantly lower cost option could be possible by promoting increased vessel movements (both tugs and bulk carriers) around the North Apron through the port operational procedure. This approach would not directly result in any increased costs (there could be some indirect costs due to additional tug time related to manoeuvring vessels around this area) but would require additional investigation to optimise the vessel movements required to limit siltation.

5.2.7 Greenhouse Gas Emissions

An assessment of the Greenhouse Gas (GHG) emissions from the key marine works (e.g. movement of marine vessels) and associated activities (e.g. consumption of purchased electricity) was made for each solution.

The GHG emissions assessment was undertaken in accordance with the internationally recognised methodology outlined in the GHG Protocol (WRI & WBCSD, 2015). 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 solutions, such as those associated with fossil fuel consumption by marine vessels during 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 solutions; 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 solutions. 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 only considered Scope 1 and Scope 2 emissions for each of the solutions over a 20 year period. The calculated GHG emissions for the various solutions are detailed in **Table 6**.

Table 6: Predicted GHG emissions.

Option	Scope 1 CO_2e Emissions over 20 Year Operational Period (Tonnes)	Scope 2 CO_2e Emissions over 20 Year Operational Period (Tonnes)
Maintenance Dredging	6,369	0
Sediment Trap	8,860	0
Fixed Position Jet Array	[2]	242,214
Drag Barring	21,454	0
Propeller Wash Agitation	23,640	0

Further details of the GHG assessment are provided in **Appendix B**.

[2] There are likely to be Scope 1 GHG emissions associated with the transport of infrastructure and staff during the construction phase of the jet array system. These are anticipated to be significantly less than the operational phase Scope 2 GHG emissions, and therefore were not calculated as part of this assessment.

5.3 Summary

A summary of the constraints, cost and GHG emission comparative assessment for the potentially feasible solution is provided in **Table 7**.

Table 7: Constraints analysis summary

Approach	Environmental Impacts	Operational Impacts	Ongoing Maintenance	Confidence	Legal Considerations	Cost over 20 years	GHG emissions over 20 years (CO_2e tonnes)
Maintenance Dredging	Low	Low	No	High	Yes	$4.9M	6,369
Sediment Trap	Medium	Low	Low	Medium - High	Yes	$6.6M	8,860
Jet Array	Low	Low	High	Low	Yes	$70.9M	242,214
Drag Barring	Medium	Medium	No	High	No	$6.8M	21,454
Propeller Wash Agitation	Medium	Low	No	Low - Medium	No	$13.2M	23,640

Table 7 indicates the following:

- Maintenance dredging results in the lowest GHG emissions and the lowest cost over the 20 year period, with a high confidence that it will be successful in maintaining the design depths at the port. However, maintenance dredging has approval requirements with associated costs and risks to consider;
- The sediment trap and drag barring options are considered potentially feasible solutions, although the GHG emissions for the drag barring is significantly higher than for the sediment trap and maintenance dredging solutions. Both have approval requirements with associated costs and risks to consider;
- The jet array solution is not considered feasible as it results in the highest emissions and costs and there is a low confidence that it would be successful; and
- The propeller wash agitation solution using a tug vessel is not considered feasible due to its relatively high cost and GHG emissions relative to maintenance dredging. However, managing the siltation in the North Apron by propeller wash agitation from a combination of tugs and bulk carrier vessels should be further investigated. This could be achieved by incorporating transit of this area into the port operational procedure which would not result in a significant increase in GHG emissions and as such could be a feasible solution with possible further benefits (cost and risk) due to the lack of a requirement for associated approvals.

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6 Maintenance Dredging Implications

This section provides details of how the solutions identified as feasible through the constraints, cost and GHG emission comparison influence the future maintenance dredging volumes at the Port of Hay Point. As detailed in **Section 5.1.1**, the ongoing maintenance requirement is expected to be:

- dredging of 75,000 m^3 from the DBCT and HPCT berths every two years; and
- dredging of the North Apron every four years.
    - after four years, dredging of 25,000 m^3;
    - after eight years, dredging of 45,000 m^3; and
    - from 12 years and onwards dredging of 65,000 m^3.

The total dredging volume over 20 years is estimated to be **1.02 million m^3**.

6.1 Sediment Trap

The sediment trap would only influence the North Apron area, the maintenance dredging requirements in the berths would not be expected to change due to this solution. The total dredging required for this option would be as follows:

- Establishment dredging of the sediment trap of 160,000 m^3;
- Maintenance dredging of the sediment trap over 20 years of 260,000 m^3; and
- Dredging of 75,000 m^3 from the DBCT and HPCT berths every two years.

The total dredged volume over 20 years is predicted to be **1.17 million m^3**. The benefit of this solution is that it reduces the frequency of maintenance dredging in the North Apron from every four years to every 10 years, but it does result in increased dredging requirements due to the establishment dredging of the trap and the potential requirement for ongoing maintenance of the siltation in the trap by bed levelling.

6.2 Drag Barring

The drag barring solution is aimed at preventing siltation in the HPCT and DBCT berths, but maintenance dredging would still be required in the North Apron. The total dredging required for this option would be as follows:

- Maintenance dredging of the North Apron every four years:
    - after four years dredging of 25,000 m^3;
    - after eight years dredging of 45,000 m^3; and
    - from 12 years and onwards dredging of 65,000 m^3.

The total dredged volume over 20 years is predicted to be **265,000 m^3**.

6.3 Propeller Wash Agitation

Targeted propeller wash agitation using a tug has been shown to not be realistic due to the comparative cost and GHG emissions relative to maintenance dredging. However, it is noted that propeller wash agitation could be adopted to manage siltation in the North Apron by using a combination of tugs and bulk carriers during operational movements rather than tugs specifically undertaking propeller wash agitation. This would involve changing the port operational procedures to promote vessels transiting this area. Further discussion with tug operators and pilots would be required as part of an optimisation study to determine feasible vessel transit options and define an optimised port operational plan.

In addition, to manage the limited volume of ongoing siltation in the departure channel, propeller wash agitation could be considered by redirecting the bulk carriers departing the Port of Hay Point along the southern side of the channel rather than down the centreline of the channel.

6.4 Exclusion

An alternative solution to those detailed would be to exclude the North Apron area from the declared depths of the rest of the apron and the departure channel. Further assessment would be required to ascertain the frequency that vessels use this area and it would also need to be discussed with the Harbour Master to determine if it was feasible. However, this would be a way of limiting future maintenance dredging in the North Apron, although some infrequent maintenance would be required to prevent the siltation reaching the north extent of the adjacent Apron area (this is likely to be beyond the 20 year period being assessed in this case). This approach would still require maintenance dredging, or a feasible siltation prevention solution, at the berths. As such, the total dredged volume required for this solution over 20 years is estimated to be **750,000 m^3**.

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7 Conclusions

This assessment has investigated possible solutions to avoid or minimise the future need for maintenance dredging at the Port of Hay Point. The study also considered approaches to manage the existing maintenance dredging requirement at the port and found that maintenance dredging is the only feasible solution.

The processes which drive the ongoing siltation at the Port of Hay Point have been considered along with a constraints, cost and GHG emission assessment to identify feasible solutions. Based on the findings of this study, the following conclusions can be made as to the future maintenance dredging requirements at the Port of Hay Point:

- maintenance dredging provides the most cost effective and lowest GHG emission solution, although there are cost and risk implications with the approval requirements. The maintenance dredging required over a 20 year period is estimated to be 1.02 million m^3;

- drag barring in the berths is a feasible solution to prevent an ongoing maintenance requirement in these areas. However, this solution is likely to be more expensive and result in higher GHG emissions than maintenance dredging. This solution would reduce the ongoing maintenance dredging requirement over a 20 year period by 750,000 m^3. As such, the maintenance dredging required over a 20 year period is estimated to be 265,000 m^3;;

- the study has demonstrated that propeller wash agitation by tugs is not a feasible solution for managing the siltation in the North Apron. However, it is recommended that this approach be further investigated through the port operational procedures to promote some tugs and bulk carriers transiting the North Apron. Following an optimisation study to define proposed changes to the port operational procedures a trial period with regular hydrographic survey (e.g. every 3-6 months) could be adopted to determine the long term feasibility of the approach. This approach is also recommended to manage the small ongoing siltation in the departure channel. This port operational procedure approach would have little to no cost or increased GHG emissions;

- it is possible to reduce the frequency of dredging required in the North Apron by deepening this area to act as a sediment trap. The solution reduces the frequency of the required maintenance dredging from every four years to every 10 years. However, it results in an increase in the maintenance dredge volumes of 160,000 m^3 over a 20 year period due to the initial establishment dredging required. As such, the maintenance dredging required over a 20 year period is estimated to be 1.18 million m^3;

- excluding the North Apron from the declared depth definition for the remainder of the Apron and Departure Channel is likely to prevent the requirement for future maintenance dredging of this area over a 20 year period and reduce maintenance dredging by 260,000 m^3. As such, the maintenance dredging required over a 20 year period is estimated to be 750,000 m^3. Further investigation is required to assess the actual usage of this area and to discuss the possibility with the Harbour Master to determine if this approach is realistic; and

- combining the drag barring with the exclusion approach or possibly the vessel agitation through operational procedures approach could result in no ongoing maintenance dredging requirement over a 20 year period. However, the assessment has indicated that the drag barring is more expensive and results in higher GHG emissions than the maintenance dredging of all the areas.

In addition, there is some uncertainty as to the effectiveness of the vessel agitation through operational procedures approach. A trial period would be required to assess its effectiveness.

8 References

Advisian, 2016. Comprehensive Beneficial Reuse Assessment, Port of Hay Point – Sustainable Sediment Management Assessment for Navigational Maintenance: Marine Sediment Properties Assessment. 23rd March 2016.

AECOM, 2016. Hay Point sediment dynamics. Prepared for North Queensland Bulk Ports, January 2016.

Bryant, J.T. and Moseley, M.D., 2007. A potential alternative to berth maintenance dredging. ASCE Ports 2007.

Carter, R.M., McCave, I.N., Richter, C., and Carter, L., Shipboard Party, 1999. Leg 181 summary: southwest Pacific paleoceanography. In: Proceedings of the Ocean Drilling Program, Initial Reports, vol. 181 .

Kroon, F., Kuhnert, K., Henderson, B., Wilkinson, S., Kinsey-Henderson, A., Brodie, J., Turner, R., 2012. River loads of suspended solids, nitrogen, phosphorus and herbicides delivered to the Great Barrier Reef lagoon. Marine Pollution Bulletin. 65, 167–181.

Lewis, S., Olley, J., Furuichi, T., Sharma, A., Burton, J., 2014. Complex sediment deposition history on a wide continental shelf: implications for the calculation of accumulation rates on the Great Barrier Reef. Earth Planetary Science Letters 393:146–158.

PIANC, 2008. Minimising Harbour Siltation. Report No. 102-2008. World Association for Waterborne Transport Infrastructure, Brussels, Be.

RHDHV, 2016a. Hay Point Port: Bathymetric Analysis and Modelling. Prepared for North Queensland Bulk Ports Corporation, February 2016.

RHDHV, 2016b. Hay Point Bathymetric Analysis: Predictive Model. Prepared for North Queensland Bulk Ports Corporation, March 2016.

Sullivan, N., 2000. The use of agitation dredging, water injection dredging and sidecasting: results of a survey of ports in England and Wales. Terra et Aqua, No. 78, March 2000.

USACE, 2003b. Potential Methods for Reducing Shoaling in Harbors and Navigation Channels, ERDC/CHL CHETN-XIV-6, June 2003

USACE, 2003a. Lessons Learned from Existing Projects on Shoaling in Harbors and Navigation Channels, ERDC/CHL CHETN-XIV-5, June 2003

Velasco, V.V., 2000. Evaluation and cost comparison of anti-siltation systems and traditional dredging methods. The University of Hawaii, December 2000.

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

Appendix A: Strategies for Minimising Siltation

A1 Keep Sediment Out

A1.1 Stabilise sediment sources

Effective catchment management practices that address soil erosion rates in upstream areas can reduce sediment supply to downstream ports and harbours where an increase in siltation and dredging requirements would otherwise arise (PIANC, 2008). This may include sustainable agricultural practices, creation of vegetated buffer strips, reforestation and installation of eroded soil interception systems.

This approach is most relevant to non-tidal ports or ports in zones of estuaries located landward of the turbidity maximum, rather than coastal ports and harbours where riverine sediments do not significantly contribute to siltation.

A1.2 Diverting sediment-laden flows

When a natural river carries and deposits significant quantities of sediment in a harbour or navigation channel, diverting the river away from these areas may be effective, depending on site conditions (USACE, 2003a). Detailed numerical modelling and data analysis are essential prior to implementing such activities. The environmental implications of changing the mixing characteristics and sedimentary processes of an estuary must also be considered.

Case studies of river diversion to address siltation issues include:

- Charleston Harbour, South Carolina. Freshwater flows through Cooper River and into the harbour were partially diverted to Santee River, reducing port and channel siltation by more than 70% (Teeter, 1989).
- Mission Bay, California, where separation of river flow from the harbour entrance reduced shoaling of navigation channels.

A1.3 Trapping sediment before it enters port

Trapping sediment before it enters a sensitive area is one of the most effective methods for managing sediment deposition (USACE, 2003a). Sediment traps can function efficiently only when the sediment is funnelled effectively towards the trap, and the location of the trap has been determined carefully.

The sediment trap itself must be dredged periodically to keep it functional. While the volume to be dredged from the trap usually offsets any reduction in shoaling within the port, key benefits of this approach include:

- no disturbance to navigation due to shoaling in the port;
- reduction of overall dredging costs due to less frequent dredging; and
- opportunities to locate the trap close to dredged material disposal areas.

The sediment trapping efficiency depends on the size and depth of the trap, mode of sediment transport (bed load or suspended load), and sediment particle size. For example, sand traps are efficient in catching bed load transport of relatively coarse sediment, while larger and deeper traps may be required for catching suspended sediments.

Sediment traps are common features of port and harbour management across the world. Some examples of sites where sediment traps have been successfully implemented include:

- Tidal Elbe River, Germany, a few kilometres downstream of the Port of Hamburg, where a sediment trap was constructed in 2008, spanning around 2 km in length across a 300 m wide navigation channel with a depth of 2 m (PIANC, 2015). The trap was observed to absorb maximum siltation rates in summer when freshwater discharges were low, and works effectively if it is maintained once a year in the spring. Annual maintenance dredging requirements from the sand trap are in the order of 1 million m^3 of fine sediments.
- Visakhapatnam Harbour, India (Parchure, 1978), where sediment traps have been constructed for both the inner and outer harbours.
- Channel Islands Harbour, California, where a sand trap located near the harbour entrance has functioned well as designed by trapping the bulk of coastal littoral drift sediment (Hobson, 1982). Regular maintenance dredging of the trap of around 770,000 m^3/year on average is necessary to maintain sand supply to downdrift beaches (BEACON, 2009). In 2014-15, around 1.7 million m^3 of trapped sand was dredged and placed on Hueneme Beach for renourishment purposes[3].
- Carolina Beach, North Carolina, where the sediment trap was initially located too close to the main flow through the inlet to be completely effective, and was subsequently located seaward of the main channel to enhance its overall sand trapping ability.
- Savannah Harbour, Georgia, where a sediment trap worked in conjunction with an upstream tide gate structure to attract sediments from the navigation channel into the trap, which reduced shoaling in the navigation channel by 30% (USACE, 2003b).

A1.4 Blocking sediment entry

Physical barriers to block the entry of sediment to ports and harbours include silt curtains, sills and entrance closure structures, as discussed below.

<u>Silt Curtains</u>

Silt curtains provide a physical barrier to sediment entering an area of interest (USACE, 2003a). They can be effective in reducing siltation in semi-closed berthing areas with limited flushing (USACE, 2003b). For areas where bed load transport rates are high, partial height curtains can be used to exclude the sediment-laden bottom water from a berthing area while still allowing normal tidal exchange to occur at the surface. These curtains can be pneumatically controlled for raising and lowering to accommodate navigation. However, pneumatic barriers are typically expensive options due to their maintenance requirements and the periodic raising and lowering. Pneumatic silt curtains have been implemented at Mare Island Naval Shipyard, California, and have shown great potential in reducing the Navy's maintenance dredging program.

In general, silt curtains are rarely used in ports and harbours because they are only partially effective and they also hinder navigation (USACE, 2003a). For example, numerical modelling investigations of siltation

[3] Source: City of Port Hueneme, available: http://www.ci.port-hueneme.ca.us/index.aspx?nid=1000, viewed 26/5/16.

in the access channels at Antwerp Harbour, Belgium, concluded that a silt screen was not applicable to the site because of possible frequent damage by ships (Pettweis and Sas, 1999).

Sills

The construction of sills across entrances can be effective in reducing siltation rates in semi-enclosed harbours (PIANC, 2008). Sills are also used to construct half-tide harbours in areas characterised by high tidal ranges (e.g. Dillingham Harbour, Alaska). They are usually constructed using rock with a crest elevation that is low enough to permit navigation through the entrance while forming a physical barrier to bed load sediments. The sill reduces the cross-sectional area of the harbour mouth, thereby reducing stagnation effects and entrainment rates (PIANC, 2008).

Entrance Closure

The ocean can be the main source of sediment entering a navigational channel or harbour, either as bed load or suspended load. For small harbours (e.g. catering exclusively for recreational or fishing vessels), intermittent closure of the inlet to block sediment entry may be feasible, although caution is required to prevent shoaling outside and choking of the inlet during periods of closure (USACE, 2003a). Furthermore, this option only works for small channels where temporary closure and periodic reopening by means of a movable structure is feasible.

For example, Dillingham Harbour, Alaska, is characterised by diurnal tidal ranges of 5 to 6 m with tidal currents exceeding 3 m/s which results in high concentrations of suspended sediments and associated shoaling in the half-tide harbour (USACE, 2003b). An entrance channel closure structure was considered for this location, consisting of a 15 m wide steel structure with a crest level of 1.2 m above the mean lower low water level constructed across the entrance channel to close off the basin from the silty waters of the adjacent bay during winter months. It was estimated that this structure would reduce annual siltation by 60%. However, it was not constructed due to practical difficulties (USACE, 2003a).

For sites with two entrances, closure of one entrance may be effective in encouraging flow patterns that reduce siltation rates. For example, Neustadt Harbour in the Port of Bremen, Germany, was constructed in the 1960s with two entrances, and was subject to high siltation rates due to flood-tide current patterns as indicated in **Figure A1** (top). The harbour channel entrance was closed in 1992, which reduced flow velocities and siltation rates within the harbour as indicated in **Figure A1** (bottom). The closure eliminated the turning basin eddy which was previously responsible for siltation rates exceeding 2 m/year (PIANC, 2008).

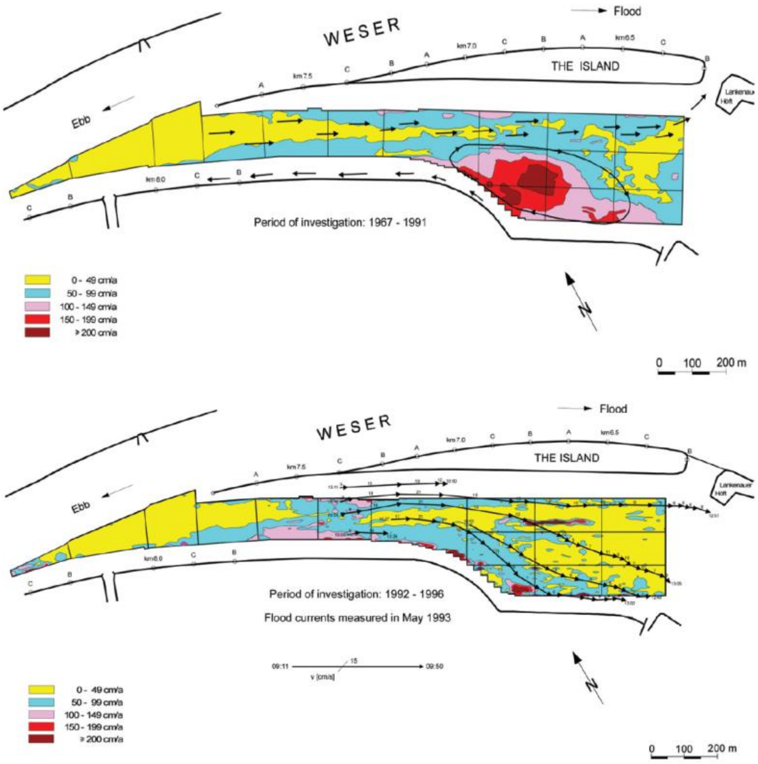

Figure A1: Flow and siltation patterns at Neustadt Harbour before (top) and after (bottom) closure of the Harbour Channel (Source: Nasner et al, 1996)

A1.5 Habitat Creation

The artificial creation of habitat such as seagrass, saltmarsh or mangroves can help to stabilise bed sediments and promote accretion in areas away from the ports. In theory this could reduce potential resuspension of sediment in these areas and therefore reduce siltation in a port or harbour.

This approach also has the potential to provide environmental benefits, including increasing local fish populations and enhancing biodiversity of marine flora and fauna species. However, limitations of this approach include:

- very large areas of new habitat would be required to measurably reduce siltation in adjacent port areas;
- generally applicable to shallow subtidal or intertidal areas only, rather than relatively deep waters that are commonly located within and adjacent to ports and harbours; and,
- the ephemeral nature of some species (e.g. seagrasses) would limit their capacity to provide continuous benefit to the adjacent port/harbour.

There is no available scientific literature available to demonstrate the potential reduction in siltation due to habitat creation, as such there is considerable uncertainty with this approach.

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A2 Keep Sediment Moving

A2.1 Structural solutions to train natural flows

Training structures are used worldwide to help prevent deposition and help keep sediment in suspension. Flow training is a means of re-establishing a dynamic equilibrium between flow conditions and channel depth in order to minimise siltation (PIANC, 2008). This approach could be applicable in a range of environments but a detailed understanding of the existing tidal currents and sediment transport pathways would be required to determine if the approach would be suitable.

Structural solutions could include training walls at river entrances, open coast breakwaters, dikes and sills in rivers, and specialised training structures such as curved deflector walls. These options are discussed below.

Training Walls

Training walls are often constructed at the mouth of estuaries to stabilise the entrance location with respect to the shoreline and to reduce shoaling of the entrance channel such that a navigable entrance can be maintained. While sand is captured on the updrift side of the structure, corresponding erosion of the shoreline occurs immediately downdrift. Sand bypassing arrangements can be made to prevent erosion on the downdrift side.

For example, the Tweed River entrance is trained by two rock walls that were constructed with the objective of maintaining safe navigation primarily for fishing and recreation vessels. A net northwards littoral transport rate of around 500,000 m^3/year resulted in substantial accretion against the southern training wall and significant erosion along the southern Gold Coast beaches. Sand bypassing operations commenced in 2001 to restore and maintain the amenity of these beaches, and to reduce shoaling in the entrance. Periodic maintenance dredging of the entrance bar is undertaken in conjunction with the bypassing operations to maintain safe navigation. An overview of the Tweed River entrance works is provided in **Figure A2**.

Figure A2: Entrance training walls and sand bypassing system at Tweed River, NSW (Image source: TRESBP, 2016)

It may be possible to implement effective flow training works of limited extent at some sites. A good example involves a flow training structure crossing intertidal mudflats at Kumamoto, Japan, which is characterised by a spring tidal range of around 4.5 m and high potential for siltation (PIANC, 2008). To minimise siltation, the main port facilities were sited offshore closer to naturally deep water with a shore access bridge provided (**Figure A3**). In 1991, 2 km of fairway walls were constructed, comprising 1 to 1.5 m high reverse T-shaped concrete blocks, which were estimated to reduce siltation by 23%.

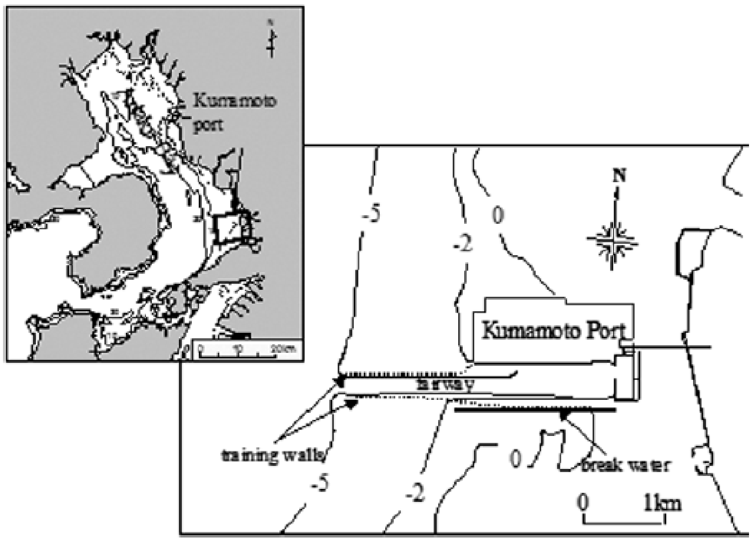

Figure A3: Kumamoto Port and training walls
(Source: PIANC, 2008)

Potential impacts of large scale-training works may include the following (PIANC, 2008):

- changes to tidal range, which typically increases upstream;
- changes to velocity conditions altering sediment transport patterns, often resulting in increased siltation upstream and (sometimes) downstream;
- the zone of salinity intrusion migrating further upstream, and other water quality impacts;
- large scale and long-term changes in estuary morphology;
- loss of sub-tidal, intertidal and sub-aerial habitat.

Furthermore, long-term impacts may arise because trained systems often take prolonged periods (possibly decades to centuries) to establish a new equilibrium between flow conditions and channel depth (PIANC, 2008), e.g. Swansea Channel, NSW. Initial success (e.g. self-scouring channels) may be followed by a need to extend the training works. For example, the training walls in the Mersey estuary, United Kingdom, have a history of being extended and raised in response to increased siltation despite significant ongoing maintenance dredging and offshore disposal (PIANC, 2008).

Finally, it is important to evaluate the financial feasibility of flow training works as it is not uncommon to find such works are more expensive than dredging options (PIANC, 2008). In addition, if the training walls do not perform as expected over the long-term it can be very expensive to remove the works at a later date.

Breakwaters

Breakwaters are generally constructed with the objective of providing protection against waves to permit safe navigation to a port or harbour, and loading/unloading operations at berths (USACE, 2003a). They are also provided for sediment management, which may include functioning as a barrier for diverting sediment. This approach relies on there being well defined sediment transport pathways and the sediment being transported primarily as bed load. In environments where the siltation in the port areas is largely due to suspended sediment settling out this approach will not be effective.

<u>Dikes and Sills</u>

Dikes are training structures with a crest elevation above the water level, usually constructed with earth or rubble, typically for applications in rivers, channels and fairways (PIANC, 2008). They are commonly placed along the sides of a dredged channel where the natural waterway is wider than the channel, which reduces the effective hydraulic width as indicated in **Figure A4**. Confining flows within a narrower channel increases velocities, thereby reducing siltation. Flow parallel structures can also keep sediment in the surrounding banks and mudflats from entering the channel.

Dikes can also be constructed perpendicular or obliquely to the shore, similar to a groyne field in coastal environments. Indeed, it may be more economical to use a series of short, shore-normal dykes located in relatively shallow areas near the water edge, rather than a long continuous dike located in relatively deep water constructed parallel to a dredged channel (PIANC, 2008).

In addition to addressing channel shoaling, dikes have also been used to provide bank protection against erosion, sand bar stabilisation, and to improve flow patterns (USACE, 2003a). Barrier dikes have also been used to separate and divert sediment-laden river flows to address siltation issues in navigation areas, e.g. Gastineau Channel, Alaska and Colorado River, Texas (USACE, 2003a).

Sills are training structures with a crest elevation below the water surface (PIANC, 2008). Sills are preferred over dikes for economic reasons when it is possible for a submerged structure to sufficiently reduce the flow area in a channel so as to eliminate siltation. However, for sites where current velocities approach the dredged channel obliquely and the channel is surrounded by relatively shallow mud flats, it is normally preferred to use dikes rather than sills because water flowing over the sills can carry sediment-laden water from the mud flats into the channel.

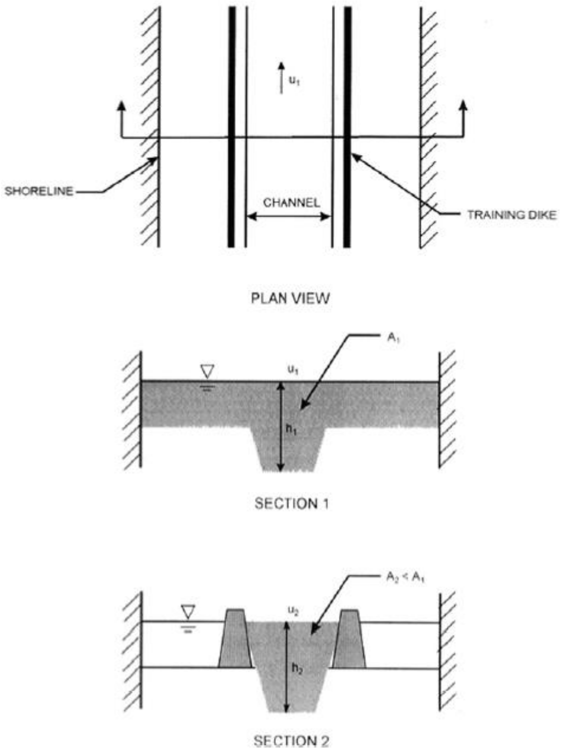

Figure A4: Flow area reduction using training dikes
(Source: PIANC, 2008)

There are innumerable examples of dikes and sills throughout the world, mostly in riverine environments. It should be noted that their design typically requires use of detailed physical or numerical modelling studies to ensure they reduce siltation rather than increasing the trapping efficiency of the area and therefore increasing siltation (USACE, 2003b).

Large scale training works have been constructed at the mouth of the Yangtze River estuary, China, for the purpose of training tidal flows to reduce maintenance dredging volumes for a proposed 75 km long shipping channel (PIANC, 2008). Several kilometres of training walls have also been constructed in the Outer Weser, Germany, which were first built in 1929 and have successfully confined flows to the main channel and produced a deepened fairway suitable for navigation of large vessels (PIANC, 2008).

Current Deflector Walls

A current deflector wall (CDW) is a fixed vertical-walled structure with a curved wall that extends throughout the water column (USACE, 2003b). The objective of a CDW is to eliminate eddy currents that cause shoaling, so it is important to distinguish eddy-generated problems that make such a structural solution feasible (USACE, 2003b).

The CDW typically comprises three parts as shown in **Figure A5**: a curved training wall, a channel between the training wall and shoreline, and a sill sited at the downstream end of the wall (PIANC, 2008). The wall curvature gives rise to limited flow separation off the wall face and pushes the mixing layer into the channel rather than the entrance. The sill intercepts high concentrations of suspended sediment near the bed as described in **Section A1.4**. Finally, the channel between the training wall and shoreline facilitates tidal filling of the entrance with relatively clear water due to the presence of the sill.

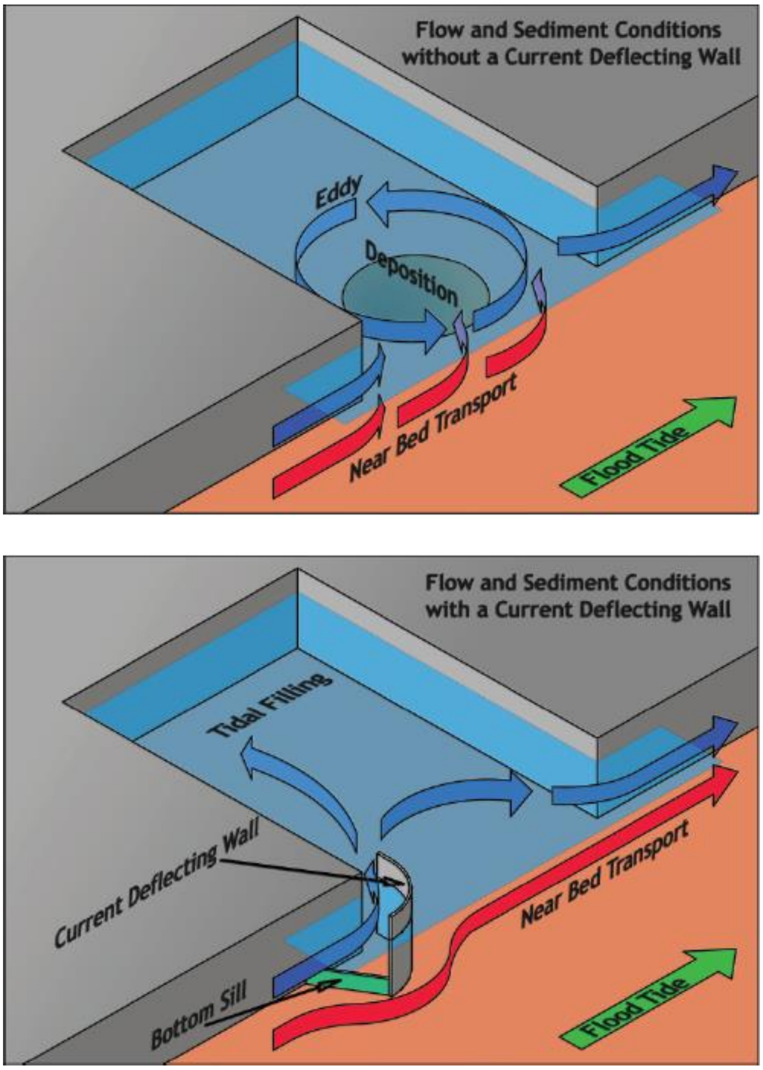

Figure A5: Flow/sediment conditions with a CDW (top) and without a CDW (bottom)
(Source: Hofland et al, 2001)

The CDW option has been successfully implemented at Kohfleet Harbour, Port of Hamburg, Germany as shown in **Figure A6** (USACE, 2003b). The site is tidal but is located around 80 km upstream of the entrance to the Elbe estuary. The CDW was constructed in 1990, and has eliminated eddy formation, improved navigation and reduced shoaling by around 40% (USACE, 2003b).

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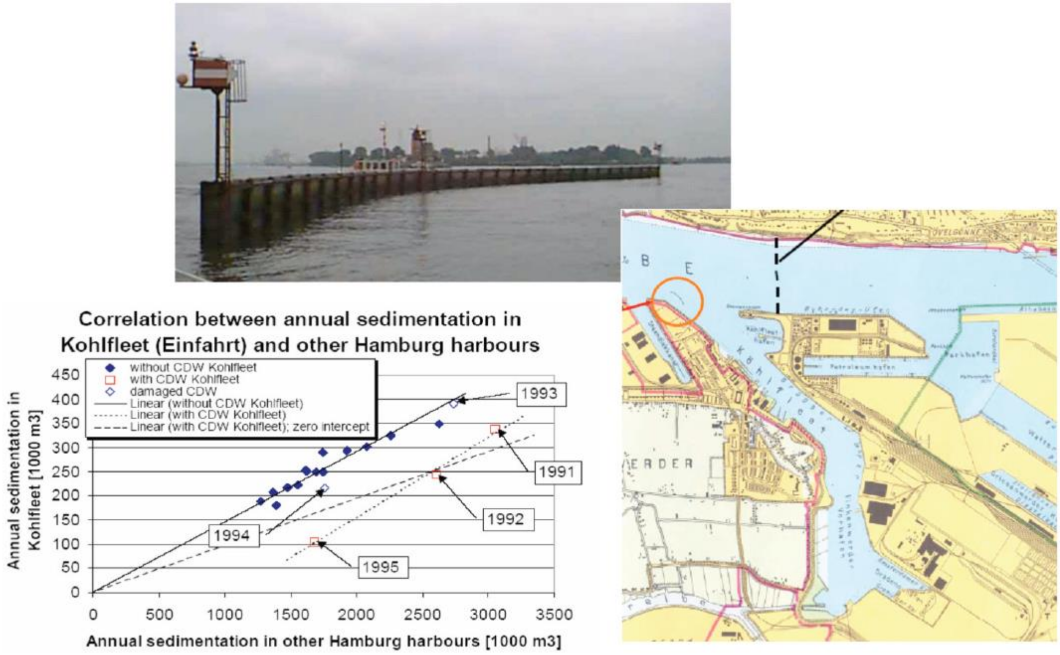

Figure A6: Port of Hamburg Current Deflector Wall
(Source: Kuijper et al, 2005)

A2.2 Devices to increase bed shear stresses

This approach aims to minimise the time that deposited material remains on the bed by artificially increasing the bed shear stress and therefore promoting resuspension. The bed material can be agitated by a variety of ways including hydraulic jets, vortex foil arrays and mechanical agitators, as discussed below. The material would typically be resuspended during a certain stage of the tide to allow the tidal currents to remove sediment from the area. This approach is aimed at replicating the natural resuspension which would occur if the dredged areas were not present; as such it does result in a local increase in turbidity. The approach is typically adopted in berths and harbours and is not usually feasible in aprons or channels.

Hydraulic Jets

Scour jet arrays consist of a series of underwater jets powered by standard water pumps, and are normally designed to scour bottom areas immediately adjacent to a deep-draft berth as indicated on **Figure A7** (PIANC, 2008). Scour jets are typically deployed adjacent to a berth face and are usually operated only during certain stages of the tide, e.g. during ebb tides to ensure there is sufficient current to transport the sediment away from the area and promote sediment deposition downstream of the site. The strong currents that typically act adjacent to a berth wall carry the suspended sediments away from the berthing area once they are suspended by the jet pumps. A trial scour jet system was installed at the Mare Island Naval Shipyard, California, and was found to be effective.

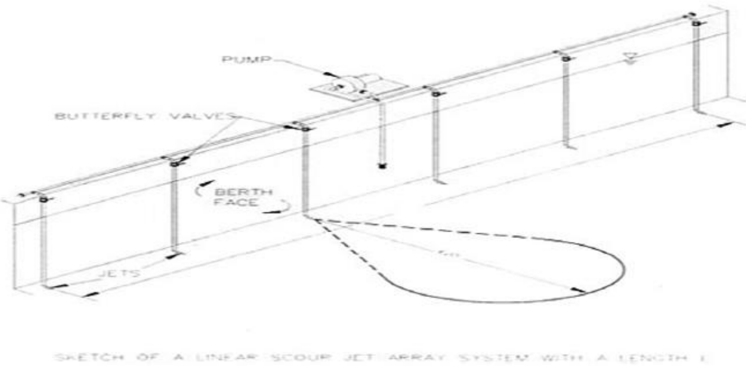

Figure A7: Typical scour jet array
(Source: PIANC, 2008)

Propeller jets are similar to scour jets but use propeller action rather than water pressure (PIANC, 2008). The propeller action causes water movement to resuspend bed sediments. Both propeller jets and scour jets were installed at Grays Harbour, Washington, which were designed to mobilise freshly deposited muds which can deposit at rates in excess of 3 m per year. The jet systems have been successful at this location, eliminating the need for dredging at the berth (PIANC, 2008).

Propeller Wash

Powerful vessels such as tugs and large, deep draft cargo vessels can result in high bed current speeds from their propeller wash. As such, propeller wash from vessels is also an approach which can be used to limit the amount of sediment that settles in the area of interest. For example, a specific vessel was built for this purpose in the Dart Harbour, UK, where they remove between 150 and 1,000 wet tonnes of silt and clay from the harbour every year (Sullivan, 2000). Propeller wash agitation can also be performed by tugs with a deflector plate behind the propeller, thereby directing the propeller wash to the bed and increasing the resultant bed currents and therefore the amount of sediment resuspended. This approach would require the agitation vessel to periodically transit areas where siltation is known to occur to resuspend the bed sediment as would occur naturally. Recent analysis of historic bathymetric surveys at the Port of Hay Point has shown that propeller wash erosion has occurred in the apron and departure channel and as such this approach is expected to be potentially feasible at the Port of Hay Point.

Vortex Foil Arrays

A vortex foil array device consists of a series of underwater foils similar in cross-section to aeroplane wings which are moored immediately above the bed (USACE, 2003b). They are designed to reduce siltation at berthing and approach areas exposed to moderate currents where fine bed sediments occur. An indicative sketch of a vortex foil array system is provided in **Figure A8**. Each delta-shaped foil is buoyant, with tidal currents flowing past the foil creating vortices that shed from the foil’s trailing edge, locally eroding the bed and creating a self-scouring shipping channel (PIANC, 2008). Suspended sediment is carried out of the berthing area by tidal currents.

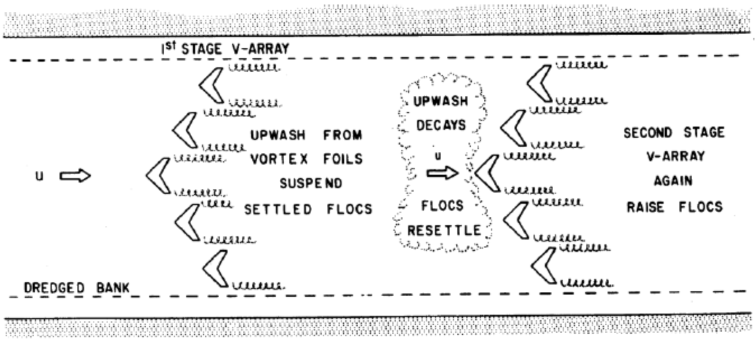

Figure A8: Indicative sketch of vortex foil array system
(Source: PIANC, 2008)

This approach was validated through field tests at the Mare Island Naval Shipyard, California, but the concept was fundamentally flawed (PIANC, 2008). The bed would need to be lowered prior to installation to ensure that the tops of the foils became the limiting/target depth. Such permanent installations would create challenges to ship masters and harbour pilots, and they would need to be removed each time any dredging is required (e.g. in gaps between or alongside the wings). Furthermore, the foils could become buried during significant episodic suspension events, such as during major floods or cyclonic events), which may render maintenance problematic.

Mechanical Agitators

Activities such as drag barring and to some extent bed levelling consist of mechanically disturbing the bed sediment by using a large bar, resulting in some resuspension of the bed sediment which is subsequently transport away from the area of interest by the currents (USACE, 2003a). This approach requires a relatively strong tidal current to ensure the resuspended material is transported away from the original area of siltation.

Mechanical bed levelling has historically been adopted in the HPCT berths at the Port of Hay Point. As a result of the bed levelling there has been limited ongoing siltation in the berths, with the berths maintaining their design depths with no recent maintenance dredging required.

A2.3 Methods to reduce sediment flocculation

This approach is aimed at adopting structural designs for wharfs and harbour walls which reduce turbulence and therefore flocculation of suspended sediment particles. For example, solid wharf walls instead of pile-supported wharfs tend to limit the capacity for flocculation and subsequent deposition to occur adjacent to berths. There is limited direct evidence to demonstrate the effectiveness of this solution, and given the likely high costs and operational impacts it is not thought to represent a realistic solution to reduce siltation in most cases.

A3 Keep Sediment Navigable

A3.1 Passive Nautical Depth

For sites where bed sediments comprise fine silts and clays, a layer of fluid mud can develop near the bed. In general, large deep draught vessels can safely navigate through fluid muds, and the depth of this layer can be included in the overall navigable depth. This is referred to as nautical depth, which can be defined as the distance from the water surface to a given wet density, typically in the range of 1,100 to 1,300 kg/m^3.

For example, extensive testing in Rotterdam and Antwerp harbours demonstrated that vessels can safely navigate through layers of fluid mud more than 1.8 m thick when the wet density is less than 1,200 kg/m^3 (Johnson et al., 2010). Based on this the seabed is described on navigation charts as being where the wet density is more than 1,200 kg/m^3. The Port of Rotterdam has implemented the nautical depth approach since the 1970s, and the port has never had to close to deep draught vessels since (PIANC, 2008).

Other ports that have adopted the nautical depth approach include Bangkok (Thailand), Zeebrugge (Belgium), Yangtze (China), Avonmouth (UK), Dunkirk and Bordeaux (France), and Emden (Germany) (PIANC, 2008).

Adopting the nautical depth approach limits the amount of dredging that would otherwise be required. Dredging the fluid mud layer, also known as “black water”, is both inefficient and unnecessary (PIANC, 2008). Furthermore, applying a nautical depth can also reduce siltation rates in cases where the dredged depth is reduced relative to the morphological equilibrium depth (PIANC, 2008).

This approach could be applicable in some areas of ports with high siltation rates and where the siltation is predominantly fine silt and clays (typically only localised areas of any port). In areas where the deposited sediment is made up of coarser material this approach is not applicable. However, this approach will disturb the fluid mud deposits and result in localised turbidity plumes. Monitoring of pilot studies would be required to determine if the frequency and intensity of these plumes pose a greater risk to local environmental values compared to the plumes resulting from periodic maintenance dredging.

A4 References

Beach Erosion Authority for Clean Oceans and Nourishment (BEACON), 2009. *Coastal Regional Sediment Management Plan*, Final Report, January 2009

Hofland, B., Christiansen, H., Crowder, R.A., Kirby, R., van Leeuwen, C.W. & Winterwerp, J.C., 2001. The Current Deflecting Wall in an estuarine harbour. *Proceedings of the XXIV IAHR Congress*, Beijing, pp 242-250.

Kuijper, C., Christiansen, H., Cornelisse, J. & Winterwerp, J.C., 2005. Reducing harbour siltation. Part II: Application to Parkhafen, Hamburg. ASCE, Journal of Waterways, Port, Coastal & Ocean Engineering, Nov/Dec

Nasner, H., Pieper, R. & Torn, P., 1996. Influence of the Closure of One Entrance to the Neustadt Harbour in Bremen. *Proceedings 11th International Harbour Congress,* Antwerp.

Parchure, T.M., 1978. Movable bed model studies for Visakhapatnam outer harbor project. *Proceedings, 47th Annual Research Session of Central Board of Irrigation and Power*. Poona, India.

Pettweis, M. and Sas, M., 1999. On the siltation of mud in access channels to the Harbor of Antwerp, *PIANC Bulletin No. 101*. Permanent International Association for Hydraulic Research, Brussels, Belgium: pp 53-58.

PIANC, 2008. *Minimising Harbour Siltation*. Report No. 102-2008. World Association for Waterborne Transport Infrastructure, Brussels, Be.

PIANC, 2015. *Anti-Siltation Systems for Marinas and Yacht Harbours*. Report No. 130-2015. World Association for Waterborne Transport Infrastructure, Brussels, Be.

Sullivan, N., 2000. The use of agitation dredging, water injection dredging and sidecasting: results of a survey of ports in England and Wales. Terra et Aqua, No. 78, March 2000.

Teeter, A.M., 1989. *Effects of Cooper River rediversion flows on shoaling conditions at Charleston Harbor, Charleston, South Carolina*. Technical Report HL-89-3. Vicksburg, MS: US Army Engineer Waterways Experiment Station, Hydraulics Laboratory

Tweed River Entrance Sand Bypassing Project (TRESBP), 2016. NSW Government, accessed 29 May 2016, <http://www.tweedsandbypass.nsw.gov.au/>

USACE, 2003a. *Lessons Learned from Existing Projects on Shoaling in Harbors and Navigation Channels*, ERDC/CHL CHETN-XIV-5, June 2003

USACE, 2003b. *Potential Methods for Reducing Shoaling in Harbors and Navigation Channels*, ERDC/CHL CHETN-XIV-6, June 2003

Appendix B: Greenhouse Gas Emissions' Assessment

Note

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Industry & Buildings

To:	Andrew Symonds (Royal HaskoningDHV)
From:	Joe Parsons & Charles Haine (Royal HaskoningDHV)
Date:	28 June 2016
Our reference:	I&BN001D01_PB5694
Classification:	Project Related

Subject: **Sustainable Sediment Management Assessment for Navigational Maintenance, Port of Hay Point: Greenhouse Gas Emissions' Assessment**

1 Introduction

North Queensland Bulks Port Corporation (NQBP) is undertaking a long-term strategic assessment for the ongoing management of marine sediments at the Port of Hay Point. The Port of Hay Point is located on the central east coast of Queensland, approximately 15 kilometres to the south of Mackay.

Dredging is required as part of an ongoing maintenance programme for its two operational export terminals: the Dalrymple Bay Coal Terminal (DBCT) and the Hay Point Coal Terminal (HPCT). Royal HaskoningDHV was appointed by NQBP to investigate possible solutions to avoid or minimise the future need for maintenance dredging at the Port of Hay Point ('the Port'). As part of the preliminary feasibility assessment four potentially feasible solutions were identified as well as ongoing maintenance dredging. This technical note details the assessment of the Greenhouse Gas (GHG) emissions emitted from the key marine works (e.g. movement of marine vessels) and associated activities (e.g. consumption of purchased electricity) for each option.

2 Legislation

The United Nations Framework Convention on Climate Change (UNFCCC) was ratified by Australia in 1992, and adopted in March 1994. Australia ratified the Kyoto Protocol in March 2008 which commits State Parties to reduce GHGs through a series of emissions' targets.

The Australian Government Department of the Environment publishes Australia's National Greenhouse Accounts to meet Australia's commitments adopted under the UNFCCC and tracks progress against their Kyoto Protocol targets. The National Greenhouse Account emissions are estimated using methods provided by the Intergovernmental Panel on Climate Change (IPCC). The Department of the Environment provides country-specific methodologies and Emissions Factors (EF), which are consistent with the IPCC guidelines.

Australia's total GHG emissions, excluding the land use, land use change and forestry (LULUCF) sector were estimated to be 541.9 million tonnes (Mt) of carbon dioxide equivalent[1] (CO_2e) in 2013. This was a

[1] Expressed by parts per mission by volume (ppmv), the terms carbon dioxide equivalent (CDE) and equivalent carbon dioxide (CO_2e and CO_2eq) are two measures for describing how much global warming a given type and amount of GHG (e.g. methane, nitrous oxide) may cause. A calculation uses the functionally equivalent amount or concentration of CO_2 as the 'reference' and is considered to be more accurate than using only CO_2. These additional GHG emissions have a different global warming potential (GWP) to CO_2, i.e., CH_4 emissions are 25 times the GWP of CO_2 and N_2O emissions 298.

decrease of 7.8Mt, or 1.4% on net emissions from 2012, and an increase of 26.5% (113.6 Mt CO_2e) from 1990 (i.e. base year) levels[2].

3 GHG Assessment Methodology

3.1 Project Boundaries

The boundary for the GHG emissions' assessment for each option was determined to include the:

- Journey that each marine vessel would make to travel to and from the Port of Hay Point;
- The usage of each marine vessel required as part of the options; and
- The usage of any marine infrastructure required as part of the options.

GHG emissions from onshore infrastructure, and staff travelling to the Port of Hay Point via road vehicle were not accounted for in the GHG assessment (see **Section 3.4**).

3.2 The Three Scopes in GHG Emissions Assessment/Footprinting

The GHG emissions assessment was undertaken in accordance with the internationally recognised methodology outlined in the GHG Protocol[3]. The GHG Protocol defines three groups of GHG emissions that arise from an organisation's operational entity:

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

This GHG assessment considered only Scope 1 and Scope 2 emissions from each of the options over a 20 year operational life. The four options along with ongoing maintenance dredging are discussed in the following sections.

3.3 Options

3.3.1 Option 1: Maintenance Dredging using the THSD Brisbane

It has been assumed that the trailing suction hopper dredger (TSHD) 'Brisbane' would be used to undertake the maintenance dredging at the DBCT and HPCT berths as well as at the North Apron. It has been assumed that the TSHD Brisbane would be travelling from the Port of Gladstone to the Port of Hay

[2] Australian Government (2015); Department of the Environment, National Inventory Report, Volume 1, The Australian Government Submission to the United National Framework Convention on Climate Change, Australian National Greenhouse Accounts, May 2015

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

Point and then on to the Port of Townsville for each visit, with half of this overall travel distance included in the GHG emission calculations. It has been assumed that the dredger would be working for five days every two years to remove siltation from the berths and for between 1.5 and four days for the North Apron. During this maintenance dredging exercise, the following assumptions were made:

- 50% of the time the vessel is dredging, 50% of the time the vessel is transiting to and from the material placement site;
- During cruising periods, including travelling to the Port of Hay Point and to the placement site, the THSD Brisbane was assumed to operate engines at 65% of power; and
- During the dredging period, it was assumed that the engines operated at 31% of full power, and the pumps would operate at full capacity.

3.3.2 Option 2: Sediment Trap

For both the establishment dredging and ongoing maintenance dredging required for the sediment trap solution it has been assumed that the TSHD Brisbane would be used. The production rate for establishment dredging has been assumed to be 25% lower than for the maintenance dredging. As such it has been assumed that 15.3 days of establishment dredging would be required to create the sediment trap and that every 10 years 8.3 days of maintenance dredging of the trap would be required. Five years after the establishment dredging and the subsequent maintenance dredging campaigns 14 days of bed levelling using the Pacific Conquest has been included to redistribute the siltation within the North Apron and maximise the duration before maintenance dredging is required. In addition, 5 days of maintenance dredging of the berths would be required every two years.

3.2.4 Option 3: Fixed Position Jet Array

The fixed position jet array system would be installed within the berths to create high near bed currents to re-suspend recently deposited bed material. The jet array system would be powered using purchased electricity, and predicted consumption for each tide cycle would be 1,500kWh per pump. This was derived based on the operation of the system for three hours per tide, twice a day. This was considered to be conservative as during some periods of the year, the system is likely to be required for a shorter time period than three hours per tide cycle. It was anticipated that two pumps would be required for each of the seven berths at the Port of Hay Point for the jet array system.

3.3.3 Option 4: Drag Barring using the Pacific Conquest

It has been assumed that all drag barring would be undertaken at the berths of Hay Point using the 'Pacific Conquest' marine vessel. During the bed levelling, the Pacific Conquest would drag a bar up and down the berths to re-suspend the bed sediment. The Pacific Conquest would travel to the site from the Port of Gladstone, approximately 415km to the south of the site. The bed levelling would be undertaken for four consecutive days six times through the year. During cruising, to and from the Port of Hay Point, it was assumed that the vessel engines would operate at 90% of full power. During the bed levelling periods, the Pacific Conquest engines would operate at full power.

3.3.4 Option 5: Propeller Wash using a Tugboat from the Port of Hay Point

It has been assumed that a tugboat from the Port of Hay Point tug harbour would be used to agitate the bed through the effects of propeller wash. It was assumed that the propeller wash approach would be undertaken for a total duration of 20 days during the year, with visits to the North Apron approximately three times a week. The vessel specifications for the tugboat that would be utilised were based upon a 50 – 60 tonnes BP Stern Drive Tug, which is similar to the tugboats which currently service the Port of

Hay Point. It was assumed that the tugboat would operate its engines at 90% of full power travelling to the site, and at full power during the propeller wash agitation process.

3.4 Assumptions

The following assumptions were used in the assessment of GHG emissions:

- Low sulphur diesel fuel is used in all of the marine vessels considered in the assessment;
- The fuel for the vessels should be considered to be supplied by the Port of Hay Point 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. Under circumstances where the Port of Hay Point appoint a third party contractor that provides their own fuel, these could be considered to comprise Scope 3 GHG emissions instead and would therefore be omitted from the comparison;
- For each marine vessel it was assumed that one generator with a total power of 800kW was operated at full capacity to supply power for the on board facilities;
- Emissions from onshore vehicle movements and facilities were not known at the time of assessment. GHGs from these activities were anticipated to be minimal for each option, therefore were not considered in the GHG assessment;
- Purchased electricity used to power the jet array system in option 3 was assumed to be generated in Queensland and purchased from the national grid; and
- GHG emissions were calculated over a 20 year operating period for each option in the GHG assessment. We assume that the same equipment, available today, is used and that no technology improvements over time are included.

3.5 Emission Factors and Calculations

3.5.1. Scope 1 GHG Emissions Calculations and Factors for Options 1, 2 and 3

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*'. [4] The emission parameters and emission rates used were derived using the USEPA methodology. The vessel parameters were determined from the marine vessel specifications to be used in each option.

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

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

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]).

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

GHG emissions were calculated using fuel consumption associated with the transport of the marine vessels to the site, and throughout the duration of the option procedure. Emissions of carbon dioxide (CO_2), methane (CH_4) and Nitrous Oxide (N_2O) were determined from each option.

The marine vessel parameters and emission factors utilised to calculate GHG emissions are detailed in **Table 1.**

Table 1: Marine Vessel Emission Parameters & Factors Utilised in the GHG Assessment

Option	Marine Vessel	Engine Power (kW)	Load Factor*	CO_2 Emission Factor* (g/kWh)	CH_4 Emission Factor* (g/kWh)	N_2O Emission Factor* (g/kWh)
Maintenance Dredging	THSD Brisbane	3,700	0.69	690	0.09	0.02
Drag Barring / Bed Levelling	Pacific Conquest	1,322	0.69	690	0.09	0.02
Propeller Wash	50 – 60 tonne BP Stern Drive Tug	3,600	0.68	690	0.09	0.02

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

3.5.2. Scope 2 GHG Emissions Calculations and Factors for Option 4

Indirect GHG emissions from the consumption of purchased electricity to power the jet array system for Option 3 were calculated using EFs from the Department of the Environment[5]. The Australian National Greenhouse Accounts provides a list of EFs for the consumption of electricity applicable for each state in Australia. As the Port of Hay Point does not control the energy provider for the HPCT and DBCT, 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.

4 Results of GHG Calculations

Based on the approach outlined in Section 3, the predicted GHG emissions associated with each option over a 20 year operational period are detailed in **Table 2**. The results were separated for Scope 1 and Scope 2 emissions for each option.

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

Table 2: Predicted GHG Emissions from Each SSM Project Option

Option	Scope 1 CO_2e Emissions over 20 Year Operational Period (Tonnes)	Scope 2 CO_2e Emissions over 20 Year Operational Period (Tonnes)
Option 1 – Maintenance Dredging	6,369	0
Option 2 – Sediment Trap	8,860	0
Option 3 – Fixed Jet Array	[6]	242,214
Option 4 – Drag Barring	21,454	0
Option 5 – Propeller Wash	23,640	0

The results show that maintenance dredging would produce the lowest quantity of GHG emissions over the assumed 20 year period. GHG emissions associated with the consumption of purchased electricity to power the jet array system in option 3 was predicted to produce the highest GHG emissions over the 20 year period. If the Port of Hay Point has alternative sources of electricity, such as an onsite renewable source, or the purchase of electricity from a renewable or green source (with recognised certification that these can be used in company GHG/Carbon accounting), then the GHG emissions associated with option 3 could be significantly reduced.

5 Conclusions

A GHG emissions' assessment was undertaken for maintenance dredging and four alternate solutions as part of a navigational maintenance study at the Port of Hay Point. The assessment was undertaken in accordance with the global standard methodology provided by the GHG Protocol. Scope 1 GHG emissions were calculated from low sulphur bunker fuel consumption associated with the operation of marine vessels. Indirect Scope 2 emissions from the consumption of purchased electricity to power the jet array system in the option 3 was also undertaken. Maintenance dredging using the THSD Brisbane in option 1 was predicted to produce the smallest quantity of GHG emissions over a 20 year period. Option 3, the fixed jet array, was predicted to produce the largest quantity of GHGs from the options considered.

[6] There are likely to be Scope 1 GHG emissions associated with the transport of infrastructure and staff during the construction phase of the jet array system. These are anticipated to be significantly less than the operational phase Scope 2 GHG emissions, and therefore were not calculated as part of this assessment.