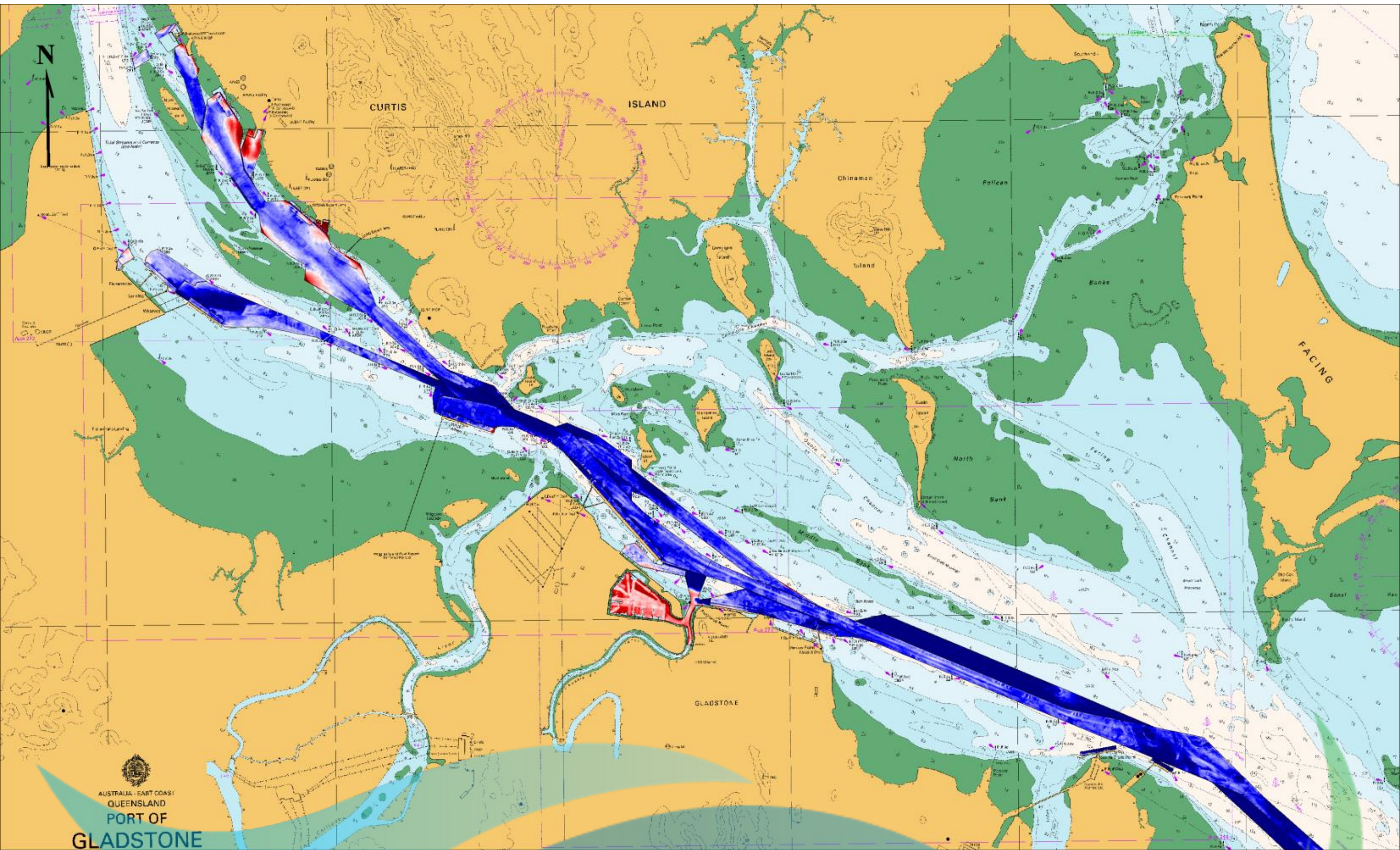
PORT & COASTAL
SOLUTIONS

Sustainable Sediment Management Project

Avoid Assessment

Final 1.0



Gladstone Ports Corporation
Technical Report
December 2018

Sustainable Sediment Management Project

Avoid Assessment

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ACRONYMS

APLNG	Australia Pacific Liquified Natural Gas
BPAR	Benthic Photosynthetic Active Radiation
DoEE	Department of Environment and Energy
DTMR	Department of Transport and Main Roads
DWT	Dry Weight Tonnes
EBSDS	East Banks Sea Disposal Site
EMS	Environmental Management System
GBRMP	Great Barrier Reef Marine Park
GBRMPA	Great Barrier Reef Marine Park Authority
GBRWHA	Great Barrier Reef World Heritage Area
GLNG	Gladstone Liquified Natural Gas
GPC	Gladstone Ports Corporation
LAT	Lowest Astronomical Tide
LNG	Liquified Natural Gas
PCS	Port and Coastal Solutions
PoG	Port of Gladstone
QCLNG	Queensland Curtis Liquified Natural Gas
QLD	Queensland
RHM	Regional Harbour Master
SSM	Sustainable Sediment Management
TSHD	Trailing Suction Hopper Dredger
UKC	Under Keel Clearance
WICT	Wiggins Island Coal Terminal

Executive Summary

Gladstone Ports Corporation (GPC) commissioned Port and Coastal Solutions (PCS) to undertake a number of tasks as part of their Sustainable Sediment Management (SSM) Project for the Port of Gladstone (PoG).

Aims: There were two main aims of this study:

- to undertake a detailed assessment of the accumulation rates within the dredged areas of the PoG and use this to predict the future sedimentation and declared depths in the PoG; and
- to undertake an options assessment for completely avoiding sedimentation, the placement of dredged material at sea and maintenance dredging.

Future Sedimentation: based on analysis of historical bathymetric surveys, future sedimentation above the declared depths in the PoG is predicted to be 213,000 and 317,000 m^3/yr (in-situ volume) for typical and worst case years. The majority of this sedimentation is within the Inner Harbour (see Figure 2), with more than 60 percent being in the Liquified Natural Gas (LNG) Terminal berths and swing basins in the Jacobs Channel region. If no sediment management (i.e. no maintenance dredging or drag barring/bed levelling) is undertaken then future sedimentation above declared depths is predicted to be 1.2 M m^3 (in-situ volume) of sediment after 5 years, 2.7 M m^3 (in-situ volume) after 10 years and 5.9 M m^3 (in-situ volume) after 20 years.

Operational Implications: after one (1) year of sedimentation with no sediment management there is predicted to be reduced loading for the majority of vessels at five of the berths in the PoG (influencing the LNG, chemical manufacturing and aluminium industries) and reduced loading for Cape size vessels at one berth (influencing the coal industry). After five years of sedimentation there is likely to be no access to the Port for Cape size vessels, a tidal constraint for Panamax vessels and insufficient depth for vessels at a further four (4) of the berths (nine (9) in total, also influencing the cruise industry). After 20 years of sedimentation access through the Golding Channel is unlikely to be possible for most unladen vessels which would mean that the PoG would not be able to continue operation.

Ongoing Maintenance Dredging Requirements: to maintain declared depths within the PoG a number of regions of the Port will require annual dredging, with typical and maximum volume estimates of 170,000 to 260,000 m^3/yr (in-situ volume), while other regions will require biennial (or less frequent) dredging, with typical and maximum volume estimates for these regions of 90,000 to 100,000 m^3 (in-situ volume) every two years. Based on this, the total annual average (averaged between annual and biennial years) maintenance dredging requirement for the PoG is between 210,000 and 265,000 m^3/yr (in-situ volume) (excluding any over/insurance dredging) depending on whether the sedimentation which has occurred is typical or worst case.

Avoid Assessment: options for completely avoiding sediment accumulation, the placement of dredged material at sea and maintenance dredging have been assessed. Based on the future sedimentation predictions for the PoG it was found that there are no realistic options available to completely avoid sedimentation or maintenance dredging with the PoG remaining operational. There are possible options which could be considered for localised areas to avoid sedimentation and maintenance dredging, but none of these could be adopted for the entire PoG. As such, these options would reduce the total sedimentation and therefore maintenance dredging in the PoG, rather than completely avoiding it, and so will be considered as part of a subsequent assessment into reducing sedimentation and maintenance dredging in the PoG.

The only available options to completely avoid sea placement of maintenance dredged sediment would be for all of the sediment to either be used for beneficial reuse or to be

placed on land. These options will be further assessed as part of the subsequent beneficial reuse investigation.

PORT & COASTAL SOLUTIONS

1. Introduction

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

- Task 1: to undertake a detailed assessment of the accumulation rates within the dredged areas of the PoG and use this to predict the future sedimentation and declared depths in the PoG. This will include an assessment of when in the future the depths of the channels, approaches, swing basins and berths within the PoG will become too shallow for safe operation of the vessels which currently use the Port; and
- Task 2: to undertake an options assessment for completely avoiding sedimentation, the placement of dredged material at sea and maintenance dredging.

The report herein is set out as follows:

- an introduction and background to the study is provided in **Section 1**;
- accumulation rates and future sedimentation within the PoG is defined in **Section 2**;
- the avoid assessment is detailed in **Section 3**; and
- a summary of the key findings from the assessment is provided in **Section 4**.

1.1. Project Overview

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

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

Maintenance dredging is conducted to provide and operate effective and efficient port facilities and services under the *Transport Infrastructure Act 1994*. The PoG maintenance dredging and disposal activities associated with the main channels, swings basins and berth pockets are usually undertaken annually, with dredged material placed at the approved East Banks Sea Disposal Site (EBSDS - first approved in 1980).

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

- undertake research and monitoring relating to the consequences of dumping maintenance dredged material into the marine environment. It is noted that among other things the research and monitoring may include:
  - establishment of a quantitative sediment budget and sediment dynamics model for Port Curtis (the large natural harbour within which the PoG is located), Queensland, including quantifying impacts and extent of sediment transport and resuspension from Dumping Activities at the East Banks Sea Disposal Site with specific reference

  - to sensitive receptors and potential impacts on the Great Barrier Reef World Heritage Area; and
  - monitoring changes in water quality (including turbidity and benthic photosynthetic active radiation (BPAR)) resulting from or as a consequence of Dumping Activities.
- investigate the possibility of avoiding or reducing the need for further dumping of maintenance dredged material into the marine environment; and
- report to the DoEE the results of any research, monitoring or investigation undertaken by GPC in accordance with the Deed.

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

The SSM Project has been developed to build on the information collected to date within the PoG, to develop a sediment budget and associated model to better understand the contribution of GPC's activities to the overall sediment system and to investigate possibilities to avoid or reduce the need for further placement of sediment into the marine environment. In addition to delivering GPC's commitments made in the Deed, this Project will assist GPC implement the relevant aspects of the Maintenance Dredging Strategy (Department of Transport and Main Roads (DTMR), 2016).

This report is aimed at understanding the potential options for and implications of avoiding sedimentation, the placement of dredged material at sea and maintenance dredging.

1.2. Port of Gladstone

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

In the 2016/17 financial year the PoG handled approximately 120.4 million tonnes of commodities. This was predominantly made up of coal, alumina/aluminium related products and Liquified Natural Gas (LNG), although other products including cement, petroleum, industrial chemicals, grain and containers were also handled (GPC, 2017).

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

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

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

The PoG consists of approximately 50 km of shipping channels to ensure safe navigation from the entrance to Port Curtis to the wharves (Figure 2). Maintenance dredging is undertaken to ensure that the depths of the channels and berths are maintained at their declared depths (Table 1). The declared depth is the depth designated by the Regional Harbour Master and typically reflects the shallowest depth within the area.

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

Channel	Declared Depth (m LAT)
Outer Harbour	
Wild Cattle Cutting	-16.1
Boyne Cutting	-16.1
Golding Cutting	-16.1
South Bypass Channel	-7.3
Gatcombe Channel	-16.3
Gatcombe Bypass	-12.5
Inner Harbour	
Auckland Channel	-15.8
Auckland Bypass	-6.8
Clinton Channel	-16.0
Clinton Bypass	-13.0
Targinnie Channel	-10.6
Jacobs Channel	-13.0
WICT departure channel	-16.0

Capital dredging has historically been undertaken in the PoG as the port has grown. Most recently, between 2011 and 2013, capital dredging associated with the construction of three LNG terminals was undertaken. Table 2 provides details of the maintenance and capital dredging, which has been undertaken at the PoG when sediment has been placed at the EBSDS over the last 10 years. It is important to note that the table does not include the volume of sediment removed from the Marina as to date this sediment has been placed on land. Historic maintenance dredging of the Marina has included the removal of 352,000 m^3 (in-situ volume) in 2009 and 305,000 m^3 (in-situ volume) in 2015. The table also does not include areas where occasional sediment management has been required either in the form of bed levelling or dredging (with the sediment placed on land) such as boat harbours and ramps and river entrances (e.g. Boyne River and Upper Auckland Inlet).

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

Year	Maintenance Dredging (in-situ m³)	Capital Dredging (in-situ m³)
2007	160,972	
2008	17,995	
2009	282,000	
2010	0 (dredging was at start of 2011)	
2011	309,000	5,113,475
2012	150,000	
2013	0 (dredging was at start of 2014)	
2014	550,366	
2015	68,000	
2016	455,000	
2017	209,456	
Total (2007-2017)	**2,202,789**	**5,113,475**

Note: PoG Sea Dumping Permit requires to report in-situ cubic metres delivered by the dredger to the EBSDS. These in-situ cubic metres are derived from dredge logs hopper dry tonnes by applying a conversion of factor of 1.1 (e.g. 1 m³ (in-situ) = 1.1 tonne (dry weight)).

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

A breakdown of the volumes of sediment dredged throughout the different areas of the PoG during the 2017 maintenance dredging is shown in Figure 3. The plot shows that approximately 70,000 m³ was removed from the Golding, Boyne and Wild Cattle Cuttings, over 100,000 m³ was removed from the areas to the north of the RG Tanna Wharves (north of Clinton Channel, WICT berths, Targinnie Channel and Jacobs Channel) and the remaining volume was removed from the area between the RG Tanna Wharves and the eastern end of the Gatcombe Channel.

The PoG is commonly separated into Inner and Outer Harbour regions; the Outer Harbour region extends from the Wild Cattle Cutting to the Gatcombe Channel and the Inner Harbour is the area inshore from Auckland Channel and the most southerly wharf (Boyne Wharf), which is sheltered from offshore wave activity by Curtis and Facing Islands (Figure 2).

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

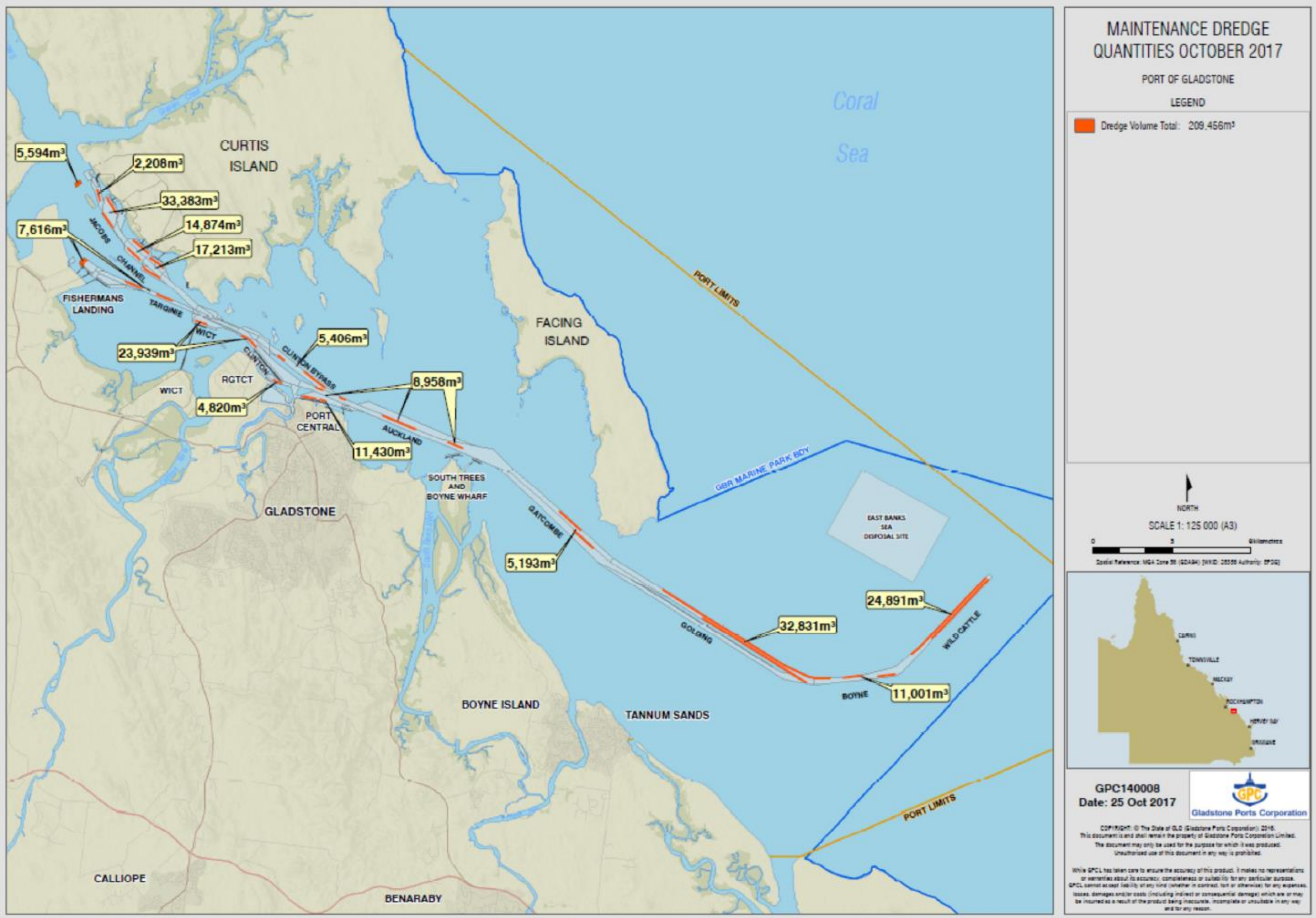

Figure 3. Port of Gladstone maintenance dredging volumes for main channels and berths from 2017 (Vision Environment, 2017).

2. Accumulation Rates

The declared depth is the depth nominated by the Regional Harbour Master (RHM) and shown on navigational charts to represent the maximum legal and safe vessel draft for an area (Figure 4). Channels and berths can also have a design depth which is below the declared depth and includes an insurance depth to allow for natural sedimentation over the period between maintenance dredging campaigns to allow safe navigation to continue. In addition, as dredgers are not able to dredge to an exact level, it is common for the dredger to over-dredge to ensure that the design levels have been achieved throughout, over-dredging of between 0.1 to 0.3 m is typical. In the PoG the declared depth and the design depth are the typically the same, and although there isn't a specific dredge depth this can be assumed to be between 0.1 to 0.3 m below the declared depth.

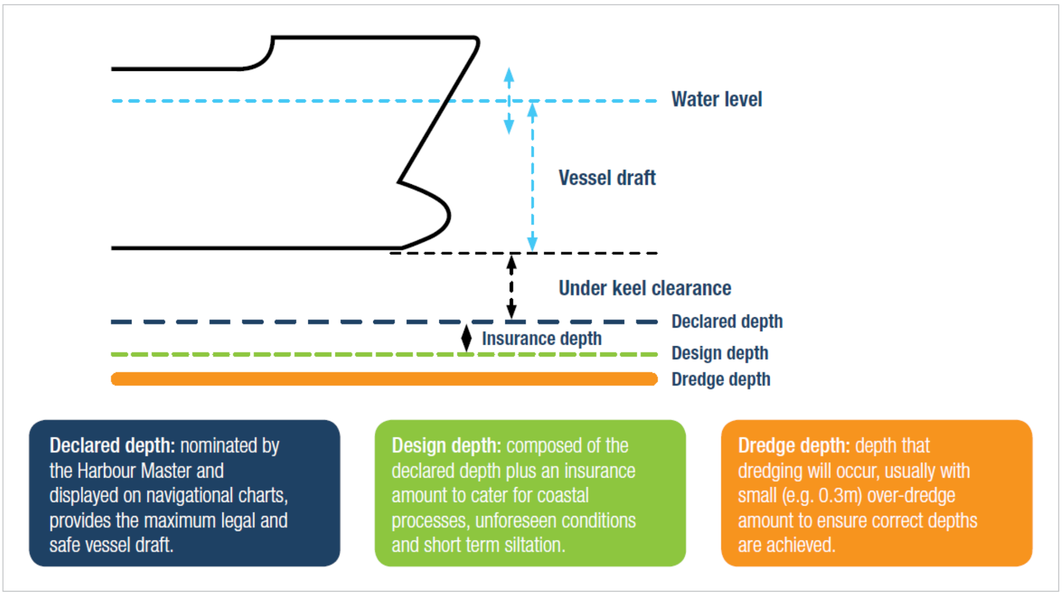

Figure 4. Schematic of depths for navigation and dredging purposes (Ports Australia, 2016).

To better understand how the historic sedimentation which has been observed in the PoG could potentially influence maintenance dredging and navigation in the future, it is necessary to undertake a detailed analysis of the bathymetric changes relative to the declared depths in the PoG.

As part of the Conceptual Sediment Budget study the ongoing sedimentation in the areas where regular sediment management practises (e.g. maintenance dredging or drag barring) have been required, was estimated to be approximately 600,000 m^3/yr (PCS, 2018), with more than a third of this being in the Jacobs Channel region (including the LNG berths). It is important to note that only some of the sedimentation will be above the declared depths within the PoG and any sedimentation which is below the declared depths will not directly influence navigation and require management. Therefore, this assessment will further analyse the bathymetric data to understand how much of the sedimentation has been above the declared depths, and to predict future sedimentation above the declared depths in the future.

2.1. Declared Depths

To assess how sedimentation will influence the PoG it is important to understand how sedimentation above the declared depths will be acted upon by the RHM. The declared depth is the depth designated by the RHM and typically reflects the shallowest depth within the area. As part of this assessment the RHM for Gladstone (from Maritime Safety

Queensland), has provided an overview of the general principles that would be adopted when considering sedimentation above the declared depths:

- Berths: if there has been sedimentation above the declared depth, then the berth depth will be re-declared. A minimum under-keel clearance (UKC) of 0.5 m is adopted for all berths within the PoG, except for the berth at Barney Point where a minimum UKC of 1 m is required (DTMR, 2018); and
- Channels: there is some flexibility when sedimentation above the declared depth occurs in the channels. If the sedimentation is along the sides of the channel and there is sufficient width below the declared depth in the centre of the channel (110 m as a minimum), then the depth might not have to be re-declared. If the channel width below the declared depth reduced to less than 110 m, then the channel depth would need to be redeclared as navigational safety would start to be a concern. The minimum UKC required in the channels varies between the Inner (from Jacobs Channel to the eastern end of Auckland Channel) and Outer Harbour regions (due to increased wave action in the Outer Harbour) and is also dependent on the vessel type. In the Inner Harbour the minimum UKC in the channels varies from 0.7 m (vessels less than 85,000 dry weight tonnes (DWT)) to 1.2 m (all other vessels), while in the Outer Harbour it varies from 1.2 m (LNG vessels) up to 2.0 m (vessels more than 200,000 DWT) (DTMR, 2018).

GPC provided details of the drafts of vessels which have visited the various berths in the PoG, these are summarised in Table 3 along with the declared depths for the berths.

Table 3. Declared depth and the typical range in vessel drafts for the berths in the PoG.

Berths	Declared Depth (m LAT)	Unladen Draft (m)	Fully Laden Draft (m)
Jacobs LNG Berths	-13.0 & -14.0	9.4 – 10.5	11 – 12
Fisherman's Landing Berths 4 & 5	-11.2	5.9 – 7.9	9.6 – 11.8
Fisherman's Landing Berths 1 & 2	-12.9	6 – 9	10.6 – 12.9
WICT Berths	-18.8	7.2 – 12.7	12.9 – 17.5
Clinton Berths	-18.8	6 – 12.5	8.8 – 18
Auckland Point Berths	-11.3 & -11.4	6.5 – 9.5	9.2 – 12.3
Barney Point Berths	-15.0	6.5 – 7.5	10.5 – 11.7
South Trees Berths	-12.8	6.5 – 8.6	10.7 – 13.5
Boyne Smelter Berth	-15.0	6 – 8	10 – 13

2.2. Accumulation Analysis

The declared depths for the PoG along with the names adopted for the accumulation assessment are shown in Figure 5 and Figure 6. The assessment includes the main navigation channels, berths and swing basins in the PoG as well as Gladstone Marina. The assessment does not include other smaller areas such as boat harbours and ramps and river entrances (e.g. Boyne River and Upper Auckland Inlet) where occasional sediment management is required. Based on historical sediment management requirements it has been estimated that these areas will require 140,000 m^3 of sediment accumulation to be removed over a five year period (GPC, 2018).

The high resolution gridded Digital Elevation Models (DEMs) created for each of the bathymetric surveys from 2007 to 2017 were compared to the declared depths for the PoG, (see PCS (2018) for further details regarding the DEMs). The difference between the

October 2017 (pre-maintenance dredging) measured bathymetry and the PoG declared depths is shown in Figure 7 and Figure 8. The plots show the following:

- the bathymetry in October 2017 was below the declared depths for the majority of the PoG;
- the main areas where the bathymetry was above the declared depth were in the Jacobs Channel region, in the Tug Base and in the Marina;
- some localised areas adjacent to the channel edge were above the declared depth in the Golding and Boyne and Wild Cattle Cuttings and in the Clinton Channel;
- areas of some of the berths were above the declared depths, these were typically either along the wharf side of the berth or at the ends of the berth; and
- when the plots are compared to the total bathymetric change plots presented in PCS (2018) it can be seen that much of the sedimentation which occurs in the PoG is below the declared depths and so is not currently an issue for navigation or future maintenance dredging.

The volume above the declared depth was compared between the post maintenance dredging surveys and the following pre-maintenance dredging surveys, to calculate the change in volume above the declared depths for each year. The duration between the two surveys was then calculated and the volume differences adjusted so that they are representative of the change in volume per year. The results from the analysis are presented in Table 4. It is important to note that in cases when either the post dredge or the pre-dredge survey did not cover the entire region, the change in volume above the declared depth could not be calculated and so the value has been left blank. Based on the above, the table shows the following:

- there has been a significant increase in the annual sedimentation above the design depth since the completion of the Jacobs Channel and LNG terminals in 2014;
- before 2015 the sedimentation above the declared depth was approximately comparable between the Inner and Outer Harbour regions;
- between 2015 and 2017 more than 85% of the sedimentation above the declared depths in the PoG has been in the LNG Terminals in the Jacobs Channel region[1]; and
- regular ongoing sedimentation above the declared depth has occurred in numerous regions of the PoG, these are highlighted in red in the total increase column. The locations include all the regions around the Jacobs Channel, the northern end of the Targinnie Channel (Targinnie North), Clinton Channel, Tug Base, Marina, Golding Cutting, Boyne and Wild Cattle Cutting and a number of the berths in the PoG.

As the maintenance dredging in the Marina is carried out by a small Cutter Suction Dredge (CSD) and not the Trailing Suction Hopper Dredge (TSHD) *Brisbane*, the dredging does not coincide with the pre and post maintenance dredging surveys, which are based on when the TSHD *Brisbane* undertakes maintenance dredging. As a result, both the pre and post dredge surveys are not typically undertaken for the Marina, which means that the sedimentation above the declared depth shown in Table 4 for the Marina does not provide an accurate representation of the natural sedimentation which has occurred. Maintenance dredging of the Marina occurred in 2010 and 2014/15 and so the available surveys between these periods have been used to calculate the natural sedimentation which has occurred above the declared depth. It was calculated that over this four year period, the sedimentation above the declared depth varied between 30,000 m^3/yr and 46,000 m^3/yr with a mean rate of 39,000 m^3/yr.

[1] it is important to note that the sedimentation in the Marina was not included in these calculations, if it was included then the percentage contribution of the LNG Terminals would be approximately 70%.

The increase in sedimentation results show that the Tug Base is prone to sedimentation above the declared depth, but due to the pre and post maintenance dredging surveys not always covering the entire Tug Base region there is only a single sedimentation rate available in Table 4. Analysis of the surveys indicates that limited maintenance dredging was undertaken within the Tug Base between the December 2013 and March 2014 surveys and as both surveys cover the entire Tug Base the annual sedimentation above the declared depth was calculated as 3,758 m^3/yr for this period to provide a second measure of sedimentation for the region.

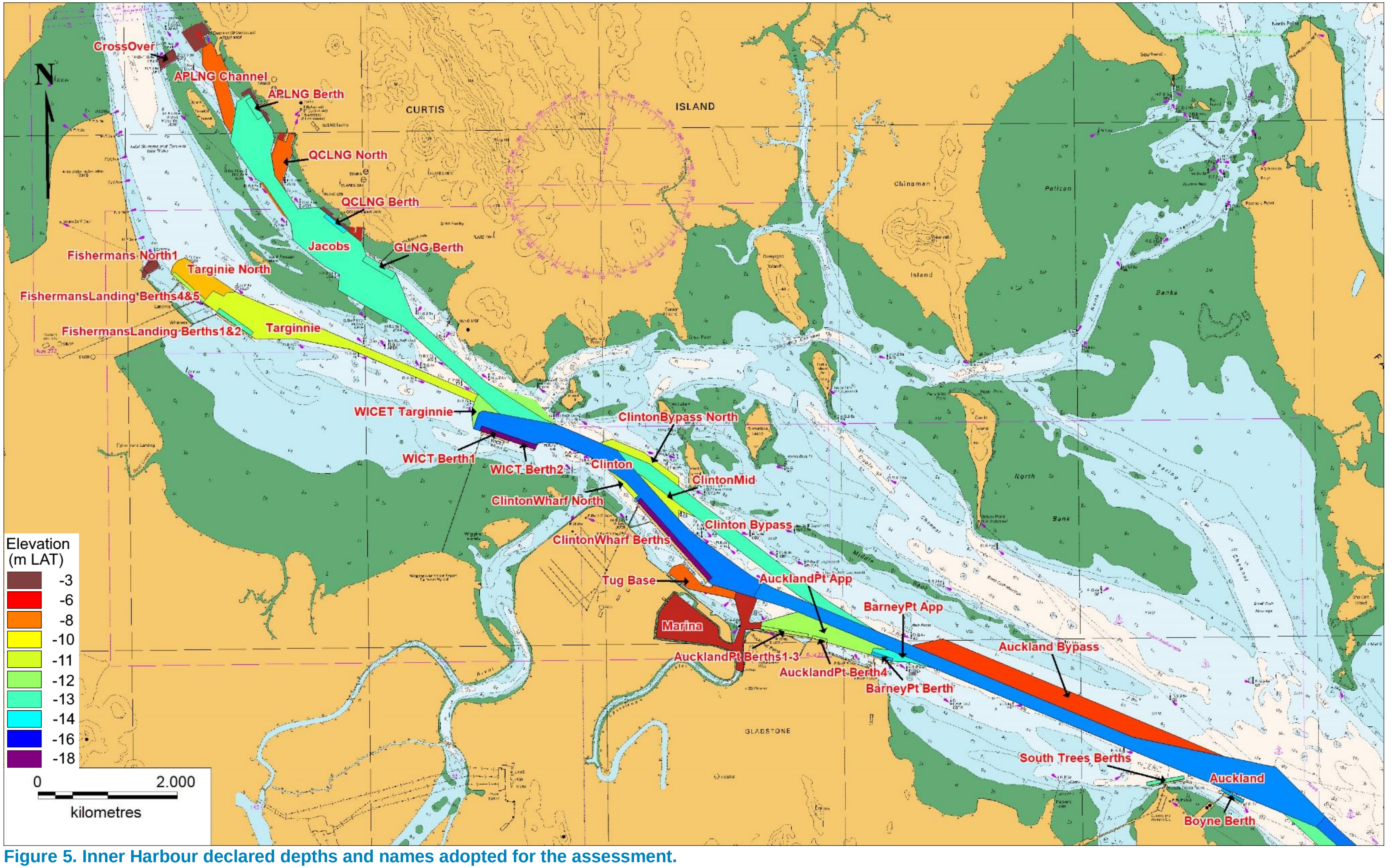

Figure 5. Inner Harbour declared depths and names adopted for the assessment.

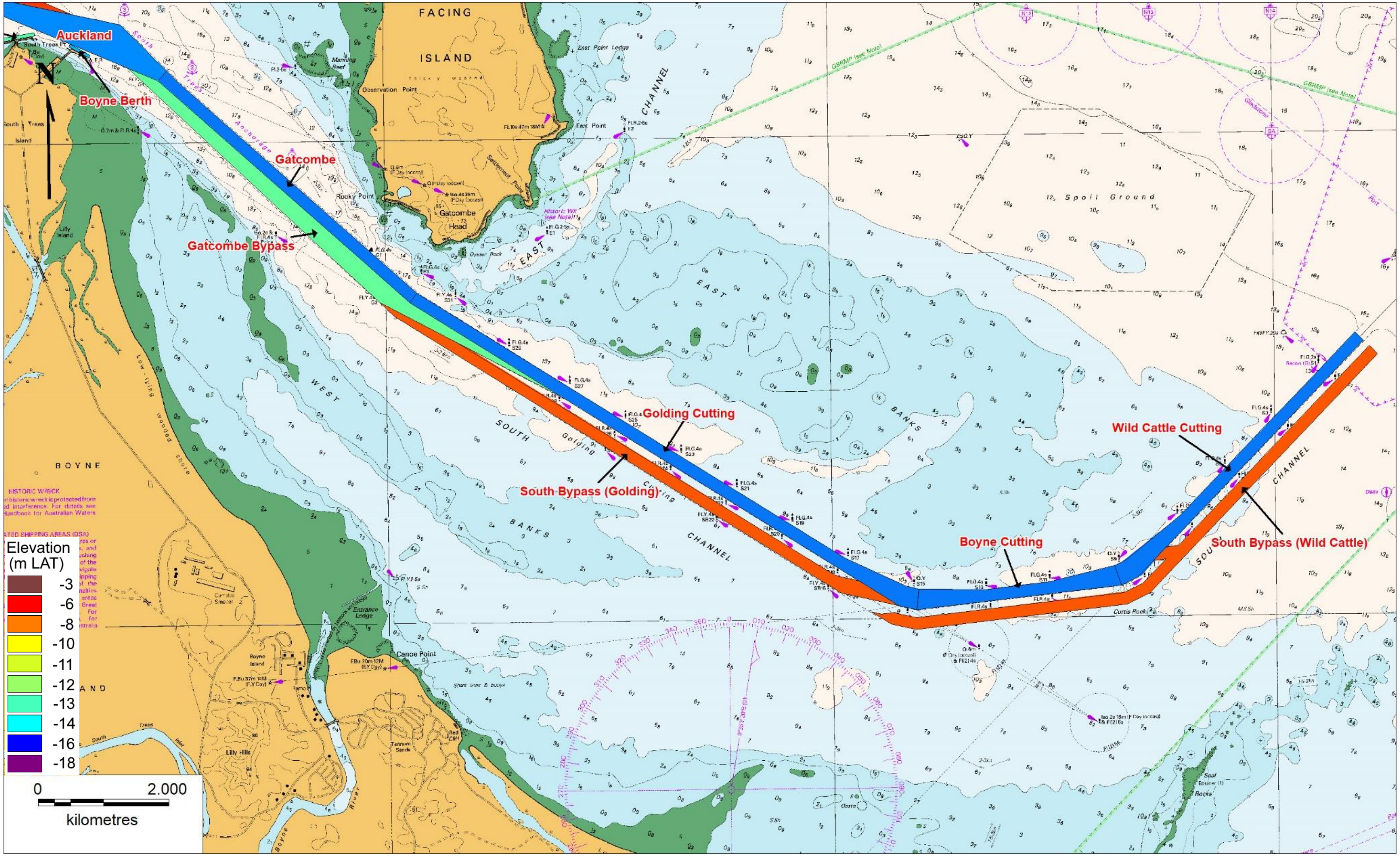

Figure 6. Outer Harbour declared depths and names adopted for the assessment.

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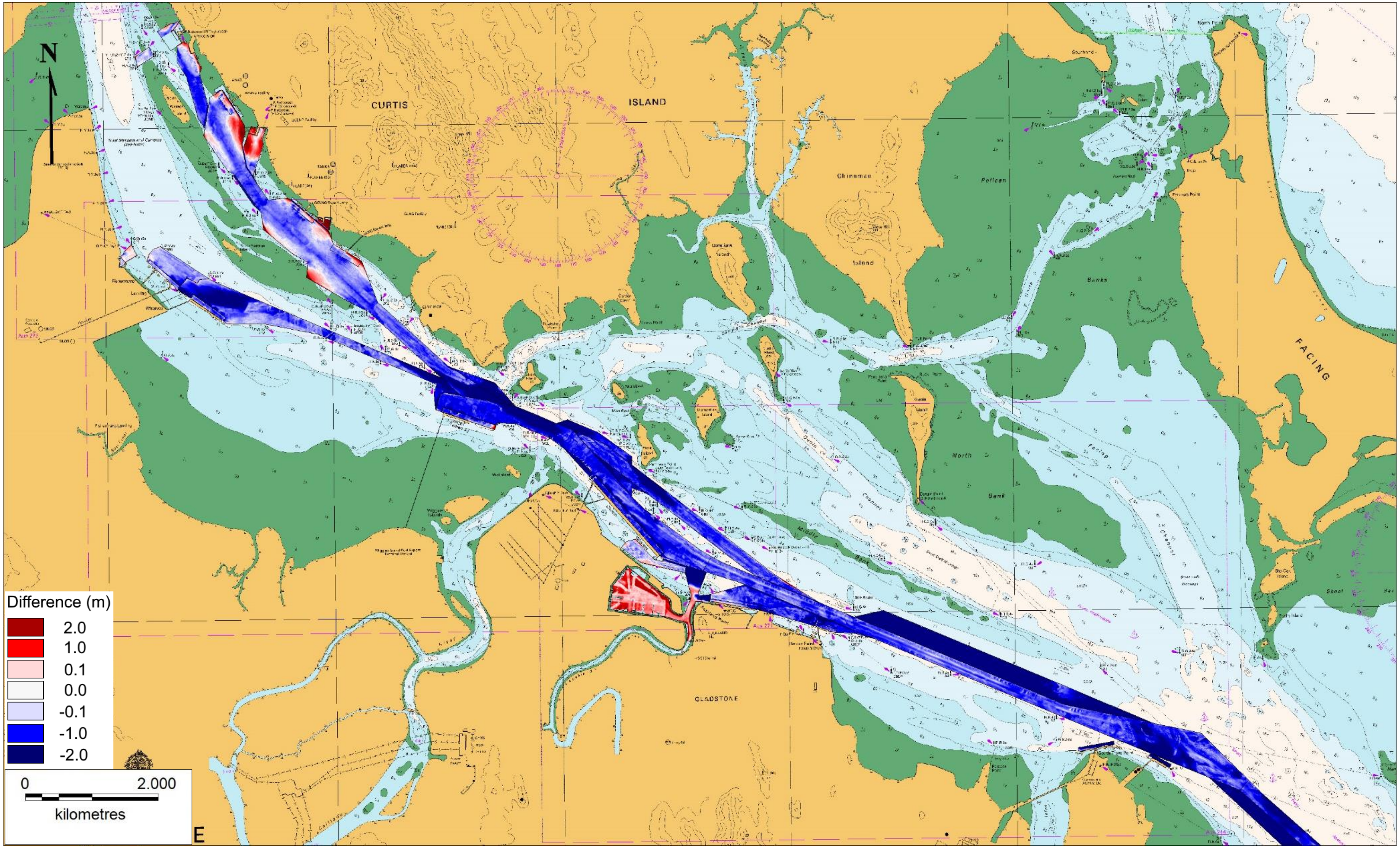

Figure 7. Inner Harbour depth above (red) and below (blue) declared depth in October 2017, pre-maintenance dredging.

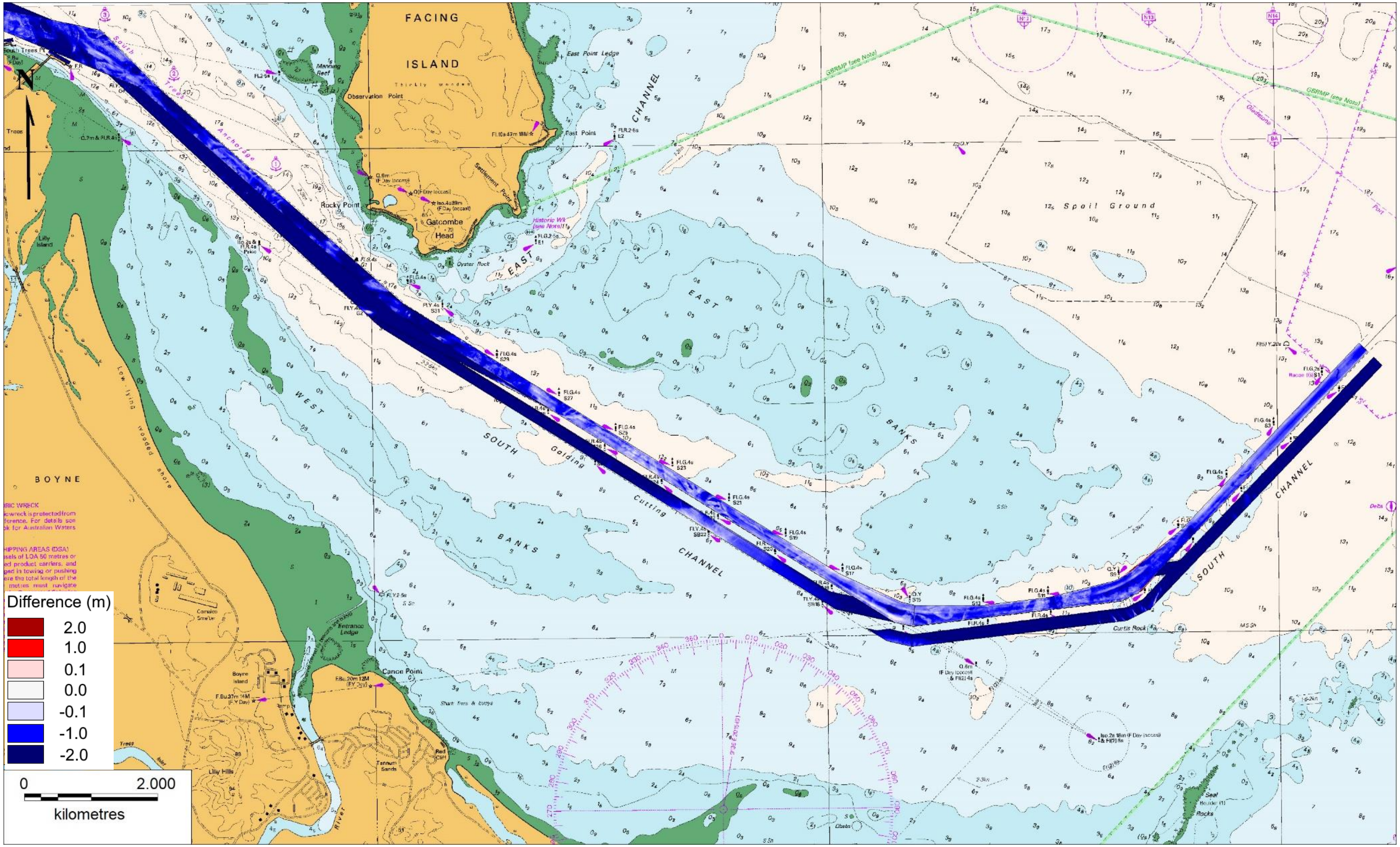

Figure 8. Outer Harbour depth above (red) and below (blue) declared depth in October 2017, pre-maintenance dredging.

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Table 4. Change in volume above declared depth (m^3/yr) in the PoG from 2008 to 2017.

Region	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Total Increase	*Mean*	*Median*	*Max.*
Cross Over								5,229	3,664	-797[3]	5,229	4,447	4,447	5,229
APLNG Channel								7,564	17,627	-9,234[3]	25,191	12,595	12,595	17,627
APLNG Berth & Basin								61,652	76,408	56,026	194,086	64,695	61,652	76,408
QCLNG North								13,505	14,588	33,438	61,531	20,510	14,588	33,438
Jacobs Channel North								3	0	1	4	1	1	3
QCLNG Berth & Basin								29,027	14,095	20,829	63,951	21,317	20,829	29,027
GLNG Berth & Basin								32,895	31,296	32,017	96,208	32,069	32,017	32,895
Jacobs Channel South								161	-22	-12	161	161	161	161
Fisherman's North1					1,122		-5,279				1,122	*-2,079*	*-2,079*	*1,122*
Fisherman's Landing Berths 4 & 5	-158	404	109	542	2,253	8,716		1,142	1,357	326	14,848	*1,632*	*542*	*8,716*
Fisherman's Landing Berths 1 & 2	2	4	-1	2	-34	189		122	27	122	468	*48*	*4*	*189*
Targinnie North	-379	132	178	1,071	2,129	11,321	1,695	4,636	806	906	22,874	*2,250*	*989*	*11,321*
Targinnie Channel				91	302	1,118	-1,269	702	678	320	3,210[2]	*277*	*320*	*1,118*
WICT/Targinnie							-1	0	-1	0	0	*-1*	*-1*	*0*
WICT Berth 1							23	38	121	89	272	*68*	*64*	*121*
WICT Berth 2							835	962	1,410	353	3,560	*890*	*899*	*1,410*
Clinton Channel							7,349	5,726	4,447	86	17,608	*4,402*	*5,087*	*7,349*
Clinton Bypass North	0	3	-5	0	0	-4	-1	0	-2	-1	3	*-1*	*-1*	*3*
Clinton Wharf North	-1	1	12	6	-1	-1	0	0	0	0	18	*2*	*0*	*12*
Clinton Wharf Berths	-196	56	108	137	731	1,036		2,033	-24	68	4,168	*439*	*108*	*2,033*
Clinton Mid	26	-91	0	0	-22	-17	-1	0	-1	-1	26	*-11*	*-1*	*26*
Clinton Bypass							1,990	1,928	516	-395	4,434[2]	*1,010*	*1,222*	*1,990*

Note: The total volumes above declared depth in red represent the regions which where future sedimentation above declared depth calculations will be undertaken.
The years shown represent the year of the pre-dredge survey.

[2] although the total increase in volume above the declared depths are of a similar magnitude to some of the areas selected for calculating future sedimentation, due to the plan area of the channels relative to the increases the sedimentation is not considered to be significant in terms of future navigation of the PoG over the 20 year time frame associated with this assessment.

[3] bed levelling was undertaken in the region over this period and so the reduction in volume above the declared depths is not a result of natural processes.

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Region	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Total Increase	*Mean*	*Median*	*Max.*
Tug Base							-5,832[3]	7,702			**7,702**	*7,702*	*7,702*	*7,702*
Marina		-7,065		2,471	29,848		594		2,971		**35,883[1]**	*5,764*	*2,471*	*29,848*
Auckland Pt App	298	-709	101	466	95	2,320	-1,239	197	-13	-230	**3,478**	*129*	*98*	*2,320*
Auckland Pt Berths 1-3	238	-474	2,559	-798		7,629		2,684	404	1,328	**14,841**	*1,696*	*866*	*7,629*
Auckland Pt Berth 4	-9	0	2	-3		2		-1	1	-1	**4**	*-1*	*-1*	*2*
Barney Pt App	-182	-272	-310	-76	-15	2	-82	-43	26	-65	**27**	*-102*	*-71*	*26*
Barney Pt Berth					-118	188		693			**881**	*254*	*188*	*693*
Auckland Channel	-2,263	39	354	-442	131	436	-1,044	205	794	-899	**1,958[2]**	*-269*	*85*	*794*
Auckland Bypass	-41	23	-42	2	1	-54	-11	-1	-14	-8	**27**	*-15*	*-10*	*23*
South Trees Berths	134	45	372	1,150		2,214		108	467	623	**5,112**	*639*	*420*	*2,214*
Gatcombe Channel	17	-4	-31	19		-21		4	2	6	**49**	*-1*	*3*	*19*
Gatcombe Bypass	71	60	-63	-13		-243		56	124	-41	**310**	*-6*	*22*	*124*
Golding Cutting	-2,423	4,156	2,167	-5,382		21,662		5,553	6,288	-2,071	**39,826**	*3,744*	*3,162*	*21,662*
South Bypass (Golding)	-5	38	-69	38		-131		-63	493	-164	**569**	*17*	*-34*	*493*
Boyne & Wild Cattle Cutting	905	-771	1,430	4,140		2,066		3,214	1,945	-460	**13,700**	*1,559*	*1,688*	*4,140*
South Bypass (Wild Cattle)	247	285	-177	264		-340		194	-96	-103	**990**	*34*	*49*	*285*
Total Increase in Volume	**1,937**	**5,246**	**7,393**	**10,399**	**36,612**	**58,897**	**12,486**	**205,245**	**198,894**	**140,703**	**647,935**	***64,794***	***24,549***	***187,872***
Jacobs Area Total Increase								*150,035*	*157,677*	*142,312*	***450,025***	*150,008*	*150,035*	*157,677*
Inner Harbour Total Increase	*697*	*706*	*3,795*	*5,939*	*36,612*	*35,169*	*12,486*	*178,851*	*171,703*	*146,532*	***592,490***	*59,249*	*23,828*	*178,851*
Outer Harbour Total Increase	*1,240*	*4,539*	*3,598*	*4,461*		*23,728*		*9,021*	*8,852*	*6*	***55,445***	*6,931*	*4,500*	*23,728*

Note: The total volumes above declared depth in red represent the regions which where future sedimentation above declared depth calculations will be undertaken.
The years shown represent the year of the pre-dredge survey.

[1] the values for the Marina are underestimated as the Marina is not consistently surveyed during the pre and post maintenance dredging survey. A different approach has been adopted to allow a more accurate representation of the change in volume above the declared depth, this is discussed later in this Section.

[2] although the total increase in volume above the declared depths are of a similar magnitude to some of the areas selected for calculating future sedimentation, due to the plan area of the channels relative to the increases the sedimentation is not considered to be significant in terms of future navigation of the PoG over the 20 year time frame associated with this assessment.

[3] bed levelling was undertaken in the region over this period and so the reduction in volume above the declared depths is not a result of natural processes and has been excluded from the statistical calculations of the mean, median and maximum values.

Maps showing where the bathymetry in the October 2017 pre-maintenance dredging survey was above the declared depths in the PoG (Figure 7 and Figure 8) indicate that the sedimentation is not evenly distributed over the regions. The sedimentation above the declared depths has typically occurred adjacent to the edges of the channels and berths. It is important to understand how the sedimentation volumes above the declared depths relate to reductions in depth and therefore the potential changes to the declared depths in the regions. A series of transects have been plotted in the locations where ongoing sedimentation above declared depths has occurred. The transect locations are shown in Figure 9 to Figure 12. The most relevant bathymetry along with the declared depths are shown for the transects in Figure 13 to Figure 28. These plots can be correlated to the sedimentation volumes above the declared depths in Table 4 to infer how the volumes reduce depths in the regions. The plots show the following:

- LNG Terminals (Figure 13 to Figure 17): there has been significant sedimentation above the declared depths in areas of the berths and swing basins of the LNG terminals located adjacent to Jacobs Channel. Generally, sedimentation has occurred at the southern end of the berths and within the adjacent southern area of the swing basin, with the largest reduction in depth being in the order of 1 m/yr. Maintenance dredging has not removed all the sediment above the declared depths in the corners of the swing basins (as these areas are not used for navigation), with between 1 and 2.5 m of sedimentation above the declared depths remaining at the southern end of some of the transects.
- Jacobs Channel (Figure 18): there hasn't been any sedimentation along the centre of Jacobs Channel, with some erosion having occurred which is likely to be from propeller wash from the fully laden vessels leaving the terminals.
- Fisherman's Landing Berths 4 & 5 (Figure 19): the northern end of berth 5 has been subject to sedimentation as well as the adjacent apron located to the north. Sedimentation above the declared depth of up to 1 m in berth 5 and 0.5 m in the apron has occurred over a year.
- WICT Berths (Figure 20): consistent sedimentation above the declared depth has occurred along the south-eastern end (approximately 80 m length) of berth 2 (the most south-eastern of the two berths). It is worth noting that there is no wharf at this berth and so the berth is not currently in use. The sedimentation in this area was not completely removed by maintenance dredging and so based on the October 2017 survey data the bathymetry at the south-eastern end of berth 2 was approximately 2 m shallower than the declared depth (this has not been an issue for navigation as the berth is not currently used).
- Clinton Channel (Figure 21): a series of sand ridges consistently form along the seabed on the western side of the Clinton Channel, to the north of the Clinton Wharf berths. The peaks of the sand ridges that develop have been very variable over time, with peaks of between 0.2 to 1.5 m above the declared depth developing during different years. The maintenance dredging has consistently removed the areas of the ridges which are above the declared depth.
- Clinton Wharf Berths (Figure 22): minor sedimentation has occurred at the southern end of the berths extending up to 15 m from the southern edge of the berth. There has been minimal change elsewhere in the berth pockets. The apparent accretion shown by the December 2015 survey at the northern end of the berths (chainage 1300 to 1500 m) is thought to be erroneous as the subsequent surveys return back to the depths shown by the January 2015 survey.
- Tug Base (Figure 23): the tug base has been subject to relatively consistent sedimentation occurring in a number of locations. The surveys show that the sedimentation has resulted in a reduction in depth of up to 0.3 m above the declared depth.

- Marina (Figure 24): sedimentation has occurred throughout all of the Marina footprint (chainage 0 to 650 m represent the approach channel to the Marina), with sedimentation of up to 1.2 m above the declared depth.
- Auckland Point Berths 1 to 3 (Figure 25): significant, consistent sedimentation has occurred along the western 500 m of the berths (Berth 1). The amount of sedimentation has been variable depending on the year, with the maximum sedimentation per year being between 0.5 and 1.3 m. Annual maintenance dredging has been undertaken which has generally reduced the depths back to the declared depths.
- South Trees Berths (Figure 26): the majority of the South Trees berths are naturally deeper than the declared depth. The westernmost 15 m of the berths is the only area which has been subject to sedimentation which has resulted in the depth increasing above the declared depth. In this area the sedimentation has resulted in sedimentation of more than 1 m above the declared depth.
- Golding Cutting (Figure 27): consistent sedimentation has occurred along the sides of the channel with the depths increased by more than 1 m above the declared depth. The increase in depth above the declared depth at both sides of the channel results in a narrowing of the channel, with historical narrowing of up to 55 m (180 m wide reduced to 125 m wide) having occurred over a year.
- Boyne and Wild Cattle Cutting (Figure 28): consistent sedimentation has occurred along the southern side of the channel resulting in depths increasing by up to 1.5 m above the declared depth. However, this is partially due to multiple years of sedimentation as the maintenance dredging has not returned all the area adjacent to the southern channel edge to the declared depth. There has also been some sedimentation along the northern side of the channel, although this has only been 0.1 m above the declared depth. The increase in depth above the declared depth at both sides of the channel resulted in a narrowing of the channel from 165 m to 155 m over the year when the most sedimentation occurred (2015).

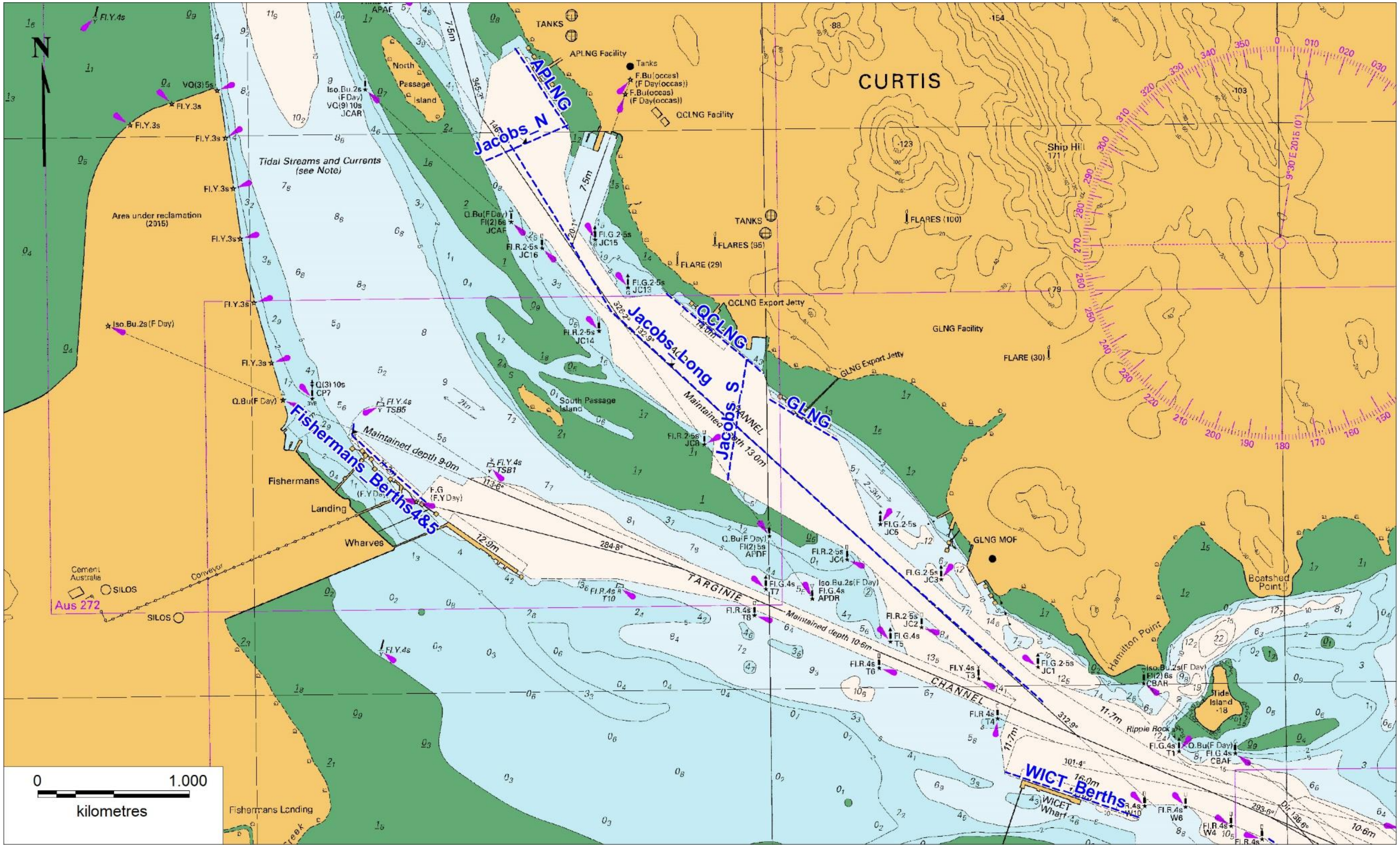

Figure 9. Transect locations at Jacobs Channel, Fisherman's Landing and the WICT Wharf.

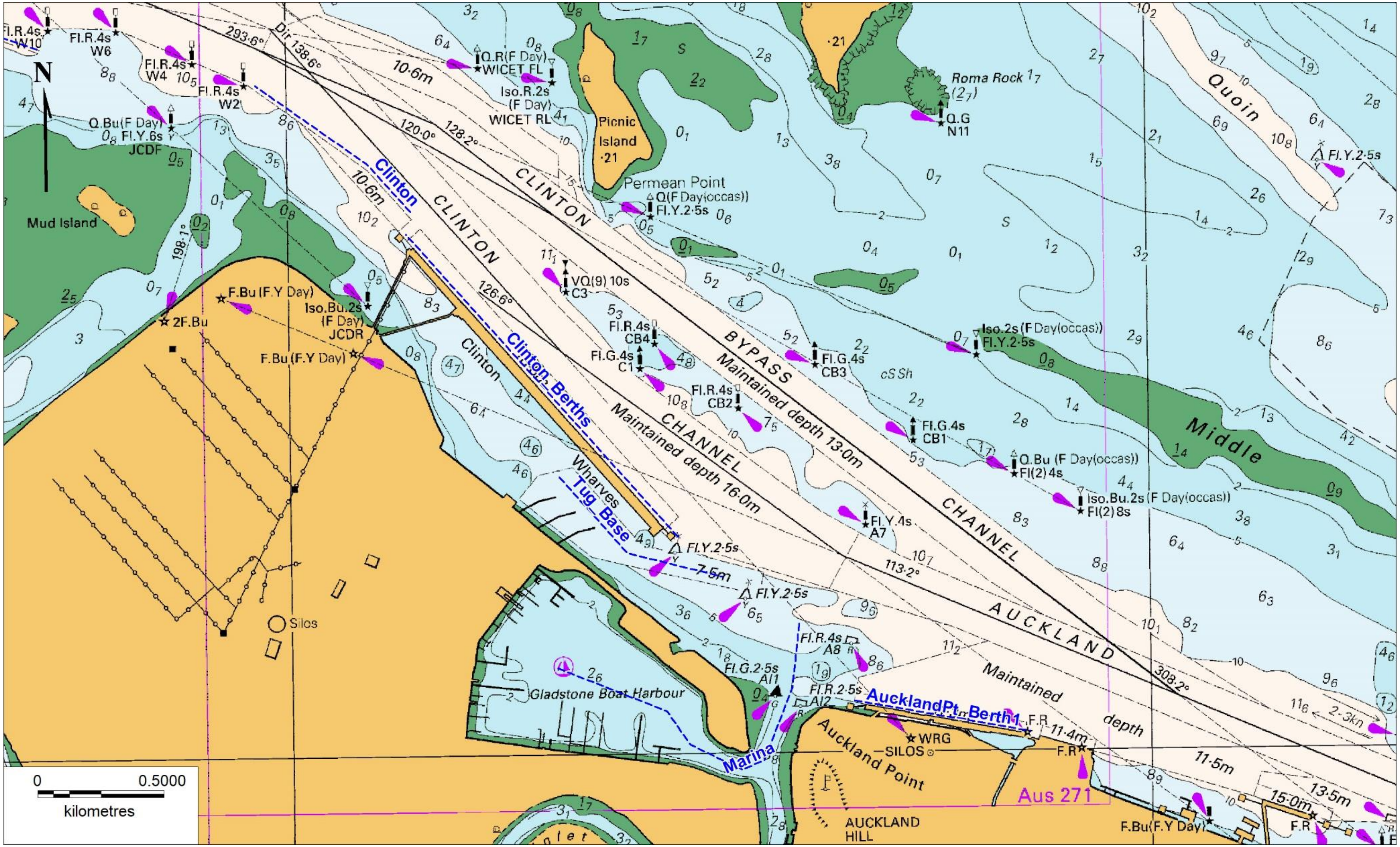

Figure 10. Transect locations at Clinton Channel, the Marina and Auckland Point.

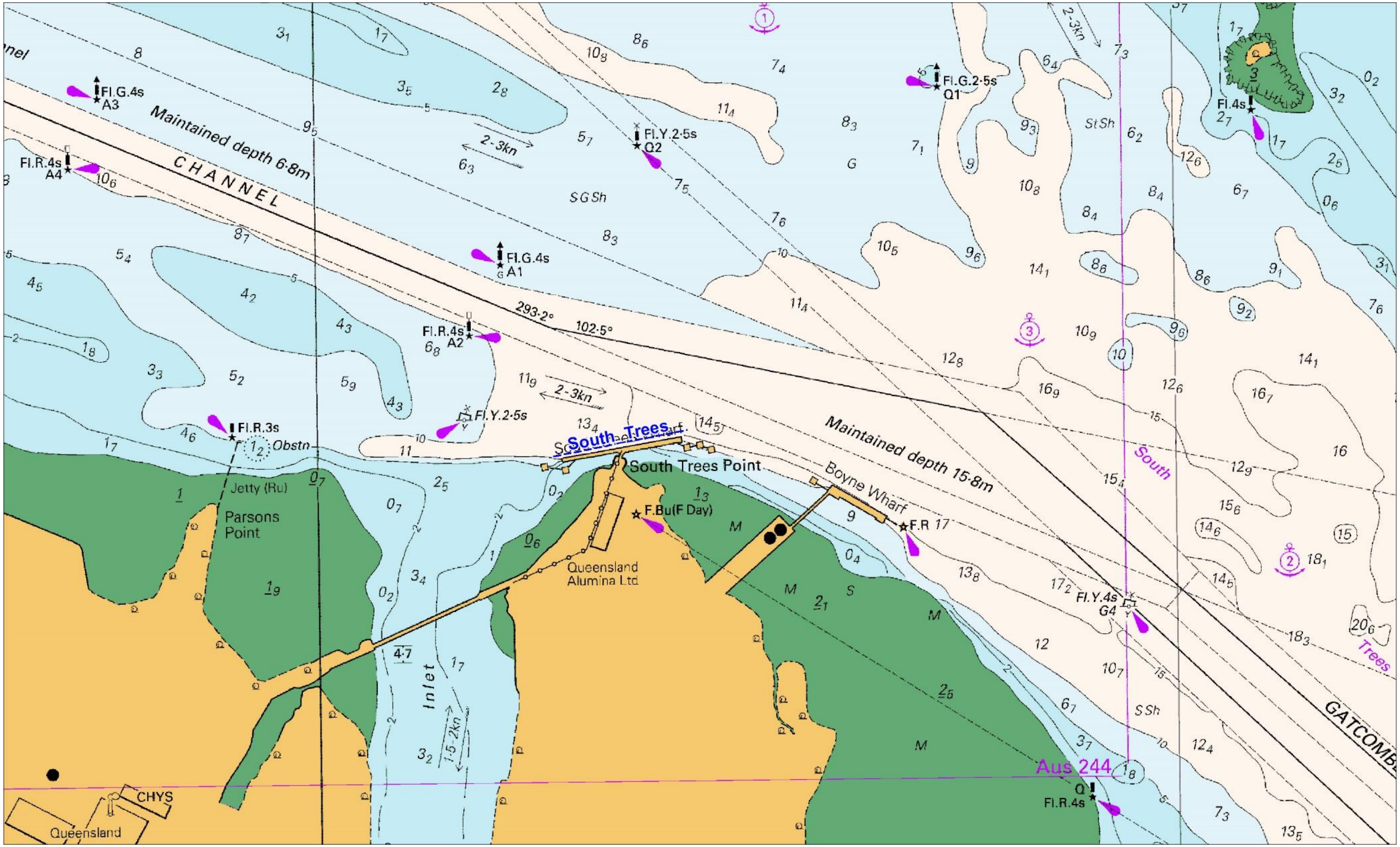

Figure 11. Transect locations at South Trees.

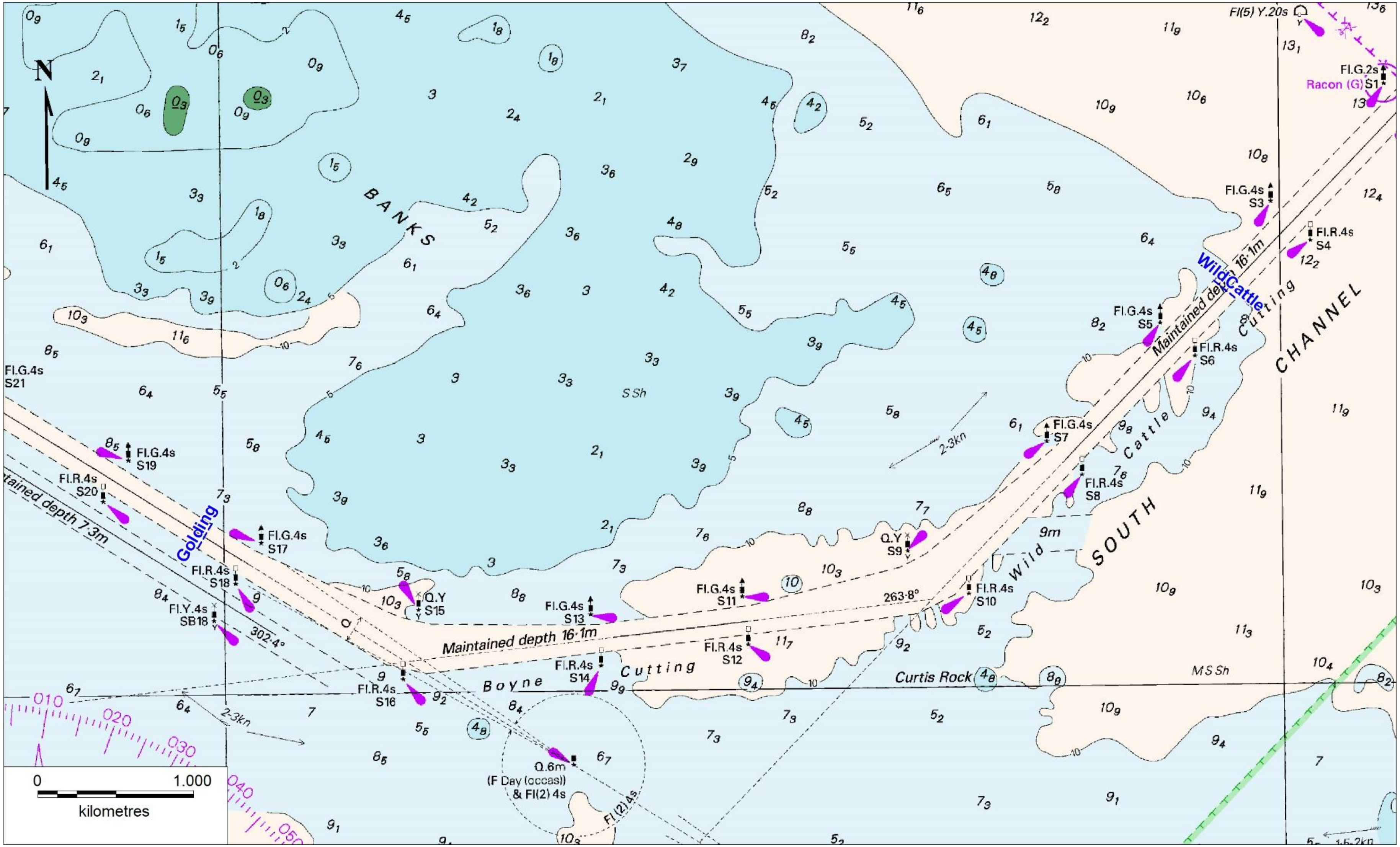

Figure 12. Transect locations at Golding Cutting and Boyne and Wild Cattle Cutting.

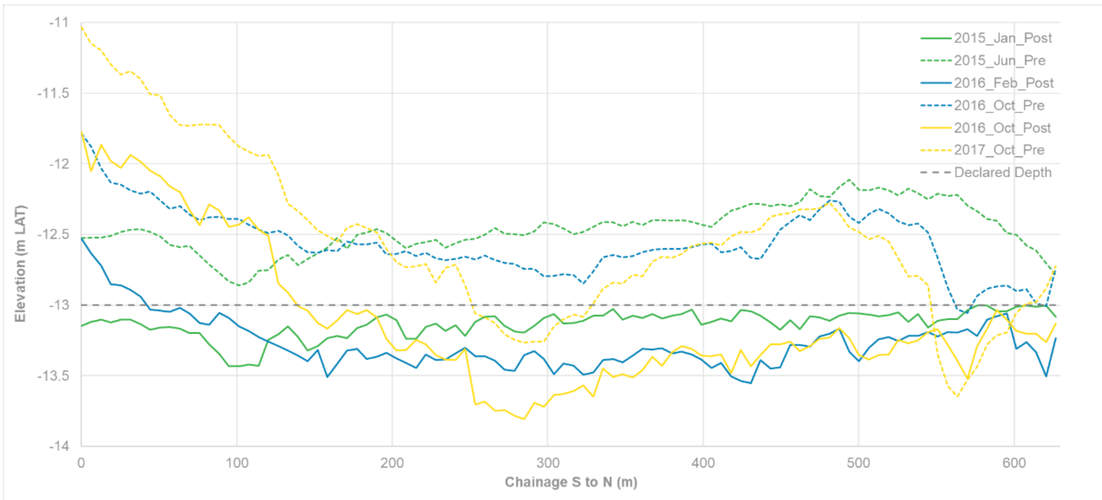

Figure 13. Historic bathymetry along APLNG transect.

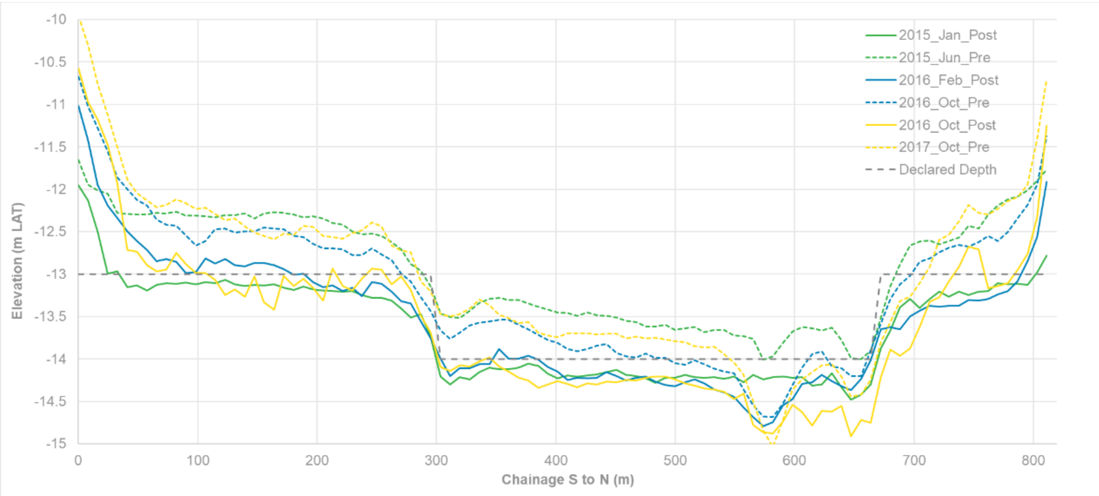

Figure 14. Historic bathymetry along QCLNG transect.

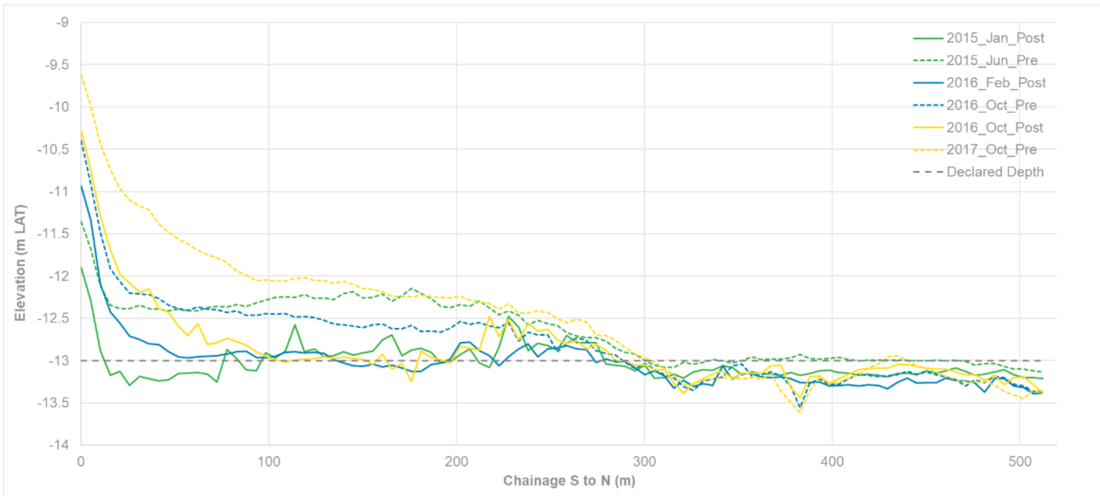

Figure 15. Historic bathymetry along GLNG transect.

Figure 16. Historic bathymetry along Jacobs N transect.

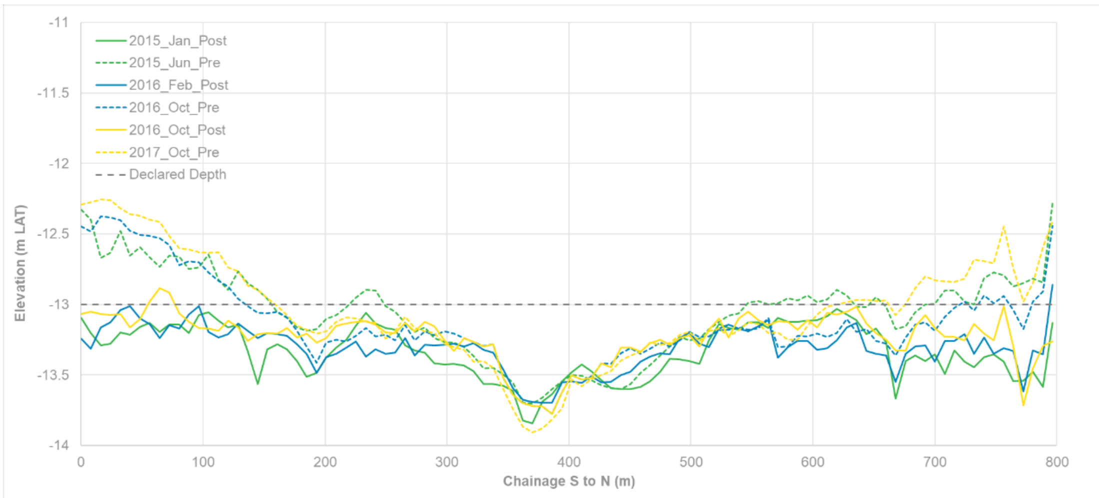

Figure 17. Historic bathymetry along Jacobs S transect.

Figure 18. Historic bathymetry along Jacobs Long transect.

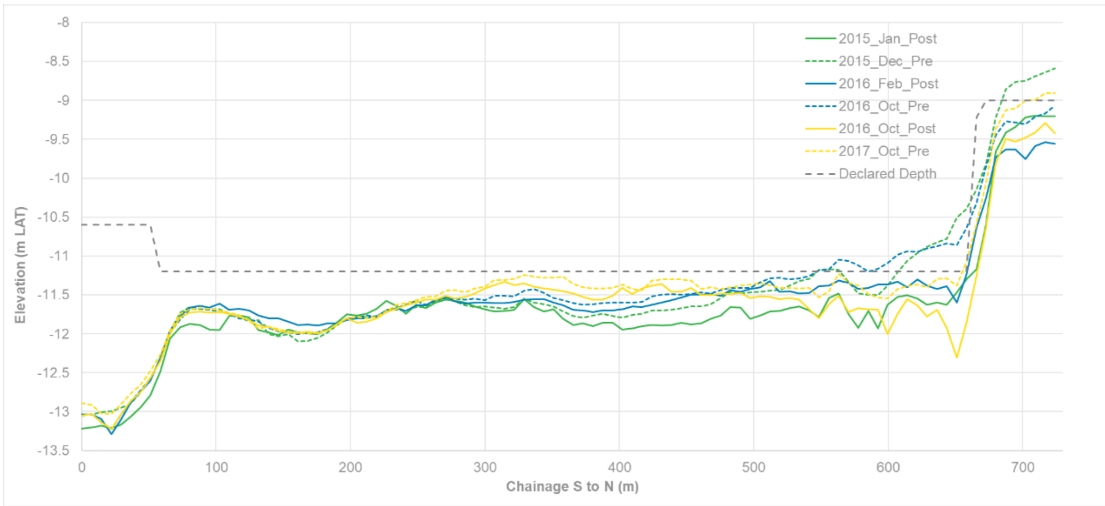

Figure 19. Historic bathymetry along Fisherman's Berths 4&5 transect.

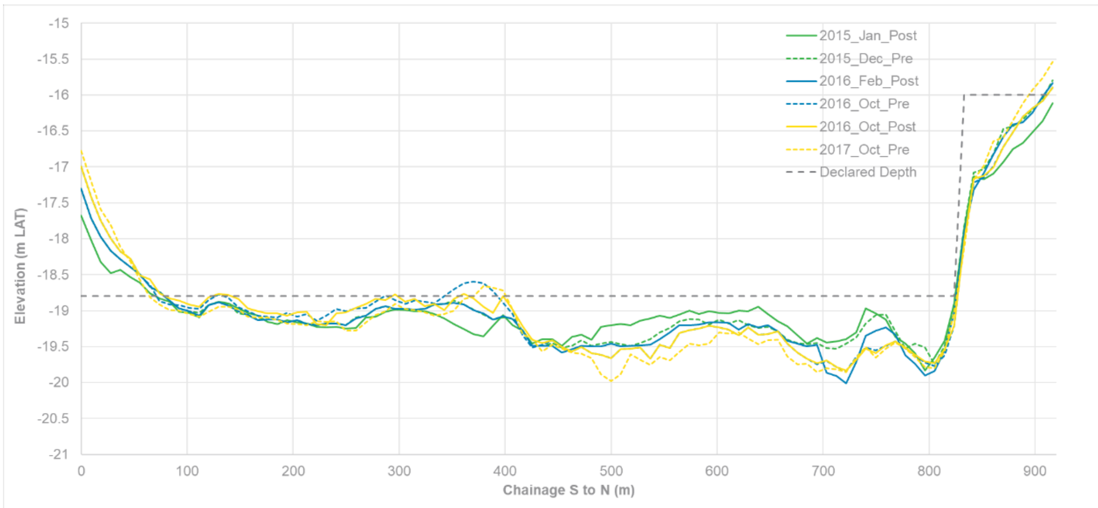

Figure 20. Historic bathymetry along WICT Berths transect.

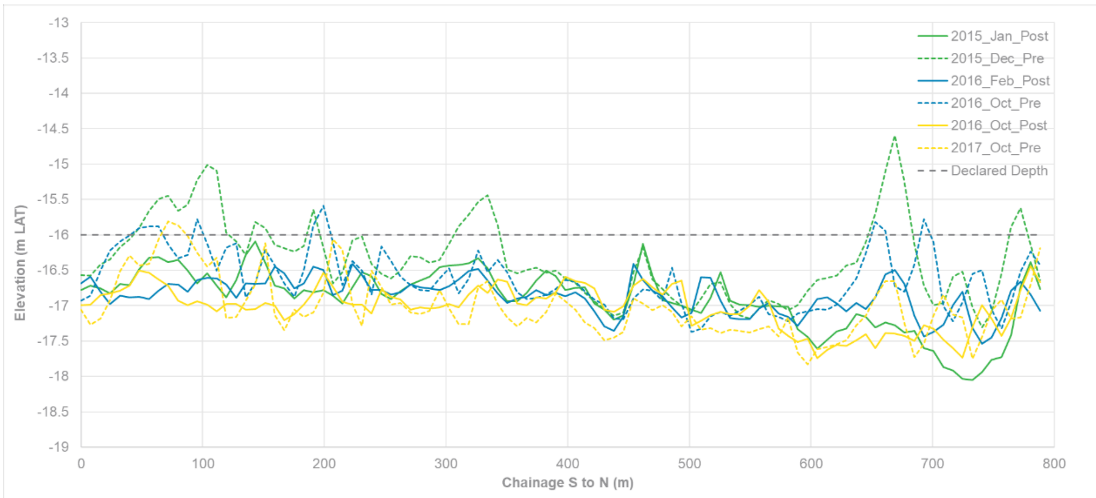

Figure 21. Historic bathymetry along Clinton transect.

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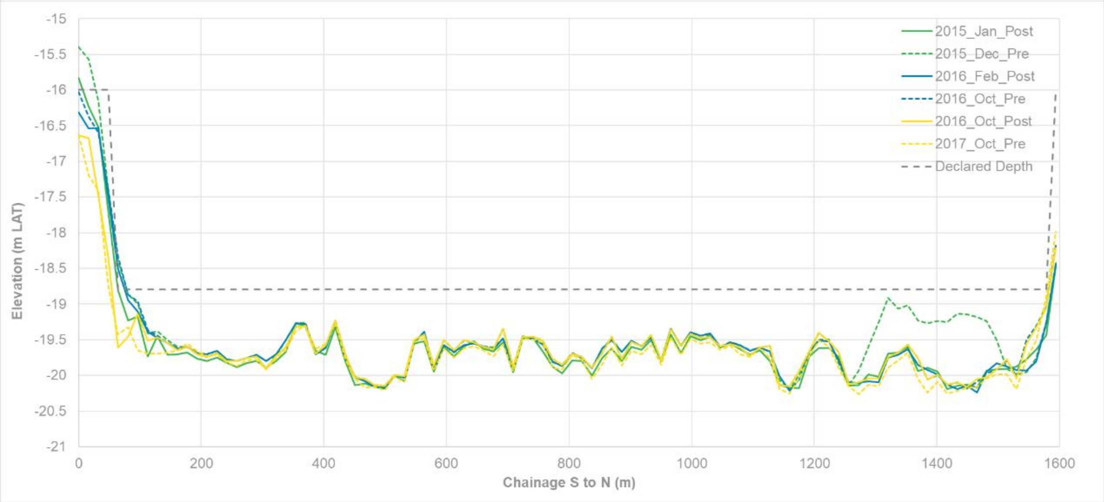

Figure 22. Historic bathymetry along Clinton Berths transect.

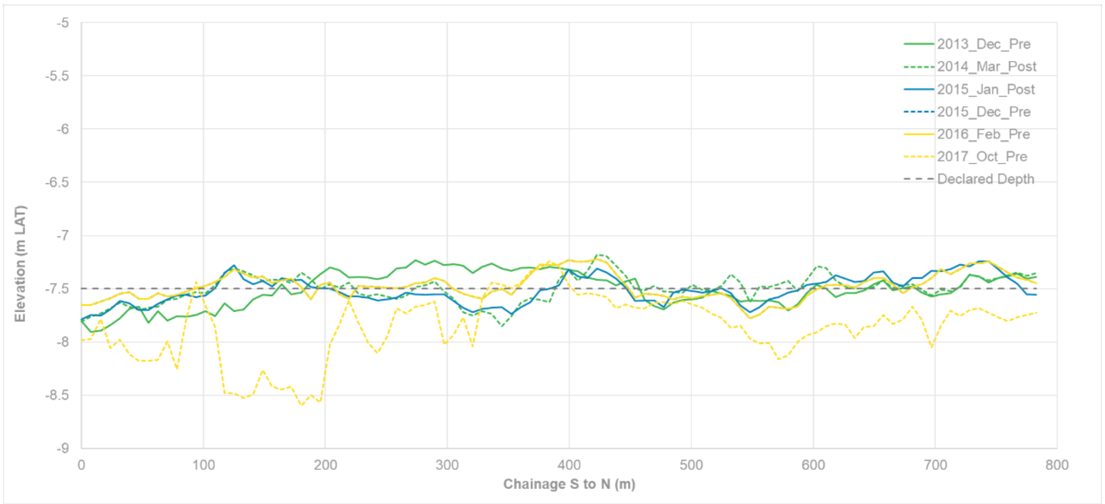

Figure 23. Historic bathymetry along Tug Base transect.

Note: the December 2015 bathymetry behind the February 2016 bathymetry line in the plot. In addition, it is assumed that either maintenance dredging or bed levelling was undertaken between the 2016 and 2017 surveys which is why there was a significant reduction in bed elevation.

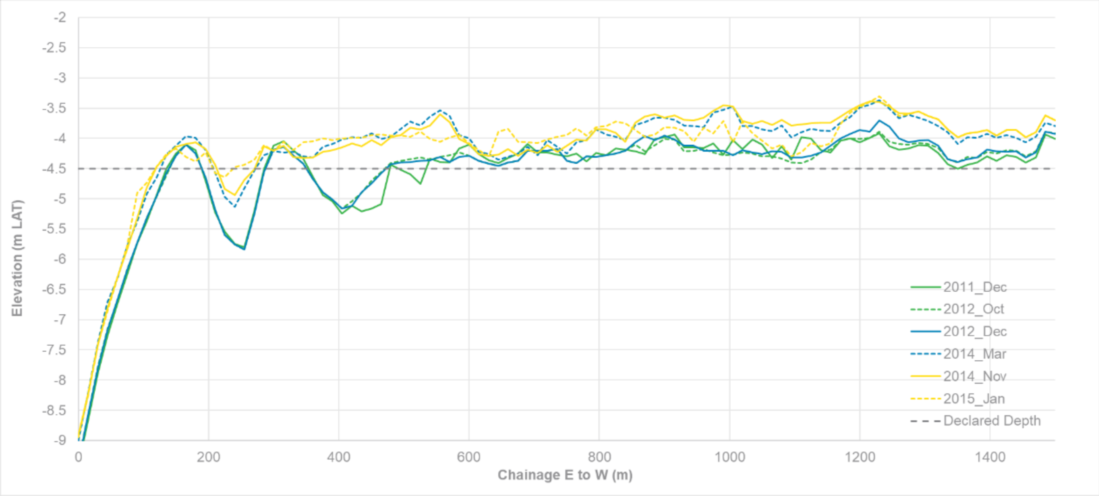

Figure 24. Historic bathymetry along Marina transect.

Figure 25. Historic bathymetry along Auckland Pt Berth1 transect.

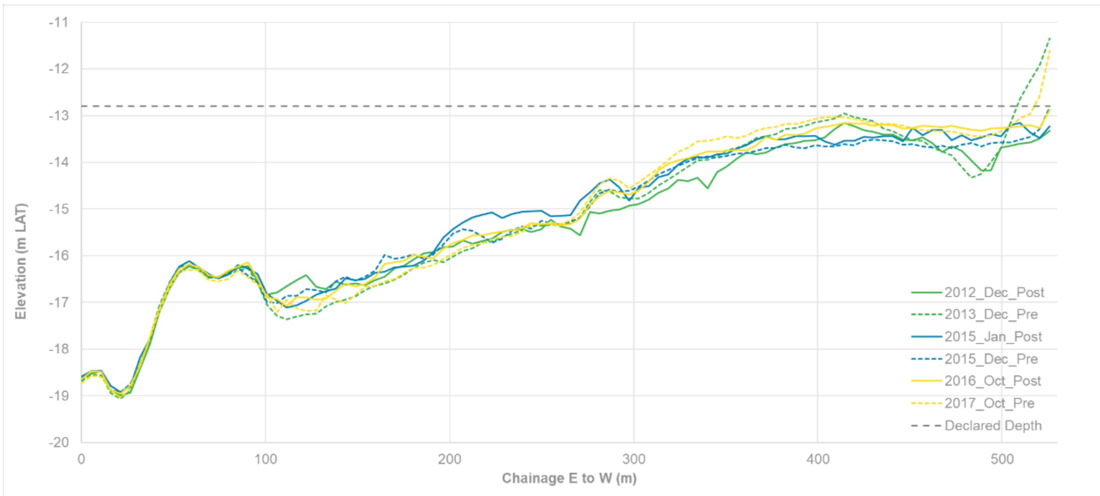

Figure 26. Historic bathymetry along South Trees (berths) transect.

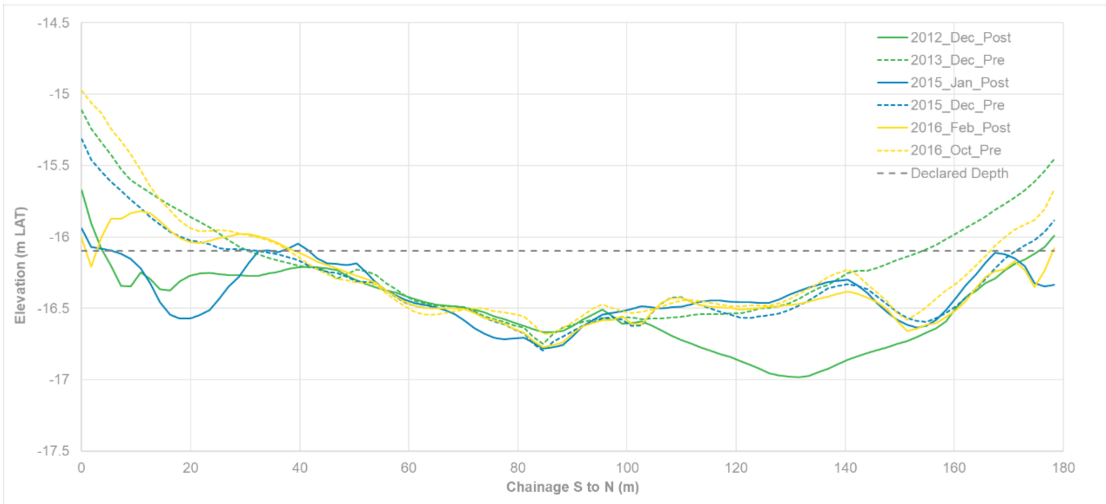

Figure 27. Historic bathymetry along Golding transect.

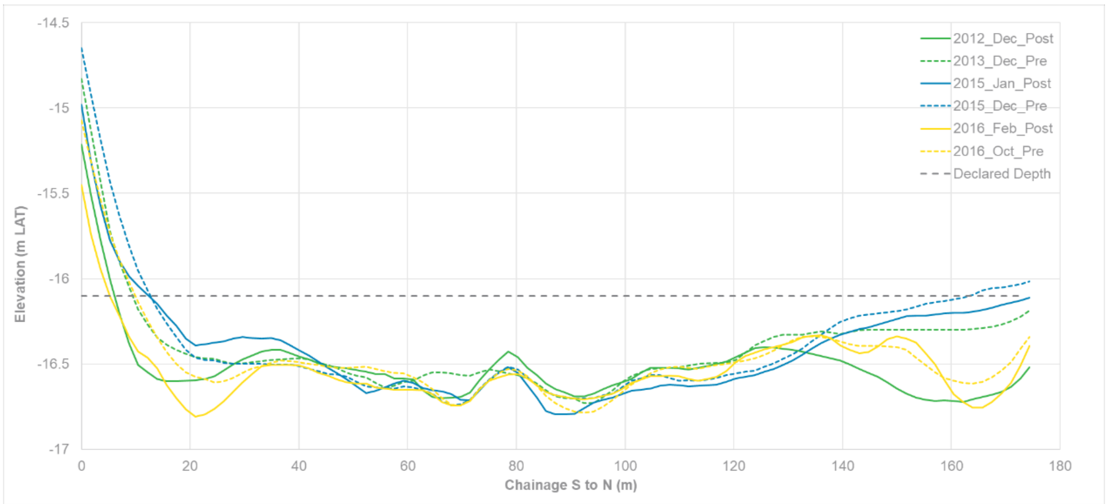

Figure 28. Historic bathymetry along Wild Cattle transect.

2.3. Future Sedimentation Predictions

Predictions of future sedimentation and the corresponding declared depth are presented in this section for the regions of the PoG which have been shown to be subject to regular ongoing sedimentation. The predictions are based on the analysis undertaken in the previous sections of the report and assume that no ongoing sediment management (e.g. maintenance dredging and drag barring) is undertaken. For the predictions to be made a number of assumptions were required:

- the maximum historic sedimentation occurs every five years (starting at year 1), with the subsequent years being subject to mean/median sedimentation (depending on the number of years of sedimentation available (>3 years = median, otherwise mean)) based on the values in Table 4 and separately specified in Section 2.2 for the Marina and Tug Base. For the Clinton Channel the maximum sedimentation has only been assumed for year 1, as once the sand ridges have formed the sedimentation rate would be expected to reduce;
- the reduction in depth above the declared depth has been calculated based on information regarding average and maximum reductions from the transects shown in the previous section;
- for the Jacobs Channel region (including the LNG terminals) it has been necessary to assume that the sedimentation above the declared depths, which has occurred between 2015 and 2017, is representative of future sedimentation. It is possible that sedimentation will reduce in the future, but it is not possible to quantify this and it is therefore considered more robust to adopt the data from 2015 to 2017;
- based on the advice from the RHM the minimum depth in the berths has been adopted as the declared depth. In Jacobs Channel, Golding Cutting and the Boyne and Wild Cattle Cutting, the width of channel below the declared depth is considered until the width reduces to less than 110 m and then the change in declared depth is presented. Once the majority of the channel is above the declared depth then the total sedimentation from the Conceptual Model (PCS, 2018) was adopted, as opposed to the sedimentation above declared depth calculated in this report; and
- the shallowest bed elevation which can occur due to sedimentation has been based on the adjacent natural seabed depths.

Results from the future predictions of sedimentation above the declared depths are presented in Table 5. To show how the values in Table 5 have been defined, a worked example of how the sedimentation above the declared depth for the APLNG Berth & Basin in Year 2 has been calculated is provided below:

- Year 2 Sedimentation Volume above Declared Depth = Year 1 Sedimentation above Declared Depth + Year 2 Sedimentation above Declared Depth.

  The calculations are based on the values presented in Table 4:

  Year 1 Sedimentation Volume above Declared Depth = Maximum Historic Sedimentation above Design Depth = 76,400 m^3;

  Year 2 Sedimentation Volume above Declared Depth = Mean Historic Sedimentation above Design Depth (as only 3 yrs of data) = 64,700 m^3;

  Year 2 Sedimentation Volume above Declared Depth = 76,400 + 64,700 = 141,100 m^3 (numbers in Table 5 have been rounded to the nearest 100 m^3).

The table shows that between 213,000 m^3 and 317,000 m^3 of sedimentation above the declared depths is expected to occur in the PoG per year. The results also highlight how the declared depth would be expected to change over time, assuming that no maintenance dredging or bed levelling was undertaken.

Table 5. Predicted future sedimentation above declared depth for the areas of the PoG where regular sedimentation occurs.

Region	Declared Depth (m LAT)	Year 1		Year 2		Year 5		Year 10		Year 20	
		Vol (m^3)	Depth (mLAT)	Vol (m^3)	Depth (mLAT)	Vol (m^3)	Depth (m LAT)	Vol (m^3)	Depth (m LAT)	Vol (m^3)	Depth (m LAT)
Cross Over	**-3.3**	5,200	-3.0	9,700	-2.7	23,000	-1.8	46,000	-1.0	92,100	-1.0
APLNG Channel	**-7.5**	17,600	-6.8	30,200	-6.5	68,000	-5.4	136,000	-3.3	272,000	-2.0
APLNG Berth & Basin	**-13**	76,400	-12.1	141,100	-11.4	335,200	-9.4	670,400	-5.7	1,340,800	-2.0
QCLNG North	**-7.5**	33,400	-7.0	53,900	-6.6	115,500	-5.3	231,000	-3.0	461,900	-2.0
QCLNG Berth & Basin	**-14**	29,000	-13.3	50,300	-12.7	114,300	-10.9	228,600	-7.8	457,200	-2.0
GLNG Berth & Basin	**-13**	32,900	-12.0	65,000	-11.2	161,200	-8.9	322,300	-4.7	644,700	-2.0
Jacobs Channel (North & South)	**-13**	200	-13	200	-13	300	-13	700	-13	1,400	-13
Fisherman's Landing Berths 1&2	**-12.9**	200	-12.9	200	-12.9	300	-12.9	600	-12.9	1,200	-12.9
Fisherman's Landing Berths 4&5	**-11.2**	8,700	-10.4	9,600	-9.9	12,100	-8.4	24,200	-5.6	48,300	-5.0
Targinnie North	**-9**	11,300	-8.4	12,300	-8.1	15,300	-7.2	30,600	-5.4	61,100	-5.0
WICT Berth 1	**-18.8**	100	-18.8	200	-18.8	400	-18.8	800	-18.8	1,500	-18.8
WICT Berth 2	**-18.8**	1,400	-18.5	2,300	-18.2	5,000	-17.3	10,000	-15.7	20,000	-12.6
Clinton Channel	**-16**	7,300	-14.6	12,400	-14.2	27,700	-13.0	53,100	-11.0	104,000	-7.0
Clinton Wharf Berths	**-18.8**	2,000	-18.3	2,100	-18.2	2,500	-17.7	4,900	-16.6	9,900	-14.4
Tug Base	**-7.5**	7,700	-7.3	11,500	-7.2	22,700	-6.9	45,500	-6.2	90,900	-4.9
Marina	**-4.5**	45,800	-3.9	85,000	-3.5	202,600	-2.3	405,100	-0.1	810,200	0.0
Auckland Pt Approach	**-11.5**	2,300	-11.2	2,400	-11.0	2,700	-10.4	5,400	-9.3	10,900	-7.1
Auckland Pt Berth 1	**-11.3**	7,600	-10.0	8,500	-9.4	11,100	-7.6	22,200	-4.0	44,400	-4.0
South Trees Berths	**-12.8**	2,200	-11.0	2,600	-10.0	3,900	-7.0	7,800	-5.0	15,600	-5.0
Golding Cutting	**-16.1**	21,700	-16.1	24,800	-16.1	34,300	-14.9	416,000	-12.7	1,316,000	-8.3
Boyne & Wild Cattle Cutting	**-16.1**	4,100	-16.1	5,800	-16.1	10,900	-16.1	21,800	-16.1	43,600	-14.0
Total Sedimentation		**317,100**		**530,200**		**1,169,500**		**2,683,900**		**5,849,500**	
Ave. Annual Sedimentation		**317,100**		**265,100**		**233,900**		**268,400**		**292,500**	

Note: the values in red highlight when the shallowest bed elevation has been reached (this was inferred based on the surrounding natural seabed elevations).

2.3.1. Vessel Operation Impacts

Based on the typical vessel drafts which operate in the different regions of the PoG (Table 3) and the average annual sedimentation calculations presented in Table 5, the reduction in declared depths would be expected to have the following impacts to vessel operations:

- Year 1 onwards, impacts to vessels associated with LNG, chemical manufacturing, aluminium and coal:
  - reduced loading at berths located at APLNG, GLNG, QCLNG (after year 3), Fisherman's Landing Berth 5 (chemical manufacturing) and South Trees western berth (alumina).
  - reduced loading for Cape size vessels at Clinton Coal Facility berth 4 (coal).
  - insufficient draft for laden vessels (excluding cruise ships) at Auckland Point berth 1 at low water.
- Year 5 onwards, additional impacts to vessels associated with cruise industry:
  - no access for fully laden Cape size vessels through Golding Cutting, meaning that it would be unlikely for it to be economically feasible for these vessels to continue to operate in the PoG.
  - tidal constraint for fully laden Panamax vessels through Golding Cutting (no access during low water).
  - insufficient depth for unladen LNG vessels at APLNG and GLNG berths.
  - highly restricted access at Auckland Point berth 1 (impacting cruise ships), with sufficient draft only around high water for vessels with a draft of 10 m or less (potential that this would make the berth unusable for the majority of cruise ships which currently operate there).
  - limited loading potential at South Trees western berth with sufficient depth only for unladen vessels throughout the tidal cycle and fully laden vessels only at high water.
  - restricted access for larger laden vessels (Cape size and Panamax) in Clinton Channel, with Panamax size vessels limited to mid tide to high water and Cape size vessels restricted to high water.
- Year 10 onwards, additional impacts to commercial and recreational vessels in the Marina:
  - no access for fully laden Panamax size vessels through Golding Cutting, meaning that it would be unlikely for it to be economically feasible for these vessels to continue to operate in the PoG.
  - insufficient depth for unladen LNG vessels at QCLNG.
  - insufficient depth for unladen vessels at Fisherman's Landing berth 5 and the adjacent Targinnie North apron area.
  - insufficient depth for unladen vessels at Auckland Point berth 1.
  - insufficient depth for unladen vessels at South Trees western berth.
  - insufficient depth in the Marina for any vessels which cannot sit on their hull during low water.
  - tidal constraint for tug vessels operating from the Tug Base with no access around low water. This would have significant implications to the operation of the PoG as the tugs are required throughout the tidal cycle for vessel navigation and berthing.
- Year 20 onwards, impacts to all existing trades operating in PoG:
  - no access for most unladen vessels through Golding Cutting and all laden vessels (i.e. no vessel operations possible so all shipping/Port operations would cease prior to this time).

2.3.2. Predicted Maintenance Dredging Requirements

Based on the analysis undertaken as part of this assessment it is possible to estimate the future in-situ volume of sediment that requires management. If we assume that the sediment continues to be managed through dredging then it is possible to estimate the in-situ volumes and frequency required for the regions of the PoG to maintain declared depths (Table 6).

The frequency has been determined to limit sedimentation above declared depths. However, as noted in Section 2.1, it is at the discretion of the RHM whether any sedimentation above the declared depth results in the depths being redeclared. Therefore, a range of frequencies have been included for some of the channels, with the higher frequency representing when sedimentation is expected to reduce the depths above the declared depth and the lower frequency representing when the sedimentation would likely result in the RHM redeclaring the depths in the channel.

Typical year and worst case in-situ volumes requiring maintenance dredging (i.e. sedimentation above the declared depth) are also presented in the table. The typical year is the mean/median value based on the historic analysis and the worst case is the maximum value from the historic analysis (see Table 4).

Table 6. Predicted maintenance dredging in-situ volumes and expected frequency of dredging.

Region	Typical Year (m^3/yr)	Worst Case (m^3/yr)	Frequency (yrs)
Cross Over	4,500	5,200	1
APLNG Channel	12,600	17,600	1
APLNG Berth & Basin	64,700	76,400	1
QCLNG North	20,500	33,400	1
QCLNG Berth & Basin	21,300	29,000	1
GLNG Berth & Basin	32,100	32,900	1
Jacobs Channel (North & South)	100	200	>10
Fisherman's Landing Berths 1&2	0	200	>10
Fisherman's Landing Berths 4&5	900	8,700	1
Targinnie North	1,000	11,300	1-2
WICT Berth 1	100	100	>10
WICT Berth 2	900	1,400	1-2
Clinton Channel	5,100	7,300	1-2
Clinton Wharf Berths	100	2,000	1-2
Tug Base	3,800	7,700	2-5
Marina	39,200	45,800	2-5
Auckland Pt Approach	100	2,300	1-2
Auckland Pt Berth 1	900	7,600	1
South Trees Berths	400	2,200	1
Golding Cutting	3,100	21,700	1-2
Boyne & Wild Cattle Cutting	1,700	4,100	2-5
Total Sedimentation	**213,100**	**317,100**	

If it is assumed that the highest frequency for the maintenance dredging is required (if a range of frequencies are shown in Table 6) and volumes are presented for both the typical and worst case years, then the ongoing maintenance dredging (rounded to the nearest 1,000 m^3) would be as follows (not allowing for any over/insurance dredging):

- Annual Requirement: **Total = 170,000 - 260,000 m^3/yr** (rounded to the nearest 10,000 m^3)
  - LNG Terminals and associated aprons/channels: 155,000 - 195,000 m^3;
  - Fisherman's Landing Berths 4 & 5 and adjacent apron (Targinnie North): 2,000 - 20,000 m^3;
  - WICT Berth 2 : 1,000 m^3;
  - Clinton Channel and Clinton Wharf Berths: 5,000 - 9,000 m^3;
  - Auckland Point Berth 1 and adjacent approach: 1,000 - 10,000 m^3;
  - South Trees Berths: 1,000 - 2,000 m^3;
  - Golding Cutting: 3,000 - 22,000 m^3.
- Biennial Requirement: **Total = 90,000 - 100,000 m^3 every two years** in addition to the annual requirement (rounded to the nearest 10,000 m^3)
  - Tug Base: 8,000 - 12,000 m^3;
  - Marina: 78,000 - 85,000 m^3;
  - Boyne and Wild Cattle Cutting: 3,000 - 6,000 m^3.
- Occasional (10 years): **Total = 2,000 m^3 every ten years** in addition to the annual and biennial requirements
  - Fisherman's Landing Berths 1 & 2: 1,000 m^3;
  - WICT Berth 1: 1,000 m^3.

Based on the above, the total annual average (averaged between annual and biennial) maintenance dredging requirement for the PoG is between 210,000 and 265,000 in-situ m^3/yr, depending on whether the sedimentation which has occurred is typical or worst case. The 265,000 m^3/yr is lower than the 317,000 m^3/yr shown for the worst case year in Table 6 as the value has been averaged over two years which assumes a worst case year and a typical year.

3. Avoid Assessment

A requirement of the Deed associated with the Sea Dumping Permit for maintenance dredging between GPC and DoEE is to investigate the possibility of avoiding or reducing the need for further placement of maintenance dredged material into the marine environment (see Section 1.1). This assessment considers the possibility of avoiding, which is the highest level in the hierarchy of response, and a subsequent assessment will consider the possibility of reducing the need for further placement of maintenance dredged material into the marine environment.

To understand the potential options for completely avoiding sedimentation, the placement of dredged material at sea and maintenance dredging, it is necessary to undertake an options assessment. This section details that assessment. Subsequent assessments will be undertaken to understand options to reduce sediment accumulation, reduce maintenance dredging and reduce placement of dredged material at sea (including beneficial reuse and on land placement) and as such this assessment is only concerned with options to completely avoid and not just to reduce.

3.1. Sedimentation

In order to consider avoid options it is necessary to understand where sedimentation which has the potential to influence port operations is occurring in the PoG, what the composition of the sediment is and what is causing the sedimentation. The future sedimentation predictions in Section 2.3 show that sedimentation above declared depths has occurred in both the Inner and Outer Harbour regions of the PoG, with the majority has been in the Inner Harbour with the highest rates in the LNG Terminal berths and swing basins in the Jacobs Channel region. It is noted by PCS (2018) that the sediment which has been deposited in the Inner Harbour region was predominantly fine-grained silt and clay, while in the Outer Harbour region it was more variable with approximately equal proportions of sand to silt/clay in the Golding Cutting but predominantly sand in the Wild Cattle Cutting. A summary of the processes which result in sedimentation in the Inner and Outer Harbour regions of the PoG is provided by PCS (2018):

- Inner Harbour: resuspension and sediment transport in the Inner Harbour region is dominated by the tidal currents. The strong tidal currents are the dominant process for resuspending sediment in the Inner Harbour, although small locally generated wind waves and wind induced currents can also result in resuspension in shallow areas where fine-grained sediment is present. Therefore, the bed sediment in the Inner Harbour are regularly mobilised, transported and redeposited until they are either transported to a sheltered location where ongoing sedimentation occurs or out of the region by the ebb tidal currents. The Inner Harbour region can be considered a sediment sink, with extensive sources of fine-grained and coarser sands and gravels already present due to deposition over geological timeframes. In addition to the available sediment already present in the Inner Harbour, new sediment is added to the region by the suspended sediment being discharged from the Calliope River and from fluxes of suspended sediment being transported through the three entrances to the Inner Harbour. Although it is likely that the gross flux of suspended sediment through the main entrance of the Inner Harbour will be high during a spring tide, the net flux is likely to be comparatively small compared to the mass of sediment resuspended within the Inner Harbour. The relatively high tidal current speeds which occur throughout much of the Inner Harbour limit the build-up of fine-grained sediment in the main channels. However, in sheltered areas adjacent to the channels, in closed-end channels (e.g. Jacobs and Targinnie Channels) and in vegetated areas (e.g. areas with seagrass or mangroves which promote deposition) regular sedimentation of fine-grained sediment can occur.
- Outer Harbour: the Outer Harbour is influenced by a combination of offshore waves and tidal currents. The wave action is the dominant process for resuspending sediment in the Outer Harbour, while the tidal currents will be the dominant process for transporting the

suspended sediment. The majority of the Outer Harbour region is an ebb tidal delta which has developed over time at the mouth of the Port Curtis estuary. Therefore, the region is a natural sediment sink, which is further highlighted by the presence of the East and West Banks (located to the north and south of the Golding Cutting) and is expected to continue to act as a sink over time. Due to the influence of the offshore wave action the majority of the sediment which has accumulated is sand. In addition to the available sediment already present in the Outer Harbour, sediment is added to the region by the net northerly longshore transport of sediment (sand and fine-grained silt/clay) along the coastline, the suspended sediment being discharged from the Boyne River and from fluxes of suspended sediment being transported out of the Inner Harbour through the two entrances. The relatively high tidal current speeds which occur close to the entrance to the Inner Harbour limit sedimentation of fine-grained sediment in this area. As the current speeds reduce and the trapping efficiency of the channels increase (i.e. depth of channel below adjacent seabed), some deposition of sand and silt/clay sized sediment occurs. Along the sides of the Golding Cutting a combination of sand, silt and clay has built-up, while in the Wild Cattle Cutting the sediment is predominantly made up of sand. The reason for this difference is thought to be a combination of the trapping efficiency of the channels (Wild Cattle Cutting has a lower trapping efficiency due to the naturally deeper adjacent bathymetry), the exposure to wave action (Wild Cattle Cutting is more exposed as East Bank will provide some shelter to the Golding Cutting) and the configuration of the channel (the bend between the Golding and Wild Cattle Cuttings will also influence the trapping efficiency and local conditions). In both channels the sedimentation which has occurred has been predominantly along the edges of the channels, this is due to the natural current speeds being lowest along the edges of the channels and the propeller wash from vessels sailing along the centreline of the channel resulting in increased disturbance along the centre of the channel and therefore preventing sediment from building up here.

3.2. Avoid Sediment Management

Details of the operational impacts if all future sediment management in the PoG is stopped is provided in Section 2.3.1. It was found that after the first year reduced vessel loading (i.e. insufficient depth for full vessel draft throughout the tide) would be required at a number of berths and after five years the sedimentation in the Golding Cutting would start to affect the Cape and Panamax size vessels when fully laden. Between 10 and 20 years the ongoing sedimentation is predicted to result in the depth in the Golding Cutting to limit access for the majority of unladen vessels entering the PoG, effectively preventing any ongoing port operations. As such, for the PoG to remain operational it is not possible to completely avoid all future sediment management. Therefore, the options to avoid sedimentation, maintenance dredging and sea placement individually are discussed in the following sections.

3.3. Avoid Sedimentation

As discussed in Section 3.1, the sedimentation which occurs in the PoG is the result of natural processes which act to resuspend, transport and deposit sediment within the PoG, combined with the high trapping efficiency of berths and some channels (due to the relative difference in depth between the channel/berth and the adjacent natural seabed), resulting in increased sedimentation of natural sediment in these areas.

The Technical Supporting Document of the Maintenance Dredging Strategy (RHDHV, 2016) provides a summary of approaches recommended by PIANC (PIANC, 2008) and the United States Army Corps of Engineers (USACE) (USACE, 2003) to minimise harbour and channel sedimentation (Table 7). It is noted that the applicability of the approaches are dependent on the port configuration, sediment type, natural environment and processes (RHDHV, 2018). There are two overall strategies which could be applied to avoid sedimentation (the third strategy does not influence sedimentation), the first involves keeping sediment out of the Port area and the second involves keeping sediment in the Port area moving, these two strategies are discussed below:

- keep sediment out: this strategy involves adopting a range of approaches to keep the sediment out of the Port area. These approaches are typically more successful in areas where there are large fluvial inputs (stabilising sediment sources and diverting sediment-laden flows), where the majority of the sediment transport is by bedload (trapping sediment before it enters the port) and in harbours where there is only a single entrance to the port (blocking sediment entry). As the majority of the sediment transport within the PoG is due to local resuspension of sediment within Port Curtis and the immediate surrounds, most of the sediment transport occurs in suspension and the majority of the PoG is not enclosed none of these approaches will be successful to completely avoid sedimentation. There is the potential that some approaches could be implemented to reduce sedimentation in some areas of the PoG, this will be further assessed as part of the subsequent reduce study.
- keep sediment moving: this strategy involves adopting a range of approaches to limit sedimentation by keeping the sediment mobile. These approaches can be very successful at preventing or reducing local sedimentation in certain areas, especially in berths, but it is unrealistic to consider that the approaches could avoid all sedimentation within the PoG given its scale and the variability in the locations where sedimentation occurs. Similar to the keep sediment out strategy there is the potential that some approaches could be implemented to reduce sedimentation in some areas of the PoG, this will be further assessed as part of the subsequent reduce study.

Table 7. Summary of approaches to minimise sedimentation (RHDHV, 2016).

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

Based on the processes which cause sedimentation, combined with the overall scale of the PoG and the number of locations where sedimentation occurs, it is not realistic to avoid all sedimentation in the PoG. There would be options available which could, in theory, avoid ongoing sedimentation in localised areas (e.g. berths), but as these would only be reducing the overall sedimentation which occurs they will be considered as part of the subsequent reduce study.

3.4. Avoid Maintenance Dredging

The previous sections concluded that it is not possible to avoid all sedimentation within the PoG and that if no sediment management is undertaken port operations could not continue due to the sedimentation. Therefore, it is necessary to understand if there are alternative sediment management options to maintenance dredging which can be adopted to avoid maintenance dredging in the PoG. The only realistic alternative sediment management approach to maintenance dredging is bed levelling/drag barring. This involves lowering a heavy metal bar to a set depth and dragging the bar across the seabed. The dragging of the bar removes any high points and redistributes the sediment to surrounding deeper areas. The process can also result in the resuspension of some fine-grained sediment, which if the currents are strong enough will be transported away from the area. This is a very efficient approach of removing any high points in areas and is often adopted between maintenance dredging campaigns to maintain navigability. However, there are a number of reasons why the approach cannot be adopted to replace maintenance dredging:

- it is redistributing the majority of the sediment on the seabed rather than removing the sediment from the area like a dredger. Therefore, it is able to provide a short-term solution by moving high points formed by sedimentation into adjacent areas which are below the declared depth, but in an area subject to ongoing sedimentation (e.g. a berth) eventually all areas will be above the declared depth and so the drag barring will not be able to reduce the level back to declared depth; and
- the relative success of drag barring is dependent on the sediment properties. For recently deposited, unconsolidated silt and clay it is effective, but when the silt and clay starts to become consolidated (e.g. after six months to a year of being deposited) the drag barring becomes ineffective and is unable to move the sediment. Drag barring can be adopted for sand but the rate it can move the sediment can be an order of magnitude lower than for unconsolidated silt and clay.

Based on this assessment it can be concluded that there are no realistic options available to avoid all maintenance dredging within the PoG and enable the Port to remain operational. Although alternative options such as drag barring/bed levelling can be adopted for localised areas, where there is either sufficient natural current to transport the resuspended sediment away from the area or adjacent deep areas where the sediment can be pushed into, this type of option is not realistic for all areas of the PoG as the conditions and material are not always suitable. As such, this type of option could be adopted to reduce maintenance dredging and ongoing sedimentation, but not to completely avoid it and so it will be considered as part of the subsequent reduce study.

3.5. Avoid Sea Placement

Based on the previous sections there are no realistic options available to either completely avoid sedimentation or maintenance dredging and enable the PoG to remain operational. As such, there will continue to be a requirement for dredged sediment to be relocated from the dredged areas of the Port. At present all of the sediment which is removed by the TSHD *Brisbane* during the annual maintenance dredging campaigns is placed at the EBSDS. Bathymetric analysis of the EBSDS shows that if an upper elevation of -8 m LAT is assumed for the site then there is currently 38 M m^3 of capacity, which equates to approximately 150 years of maintenance dredging assuming an average annual volume of 250,000 m^3.

There are a number of alternatives for maintenance dredge sediment as opposed to placement at the EBSDS. These include rainbowing sediment offshore of beaches for beach nourishment and pumping sediment to shallow intertidal environments such as mudflats and mangroves. However, these options would only be suitable for specific sediment types and would not be realistic for the volumes of sediment required for annual maintenance dredging at the PoG. As such, they will subsequently be assessed in more detail as part of the beneficial reuse and reduce studies. The two options which could be adopted for dredged material as opposed to placement at the EBSDS are:

- side-casting: this involves depositing dredged material through a pipe to the side of the dredged area where it can then be transported away from the dredged area. This approach still involves placing the natural sediment in the sea, but it places the natural sediment adjacent to where it was deposited to allow it to subsequently be transported. In some areas this approach could be successful, but its success is dependent on the dominant processes and it is most successful in locations where there is a dominant transport direction to ensure the majority of the sediment is not transported back into the dredged area. For the PoG this approach could be considered in the Outer Harbour region where there is a dominant northerly transport, but for the Inner Harbour where there is no dominant transport direction the approach would be unlikely to be suitable; and

- fixed pipeline: in cases where regular maintenance dredging is required and the sediment is pumped either to shore or into a land reclamation area for either beneficial reuse or onshore disposal a fixed offloading pipeline could be installed. The dredger would then be able to connect to the pipeline and pump the sediment to shore. This option would require all of the sediment to either be used for on shore beneficial reuse or to be placed on land. Based on the predicted future sedimentation above the declared depths in the PoG shown in Table 5, this would equate to approximately 1.2 M m^3 (in-situ volume) of sediment after 5 years, 2.7 M m^3 after 10 years and 5.9 M m^3 after 20 years.

As part of the application for permits under the *Sea Dumping Act 1981* GPC has previously undertaken assessments into alternatives to sea placement for maintenance dredge sediment (GPC, 2018). It was concluded that the most likely alternative to sea placement would be land creation through placement of the sediment in existing reclamation sites. However, a number of constraints were identified, these included:

- retaining marine sediments in the marine environment;
- maintaining intertidal areas rather than replacing them by reclamation;
- placing dredge material into a reclamation is logistically more complex and significantly more costly than placing it at the EBSDS;
- clay and silt sized sediment in maintenance dredge material can require significant reworking and take years to dry out which would delay the future use of the land; and
- the strategic utilisation of viable reclamation areas for capital dredging is particularly important since the introduction of the Ports Act (DTMR, 2015).

Based on these constraints it was noted that although it is possible to pump some of the maintenance dredge sediment into an existing reclamation, the preferred option was placement at sea. Further investigation into the beneficial reuse and on land placement of maintenance dredge sediment will be undertaken as part of the subsequent beneficial reuse investigation.

Therefore, the only realistic options to avoiding future sea placement at the EBSDS is for all of the sediment from maintenance dredging to be pumped to shore and beneficially reused.

4. Summary

This report has provided a detailed assessment of the historic sedimentation rates above the declared depths within the dredged areas of the PoG. Based on the historic sedimentation volumes, future sedimentation volumes and associated reductions in declared depths have been predicted. These have been used to inform how sedimentation is likely to impact the future operations of the PoG if there was no future maintenance dredging.

The key findings of this assessment are:

- future sedimentation above the declared depths in the PoG is predicted to be 213,000 and 317,000 m^3/yr for typical and worst case years. The majority of this sedimentation is within the Inner Harbour, with more than 60 percent being in LNG Terminal berths and swing basins in the Jacobs Channel region;
- if no sediment management (i.e. maintenance dredging or drag barring/bed levelling) is undertaken then future sedimentation above declared depths is predicted to be 1.2 M m^3 (in-situ volume) of sediment after 5 years, 2.7 M m^3 (in-situ volume) after 10 years and 5.9 M m^3 (in-situ volume) after 20 years;
- after 1 year of sedimentation with no sediment management there is predicted to be reduced loading for the majority of vessels at five of the berths in the PoG (influencing the LNG, chemical manufacturing and aluminium industries) and reduced loading for Cape size vessels at one berth (influencing the coal industry). After five years of sedimentation there is likely to be no access to the Port for Cape size vessels, a tidal constraint for Panamax size vessels and insufficient depth for vessels at a further four of the berths (9 in total, also influencing the cruise industry). After 20 years of sedimentation access through the Golding Channel is unlikely to be possible for most unladen vessels, which would mean that the PoG would not be able to continue operation;
- to maintain declared depths within the PoG a number of regions will require annual dredging, with typical and maximum volume estimates of 170,000 to 260,000 m^3/yr, while other regions will require biennial (or less frequent) dredging, with typical and maximum volume estimates for these regions of 90,000 to 100,000 m^3 every two years. Based on this, the total annual average (averaged between annual and biennial years) maintenance dredging requirement for the PoG is between 210,000 and 265,000 m^3/yr (excluding any over/insurance dredging) depending on whether the sedimentation which has occurred is typical or worst case;
- based on the future sedimentation predictions there are no realistic options available to completely avoid maintenance dredging and the placement of dredged material at sea and for the PoG to remain operational;
- there are possible options which could considered for localised areas to avoid sedimentation and maintenance dredging, but none of these could be adopted for the entire PoG. As such, these options are considered to reduce the total sedimentation in the PoG, rather than completely avoiding sedimentation in the PoG, and so will be considered as part of a subsequent assessment into reducing sedimentation and maintenance dredging in the PoG; and
- the only available options to completely avoid sea placement of maintenance dredged sediment would be for all of the sediment to either be used for beneficial reuse or to be placed on land. These options will be further assessed as part of the subsequent beneficial reuse investigation.

5. References

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