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Sustainable Sediment Management Project

Gap Analysis and Sampling Strategy

Final 1.0

Gladstone Ports Corporation
Technical Report
August 2018

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ACRONYMS

ADCP	Acoustic Doppler Current Profiler
APLNG	Australia Pacific Liquified Natural Gas
AWAC	Acoustic Wave and Current Profiler
BoM	Bureau of Meteorology
BPAR	Benthic Photosynthetic Active Radiation
DES	Department of Environment and Science
DoEE	Department of Environment and Energy
EBSDS	East Banks Sea Disposal Site
EIS	Environmental Impact Statement
EMS	Environmental Management System
GBR	Great Barrier Reef
GBRMP	Great Barrier Reef Marine Park
GBRWHA	Great Barrier Reef World Heritage Area
GLNG	Gladstone Liquified Natural Gas
GPC	Gladstone Ports Corporation
LAT	Lowest Astronomical Tide
LISST	Laser In-Situ Scattering and Transmissometery
LNG	Liquified Natural Gas
MSQ	Maritime Safety Queensland
NAGD	National Assessment Guidelines for Dredging
NTU	Nephelometric Turbidity Units
PCS	Port and Coastal Solutions
PoG	Port of Gladstone
PSD	Particle Size Distribution
QCLNG	Queensland Curtis Liquified Natural Gas
QLD	Queensland
SAP	Sampling and Analysis Plan
SSC	Suspended Sediment Concentration
SSM	Sustainable Sediment Management
WICT	Wiggins Island Coal Terminal
WRB	Wave Rider Buoy

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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). The aim of this study is to undertake a gap analysis of the data required to convert the conceptual sediment budget into a quantitative sediment budget and based on this to create a sampling strategy to address any identified data gaps.

A gap analysis has been undertaken on the available data for the SSM Project and specifically for developing a quantitative sediment budget for the PoG. The gap analysis identified a number of data gaps which are considered important for the project. The data gaps identified are as follows:

- Temporal variability of sediment properties at the East Banks Sea Disposal Site (EBSDS): additional assessment of the temporal variability at the EBSDS around a maintenance dredging campaign would be beneficial.
- Sources of sediment: although there is sufficient information to inform some of the sources of sediment to the PoG, there is no data available to inform the source of the sediment which is being deposited into the maintained channels and berths of the PoG.
- Fluxes of sediment: as part of the SSM Project a detailed investigation into the input of sediment to the PoG through The Narrows has been undertaken. However, additional data are required to inform the relative input and export of sediment to/from the PoG through the southern and northern entrances.
- Transport of sediment from EBSDS: there are currently no measured data to show how sediment resuspended from the EBSDS behaves once it leaves the site, and this is a specific requirement of the Deed.

Based on the data gaps identified a sampling strategy has been developed. The strategy recommends that three discrete tasks are undertaken:

- Sediment sources: using the sediment samples from the 2017 Sampling and Analysis Plan (SAP), proof of concept studies should be undertaken using recognised approaches to identify the sources of sediment (e.g. rare earth elements and stable isotope analyses). It is recommended that these initial tests are undertaken to better understand how appropriate the analyses are for the PoG region and the information which the analyses can provide.
- Fluxes of sediment: the SSM Project has already undertaken a targeted data collection campaign to better understand the exchange of sediment through The Narrows, so the northern and south-eastern entrances of Port Curtis (the large natural harbour within which the PoG is located) are where additional data are required. Acoustic Doppler Current Profiler (ADCP) transects and fixed position loggers are proposed during spring and neap tides, to measure the flux of water and suspended sediment entering and leaving Port Curtis.
- EBSDS Monitoring: understanding the resuspension and transport of sediment placed at the EBSDS is considered to be a critical aspect of the SSM Project and the quantitative sediment budget. It is therefore recommended that additional monitoring is undertaken in the EBSDS region pre, during and post maintenance dredging in 2018. Five sites have been proposed, two within the EBSDS and three outside (to the west, north and east of the EBSDS). Suspended Sediment Concentration (SSC), Particle Size Distribution (PSD), settling velocity, turbidity, erosion/sedimentation, hydrodynamic, wave and sediment property data are proposed to be collected as part of the campaign. These data can be used to further calibrate and validate the TUFLOW FV model (the data will help to inform the values adopted for certain sediment transport parameters in the model) to ensure it is able to replicate any resuspension and transport of sediment placed at the EBSDS.

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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 is as follows:

- Task 1: to develop a conceptual sediment budget for the PoG;
- Task 2a: to undertake a gap analysis of the data required to convert the conceptual sediment budget into a quantitative sediment budget for the PoG, with specific focus on maintenance dredging and the East Banks Sea Disposal Site (EBSDS); and
- Task 2b: if required, to create a sampling strategy to address any identified data gaps which will allow for the completion of a quantitative sediment budget.

This report is concerned with Tasks 2a and 2b, to undertake a gap analysis and if necessary to develop a sampling strategy to address any data gaps.

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 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 also states that as part of the requirements detailed above GPC will '*establish a quantitative sediment budget and sediment dynamics model for Port Curtis, 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.*'

The Deed also 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 Port Curtis and develop a sediment budget and associated model, to better understand the contribution of GPC's activities to the overall sediment system.

This report is aimed at achieving the following:

- collating all relevant available data and information associated with the development of a sediment budget for the PoG;
- identifying any data gaps which will be required to allow the conceptual sediment budget to subsequently be updated into a robust quantitative sediment budget for the PoG; and
- to develop a sampling strategy to address any identified data gaps and to highlight how the proposed data will assist with the future quantitative sediment budget.

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 natural sediment transport processes which can 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 Liquefied 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 eight (8) 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 3). Maintenance dredging is undertaken to ensure that the depths of the channels and berths are maintained at their declared depths (Table 1). In addition, capital dredging has historically been undertaken in the PoG as the port has grown. Most recently, between 2011 and 2014, capital dredging associated with the construction of three LNG terminals was undertaken. Details of the maintenance and capital dredging, which has been undertaken at the PoG when the sediment has been placed at the EBSDS over the last 10 years, is provided in Table 2. The table shows that in total approximately 7.3 Mm^3 of sediment has been placed at the EBSDS over the last 10 years, with approximately 2 Mm^3 from maintenance dredging and the remainder from the capital dredging between 2011 and 2014.

A breakdown of the volumes of sediment dredged throughout the different areas of the PoG during the 2017 maintenance dredging is shown in Figure 2. The plot shows that approximately 70,000 m^3 was removed from the Golding and Wild Cattle Cuttings, over 100,000 m^3 was removed from the areas to the north of the RG Tanna Wharves (north of Clinton Channel, WICT berths, Targinnie Channel and Jacobs Channel) 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 offshore extent of the Wild Cattle Cutting to the north-western end of the Gatcombe Channel and the Inner Harbour is the area to the north-west of this which is sheltered from offshore wave activity by Curtis and Facing Islands (Figure 3).

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

Channel	Declared Depth (m LAT)
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

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

Year	Maintenance Dredging (in-situ m^3)	Capital Dredging (in-situ m^3)
2007	160,972	
2008	17,995	
2009	282,000	
2010	0 (dredging was at start of 2011)	
2011	309,000	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 m^3 (in-situ) = 1.1 tonne (dry weight)).

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

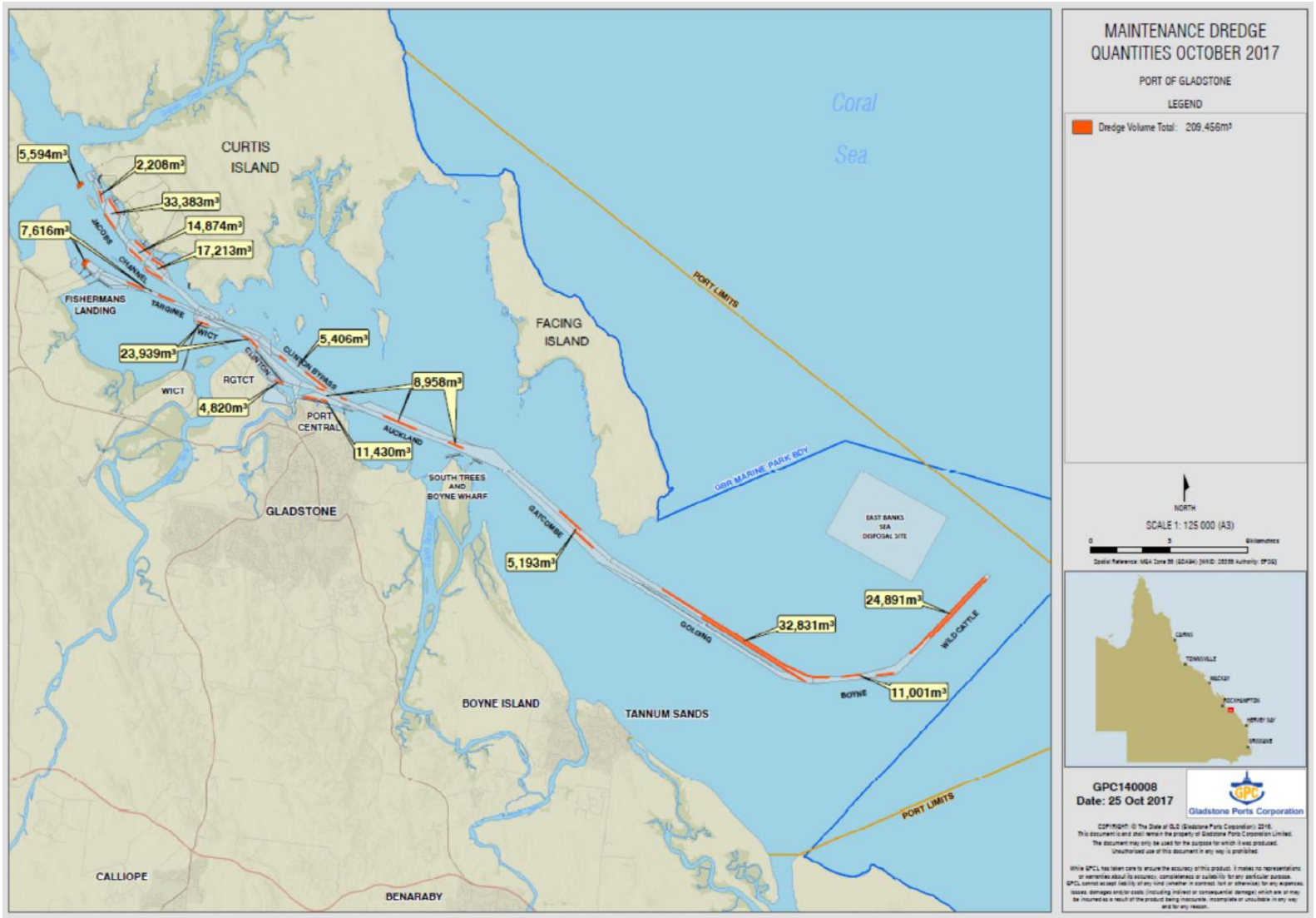


Figure 2. Port of Gladstone maintenance dredging volumes from 2017 (Vision Environment, 2017).

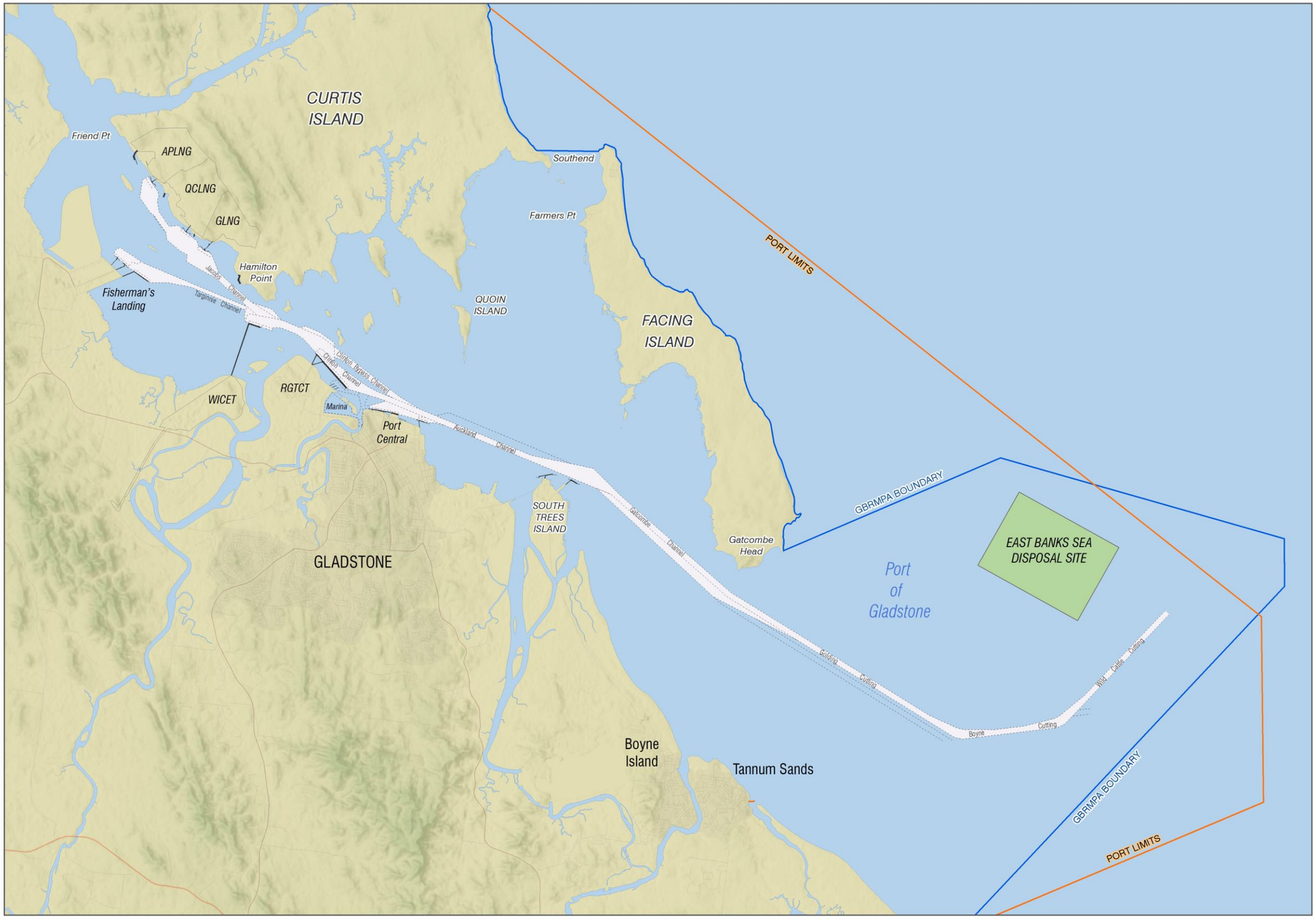


Figure 3. Port of Gladstone declared channels and sea disposal site.

1.3. Report Structure

The report herein is set out as follows:

- a summary of the relevant available data for the region is given in **Section 2**;
- the gap analysis is discussed in **Section 3**;
- a proposed sampling strategy is outlined in **Section 4**; and
- a summary of the gap analysis and sampling strategy is detailed in **Section 5**.

2. Data Review

A significant amount of data already exists for the PoG which can be used to provide background and input in the development of a sediment budget. This section discusses the available data and summarises its relevance relative to the SSM Project and more specifically the development of a quantitative sediment budget.

Relevant data which have been collected by/on-behalf of GPC are summarised to provide an overview of the key data which has historically been collected in the region. Additional relevant data which have been/are being collected in the region by other parties external to GPC are summarised in this section.

2.1. GPC Related Data

A summary of the relevant data which have been collected for different projects in the Gladstone region since 2006[1] is provided below. Further details including the date, data collected and approximate locations are provided in Table 3.

- SSM Project, Maintenance Dredging 2017 (Jackson et al, 2017)
  The data were collected specifically to better understand the potential impacts of maintenance dredging on the natural environment. A specific aim of the study was to better understand the contribution of sediment placed at EBSDS to the wider Great Barrier Reef (GBR) region.

  Some of the data from the campaign have already been used to validate the TUFLOW FV dredge plume modelling for the 2017 maintenance dredging campaign.

  The data can also be used to better understand the potential transport of sediment placed at the EBSDS, which in turn can be used to help set realistic sediment and bed properties in the TUFLOW FV model.

- SSM Project, The Narrows (RPS, 2018)
  The data can be used to better understand the relative input of suspended sediment to Port Curtis through The Narrows (during a large flood event in the Fitzroy River).

- Maintenance Dredge Compliance Monitoring (Vision Environment, 2017)
  The compliance monitoring provides useful turbidity and BPAR data. The fixed position turbidity loggers provide additional data which can be to allow the TUFLOW FV sediment transport model to be further validated for ambient conditions as well as ambient conditions during and immediately after maintenance dredging.

- Sediment Characterisation for National Assessment Guidelines for Dredging (NAGD) (Commonwealth of Australia, 2009) (AMA, 2018a)
  The data can be used to understand how the Particle Size Distribution (PSD) within the dredged areas and at the EBSDS varies spatially and temporally (see CQU (2018)). The data can then be input into the TUFLOW FV model to ensure the bed properties in the model are realistic.

- Channel Duplication Project (BMT WBM, 2018)
  The project provides 12 months of hydrodynamic, wave and turbidity data. The data can therefore be used to provide an understanding of the spatial and temporal variability in hydrodynamics, waves and turbidity in the PoG, which is critical to being able to define a realistic and robust sediment budget. In addition, the data have also been used to calibrate and validate hydrodynamics and sediment transport for the TUFLOW FV model which was used for the Channel Duplication Project. It is assumed that as this is the latest version of the model, which has been subject to the most robust calibration and validation,

[1] Data collected pre-2006 was not considered due to accuracy considerations (instrumentation has improved significantly since this time) and the fact that a large amount of relevant data are available since 2006.

this version will be adopted and further calibrated and validated to use as a tool to assist in defining the sediment budget.

- Western Basin and Fisherman's Landing Reclamation EIS studies (BMT WBM, 2009)
  These projects provide the best fixed position hydrodynamic data for the Western Basin region as well as also providing transect data for both a spring and neap tide. The TUFLOW FV model used in the Western Basin Environmental Impact Statement (EIS) investigation was calibrated and validated using these data and so it is expected that the subsequent model adopted for the Channel Duplication Project was also validated for these data.

  It is important to note that the data were collected prior to the additional reclamation at Fisherman's Landing. As such, the hydrodynamics in the region are likely to now be different in some areas due to the reclamation influencing the flow.

- WICT EIS & Boatshed Pt/China Bay Investigation (BMT WBM, 2009)
  The data are not directly relevant to the SSM Project but can be used to provide additional confidence in the TUFLOW FV hydrodynamic modelling. If the TUFLOW FV model which is adopted to model the sediment budget has been calibrated or validated to the ADCP transects then there is additional confidence that the model is able to accurately replicate the flow and exchange of water within the PoG. This is especially important as these data are for an area with complex bathymetry, large areas of intertidal and multiple islands.

- Port Curtis Integrated Monitoring Program (http://pcimp.aims.gov.au)
  The data provides a good overview of the longer-term temporal variability in water quality in Port Curtis. In addition, the data can be used to inform the variability in turbidity and PSD at a large number of sites through the region.

The points above show that there has been extensive data collection undertaken as part of the ongoing SSM Project and as part of previous projects. In particular, hydrodynamic and water quality measurements have been undertaken throughout much of the PoG, providing a valuable dataset to inform the quantitative sediment budget.

Table 3. Summary of relevant data collection campaigns in Port Curtis.

Project and (reference)	Dates	Locations	Data and Instruments	Relevance to SSM Project and Sediment Budget
SSM Project, Maintenance Dredging (Jackson et al, 2017)	Aug-Dec 2017	EBSDS (fixed sites at NW and SE corners), ADCP profiles through dredge plume and water column profiling and seabed sampling at EBSDS (see Figure 4 for water profiling locations).	Fixed sites: SSC, PSD and settling velocity (both sites) Turbidity (both sites) BPAR (one site) Hydrodynamics (x 1 site) ADCP Transects: Hydrodynamics SSC and PSD Water Sampling Water Column Profiling: SSC and PSD Turbidity and Water Quality Hydrodynamics Aerial Imagery (drone during dredging) Surface Sediment Sampling: PSD	Data collected to better understand the potential impacts of maintenance dredging on the natural environment and contribution of sediment placed at EBSDS to the wider GBR region.
SSM Project, The Narrows (RPS, 2018)	Apr 2017	The Narrows.	Fixed Sites: SSC and PSD Hydrodynamics Water Column Profiling: SSC and PSD Water quality (temperature, salinity, pH, turbidity, dissolved oxygen) Hydrodynamics	Data can be used to better understand relative input of suspended sediment to Port Curtis through The Narrows.
Maintenance Dredge Compliance Monitoring (Vision Environment, 2017)	Annually before, during and after maintenance dredging (e.g. 15/08/17 - 14/10/17)	West of WICT (NTU logging), North Channel (NTU logging), shoal between Jacobs and Targinnie Channels (BPAR logging) and various water sampling (see Figure 5 for locations).	Logging NTU sites: Turbidity Logging BPAR site: BPAR Water Sampling sites: Water samples were analysed for dissolved metals and tributyltin	Provides useful additional turbidity and BPAR data.
Sediment Characterisation for NAGD (Commonwealth of Australia, 2009**)** (AMA, 2018a)	Periodically in accordance with NAGD (2009). Most recent in Dec 2017.	Random locations within dredged areas and at EBSDS.	Surface Sediment Sampling: PSD, organic carbon & moisture, contaminants	Data can be used to understand temporal and spatial variability in PSD within dredged areas.

Project and (reference)	Dates	Locations	Data and Instruments	Relevance to SSM Project and Sediment Budget
Channel Duplication Project (BMT WBM, 2018)	Jul 2014 – Jul 2015	Throughout Port Curtis and offshore (see Figure 6).	Fixed sites: Hydrodynamics, Waves and Turbidity (near-bed) x 6 sites Turbidity (surface) and Sedimentation/Erosion x 3 sites Turbidity (surface and near-bed), BPAR and Sedimentation/Erosion x 5 sites ADCP Transects: Hydrodynamics	The 12 months of hydrodynamic, wave and turbidity data can be used to provide an understanding of the spatial and temporal variability of the PoG, assist with defining the sediment budget and model calibration and validation stages.
Western Basin and Fisherman's Landing Reclamation EIS studies BMT WBM, 2009)	Apr – Jun 2009	Western Basin region (see Figure 7).	Fixed sites: Hydrodynamics x 3 sites Water level x 1 site (plus 3 x Maritime Safety Queensland (MSQ) water level sites) ADCP Transects: Hydrodynamics during spring and neap tides	Provides best fixed position hydrodynamic data for the Western Basin region and transect data for a spring and neap tide. Data can be used for model calibration and validation.
WICT EIS & Boatshed Pt/China Bay Investigation (BMT WBM, 2009)	Apr-May 2006 & Nov 2006	Inner Harbour and Western Basin regions (see Figure 8).	Fixed sites: Hydrodynamics x 1 site Water level x 2 sites (plus 7 x MSQ water level sites) ADCP Transects: Hydrodynamics during spring and neap tides	The data is not directly relevant to the SSM Project. However, can be used to assist with providing additional confidence in numerical model.
Port Curtis Integrated Monitoring Program (http://pcimp.aims.gov.au)	Annual 2006 to 2012, Quarterly since 2012 (Mar, Jun, Sep & Dec)	Throughout Port Curtis, annual sampling was up to 169 sites, and quarterly sampling is at 54 sites.	Profiling & Water and Sediment Sampling: Physiochemical parameters (including turbidity) measured.	Data provides good overview of longer-term temporal variability in water quality in Port Curtis. Data can also be used to inform variability in turbidity and PSD at a large number of sites through the region.

Figure 4. Water profiling and sediment sampling locations for the August to December 2017 campaign (Jackson *et al.*, 2017).

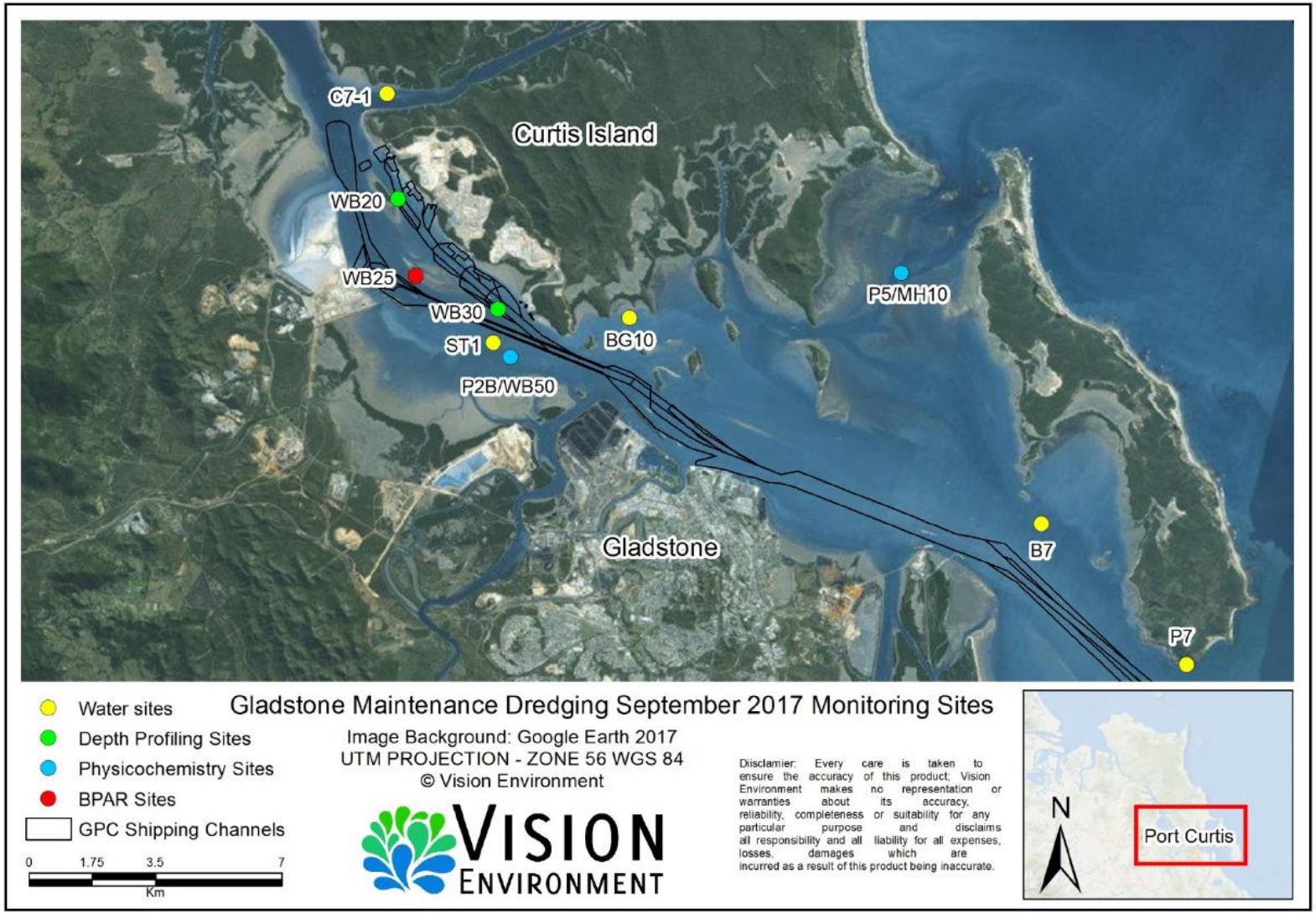


Figure 5. Site locations for the 2017 maintenance dredge compliance monitoring (Vision Environment, 2017).

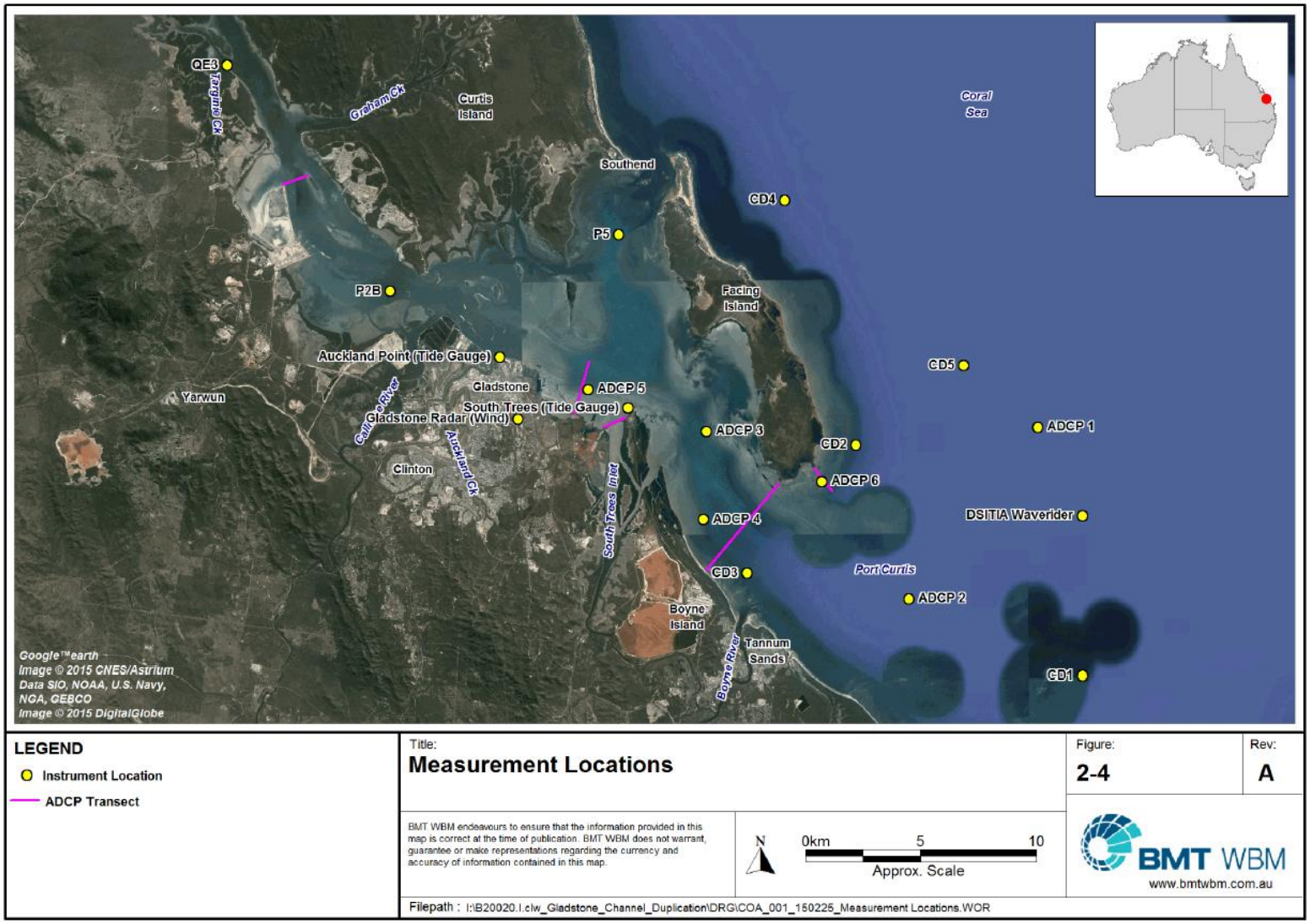


Figure 6. Site locations for the Channel Duplication Project monitoring (BMT WBM, 2018).

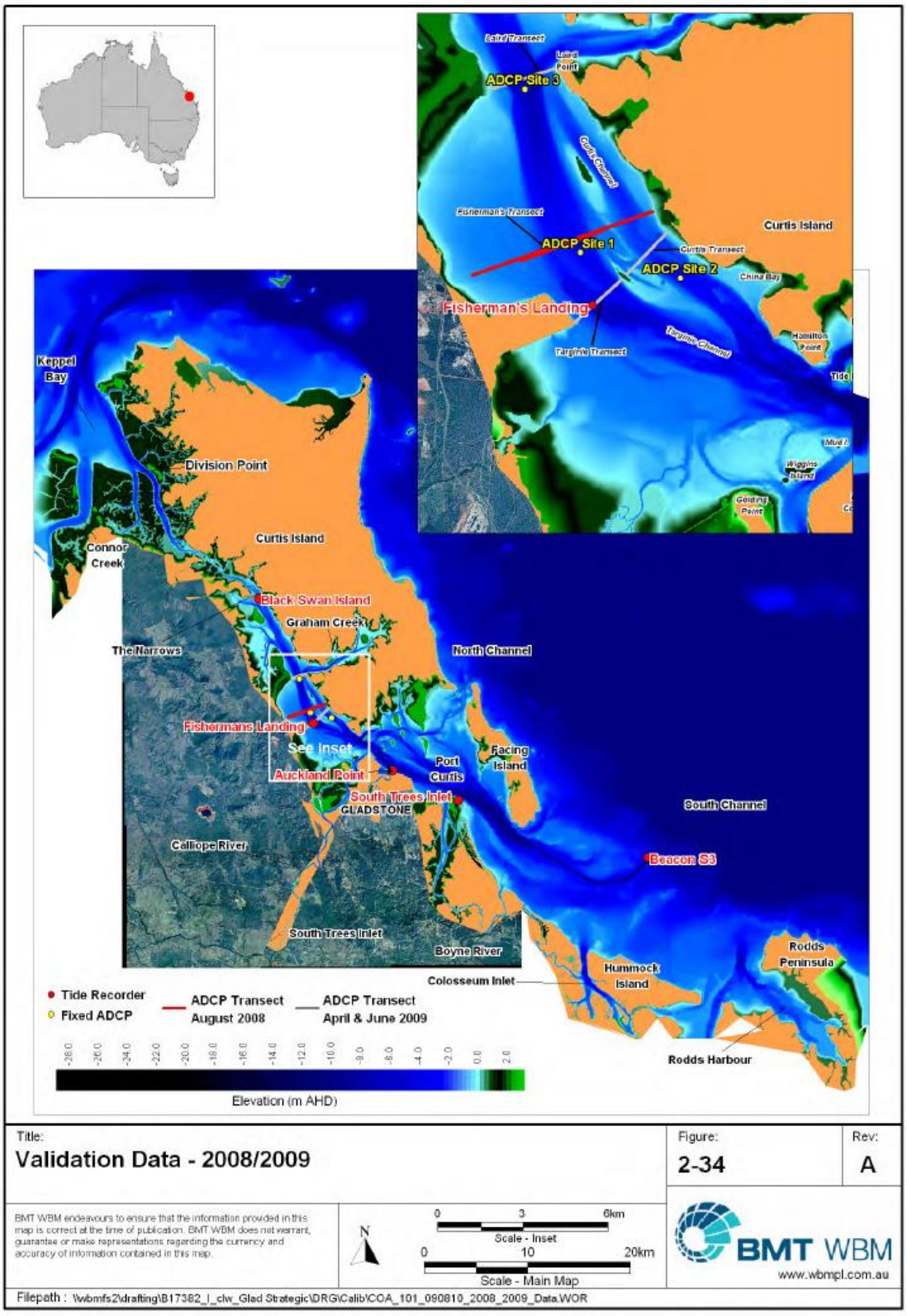


Figure 7. Location of data collected as part of the Western Basin and Fisherman's Landing EIS studies (BMT WBM, 2009).

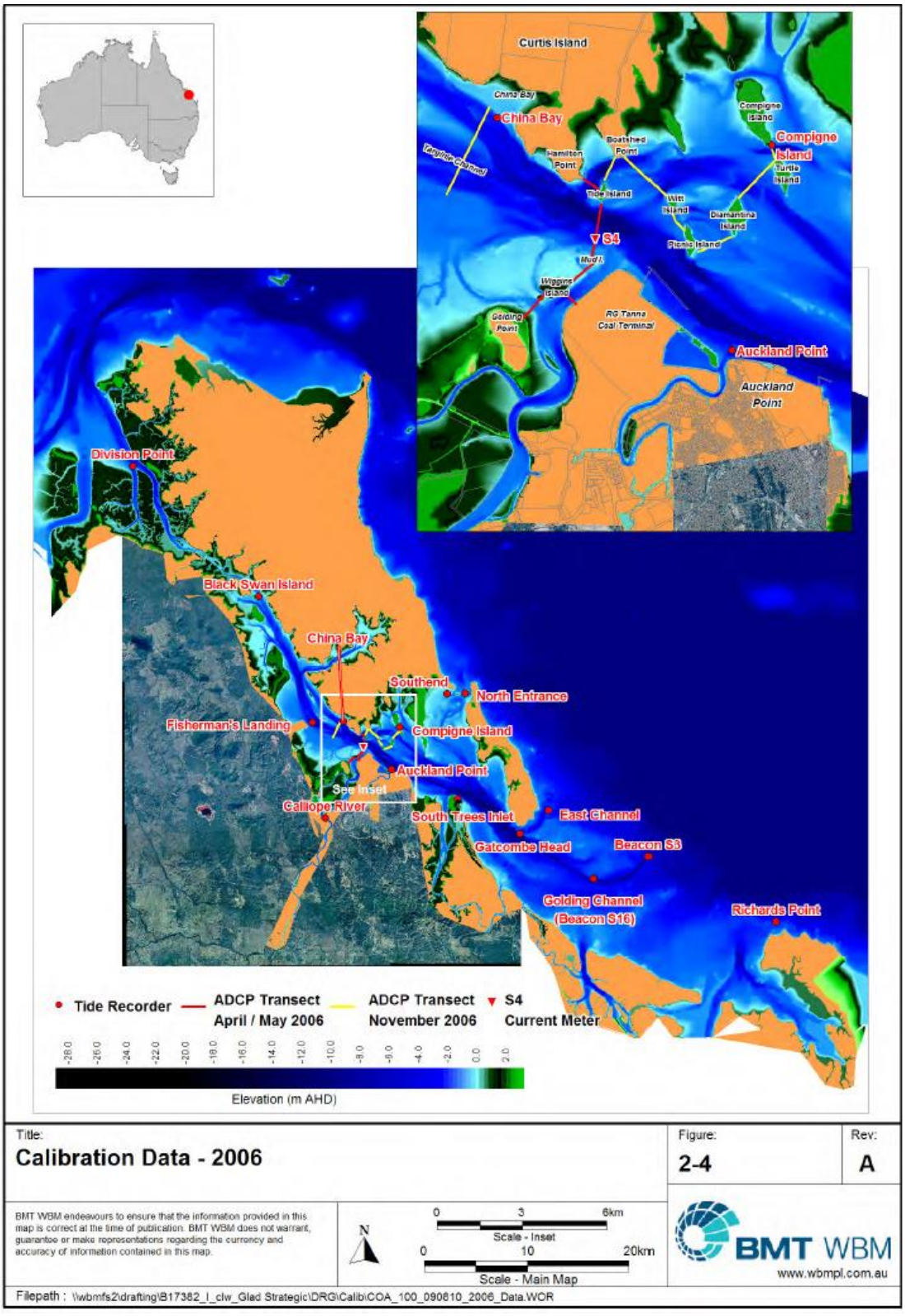


Figure 8. Location of data collected as part of the WICT EIS studies (BMT WBM, 2009).

2.2. External Data

In addition to the data which have been collected by/on behalf of GPC, additional data have also been collected by external parties. These data are discussed in the following sections.

2.2.1. Water Levels

Since 1996[2] Maritime Safety Queensland (MSQ) have collected, and continue to collect, water level data at three sites within the PoG. The water level measurement sites are located at Auckland Point, Fisherman's Landing and South Trees. These data have typically been used in the calibration and validation of the TUFLOW FV model to ensure it is providing a realistic representation of the water level variability through the PoG.

2.2.2. Meteorological Data

Wind, rainfall and other meteorological data are collected in the Gladstone region by the Bureau of Meteorology (BoM). The site closest to Port Curtis is the Gladstone Radar station (Figure 9), where data are available from 1957 to the present day. Ongoing measurements are also available at the Gladstone Airport station since 1993.

2.2.3. Wave Data

The Queensland Department of Environment and Science (DES) jointly with GPC has been collecting wave data at the entrance to Port Curtis since 2009 (Figure 9). The data are collected using a directional Waverider Buoy (WRB) which is deployed at a location where the water depth is 16 m. The instrument provides ongoing measurements of wave height, period and direction.

2.2.4. River Levels

The BoM maintain ongoing rainfall and river height stations in the catchments of the Calliope and Boyne Rivers (Figure 10). These data have been used and likely will continue to be used as inputs to hydrological and hydraulic river modelling of the catchments to estimate river and sediment discharges into Port Curtis.

2.2.5. Sediment Characteristics

In addition to the sediment characteristic data which has been collected by GPC, additional data have been collected as part of other activities including scientific research. As part of the SSM Project the historic PSD data for the Gladstone region has all been reviewed and collated into a single database (CQU, 2018). The data can be used to understand how the PSD within the dredged areas and at the EBSDS vary spatially and temporally.

2.2.6. Turbidity

In addition to the in-situ turbidity data collected in Port Curtis, the backwards scattering of light between 450 and 800 nm can be used to derive spatial maps of turbidity (e.g. Figure 11). Historic satellite data is available, but it is necessary to purchase the processed data from specialist companies which would result in additional costs to the SSM Project.

2.2.7. Bathymetry

Bathymetric surveys of the dredged areas of the PoG are undertaken by MSQ, on behalf of GPC, every year pre- and post maintenance dredging. Bathymetric data of specific areas have also been collected as part of recent GPC projects. In addition, Light Detection and Ranging (LiDAR) data are available for some of the intertidal regions, although the coverage is variable and depends on the tidal state at the time of the survey. Bathymetric data are also available from the navigation charts for the PoG.

[2] Since 1998 at one of the sites (Fisherman's Landing).

2.2.8. Urban Sources

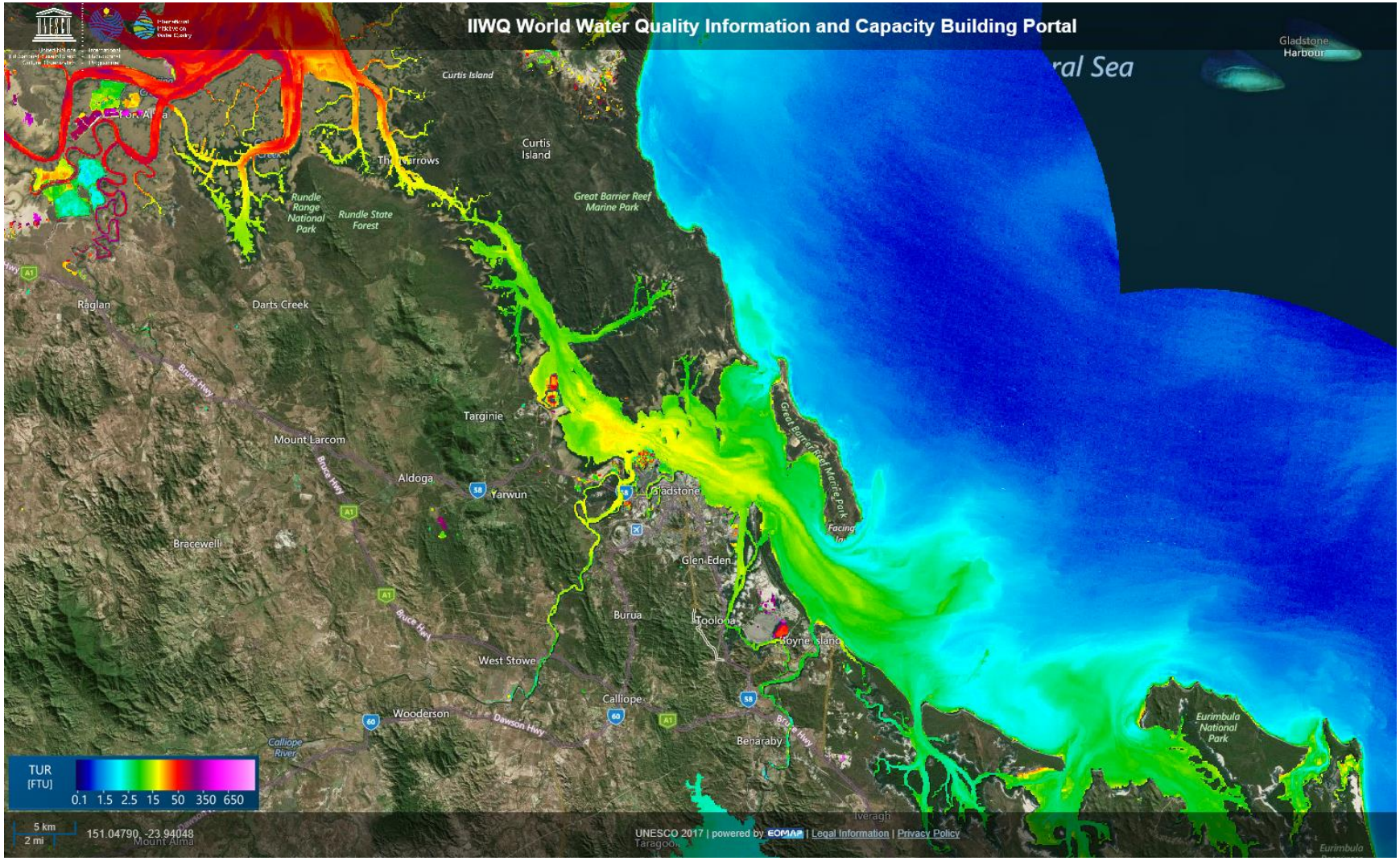
Although it is uncertain as to whether measured data are available of the input of sediment into Port Curtis from diffuse stormwater and point source discharges, it is not expected that this will be a major input source. As such, it is expected that information from literature and numerical modelling (e.g. Gunn (2015) and previous BMT WBM reports for GPC and Gladstone Regional Council) should be able to provide sufficient information to provide high-level estimates suitable for the quantitative sediment budget.

2.2.9. Vessel Operations

It is expected that sufficient data should be available through MSQ (Vessel Traffic Services) and GPC to understand the vessel movements within the PoG, both in terms of commercial and recreational vessels. The vessel movement information can then be used to estimate the potential contribution of the vessels to suspended sediment based on existing empirical tools (both for propeller wash and trawling).

Figure 9. Locations of the measured wind (Gladstone Radar) and wave data (Gladstone WRB).

Figure 10. Locations of BoM rainfall and river height station in the Boyne and Calliope catchments (www.bom.gov.au).



Note: the image shows turbidity on 26/07/2017, which is representative of a spring tide with calm offshore wave conditions. Source: http://worldwaterquality.org

Figure 11. Satellite derived water quality for the Gladstone region.

3. Gap Analysis

In order to undertake a gap analysis, it is necessary to consider the aims of the study and to then define what information is required. The data are required to convert the conceptual sediment budget into a quantitative sediment budget for the PoG, with a specific focus on maintenance dredging and the EBSDS. As such, measured data are required both to inform the overall sediment budget understanding and to input into the TUFLOW FV numerical model to ensure it is able to accurately represent the sediment transport within the PoG. In order to develop a quantitative sediment budget an understanding of the following is required:

1. the metocean conditions within the PoG and how they vary both spatially and temporally;
2. the physical characteristics of the sediment present in the upper layer of the seabed within the region;
3. sources of sediment into the PoG region and how they vary temporally (and the drivers for the variability);
4. the dominant processes which result in seabed sediment already present in the PoG region being transported and how it varies spatially within the PoG;
5. the mass of sediment in suspension within the PoG and the variability both spatially and temporally depending on the metocean conditions and anthropogenic activities;
6. the transport of sediment within the PoG and how it varies spatially and temporally depending on the metocean and anthropogenic activities; and
7. sinks of sediment within the PoG and an indication of the sedimentation rates and their variability.

In addition, as it is necessary to have a specific focus on maintenance dredging and the placement of sediment at the EBSDS, an understanding of the following is also required:

8. the sedimentation which has occurred within the maintained channels and berths of the PoG and its spatial and temporal variability;
9. the mass of sediment suspended during maintenance dredging and its subsequent transport and how this varies depending on the location in the PoG and sediment characteristics;
10. the mass of sediment suspended during the placement of maintenance dredge sediment at the EBSDS and the subsequent transport of the suspended sediment; and
11. the historic behaviour of the EBSDS in terms of retaining sediment which has been placed there by dredging.

3.1. Data Gaps

Based on the available data detailed in Section 2 and the requirements detailed in the previous section, the following data gaps have been identified along with the relative importance of the data for the quantitative sediment budget:

- Temporal variability of sediment properties at the EBSDS: additional assessment of the temporal variability at the EBSDS around a maintenance dredging campaign would be beneficial, as the data collected during the 2017 campaign was inconclusive as to whether the sediment composition changed significantly over the two months after the maintenance dredging. The data are considered to be very important to better understand how the sediment placed at EBSDS behaves (which relates directly to the Deed) and to allow the TUFLOW FV model to better define the parameters for the sediment placed at the EBSDS.
- Sources of sediment: although there is sufficient information to inform some of the sources of sediment to the PoG, there is no data available to inform the source of the sediment which is being deposited into the maintained channels and berths of the PoG.

The data are important to better understand where sediment within the PoG originates from (e.g. marine or terrestrial and then the specific river catchment). However, it is acknowledged that the type of testing required to define the specific river catchments has not been undertaken in Gladstone to date and it is therefore uncertain as to how successful the analyses would be.

- Fluxes of sediment: as part of the SSM Project a detailed investigation into the input of sediment to the PoG through The Narrows has been undertaken (RPS, 2018). However, additional data are required to inform the relative the input and export of sediment to/from the PoG through the southern and northern entrances. The data are considered to be very important to better understand the input and export of sediment from Port Curtis and to ensure that the TUFLOW FV model can accurately represent this.
- Transport of sediment from EBSDS: hydrodynamic, SSC and PSD data were collected at the EBSDS at two sites located inside the north-western and south-eastern corners of the site pre, during and post maintenance dredging in 2017. Once these data are processed they should provide valuable information as to how the SSC and PSD of suspended sediment vary due to the placement of sediment at the EBSDS. However, if these data indicate that some of the sediment from the maintenance dredging was transported out of the EBSDS there remains uncertainty as to how the sediment behaved once it left the EBSDS, and this is a specific requirement of the Deed. In addition, no erosion/sedimentation data were collected which would also have been able to indicate whether sediment was being transported out of the EBSDS following maintenance dredging. The data are considered to be very important to better understand how the sediment placed at EBSDS behaves, both at the site and away from the site if it is transported away.
- Bathymetry of intertidal regions: although high resolution LiDAR data are available for some of the intertidal regions of the PoG, there remain some areas where there is limited coverage. The data are considered to be of low to medium importance as the navigation charts already provide an indication of the elevation of the intertidal areas and therefore the increased accuracy and resolution provided by LiDAR is unlikely to significantly improve the results from the TUFLOW FV model simulations.

4. Sampling Strategy

This section outlines a sampling strategy which has been developed to address the data gaps, that were defined as either being very important or important for the development of the quantitative sediment budget. In addition, the relative benefit of the different data to the final quantitative sediment budget is noted.

4.1. Strategy Overview

The gap analysis identified four key data gaps which are required for the quantitative sediment budget. An overview of the proposed sampling strategy for each of these is provided in the following sections, with the two data gaps identified at the EBSDS combined into a single section.

4.1.1. Sources of Sediment

The sediment samples which were collected as part of the 2017 Sampling and Analysis Plan (SAP) and the subsequent targeted sampling in the areas where regular sedimentation occurs (AMA (2018a and 2018b)) have been stored and can therefore be analysed for the sources of the sediment.

There are a number of approaches which can be adopted (e.g. rare earth elements and stable isotope analyses) to identify sources of sediment. In some cases the approaches have the potential to identify the specific river catchment that the sediment originated from. However, to date, no studies of this type have been carried out in the PoG and it is therefore uncertain as to how successful the analyses would be. It is therefore recommended that initial test analyses are undertaken to better understand how appropriate the analyses are for the PoG region and the information which the analyses can provide. If the analyses are successful and provide useful information as to the sources of the sediment then additional analyses should be considered on the samples from the 2017 SAP and subsequent targeted sampling to develop an understanding of how the sources of sediment deposited within the dredged areas of the PoG vary spatially.

4.1.2. Fluxes of Sediment

It is important to understand the fluxes of sediment which go into and come out of Port Curtis, as this will help to inform whether the estuary acts as a net importer or exporter of fine-grained sediment. This will also allow the TUFLOW FV model to be calibrated to the fluxes of sediment which enter and exit the estuary on the flooding and ebbing tides, (as part of previous projects it has already been calibrated for the fluxes of water, but not the fluxes of sediment).

The SSM Project has already undertaken a targeted data collection campaign to better understand the exchange of sediment through The Narrows. However, additional data are required across the northern and south-eastern entrances of Port Curtis. The suggested data collection work is summarised in Figure 12 and involves the following:

- ADCP Transects: continuous transects are to be undertaken at both the northern and south-eastern entrances to Port Curtis over a 13 hour period during at least two different tidal ranges. Based on previous sampling within the PoG, BMT WBM has advised that sampling during neap tides is likely to show minimal sediment transport and so it is suggested that a small to medium spring tide (which results in limited overbank flow) and a large spring tide (which results in extensive overbank flow) are targeted for the campaign. The ADCP will measure the flux of water through the entrances and the backscatter, which can subsequently be post-processed (using processed water samples and in-situ measured turbidity/SSC data to convert backscatter to mg/l) to infer the flux of suspended sediment through the entrances. The transect at the south-eastern entrance is approximately 4 km in length and assuming a vessel speed of 4 knots (typical survey speed for areas with strong currents) means that individual transects will take

approximately 30 minutes to complete. If the company undertaking the transect work recommends that the survey is undertaken at a vessel speed of less than 4 knots, then it may be necessary to consider two transect vessels, each doing half of the channel, to ensure the change in current between transects is not too large.

- Fixed Loggers: over the period that the ADCP transects are undertaken bottom mounted instruments should be deployed to measure the SSC, PSD (LISST-100X), settling velocity (LISST-ST) and hydrodynamic and wave conditions (e.g. upward facing Acoustic Wave and Current (AWAC)) – due to the shallow depth it will be important for the instrument at the northern entrance to be able to measure vertical bins through the water column of 0.5 m or less). In addition, it would also be beneficial to deploy a downward facing high resolution acoustic current profiler to measure the near-bed currents which the upward facing instrument will not measure. These data will help to correlate the backscatter to SSC (mg/l) and provide a fixed point where the hydrodynamic and wave conditions can be validated in the TUFLOW FV model.
- Water Profiling and Sampling: during the ADCP transect work water profiling (using the LISST-100X or converted LISST-STX) and water sampling (subsequently analysed to determine SSC in mg/l) should be undertaken to ensure there is sufficient data available to correlate backscatter to SSC, including the variability through the water column.

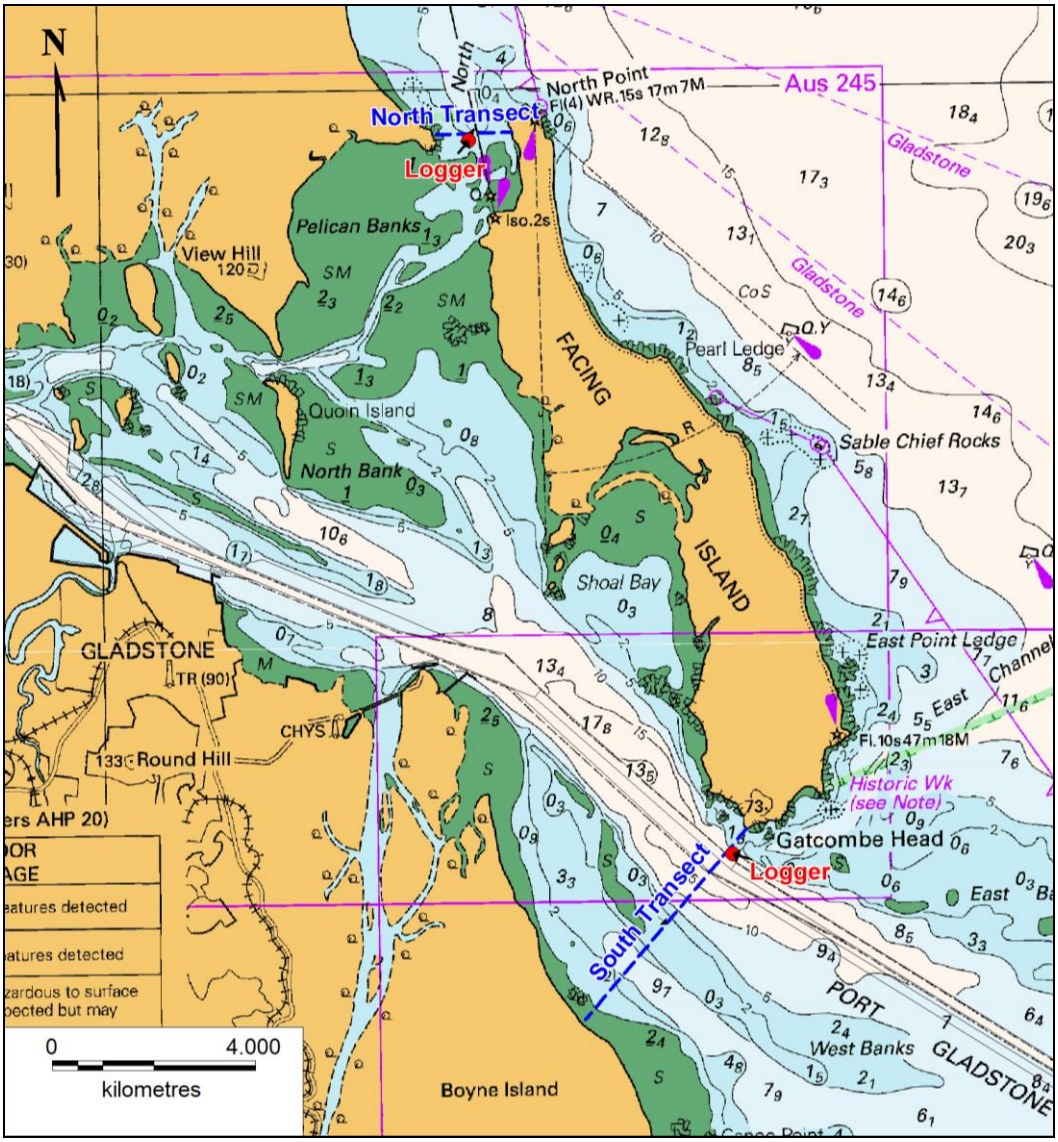


Figure 12. Proposed sampling locations for the fluxes of sediment data collection campaign.

4.1.3. EBSDS Monitoring

The resuspension and transport of sediment placed at the EBSDS is considered to be a critical aspect of the SSM Project and the quantitative sediment budget. The Deed specifically details the requirement for '*quantifying the impacts and extent of sediment transport and resuspension from Dumping Activities at EBSDS'* and for *'monitoring changes in water quality (including turbidity and BPAR) resulting from or as a consequence of Dumping Activities*.' Therefore, it is recommended that additional monitoring is undertaken in the EBSDS region pre-, during and post maintenance dredging in 2018. These data can also be used to further calibrate and validate the TUFLOW FV model (the data will help to inform the values adopted for certain sediment transport parameters in the model), to ensure it is able to replicate any resuspension and transport of sediment placed at the EBSDS. The TUFLOW FV model can then also be used to predict the fate of any sediment resuspended and transported away from the EBSDS. Although the model would be able to predict this based on the data collected in 2017, without the additional measured data collected outside of the EBSDS and the erosion/sedimentation data there would be uncertainty in the model results.

Indicative locations for the sites suggested as part of the EBSDS data collection campaign for the 2018 maintenance dredging are shown in Figure 13. It is suggested that the sampling commences four weeks prior to the maintenance dredging and continues at least four weeks after completion of the campaign. The data collection activities are detailed below:

- Sediment Sampling: surface sediment sampling be undertaken pre, immediately after and post maintenance dredging, at the same five locations as the fixed position stations (see next point, stations located within the EBSDS and outside of the EBSDS). It would be preferable if the sampling was carried out by a diver when they are servicing the loggers, as this would prevent any potential loss of loosely consolidated surface sediment which can occur when a grab sampler is used. The samples would then be analysed for PSD at a laboratory, with the analysis preferably adopting a laser diffractor to ensure there is sufficient detail of the fine-grained silt and clay fractions.
- Fixed Stations: a total of five fixed position stations are proposed where loggers will be deployed close to the bed on bed mounted frames. Two of the stations are inside the EBSDS (EBW and EBE), and three are outside of the EBSDS (to the west (OH02), north (OH04) and east (OH06)) (Figure 13). It is possible that some sediment could be transported from the EBSDS to the south, but as this would be transporting the sediment away from the GBRMP and towards a known sediment sink (East Banks) it is not considered to be as important to monitor. Details of the sites are proposed measurements are provided below:
    - EBW: located 100-200 m from the western boundary of the EBSDS to measure conditions within the EBSDS but close to the boundary. Proposed loggers measuring turbidity (e.g. WetLab), erosion/sedimentation (Altimeter), BPAR (e.g. WetLab/ Odyssey), SSC and PSD (LISST-100X), settling velocity (LISST-ST) and hydrodynamics and waves (e.g. upward and downward facing current profilers);
    - EBE: located 100-200 m from the eastern boundary of the EBSDS to measure conditions within the EBSDS but close to the boundary. Proposed loggers measuring turbidity (e.g. WetLab), erosion/sedimentation (Altimeter), BPAR (e.g. WetLab/ Odyssey), SSC and PSD (LISST-100X), settling velocity (LISST-ST) and hydrodynamics and waves (e.g. upward and downward facing current profilers);
    - OH02: located 2 km west north-west of the EBSDS to measure conditions away from the EBSDS in a westerly direction close to the GBRMP boundary. Proposed loggers measuring turbidity (e.g. WetLab), erosion/sedimentation (Altimeter) and BPAR (e.g. WetLab/ Odyssey);
    - OH04: located 1.2 km north of the EBSDS to measure conditions away from the EBSDS in a northerly direction close to the GBRMP boundary. Proposed loggers

measuring turbidity (e.g. WetLab), erosion/sedimentation (Altimeter) and BPAR (e.g. WetLab/Odyssey); and

- OH06: located 2 km east south-east of the EBSDS to measure conditions away from the EBSDS in an easterly direction. Proposed loggers measuring turbidity (e.g. WetLab), erosion/sedimentation (Altimeter) and BPAR (e.g. WetLab/Odyssey).

It is important that the Altimeters are correctly installed on the seabed to ensure that the frames they are deployed on cannot move or sink into the seabed, as this would result in erroneous data.

It is noted that due to the number of sites, the range of instrumentation proposed to be deployed at the sites and the exposed nature of the EBSDS region, there are likely to be operational restrictions for the data collection campaign. For example, the LISST instruments will require servicing every two weeks and it is unlikely that it will be possible to retrieve and redeploy the instruments on the same day. The aim of the sampling should be to minimise the gaps in data over the campaign, whilst ensuring that the instruments are correctly serviced and deployed and the work is undertaken safely.

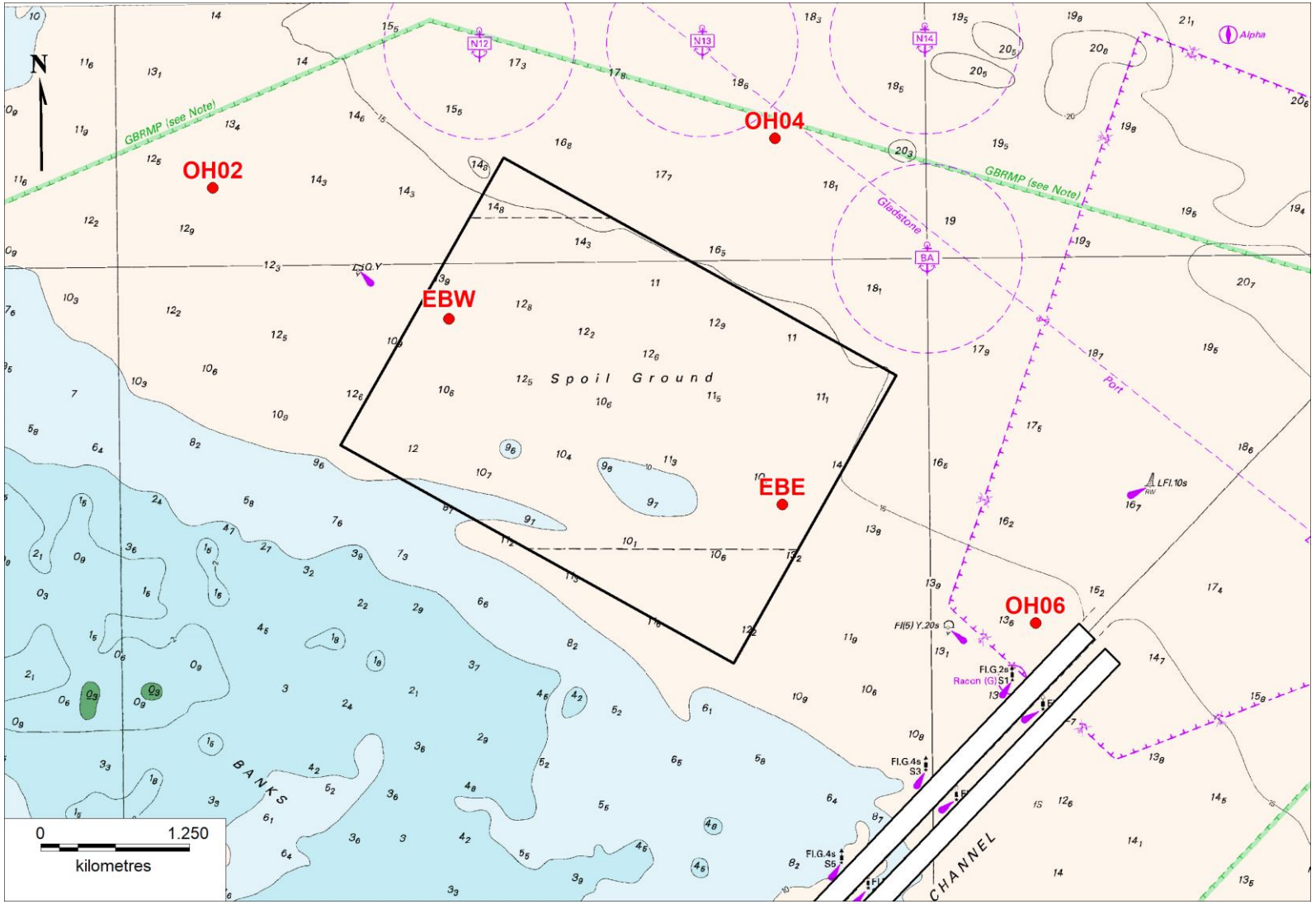


Figure 13. Proposed sampling locations for the EBSDS data collection campaign.

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5. Summary

A gap analysis has been undertaken on the available data for the SSM Project and specifically for developing a quantitative sediment budget for the PoG. The gap analysis identified a number of data gaps which are considered important for the project. The data gaps identified are as follows:

- Temporal variability of sediment properties at the EBSDS: additional assessment of the temporal variability at the EBSDS around a maintenance dredging campaign would be beneficial.
- Sources of sediment: although there is sufficient information to inform some of the sources of sediment to the PoG, there is no data available to inform the source of the sediment which is being deposited into the maintained channels and berths of the PoG.
- Fluxes of sediment: as part of the SSM Project a detailed investigation into the input of sediment to the PoG through The Narrows has been undertaken. However, additional data are required to inform the relative the input and export of sediment to/from the PoG through the southern and northern entrances.
- Transport of sediment from EBSDS: there are currently no measured data to show how sediment resuspended from the EBSDS behaves once it leaves the site, and this is specific requirement of the Deed.

Based on the data gaps identified a sampling strategy has been developed. The strategy recommends that three discrete tasks are undertaken:

- Sediment sources: using the sediment samples from the 2017 SAP, proof of concept studies should be undertaken using recognised approaches to identify the sources of sediment (e.g. rare earth elements and stable isotope analyses). It is recommended that these initial tests are undertaken to better understand how appropriate the analyses are for the PoG region and the information which the analyses can provide.
- Fluxes of sediment: the SSM Project has already undertaken a targeted data collection campaign to better understand the exchange of sediment through The Narrows. However, additional data are required across the northern and south-eastern entrances of Port Curtis. ADCP transects and fixed position loggers are proposed during spring and neap tides to measure the flux of water and suspended sediment entering and leaving Port Curtis.
- EBSDS Monitoring: understanding the resuspension and transport of sediment placed at the EBSDS is considered to be a critical aspect of the SSM Project and the quantitative sediment budget. It is therefore recommended that additional monitoring is undertaken in the EBSDS region pre, during and post maintenance dredging in 2018. Five sites have been proposed, two within the EBSDS and three outside (to the west, north and east of the EBSDS). SSC, PSD, settling velocity, turbidity, erosion/sedimentation, hydrodynamic, wave and sediment property data are proposed to be collected as part of the campaign. These data can be used to further calibrate and validate the TUFLOW FV model (the data will help to inform the values adopted for certain sediment transport parameters in the model) to ensure it is able to replicate any resuspension and transport of sediment placed at the EBSDS.

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