Fine Sediment Methodology for the Port of Cairns Shipping Development Project

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Synopsis:	**A report outlining the Fine Sediment Methodology (FSM) proposed to meet Condition 8 of the EPBC Act controlled action approval for the Cairns Shipping Development Project.**	

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Executive Summary

Ports North is advancing to the delivery stage of the Cairns Shipping Development Project (CSDP) which involves dredging a wider and deeper entrance channel and cruise ship swing basin to allow access for larger cruise ships.

This report has been prepared to address Condition 8 'Fine sediment methodology' for EPBC controlled action approval reference EPBC 2012/6538 for the Cairns Shipping Development [Trinity Inlet] Project, Queensland.

Condition 8 states:

8. *The approval holder must submit a Fine Sediment Methodology (FSM) to the Minister for approval. Dredging must not occur unless the FSM has been approved by the Minister. If the Minister approves the FSM, the approved FSM must be implemented. The FSM must include, but is not limited to:*

(a) a methodology for quantifying the amount (in tonnes) of fine sediment returned to the environment from:

(i) the dredging of stiff clays; and

(ii) the dredging of soft clays and from tailwater discharge at the Northern Sands Dredged Material Placement Area;

(b) written evidence of input and peer review by a suitably qualified person of the adequacy of the FSM and a table of any changes made in response to the peer review'.

A literature review as well as a review of desktop and field based approaches to measuring dredge sediment has been undertaken to determine the most suitable approaches to the FSM for the stiff clay dredging, soft clay dredging and tailwater release.

In developing the FSM design, the following general principles have been considered and applied:

- An existing 3D hydrodynamic and water quality numerical model will be used for the FSM. The numerical model is fit for purpose and has been subject to third party peer review as part of the Cairns Shipping Development EIS process;
- The existing model will be updated for the FSM, using:
    - Actual dredge logs (hypothetical dredge logs were used in the EIS);
    - Actual tailwater discharge data (flow volumes and quantities of fine sediment fractions);
    - Pre- and post dredge bathymetry data for the dredge channel to calculate the actual volume of fine sediment removed;
    - The most up to date geotechnical data for the dredge site;
- A robust field data collection program using industry accepted and proven methods will be required to inform numerical modelling assessments;
- Multiple sampling methods and approaches are proposed in order to ensure multiple sources of data to inform the results. For example, water samples will be collected and taken for laboratory analysis in parallel with field based in-situ instrumentation and the results compared against modelled outputs; and

- Outputs from the numerical modelling, in combination with interpretation of field data, will then be interrogated to calculate the quantity of fine sediment fractions returned to the environment.

A peer review of the draft FSM was been undertaken by Dr Alistair Grinham from the University of Queensland and is contained within the Appendices to this report.

The key findings of the peer review were that the methodology will provide a useful comparative approach capable of providing a defensible estimate of soft and stiff clay returned to the environment. The strengths of the approach were identified as utilising a number of different pathways to estimate the fine sediment returned to the environment which is considered prudent for estimating losses in such complex marine environments. The peer reviewer found that the methodology also acknowledges the inherent uncertainty in quantifying fine sediment returns from dredging operations and provides an appropriate, conservative estimate for each dredge method as well as the tailwater discharge.

The only significate change to the draft FSM as a result of the peer review that has been addressed in the final FSM is the inclusion of an evaluation of the relative success of individual estimation pathways at project completion.

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1 Introduction

1.1 Statement of Requirement

This report has been prepared to address Condition 8 'Fine sediment methodology' for EPBC controlled action approval reference EPBC 2012/6538 for the Cairns Shipping Development [Trinity Inlet] Project, Queensland.

The relevant conditions from the approval are appended below:

***8**. The approval holder must submit a Fine Sediment Methodology (FSM) to the Minister for approval. Dredging must not occur unless the FSM has been approved by the Minister. If the Minister approves the FSM, the approved FSM must be implemented. The FSM must include, but is not limited to:*

(a) a methodology for quantifying the amount (in tonnes) of fine sediment returned to the environment from:

(i) the dredging of stiff clays; and

(ii) the dredging of soft clays and from tailwater discharge at the Northern Sands Dredged Material Placement Area;

(b) written evidence of input and peer review by a suitably qualified person of the adequacy of the FSM and a table of any changes made in response to the peer review'.

Condition 10A 'Dredging Completion Report' is relevant to and links to Condition 8. Condition 10A states that –

***10A.** 'The approval holder must submit a Dredging Completion Report (DCR) to the Department within 6 months of the completion of dredging. The DCR must include, but is not limited to:*

(c) the amount of fine sediment returned to the environment calculated in accordance with condition 8(a)(i) and condition 8(a)(ii);

Fine sediments are defined in the glossary of the controlled action approval as:

***Fine sediment** means material less than 15.6 micrometres (µm).*

Taken together, these conditions require the proponent (Ports North) to measure through some form of field measurement and/or modelling, the amount of fine sediment generated during dredging and tailwater release such that they can be reported as part of Condition 10A(c) following completion of the dredging works.

Condition 11 (a) (i) requires the amount of fine sediment returned the environment is compensated for, in accordance with Condition 8 (a) (i). i.e. dredging of stiff clays. Appendix A documents the methodology for determining material that is available for resuspension.

1.2 CSD Project Background and Context

Ports North is advancing to the delivery stage of the Cairns Shipping Development Project (CSDP) which involves dredging a wider and deeper entrance channel and cruise ship swing basin to allow access for larger cruise ships. The project also includes upgrading the wharf infrastructure within

Trinity Inlet to cater for the larger vessels and the relocation of the cargo ship swing basin to accommodate future Navy base expansion.

The widened and deepened channel and swing basin will allow larger cruise ships up to 300 metres in length to berth at the Cairns Cruise Liner Terminal to accommodate the forecast demand for 70 additional cruise ships through the Port of Cairns' Trinity Wharves each year by 2031.

More specifically, the offshore components of the scope include the following:

- The extent of the widening varies over the channel, with the outer channel being widened up to 10 m to a new maximum width of 100 m and inner channel widened by 20 m up to a new width of a 110 m. The declared depth will be increased from -8.3 m to -8.8 m lowest astronomical tide (LAT) with a target design depth of -9.1 to -10.3 m LAT to cater for the annual siltation for the outer channel.
- In the bend of the channel, further widening will be carried out to a maximum width of 180 m to provide safe manoeuvring space for the cruise vessels while passing through the bend.
- The Crystal Swing Basin diameter will be deepened to a declared depth of -8.8 m LAT outside the direct channel alignment.
- A new Smiths Creek Swing Basin to allow for expansion capability of HMAS Cairns.
- The declared depth of the berth pockets will be -9.3 m LAT, with a width of 50 m.

A Revised EIS for the CSDP was prepared by Ports North and accepted by the Queensland Government in December 2017.

A copy of the Revised EIS and Supplementary Information is available at http://statedevelopment.qld.gov.au/assessments-and-approvals/projects-draft-environmental-impact-statement-documents.html. Specifically, Appendix AG provides a detailed Hydrodynamic Modelling Report; the modelling detailed in this report will be used to validate the sediment plume. Appendix AH (Marine Sediment Quality Baseline and Impact Assessment Report) provides detailed data on geotechnical investigations undertaken to characterise dredge material.

The State Government of Queensland through the Coordinator-General, issued the Co-ordinator General's Evaluation Report (CGER) on 28 February 2018.

A controlled action approval under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) was subsequently granted and issued by the Australian Government Department of the Environment and Energy on 28 November 2018.

A dredge contractor was appointed by Ports North in early February and dredging works are set to commence in July 2019.

As per Condition 8, the FSM will need to be submitted and approved by the Minister before the dredging works can commence.

1.3 Baseline Conditions and Dredge Material Properties

The Revised EIS for the CSDP described the baseline conditions and geotechnical properties of the seabed materials to be dredged. A summary of these findings is presented below.

1.3.1 Baseline Conditions in Trinity Bay

The understanding of coastal processes and sediment movement within the Trinity Bay area where the CSDP will occur has developed over several decades and numerous studies including those referenced in Chapter B3 - Coastal Processes, of the CSDP Revised EIS.

Numerous scientific studies into the coastal processes and sedimentology of Trinity Bay have clearly demonstrated that even under calm conditions there is a very significant and multi-directional sediment movement on a large scale occurring on an ongoing basis.

As outlined in Carter *et al* 2002. water motions and therefore sediment transport within the Cairns' coastal region are strongly influenced by:

- Southeasterly trade winds in winter;
- Variable north and northeasterly winds during summer;
- A daily easterly coastal sea-breeze;
- Diurnal tidal currents (southeast flood; northwest ebb); and
- Intermittent tropical cyclones.

In combination, these processes are responsible for the generally high background turbidity which is present in Cairns' coastal waters (20 – 200 mg/L) which is caused by the resuspension of mud from the seabed.

In a report by Brinkman *et al* (2004), the prevailing fine sediment "nepheloid layer" present along the Cairns shoreline was quantified and described. The study modelled the patterns of movement of the layer of material within the general confines of Trinity Bay and in the broad context along the tropical coast, in both calm and strong wind conditions. Conceptual numerical modelling suggested that the layer acts as a negatively buoyant plume that is deflected longshore alternatively northward and southward by prevailing, reversing oceanic currents, out to around the 20m depth contour. Concentrations of the layer were noted as being up to 1000mg/L (SSC) and up to 10m in thickness.

During 2018 the outputs of Reef 2050 Long Term Sustainability Plan action for WQA17 were completed by Qld Ports Association, and included a contemporary evaluation of the relative contributions of sediments at and adjacent to the Port of Cairns.

Based on this study, Trinity Bay is estimated to receive on average over 80,000 tonnes of fluvial sediment per year which contributes to a store of over 1.2 billion tonnes of existing sediment of terrigenous origin in the Bay.

Further, there is estimated to be a volume on the order of 14 million tonnes per year moving within the bay that is naturally resuspended by regular processes such as tidal currents as well as episodic wind and wave events.

Given these background conditions, distinguishing dredge-generated turbidity and total suspended solids from background conditions in the field can be problematic, particularly during poor and/or variable weather conditions.

1.3.2 Dredge Materials and Methodology

The seabed materials proposed to be dredged as part of the CSDP consist of two physically different and visually distinguishable material types originating as either terrigenous sedimentary deposits or marine sediment, as shown in Figure 1-1 and Figure 1-2.

Stiff clays are defined in the controlled action approval as follows:

*‘**Stiff clays** means sediment to be dredged that has an undrained shear strength of greater than 50 kilopascals (kPa) (as per Australian Standard ASl726-1993).’*

Particle size distribution analysis of the stiff clay material samples obtained as part of geotechnical investigations for the CSDP indicate that the stiff clay samples have fines contents (<15.6 µm) ranging from 40% to 82% by mass, with an average of 70% fines.

Soft clays are defined in the controlled action approval as follows:

*‘**Soft clay** means any material to be dredged that is not stiff clays’*

Particle size distribution analysis of the **soft clay material** samples indicated an average of around 75% fines contents (based on the <15.6 µm criteria).

Consistent with the Revised EIS, two types of dredge plant will be required to undertake the CSDP works.

The soft marine clays, muds and sediments will be dredged by a Trailing Suction Hopper Dredge (TSHD) and the stiffer clay material by a backhoe dredge (BHD).

These plant will operate in different parts of the channel (for navigational safety and based on the location and distribution of stiff and soft clays) but may be operating simultaneously during the dredge campaign.

As part of detailed design process for the CSDP, it has been determined that a smaller volume than what was approved in EPBC Condition 2 will be dredged from the channel as part of the CSDP.

The revised dredge volume of material (developed by project geotechnical consultants Golder using a 3D model of the channel) has been estimated to be approximately:

- 698,755 m^3 soft clays.
- 92,309 m^3 stiff clays.
- 791,064 m^3 total volume.

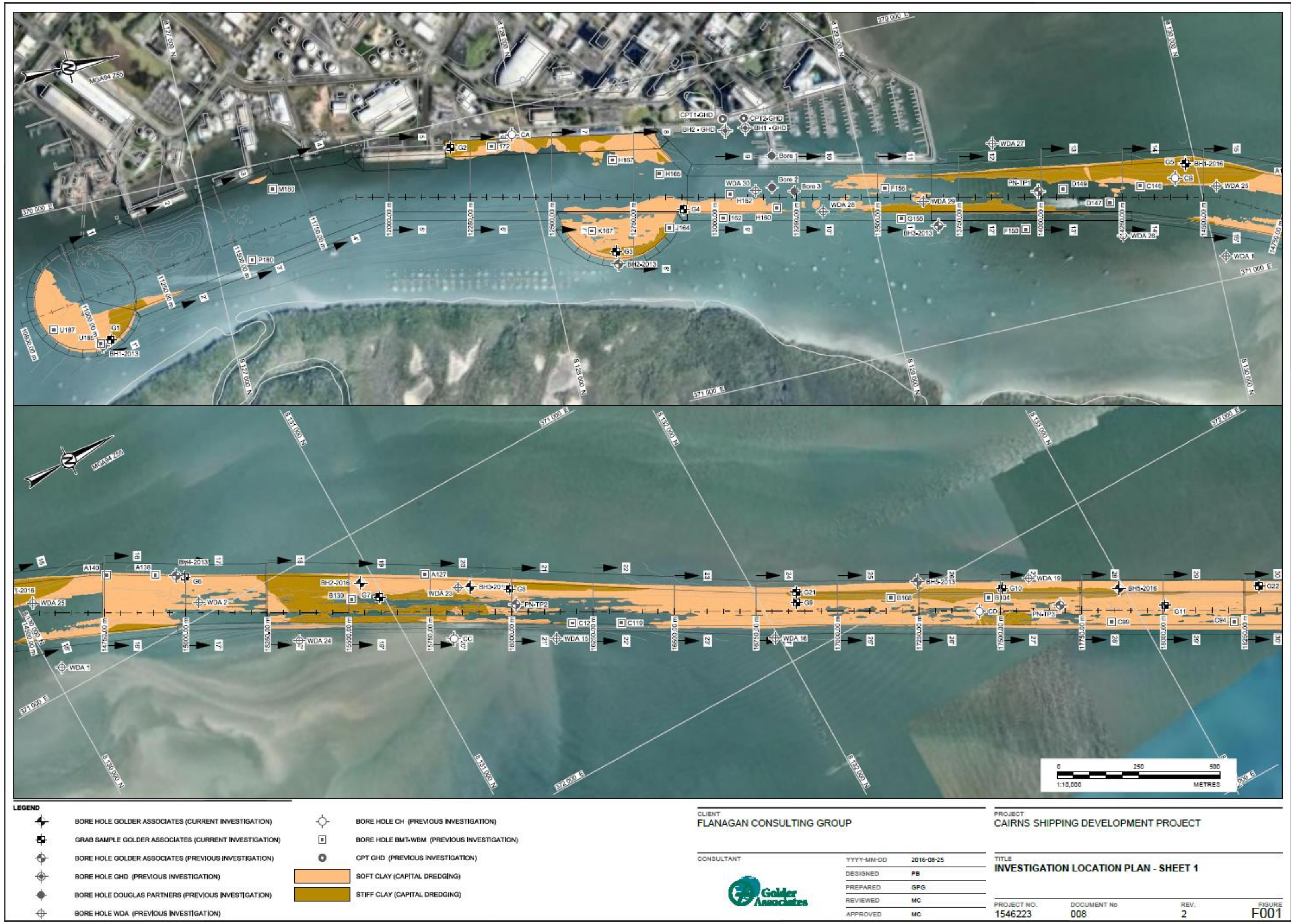

Figure 1-1 Distribution of Soft Clay and Stiff Clay in the Dredge Footprint (inner port and channel)

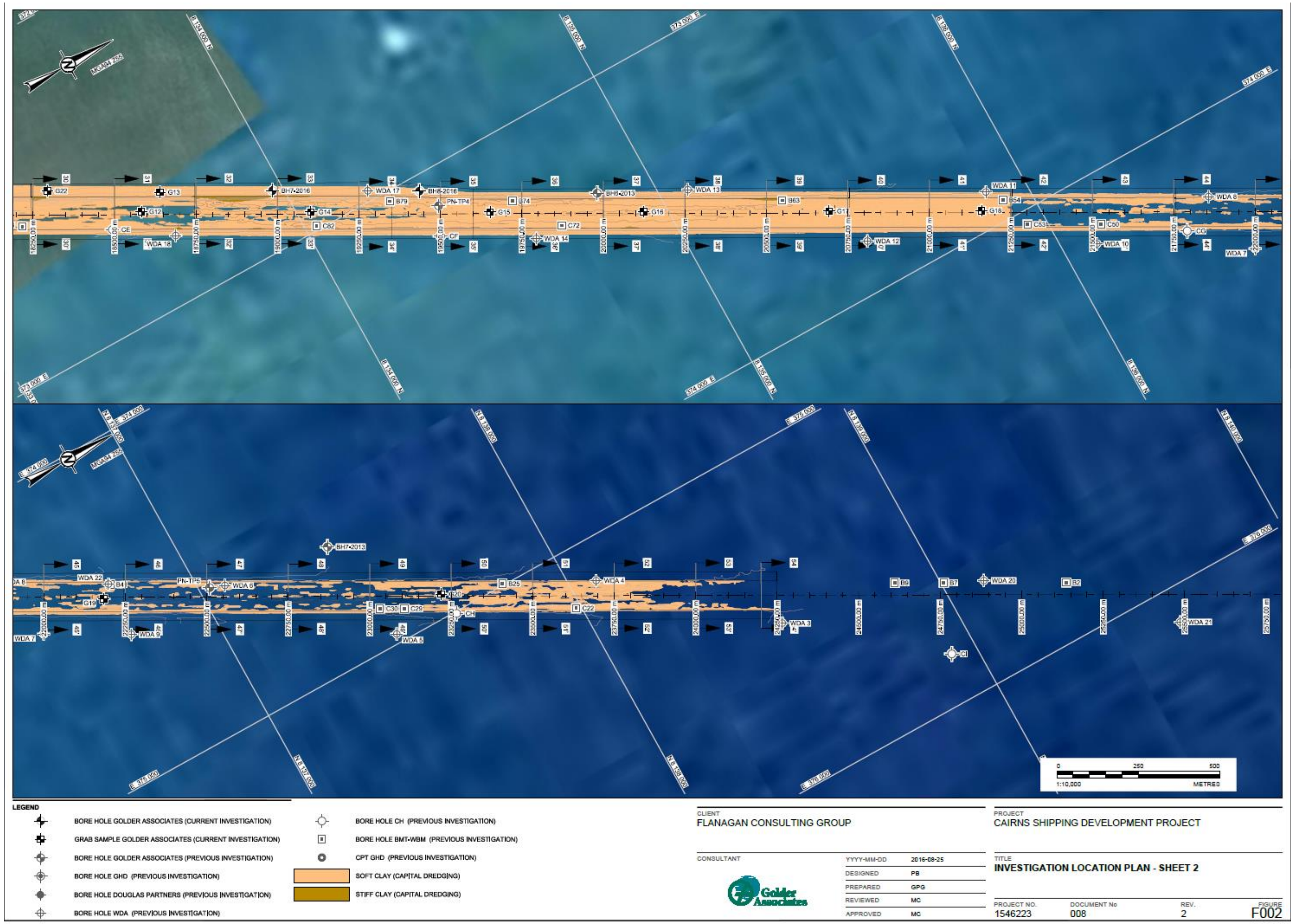

Figure 1-2 Distribution of Soft Clay and Stiff Clay in the Dredge Footprint (outer channel)

1.3.3 Preliminary Estimates of Fine Sediment Release

While it should be noted that an environmental offset under Condition 11 of the EPBC approval is only payable for the stiff clay component of Condition 8(a)(i), the FSM and reporting requirement under Condition 10A applies to all sources of fine sediment released to the environment (stiff clays, soft clays and tailwater).

The sections below outline a conservative estimate of the fine sediment (based on desktop calculations and assumptions) that could be returned to the environment from the dredging and tailwater release activities.

The spill rates from dredge plant used in the calculations are the same as those that were adopted and used in the numerical water quality modelling from the Revised EIS and are based on professional advice from expert dredge consultants and contractors (Akuna Dredging Solutions Pty Ltd, ProDredge Pty Ltd and BMT-JFA).

Collectively, these estimates provide the baseline assumptions of the likely fine sediment that could be generated and released to the environment from the action that will then be field verified and tested during construction as part of the FSM as described in Section 3 to the extent practicable as outlined in the methodology.

'Returned to the environment' in this context is not defined in the EPBC approval but is taken to mean any fine sediments that are disturbed and resuspended by capital dredging activities. This includes, for example, fine sediment disturbed and resuspended by the dredge head, fine sediment released as part of hopper overflow waters or fine sediment released as part of supernatant tailwater from the DMPA. However, it will also need to be recognised in the final accounting of the fine sediment that some of this fine sediment material will re-settle within the existing channel and thereafter be dealt with as maintenance dredge material. Accordingly, field sampling as outlined in Section 3 will seek to be undertaken outside of the channel where practicable so as not to be measuring fine sediment that is simply falling back into the channel and is not technically 'returned to the environment'.

Further information on how these terms and estimates were derived is provided in Appendix A.

1.3.3.1 Estimated Fine Sediment Release from Stiff Clay Dredging by BHD

The calculated fine sediment returned to the environment from the BHD operation has been estimated by multiplying the relevant numbers for all of the following terms:

- Percentage fines within stiff clay dredge material (70%).
- Fine sediment source term (spill rate) from the dredging process (3%).
- Dredge material dry density (1.6 tonnes/m^3).
- Stiff clay volume to be dredged (95,000 m^3 [rounded up from 92,309]).

Multiplying the figures gives: 0.7 x 0.03 x 1.6 x 95,000 = 3,192 tonnes.

Allowing a further factor of approximately 1.5 for conservatism we have suggested a maximum of 5,000 tonnes.

1.3.3.2 Estimated Fine Sediment Release from Soft Clay Dredging by TSHD

The calculated fine sediment returned to the environment from the TSHD operations in soft clays has been estimated by multiplying the relevant numbers for all of the following terms:

- Percentage fines within soft clay dredge material (75%).
- Fine sediment source term (spill rate) from the dredging process (7%-15% - depending on time spent overflowing [note that the lower bound corresponds to 10 min overflow and upper bound to 30 min overflow]).
- Dredge material dry density (0.96 tonnes/m^3).
- Soft clay volume to be dredged (700,000 m^3 [rounded up from 698,755]).

Multiplying the figures gives: 0.75 x 0.07 to 0.15 x 0.96 x 700,000 = 35,280 to 75,600 tonnes.

Allowing a further factor of approximately 1.5 for conservatism we have suggested an estimate between 50,000 tonnes and 114,000 tonnes.

1.3.3.3 Estimated Fine Sediment Release from Tailwater Discharge

Reclamation modelling undertaken as part of the EIS and detailed design process predicted the initial placed volume of the dredged material, its settlement rates and the corresponding surface water quality in the reclamation pond for the planned filling sequence.

Concurrent with that work, BMT made assumptions on an achievable tail water quality and modelled and assessed the tail water discharge impacts based on those assumptions.

The tailwater quality assumptions (which strongly correlated with the eventual conditions of approval for tailwater release imposed by the Queensland Government under the project Environmental Authority) were;

- A maximum discharge concentration of 50 NTU (which relates to a corresponding TSS concentration of approximately 85 mg/L).
- A maximum daily discharge volume of 87 megalitres per day.
- A total modelled dredge priming, pumping and flushing soil and water volume of 5,534,339 m^3A total pumped soil in-situ volume of 882,650 m^3.

The theoretical maximum tail water discharge volume is 4,651,689 m^3 noting a large proportion of the soil is expected to remain fully saturated (retaining a mass of pore water at about 60%-70% of the mass of the soil). For simplicity and to be conservative it is assumed that all the tail water TSS is fine sediment (e.g. <15.6 µm).

Noting that TSS levels will fluctuate throughout the tailwater campaign, by adopting an average 50mg/L tailwater condition this equates to approximately 233 tonnes of fine sediment. Allowing a further factor of approximately 1.5 for conservatism we have suggested a maximum of 350 tonnes of fine sediment.

2 Literature Review and Previous Field Investigations

2.1 Background

As described in Section 1, the FSM seeks to quantify the total quantity of fine sediment released to the environment associated with dredging and tailwater discharges. In doing so, there are four key factors that need to be considered when developing a fine sediment mass estimate for material returned to the environment:

(1) It must individually consider the two sediment types as defined in Section 1;

(2) It must consider the total amount of amount of fine sediment, for the total duration of the Project program, returned to the environment due to both dredging and tailwater discharges from the onshore disposal site;

(3) It must be able to be able to distinguish sediment material generated by the Project from background/ambient sediments. This is an important consideration given that the dredge site and receiving environment of tailwaters have high ambient total suspended solid concentrations; and

(4) The physio-chemical processes controlling the behaviour of very fine particles in aquatic environments need to be considered. Clay particles in the marine environment have a cohesive nature and tend to aggregate together through the process of flocculation. This is an important consideration from a sampling/analysis perspective.

The following sections provides a review of relevant literature as well as an overview of different desktop and field based approaches used in previous dredging monitoring projects to develop a fine sediment mass estimate.

2.2 Literature Review

The process and importance of validating numerical model predictions related to dredge plumes at the start-up of a dredging project is well documented and is now a standard requirement of most environmental permits. However, there is considerably less information on methods for relating the field measurements back to the assumed sediment flux rates for dredge plant that have been utilised in the numerical modelling.

Two of the key industry-based literature sources that are relevant to this point are summarised below:

VBKO (2003) Protocol for the Field Measurement of Sediment Release from Dredgers

Most reviewed papers and articles are referenced back to a white paper (VBKO 2003), entitled "Protocol for the Field Measurement of Sediment Release from Dredgers", produced for the VBKO TASS Project by HR Wallingford and Dredging Research Ltd. The protocol was developed by HR Wallingford as a secondary outcome of an industry funded program to develop models to predict the rate of sediment release from various types of dredging plant. The primary study identified issues with varying and inconsistent approaches to the field measurement methods and thus it was an attempt to try and standardise the process.

Chapter 4 of VBKO provides details of the primary recommended method for stationary dredgers (e.g. the Backhoe dredge plant). The method is based around the use of towed Acoustic Doppler Profiler (ADP) in order to collect data with a high degree of spatial resolution. The chapter includes a section on some of the limitations of using an ADP for collection of data, in particular near bed and near surface zones. Methods for the field calibration of the ADP are provided, based around the collection of water samples in the plume through depths whilst the ADP is recording.

Secondary methods of data collection are provided in Chapter 5, in particular the use of towed arrays and profiling turbidity meters (raising and lowering of a turbidity meter through depth, and through time).

Chapter 7 of VBKO provides a description for the measurement methods for Trailing Suction Hopper Dredgers. The chapter provides a detailed protocol for the measurement of sediment release for each of the following mechanism:

- Release through overflow;
- Release by Lean Mixture Overboard (LMOB) Systems;
- Resuspension by the draghead; and
- Far field plume decay.

De Wit L. (2015) 3D CFD modelling of overflow dredging plumes

De Wit's thesis in 2015 on the 3D CFD modelling of overflow dredging plumes included a field validation component in which the CFD modelling results were compared with field data collected at three separate dredging campaigns involving TSHDs. Each campaign had different sized TSHD and differing materials. The method of the field data collection, including some of the challenges encountered and data quality is described in Chapter 8 – "Validation of near field dredging plume – field scale".

The field surveys were typically carried out in accordance with the VBKO protocols for field measurements (discussed above). Data and measurements were collected both on the dredge and around the dredge during operation.

The following information from the operating dredge was collected:

- TSHD location, speed, direction, total loading and suction discharge and suction density (logged by the TSHD onboard sensors).
- Overflow mixture was sampled to determine the overflow density and PSD profile.

Separately, plume measurements were undertaken in the field from a survey vessel using a combination of side scan sonar, ADCP's and optical back scatter instruments. Attempts to correlate the ADCP backscatter and turbidity with suspended solid concentration had varied success from the three programs.

2.3 Desktop and Field Based Approaches

Informed by the literature mentioned above, the primary methods for developing a fine sediment mass estimate can be broadly grouped as follows:

(1) Estimates of the total amount of material dredged based on:

   (a) Geotechnical data for the dredged channel;

   (b) Bathymetry survey data collected before and after dredging; and

   (c) Dredge production logs, which provide estimates of the volume of sediment dredged.

(2) Field-based measurements of sediments in the water column.

(3) Numerical modelling of sediments released to the environment by dredging and tailwater releases.

Each is discussed in the sections following.

2.3.1 Quantifying Fine Sediment Quantities in Dredged Material

The total amount of fine sediment dredged can be estimated using a variety of approaches. An understanding of the amount and types of dredged material is a critical input into the planning and implementation of dredging operations (Kemps and Massini 2017).

Geotechnical characterisation of sediments to be dredged provides an estimate of the quantity of different sediment fractions to be dredged. A variety of methodologies are routinely used to characterise sediment properties, laboratory analysis of core samples, seismic methods and in situ measurements using accelerometers (reviewed by Mills and Kemp 2017). Geotechnical data, hydrographic survey data (conducted before and after dredging) and dredge logs, are used to estimate the total quantity of different sediment classes dredged (BMT WBM 2017; Mills and Kemp 2017).

These approaches in isolation do not provide a basis for determining the amount of fine sediment fractions returned to the environment; however, these data can be used to derive source terms for dredge plume modelling (e.g. Kemps and Massini 2017; Mills and Kemp 2017; BMT WBM 2017).

2.3.2 Measuring Fine Sediments Quantities in the Water Column

Mills and Kemps (2017) reviewed several case studies to describe the state of the knowledge regarding the behaviour of dredge plumes in an Australian context, with a focus on hydraulic dredging (trailer suction and cutter suction dredging). They concluded that despite many examples of dredge plume monitoring studies in the literature *"…there is currently very little published data on the PSD development in actual dredged material at various points along the full-scale dredging production line".*

In Queensland, the primary focus of dredge plume monitoring studies over the past decade (many of which have been undertaken by BMT) has been around field validating the amount of sediment in the form of TSS or turbidity in the plume from different dredging equipment, with the notable exception of Beecroft *et al*. (2019).

While these dredge plume monitoring studies typically have not specifically sought to define the fine sediment component (e.g. less than 15.6 µm) of the overall spill budget of total suspended solids they are relevant to designing an FSM.

2.3.2.1 Case Studies

Port of Gladstone – Western Basin Capital Dredging Project

This project undertaken by BMT involved:

- Field-based measurements of sediment plume generated by dredging (trailing arm suction dredging) – examining all sediment fractions collectively.
- Field-based measurements of sediments in tailwater discharges from an on-land disposal site – examining all sediment fractions collectively.
- Numerical modelling of the behaviour of sediment plumes generated by dredging (backhoe, trailing arm suction, and cutter suction dredgers) and tailwater releases.

Between 2011 and 2014, Gladstone Ports Corporation co-ordinated an intensive program of capital dredging within the Western Basin of Gladstone Harbour. This involved the development of Jacobs Channel using both backhoe dredges to remove stiff clays and rocky material and trailing arm suction dredges to remove the bulk of unconsolidated silt from the channel alignment and in this respect mirrors the proposed operational dredging methods for channel development at the Port of Cairns. Subsequent capital dredging developments at the Wiggins Island Coal Terminal and at the Clinton Bypass channel were undertaken principally by trailing arm suction dredgers, being supplemented by cutter suction dredges at Wiggins Island. Whilst most of the sediment dredged from the Clinton By-Pass and Wiggins Island Coal Terminal was placed at sea, the major component of capital material dredged from Jacobs Channel was pumped to the Western Basin Dredged Material Reclamation at Fisherman Landing.

BMT was engaged to use its calibrated hydrodynamic model of Gladstone Harbour to predict the likely impacts of sediment resuspension dredge plumes associated with both backhoe and trailing arm suction dredging plant upon the background water quality of Gladstone Harbour. The modelling predictions were based on field measurements of turbidity, optical and acoustic backscatter within the dredging plumes created by around the operational backhoe and trailing arm dredging plant under specified tidal conditions (typically spring and neap tidal conditions). The field turbidity, optical and acoustic backscatter measurements were later converted to Total Suspended Solids (TSS) concentrations based upon the concurrent field collection and subsequent laboratory analysis of many dredge plume and background water samples. Predicted dredge plume model outputs in TSS concentrations were based upon the selective laboratory analysis of a range of near source (e.g. dredge hopper and near-field plume water) and far-field dredge plume samples for particle sizes to yield source generation rates for the various items of dredging plant.

Similar subsequent analyses based on snapshot field measurements and water sample collection and analyses for the discharged sediments from the Western Basin reclamation bunded area were used to quantify and predict the extent and concentration of sediment within the tailwater discharge plume under a range of dredging and detention scenarios.

The project did not seek to quantify the amount of different sediment fractions.

Port of Cairns – Maintenance Dredging Monitoring

This project undertaken by BMT involved:

- Field-based measurements of sediment plume generated by dredging (trailing arm suction dredging).
- Numerical modelling of the behaviour of sediment plumes generated by dredging (trailing arm suction dredger).

The extent and longevity of maintenance dredging plumes within Trinity Inlet was investigated by BMT WBM in 2016. Maintenance dredging and dredged material placement plumes created by the Port of Brisbane trailing arm suction dredger 'Brisbane' were measured during flood and ebb spring tidal conditions using a vessel mounted acoustic doppler current profiler, turbidity and optical backscatter sensors, together with the collection of water samples for TSS and particle size in conjunction with aerial drone surveillance and mapping of the dredge plumes evident at the water surface. The water quality measurements and aerial mapping photographs were undertaken at a range of times following their formation, allowing predictive hydrodynamic models of the dredging and placement plumes to be developed, calibrated and verified using sediment particle sizes, source generation rates and sediment settling rates inferred from the plume measurements.

It is envisaged that the existing BMT hydrodynamic model of Trinity Inlet would form the basis of the future predictive model used to determine the fine particle sediment losses to the environment in the forthcoming capital dredging programme at the Port of Cairns. It is anticipated that the model would be refined for the calculation of fine particle sediment losses to the environment based on several measurement snapshots to correspond with differences in the dredging plant, texture of dredged material and tidal conditions as they will occur through the term of the dredging programme.

The project did not seek to quantify the amount of different sediment fractions.

Sunshine Coast Airport Expansion - Tailwater Monitoring

This project undertaken by a dredge contractor and supervised by BMT involved:

- Field-based measurements of sediments in tailwater discharges from an on-land disposal site.
- Monitoring of surface water quality in receiving waters.

The Sunshine Coast Airport Expansion Project required a supply the sand to construct the new runway and taxiway system. Dredging was undertaken in 2018 at the Spitfire Realignment Channel in Moreton Bay to supply this sand which was pumped to an onshore placement area. The placement area had a tailwater polishing pond which discharged supernatant tailwater in the adjacent Marcoola Drain and Maroochy River.

The discharged tailwater was required to meet certain discharge quality criteria, including TSS and turbidity. The approval conditions stated that turbidity could be measured and used as the compliance limit as long as a correlation between TSS and turbidity was established. As such, the dredge contractor conducted an intensive sampling effort at the commencement of the dredge material placement phase, whereby they collected a number of samples in the tailwater polishing pond and analysed the samples for TSS and turbidity to establish a site-specific correlation. This correlation was then used by the dredge contractor to establish a turbidity compliance limit that was used as a proxy for assessing compliance with the TSS limit for the duration of the project.

If the dredge contractor had also measured flow rate from the tailwater polishing pond, then the Testability correlation and flow rate could have been used to determine total sediment loads discharged to the receiving environment. However, a breakdown of sediment fraction loads would not have been achievable with this data as no particle size data were collected.

Port of Brisbane – Offshore Dredged Material Disposal

This project undertaken by Beercroft *et al*. (2019) involved:

- Field-based measurements of sediments within the water column before, during and after dredge placement operations.
- Field-based measurements of sediments within the water column during baseline conditions were no dredging was occurring.

Beecroft *et al*. (2019) evaluated maintenance dredging operations (trailer suction dredger) with respect to natural sediment transport processes in western Moreton Bay. Monitoring investigated the contribution of dredge placement operations at the Mud Island dredged material placement area to the natural suspended sediment regime and water quality within Morton Bay. Monitoring was conducted prior, during and post dredge placements to evaluate the context of dredge material delivery with respect to natural suspended sediment drivers in proximity to the placement site and to contrast the near-bed suspended sediments concentrations and particle size characteristics. Baseline natural processes were compared to the intensive dredging activities that involved 200 placements over the duration of monitoring which was sourced mainly from the port's network of wharfs and swing basin.

Monitoring at Mud Island was conducted predominately using a Sequoia Scientific Inc. LISST-100X; a fast response Concerto conductivity, a temperature and density probe; a Pentair Greenspan MP47 turbidity sensor; and an acoustic doppler current profiler. To monitor turbidity the Pentair turbidity sensor was mounted below the surface for several days on two monitoring periods at the beginning and end of 2016. The suspended sediment concentration and particle size distribution was measured in situ by vertically profiling from the surface to 0.15 m above the bed to create a downcast profile. Wind, wave and current velocities were measured to monitor natural sediment resuspension. The in-situ particle-sizing techniques are crucial to identifying the low-density flocculated material as the key transport of fine cohesive fractions and should help establish a more robust assessment criteria for dredging operations.

2.3.3 Numerical Modelling

Numerical modelling is the primary tool used to provide quantitative predictions of dredge sediment in environmental impact assessment studies (e.g. Mills and Kemp 2017). Numerical modelling also allows the quantification and fate of dredged sediments released into the environment at spatial and temporal scales relevant to the FSM.

Examples of numerical modelling projects in a Queensland port context includes recent capital dredging projects (Cairns Shipping Development Project EIS, Port of Townsville Port Expansion

Project EIS, Port of Gladstone Western Basin Project), as well as maintenance dredging assessments for Ports of Cairns, Townsville, Gladstone and Brisbane. These projects quantified sediment releases to the environment during dredging (all projects), ocean disposal (i.e. maintenance dredging projects) and/or tailwater releases (all the capital dredging projects and maintenance dredging at Gladstone).

Dredge plume modelling can be undertaken in order to quantify the release and track the subsequent movement of different sediment fractions. This has been undertaken for the above examples, however the models were not specifically configured to separately assess the fine sediment fraction as specifically defined in the EPBC conditions for the CSDP.

2.4 Suitability of Approaches for FSM

Table 2-1 is a summary of different approaches that could be used to quantify sediment loads entering the environment.

In reviewing the various approaches presented in Table 2-1, it is concluded that there is no single tool or method that, in insolation, can adequately address all the key factors to provide a robust fine sediment mass estimate. As such a combination of methods will need to be employed.

In summary, some of the key findings are:

- The approaches used to calculate dredged material quantities do not take into account the amount of sediment returned to the environment, and therefore over-estimate fine sediment quantities.
- Field-measurements of sediments in dredge plumes all have pros and cons, most importantly being that because they represent snap-shots in time and space, they cannot provide a complete record of fine sediment quantities generated by the project.
- Numerical modelling-based approaches can provide an estimate of different fine sediment fractions returned to the environment at appropriate temporal and spatial scales, but are predictive rather than actual measurements. However, with appropriate calibration to field measurements in order to derive properly validated dredge plume source terms, numerical modelling can then provide a robust means of quantifying the total release of different sediment particle classes over the entire project, that is filling the gaps between episodic field measurements. In addition, the numerical models can provide valuable information regarding the subsequent fate of the released sediment.

Table 2-1 Approaches for Estimating Suspended Sediments in Waters

Category	Approach	What Is Assessed?	Spatial and Temporal Context	Advantages	Limitations	Case studies
Estimate of the Quantity of Dredged Material	Geotechnical data interpretation (3D mapping)	• Quantity of fine sediment fractions to be dredged, as determined through a review of existing 3D sediment model	• No. dimensions: 3D • Spatial resolution: Low resolution • Spatial extent: 3D model available for all the channel • Temporal replication: N/A (contemporary data are available)	• Provides a coarse estimate of the total amount of fine sediment to be dredged	• Does not estimate the quantity of material released to the environment • Low spatial resolution	• The use of 3D models to estimate the quantity of different sediment fractions is routinely used for dredging design
	Hydrographic surveys	• Quantity of fine sediment removed by dredging, as estimated by surveys before and after the dredging campaign	• No. dimensions: 3D • Spatial resolution: High resolution • Spatial extent: data available for all the channel • Temporal replication: N/A (contemporary data are available)	• Provides an estimate of the total amount of sediment actually dredged, which in combination with geotechnical data, provides a basis for quantifying the amount of each sediment fraction removed	• Does not measure the quantity of material released to the environment	• Hydrographic survey is the standard method for quantifying the total amount of sediment removed in most dredging projects
	Dredge production logs	• Amount of material dredged	• No. dimensions: N/A • Spatial resolution: Low resolution • Spatial extent: data available for all the channel • Temporal replication: N/A	• Provides a comprehensive description of the dredging activities undertaken, including timing, locations, operating conditions and quantities of sediment handled.	• Does not specifically estimate the quantity of material released into the environment.	• Dredge production logs are used to inform numerical model hindcast simulations of sediment plume generation by dredging projects, including both capital and maintenance dredging activities.
Measurements of Sediment Concentrations Released into the Environment	Remote sensing to quantify horizontal plume surface extent using: • Drones • Satellite captures	• Horizontal extent of visible surface plume	• No. dimensions: 2D (horizontal - surface only) • Spatial resolution depends on technology, with greater resolution by drones (measured in metres) • Spatial extent: entire plume • Temporal replication: Single measurement in time (but can take multiple measurements)	• Provides high resolution mapping of horizontal plume extent, and depending on technology, an estimate of turbidity	• Measures all sediment fractions, and does not differentiate between fines and coarser sediments • 2D only • Snap-shots in time • Capacity to detect plumes in the lower column dependent on ambient turbidity	• Wheatstone Project, Port of Cairns
	Vessel based measurements of suspended sediments using acoustic methods (Acoustic Doppler Current Profiler)	• Estimates suspended solid concentrations (SSC) in the water column based on acoustic backscatter measurements	• No. dimensions: 2D slice through the water column • Spatial resolution: measured in 100 to 100s of cms • Spatial extent: transect typically measured in 10s to 100s of metres • Temporal replication: Provides a single measurement in time	• In combination with other measurements (turbidity, total suspended solid concentrations), provide high resolution estimates of SSC through the water column	• Measures all sediment fractions, and does not differentiate between fines and coarser sediments • 2D only • Snap-shot	• Routinely used to monitor dredge plumes (e.g. Port of Brisbane, Cairns, Townsville, Gladstone) • Key tool used in the calibration and validation of numerical modelling
	Water quality measurements (fixed or profiles) using: • *in situ* turbidity measurement instrument • grab samples for laboratory analysis of total suspended solid (TSS) concentrations and particle size distribution • LISST instrument for in situ measurement of the density of different particle fractions	• Precise measurements of turbidity and TSS concentrations (all sediment fractions) and the particle size distribution of suspended sediments	**Vessel-based profiles** • No. dimensions: 1D profile through the water column • Spatial resolution: measured in cms • Spatial extent: profiles typically extent from surface to near bed • Temporal replication: Single measurement in time **Fixed instrument:** • No. dimensions: one point in space (fixed instrument) • Spatial resolution: N/A • Spatial extent: N/A • Temporal replication: User defined, can be seconds to minutes	• Provides precise measurements of fine (and other) sediment concentrations at a point in time (profiles) or space (fixed instruments) • Profile data can provide data to calibrate ADCP measurements (see above) • LISST can provides continuous measurements of fine sediment fractions discharged to the environment via tailwater	**Vessel-based profiles:** • Snap-shot • Requires significant sampling effort to measure changes in the horizontal axes • One dimensional, therefore does not provide an estimate of total quantity of fine sediment in a dredge plume **Fixed instrument:** • LISST instrument is relatively expensive and requires regular maintenance • Turbidity is a surrogate estimate of all sediment fractions • Grab samples require high labour effort	• Routinely used to monitor dredge plume behaviour (e.g. Port of Brisbane, Cairns, Townsville, Gladstone) and calibrate numerical modelling and/or ACDP-based measurements • Turbidity loggers routinely used to continuously measure sediments in tailwaters (e.g. Sunshine Coast Airport, Port of Brisbane Future Port Expansion Area)

Category	Approach	What Is Assessed?	Spatial and Temporal Context	Advantages	Limitations	Case studies
Modelling of Sediment Concentrations Released into the Environment	Numerical modelling of suspended sediments	• Predictions of suspended sediment concentrations generated by dredging	• 3-dimensional modelling, spatial resolution measured in metres • Output time-steps determined by user (typically 15 minute intervals)	• Provides precise estimates of fine (and other) sediment concentrations at appropriate spatial and temporal scales • Can be calibrated to episodic field measurements and can help 'fill the gaps' in discrete transect measurements • Allows hindcasting of entire dredging programs	• Predictive rather than measured • For most reliable results should be calibrated to location and dredge-methodology specific measurements	• Most dredging and disposal projects in Australia • Calibrated model has been developed for the Port of Cairns

3 Fine Sediment Methodology

3.1 General Approach

Based on the review of literature and previous studies, this section outlines the Fine Sediment Methodology (FSM) proposed for approval under Condition 8. The proposed FSM framework is presented in Figure 3-1.

In developing the FSM design, the following general principles have been considered and applied:

- An existing 3D hydrodynamic and water quality numerical model will be used for the FSM. The numerical model is fit for purpose and has been subject to third party peer review as part of the Cairns Shipping Development EIS process.
- The existing model will be updated for the FSM, using:
  - Actual dredge logs (hypothetical dredge logs were used in the EIS).
  - Actual tailwater discharge data (flow volumes and quantities of fine sediment fractions).
  - Pre- and post dredge bathymetry data for the dredge channel to calculate the actual volume of fine sediment removed.
  - The most up to date geotechnical data for the dredge site.
- A robust field data collection program using industry accepted and proven methods will be required to inform numerical modelling assessments.
- Multiple sampling methods and approaches are proposed in order to ensure multiple sources of data to inform the results. Water samples will be collected and taken for laboratory analysis in parallel with field based in-situ instrumentation and the results compared against modelled outputs. The proposed methods are consistent with existing plume monitoring approaches used at the Port of Cairns and elsewhere in Australia, but with the novel inclusion of laboratory analysis of particle size distribution of suspended sediments.
- Outputs from the numerical modelling, in combination with interpretation of field data, will then be interrogated to calculate the quantity of fine sediment fractions returned to the environment.

In undertaking and implementing the FSM, it is recognised that:

- There will need to be a high degree of coordination between the FSM field sampling and measurements (likely undertaken by a consultant) and the dredge contractor. It is recognised that the two dredge vessels undertaking the works (as discussed previously) are likely to be operating at the same time in different parts of the dredge footprint during the construction period and the monitoring design will need to take this into account.
- The timing of sampling events will need to take into account representative weather and tidal conditions and/or conditions that are most suitable for obtaining the required data (for example, not undertaking measurements when naturally turbid background conditions in Trinity Bay could be masking dredge-related impacts).

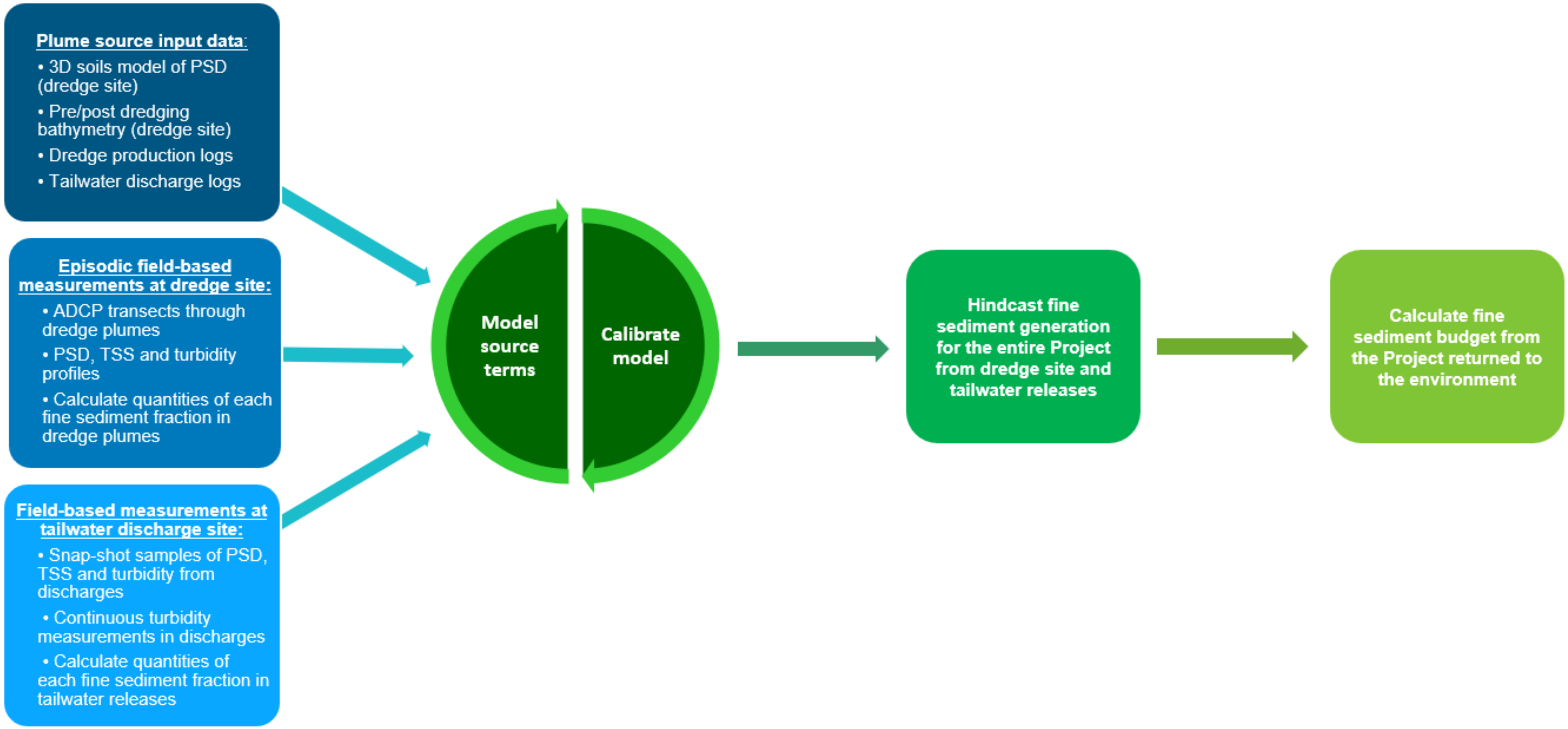

Figure 3-1 FSM Framework

- Geotechnical analysis indicates that there are differences in the distribution of sediment size fractions within and across the sediment types in the dredge areas. It is critical that sampling be designed and timed to provide representative samples of the different fine sediment types, especially the areas of stiff clays (that will be subject to environmental offsets based on the FSM calculation), which again requires the coordination between Ports North, the field team and the dredge contractor, and a review of geotechnical logs.
- Use of untested or untried equipment and technology is generally not proposed in the FSM given the need to ensure a robust and accurate validation of fine sediment release and in order to achieve the proposed project programme (with dredging set to commence in mid-2019).

The general FSM framework presented in Figure 3-1 will be applied to all project components, i.e. stiff clay dredging, soft clay dredging and tailwater discharges. There are however differences in the field data collection approaches for each of these components, in response to the following factors:

- Fixed versus moving sediment sources. It is not practical to install fixed instruments at the dredge sites as (i) both the backhoe and TSHD dredgers will move along the dredge channel to undertake works, and (ii) less critically, the dredge site is subject to tidal water movements. The tailwater discharge pipe is at a fixed location and it is therefore practical to install fixed instruments.
- Differences in dredger and plume movements. The backhoe dredge would generally operate from a more or less fixed location, thus plume generation would (by comparison with TSHD), be comparatively small scale and cyclic as the backhoe grabs a load of sediment from the seabed and is drawn through the water column to the water surface and above to be emptied in a waiting hopper barge. By comparison, the THSD is capable of generating a much larger continuous plume as it travels at slow speeds dredging and subsequently overflowing along an entire reach of the channel alignment.

The field data collection programs for each component are described in Section 3.2, and the generic modelling approach used to derive fine sediment calculations for the whole project is summarised in Section 3.3.

3.2 Field Methodologies

3.2.1 Stiff and Soft Clay Dredging

Methodology

The methodology for the measurement of the fine particle sediment returned to the environment from the dredging of stiff and soft clays would involve a program of vessel-based dredge plume monitoring to directly inform plume model validation. The suspended sediments disturbed by dredging would be identified using vessel-based acoustic and optical backscatter, turbidity, TSS and particle grain size measurements from within the dredge plumes on several occasions, corresponding to different tidal conditions and at different stages of the dredging project.

The main differences between the stiff clay and soft clay dredging are expected to be the comparative larger size and the higher initial sediment concentration of the TSHD plumes. These features will require the monitoring vessel to cover a wider spatial area for measurement and quantification of the dredging plumes and to undertake the measurements over a longer time frame to account for the initial sediment concentrations and subsequent settlement times required to account for reduced plume turbidities to near background concentrations. Additionally, there will be a need to confirm the potential sediment losses from the TSHD at the pumped discharge mooring. These losses are presently expected to be comparatively small or nil.

The monitoring vessel would be equipped with an Acoustic Doppler Current Profiler (ADCP) which, when configured in backscatter echo intensity mode, allows the user to see in real time a surrogate of the suspended particle concentrations within the water column below the vessel. By undertaking cross and long section transects, the plume which may not be totally visible from the surface, will be located and its 3-dimensional characteristics measured. The ADCP would be configured with real time navigation data from a differential GPS as well as the ADCP's own inertial navigation system so that recorded backscatter intensities would be time tagged and spatially located in real earth coordinates. The collected data would be stored in an electronic file format for future playback and review.

The vessel-based plume monitoring will include the following ensemble of measurements:

- Water column profiles throughout the water column with turbidity and optical backscatter measurement instruments.
- Co-located water grab sample collection, throughout the water column (surface, mid and near-bed) for the analysis, TSS and laser-diffraction PSD analysis, with the fine particle sediments determined from the particle size analysis of collected water samples and/or by direct profiling measurements from a laser particle sizing instrument.
- ADCP measurements, including backscatter echo intensities.

The same measurements will be conducted before, during and after dredging during each sampling campaign, and it is envisaged two sampling campaigns would be conducted (depending on locations of dredging and whether representative samples of stiff clays have been captured).

ADCP backscatter data and turbidity will be reviewed by field operators in real-time to accurately locate the survey vessel in the plume and as an initial check of data quality. It is anticipated that the dredge plume will be followed with the prevailing current and several cross and longitudinal transects conducted through the turbid plume generated by the dredging, which includes plumes both with and outside the dredge footprint. The collected data will provide a comprehensive time varying picture of the before, during and after suspended sediment concentrations at the dredging areas for initial sediment loading and model validation purposes. It would be desirable to undertake such measurements on at least one spring range flooding and ebbing tide, providing that this ties in with the dredging schedule.

It is expected that plume validation monitoring would be undertaken for each distinct capital dredging equipment type at different times through the dredging programme. Hence the BHD (used for dredging of stiff clays) and the TSHD (used to remove soft silts and clays) would be the focus of targeted plume monitoring at different times and locations. Given the overall channel length and variation in sediment properties, it is expected that targeted plume monitoring should occur for different dredging locations, possibly at different times, e.g.:

- Inner channel and swing basin reach;

- Mid channel reaches, and
- Sea channel reaches.

Targeted plume validation monitoring would occur on several separate occasions each involving around three days of field measurements to capture plume advection and dispersion behaviour under a range of tidal conditions. The difference in methodology required for the different capital dredging plant employed for the hard and soft clay removal will ultimately come down to differences in the mobility of the dredging plant and the associated size of the dredging plumes of sediment.

Outcomes Expected

- Calculation of empirical relationships between TSS, turbidity, particle grain size and acoustic backscatter.
- Characterisation of the temporal and spatial patterns of plumes generated by dredging.
- Calculations of the proportion of different sediment fractions in dredge plumes and ambient.

3.2.2 Tailwater Discharge

The placement of the dredge material on land will involve the fluidisation of the dredge material for its transport via pipeline from the TSHD hopper to the Northern Sands Dredge Material Placement Area (DMPA). The supernatant tailwater that is associated with fluidisation will need to be managed and will be monitored prior to discharge from the DMPA into the Barron River in accordance with water quality performance limits set by environmental permits and authorities.

The tailwater discharge FSM will involve the following:

Methodology

It is proposed to monitor the discharge from the DMPA into the Barron River using a recording turbidity measuring instrument which would be permanently positioned into the discharge for the duration of dredging, placement and discharge activities. The instrument would be equipped with a wiping mechanism to keep the submersible sensor optics clear of debris, slimes, or biofouling. Turbidity sensors respond well to suspensions of fine particles (in the particle size range less than 15 µm) (Guillen *et al*. 2000; Merten *et al*. 2014; Urich *et al*. 2015) and are therefore a suitable tool for examining time varying discharge and loss of fine sediment from the Dredged Material Placement Area. The instrument could either be downloaded on a weekly basis, or as needed, the recorded turbidity data could be telemetered in near real-time as a check on the performance of the dredged material placement area to detain and store fine sediment.

In addition to continuous turbidity measurements, grab water samples will be collected for the laboratory analysis of TSS and particle grain size distribution of suspended sediments. Correlation analysis will be undertaken to establish empirical relationships between the quantity of fine particles, TSS and turbidity. Together with flow rate data, the estimated fine sediment discharge over time will be based upon the integration of the particle size distribution(s) factored according to the turbidity time series measurements as a surrogate of fine sediment concentrations in the discharge.

Outcomes Expected

- Continuous records of turbidity in discharge waters, and episodic ‘grab’ samples for analysis of TSS and particle grain size.
- Calculation of empirical relationships between TSS, turbidity and particle grain size.
- Calculations of the mass of different sediment fractions in discharge waters.

3.3 Modelling Approach

An extensive description of the numerical model for Trinity Inlet and Trinity Bay and associated calibration and validation information was assessed as part of the Revised EIS for the CSDP including independent third-party review.

As part of the FSM an additional detailed calibration exercise would be undertaken for the model to determine the ‘best fit’ dredge plume source terms to match the field measurements described in Section 3.2.

The updated model with calibrated source terms can then be used to undertake a hindcast that would cover the full duration of dredging by both vessels undertaken during the CSDP using dredge logs and similar information supplied by Ports North and the dredge contractor.

Additional validation of the model would also be undertaken using the fixed instruments deployed at sensitive receptor and reference locations as part of sensitive receptors monitoring programme required under other conditions of the EPBC controlled action approval.

The validated hindcast plume model simulation of the entire Project would form the basis for accounting the fine sediment spill quantities.

The fine sediment spill modelling would also be configured so that questions about the longer-term fate of plume sediment and interaction with sensitive receptors can be answered, including the use of Lagrangian particle methods which will allow for tracking of particle ‘age’ (time since seeding) and ensure that particles are not ‘double-counted’.

The evaluation of the relative success of individual estimation pathways will be undertaken at project completion.

3.4 Reporting

A detailed monitoring plan including timing of all activities, actions required to ensure data accuracy (e.g. calibration of instruments) will be prepared prior to the commencement of field work, once dredging sequencing is finalised and in consultation with the dredge contractor, to ensure a full range of conditions are captured.

The final report will be delivered to the department no later than 6 months after completion of dredging. It will include:

- The mass balance of sediments to be dredged:
    - Information from cores for profile, including consistency (i.e. soft-stiff) and shear strength;
    - Particle size distribution (PSD), including amounts <15.6 um;

  - Methods for determining the PSD, including any uncertainties; and
  - Quantification of fines, including amounts within soft clay material and amounts within stiff clays.

Additional information on the derivation of source terms to be used in initial model validation.

- A full description of monitoring results including measured PSDs and percentage of fines, together with an assessment of the likely accuracy of each reported measurement.
- A description of the model validation process, including any adjustments made to the assumed plume release rates for each dredging activity.
- A comparison between the validated model outputs and the measured data.
- A description of the actual dredging programme undertaken, based on the dredge logs.
- Results from the full model hindcast, including detailed quantification of all fine sediment released to the environment due to (i) dredging in stiff clay materials and (ii) dredging in soft clay materials and (iii) tailwater discharge.
- Raw data from, any particle size analysis and calculations will be provided as an appendix.

4 Peer Review

4.1 Peer Reviewer

A peer review of this report has been undertaken by Dr Alistair Grinham from the University of Queensland. Dr Grinham's biographical information is summarised below:

Dr Grinham has over 20 years' experience in monitoring sediment dynamics of rivers, estuaries and coastal systems. Alistair joined the School of Civil Engineering in June 2007 to develop environmental monitoring systems to better understand sediment transport and biogeochemical processing in freshwater and coastal aquatic systems. Alistair employs a multi-disciplinary approach using traditional campaign-style monitoring programs along with advanced autonomous monitoring systems to ensure data collection occurs at appropriate spatial and temporal scales. These award winning monitoring systems have been successfully applied to water quality and sediment investigations across a diverse range of water bodies, including over 15 years of ongoing programs in coastal and coral reef systems. Research areas covered during this period include: tracking environmental pollutants from source to sink; identifying sediment transport pathways; tracking sediment plumes from point sources; and, characterising benthic sediment distribution. A key strength is Alistair's ability to develop long-term industry research partnerships which he was internationally recognised for his role in leading the $2 million "Developing Port Growth – The University of Queensland and Port of Brisbane Pty Ltd Research Partnership." Alistair has over 50 peer-reviewed scientific articles and more than 50 successfully completed industry projects with a strong focus on monitoring sediment dynamics in aquatic environments.

A copy of Dr Grinham's CV is contained in Appendix A and he is considered a *suitably qualified person* in the accordance with the controlled action approval definition which is as follows –

> *Suitably qualified person means a person who has professional qualifications, training, skills and or experience related to the nominated subject matter and can give authoritative independent assessment, advice and analysis on performance relative to the subject matter using the relevant protocols, standards, methods and or literature.*

4.2 Peer Review Comments

Dr Grinham's full peer review report is contained in Appendix C. A summary of the points raised and how they have been addressed in this report are contained in Table 4-1.

Table 4-1 Peer Review Comments and How They Have Been Addressed

Peer Review Comment	How Addressed in the FSM	Where Addressed?
Provide additional justification around the spill loss rate for BHD	The BHD 3% fines spill rate was based on advice contained in a Pro-Dredge technical memorandum (dated: 19/08/2014) – refer to Section 1.3.3.1. An independent estimate 0f 0-4% for BHD 'bucket drip' is provided in Becker et al. (2015). *Estimating source terms for far field dredge plume modelling.* Journal of Environmental Management 149 (2015) 282-293.	No action undertaken

Peer Review Comment	How Addressed in the FSM	Where Addressed?
	The BHD value will be field tested, validated and if necessary revised for use in the final spill estimates as part of the proposed FSM scope – refer to Section 3.3 (second paragraph) The BHD will target stiff-clay in-situ material while the TSHD will target overlying soft material. The fine spill component requiring an offset in the EPBC conditions is specifically linked to the stiff-clay in-situ material. The field monitoring of BHD operations should therefore specifically target operations in stiff-clay material.	
Include the evaluation of the relative success of individual estimation pathways at project completion	The recommended evaluation has been included in the FSM.	Section 3.3
Fix minor typos and standardise the units	Document has been updated.	Sections 1.1, 1.2, 1.3, 2.3, 3.2

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Appendix A Cairns Shipping Development Project – Net Benefits Approach, Background Information

Cairns Shipping Development Project – Net Benefits and Offsets Approach

Background Information

Date	Custodian	Approved	Approving Authority	Version
07/09/2018	Ports North	AGV	Ports North	Draft for Adequacy Check
07/09/2018	Ports North	AGV	Ports North	Final Draft

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Appendices

1 Introduction

In order for the Cairns Shipping Development Project (CSDP) *Environment Protection and Biodiversity Conservation Act 1999, (EPBC Act)* approval conditions to be finalised it is important for the Department of the Environment, DoE to understand the ambient conditions in Trinity Bay, the fine nature of the existing seabed material and the fact that the sediment is extremely mobile.

Finalising the *EPBC Act* approval conditions and the fine sediment and offsets approach in a way that allows to project to proceed is on the critical path.

This document, acilitates gaining early certainty on the project's offsets and fine sediment financial exposure for Ports North to ensure its project remains economic and utlines why the projects' fine sediment methodology and offsets approach needs to be cognisant of the peculiarities of the port ie; the highly mobile nature of the fine sediment

2 Purpose of this Document

The purpose of this document is to respond to DoE's request for further supporting information in regard to

- Ports North's previous advice that stiff clays are the only source of fine sediment not available for resuspension.
- The methodology and data used to determine the ranges of fine sediment volumes provided in the table below (previously provided to DoEE) and identifying any limitations in allowing for a conservative estimate of these amounts.

Table 1 – Potential Impacts (for the purposes of net benefits provision and offsets.)

Item	Description	Impact Range (tonnes or ha)
1	Estimate of fine sediment released by the backhoe dredging of the stiff clays.	0 – 5,000 tonnes
2	Estimate of fine sediment reintroduced to the marine environment at the tailwater discharge point.	0 - 1000 tonnes
3	The measured area of impact, sub-lethal and lethal, to the sensitive receptors comparing pre and post dredge sensitive receptor surveys.	0 - 10 ha

- Identification and costing of some likely mechanisms to offset the release of fine sediments."

In order to address these items, the content of this document provides a description of the background to the project and supporting information on the site setting in the context of sediment loads and movement in the project area. A number of these items have been discussed previously and the additional information in this document provides further evidence of the justification of the proposed approach to net benefits and potential offsets for this project.

It is noted that further to discussions with DoEE on the EIS prediction of no significant residual impact to sensitive receptors, including seagrass, an offset under the EPBC Act is not considered necessary to include in this document and can be addressed under the State offsets process if triggered.

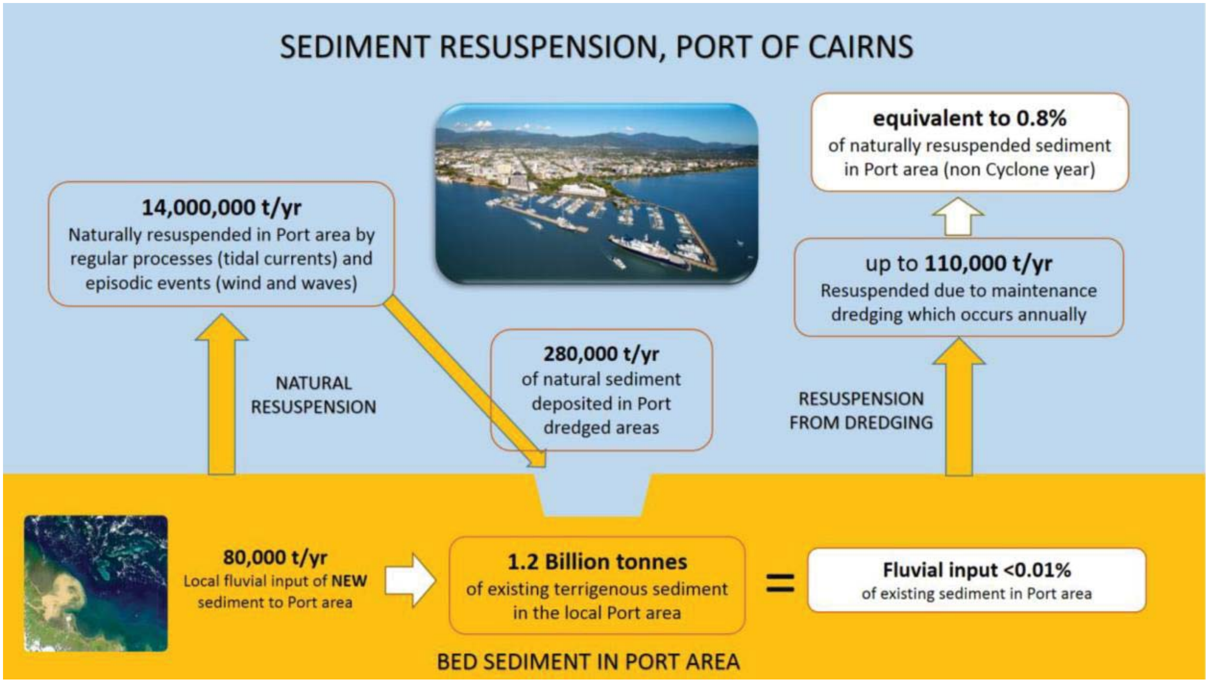
3 Background

The Net Benefits and Offset approach for the Cairns Shipping Development Project should be developed with consideration of the coastal processes and ambient conditions in the area as well as the dredged material properties. The channel re-design approach (from the initial Referral, through the Draft EIS, and then the Revised Draft-EIS design refinement stages) has been informed by these two factors and has sought to work with the natural material movement process to minimise the requirement for dredging of material not currently available for re-suspension. These three interrelated factors are further summarised below and illustrated by the referenced appendices.

3.1 Coastal Process Summary

The understanding of coastal processes and sediment movement within the Trinity Bay area has developed over several decades and numerous studies including those referenced in Chapter B3 - Coastal Processes, of the Cairns Shipping Development Project EIS. Some key references are summarised as follows.

- During 2018, the outputs of Reef 2050 Long Term Sustainability Plan action for WQA17 were completed by Qld Ports Association, and they included a contemporary evaluation of the relative contributions of sediments at and adjacent to the Port of Cairns. The overall quantum of movement of material is described in the following schematic:



  It is evident that the surface sediments of Trinity Bay area are highly mobile under natural process with a volume in the order of 14 million tonnes per year moving within the bay.

- In a report by Brinkman *et. al.* (2004), **Appendix 1,** the prevailing fine sediment “nephloid layer” present along the Cairns shoreline was quantified and described. The study modelled the patterns of movement of the layer of material within the general confines of Trinity Bay and in the broad context along the tropical coast, in both calm and strong wind conditions. Conceptual numerical modelling suggested that the layer acts as a negatively buoyant plume that is deflected longshore alternatively northward and southward by prevailing, reversing oceanic currents, out to around the 20m depth contour. Concentrations of the layer were noted as being up to 1000mg/L (SSC) and up to 10m in thickness.

- Outcomes of the 5 year Australian Research Council Grant Project, "*The Environmental Sedimentology of Trinity Bay, Far North Queensland*, (Carter *et al,* 2002), outlined the sediment movement processes and sediment fraction rates including the resulting erosion adjacent to the Shipping channel and deposition adjacent the Esplanade as indicated in the chapter summary and figure extracts in **Appendix 2.**

3.2 Dredge Materials

The materials proposed to be dredged in the project consist of two physically different and visually distinguishable material types originating as either terrigenous sedimentary deposits or marine sediment, as illustrated in the images in **Appendix 3**. The equipment required for each to be dredged is also different. The soft marine muds and sediments will be dredged by Trailing Suction Hopper Dredge (TSHD) and the stiffer material by backhoe dredge. It follows that this same point of difference defines the material naturally available or not available for re-suspension. The extent of dredging into the stiff material (not naturally available for re-suspension) has been minimised in the project design approach described below.

The quantification of volumes of dredged material available and not available for re-suspension, equates directly to the quantification of soft and stiff material which was a key project driver and clearly quantified in the project investigations and design process in order to undertake the dredge planning and modelling on which the Environmental Impact Statement was based. The material assessment and quantification is described further in Section 5 below.

3.3 Channel Re-Design Approach

The previous Cairns Shipping Channel expansion and the declaration of the State Marine Park and FHA adjacent the channel in the 1990's adopted a 200m wide corridor, 100m from and parallel to the centreline, preserved for navigational aids and future channel expansion.

This approach at that time clearly and logically assumed that any widening would occur to equal extents either side of the channel centre line. The Original Draft EIS for the CSDP, released in 2015, included for 4.4M cu.m dredging project to widen the existing 90m channel to 120m - 130m with widening on either side of the centreline. The Draft EIS at that time proposed sea-based disposal of the dredged materials.

With the re-scoping of the CSDP in 2016-17 to achieve a land-based material placement solution a reduced dredge quantity was required. A reduced scope of 1M cu.m of dredging was targeted based on knowledge of the capacity constraints at potential land placement sites. The existing channel, adjacent seabed bathymetry, sediment material types and movement processes were further examined accordingly. To minimise the dredging volumes, a ''working with nature" approach was adopted in terms of re-directing all the widening to the western side of the channel. This alignment takes advantage of the naturally occurring deeper water and ongoing erosion processes evident on the western side of the channel in the area of the widening. This reduced the capital dredging volume and also avoided cutting into the accreting Eastern bank and hence also minimised future maintenance dredging volumes. The Queensland State Government agencies have concurred with this approach and provided in principle agreement to the required Fish Habitat Area (FHA) adjustment, and Marine Parks Permit, based on the slight net increase of FHA detailed by Ports North in the EIS project proposal.

The re-scoping also involved a reduction in the depth of capital dredging and hence minimisation of dredging required into the upward protrusions of the underlying stiff clay. The reduced depths also significantly reduced the area of dredging required in the inner harbour, for much of the extent of the proposed inner channel is already at the required depth as illustrated in Figure 1 **Appendix 4**. This inner channel area has historically not required maintenance dredging. A higher proportion of the inner channel area has the stiffer material at the seabed surface which prevents further erosion. The tidal current flow conditions in this inner channel area are of sufficient velocity to prevent accretion of sediment.

3.4 Conclusion

Numerous scientific studies into the coastal processes and sedimentology of Trinity Bay have clearly demonstrated that even under calm conditions there's a very significant and multi-directional sediment movement on a large scale occurring on an ongoing basis. The vast majority of the proposed capital dredging material is the same, clearly distinguishable, soft sediment which is subject to constant remobilisation through natural processes. The channel redesign has sought to minimise the extent of dredging into the stiffer material which is not currently available for resuspension, and has been positioned to align with the zones of natural erosion of the soft material. The bathymetry records and other information provided indicates that the area proposed for capital dredging in the soft material is all available for resuspension. All the proposed soft sediment capital dredging material has the same material properties and exposure to that which has eroded away through natural processes, and therefore should not be included in a fine sediment offset determination.

4 Soft Clays Available for Resuspension Prior to Dredging

The natural sediment in Trinity Inlet and Trinity Bay is very mobile. The revised project design involves minimum deepening of 0.5m of the existing channel areas. The material in this zone has been categorised as marine 'sediment" and is highly mobile. The widening of the channel is now only proposed for the western side of the channel in an area which is regularly remobilised under normal weather and tide cycles and can be seen to be actively eroding. These concepts can be observed from the photos, contours and sections below and referenced appendices.

4.1 Sediment Mobility in Trinity Bay

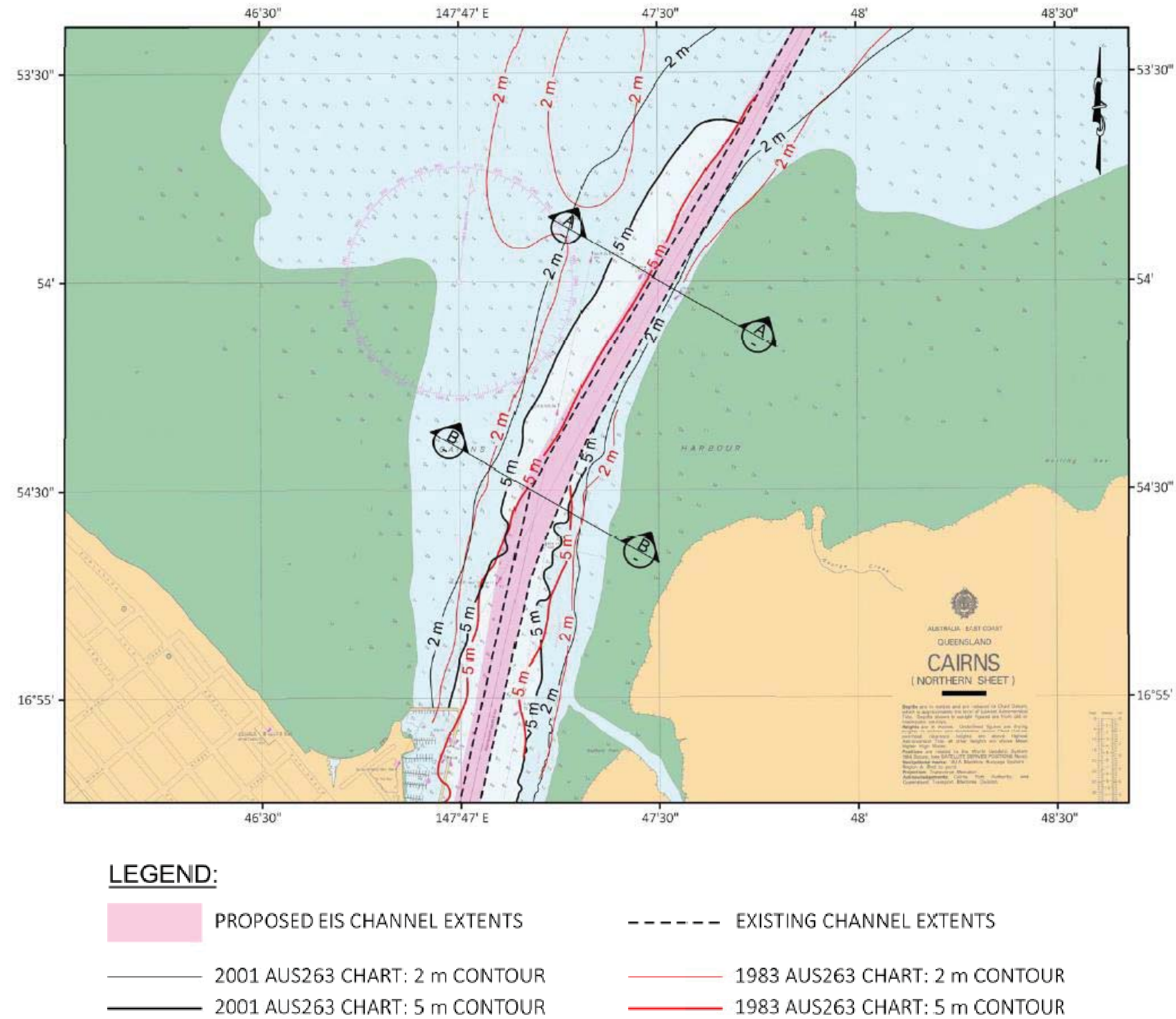
Trinity Bay and Channel during outgoing tide, calm weather 31-08-15, prior to annual maintenance dredging

4.2 Marine Sediment Consistency

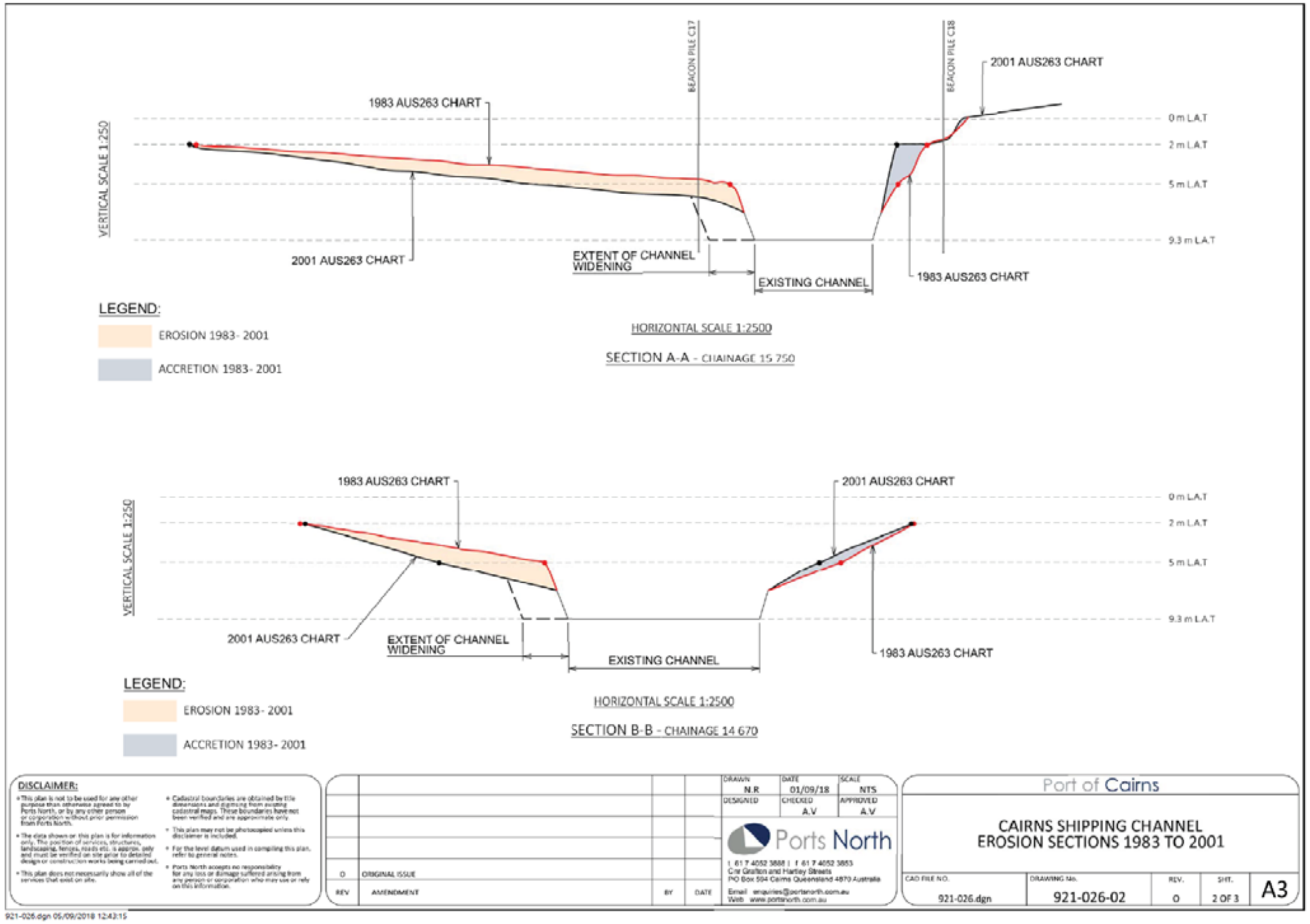
The marine sediment in the upper zone of the existing channel is of very low density as illustrated in the annual maintenance dredging sampling photos below. This material is highly fluidised and mobile. The hydrographic surveys which define the seabed surface utilise a sounding frequency set to detect the minimal density of fluidised mud that may affect navigation of shipping and this is approximately 1.1 tonnes per cubic metre. This material has been observed to be displaced by large cruise ships on which Ports North's marine pilots have observed depth sounding instruments showing consistently greater depths than surveyed and charted.

4.3 Seabed Erosion Profiles

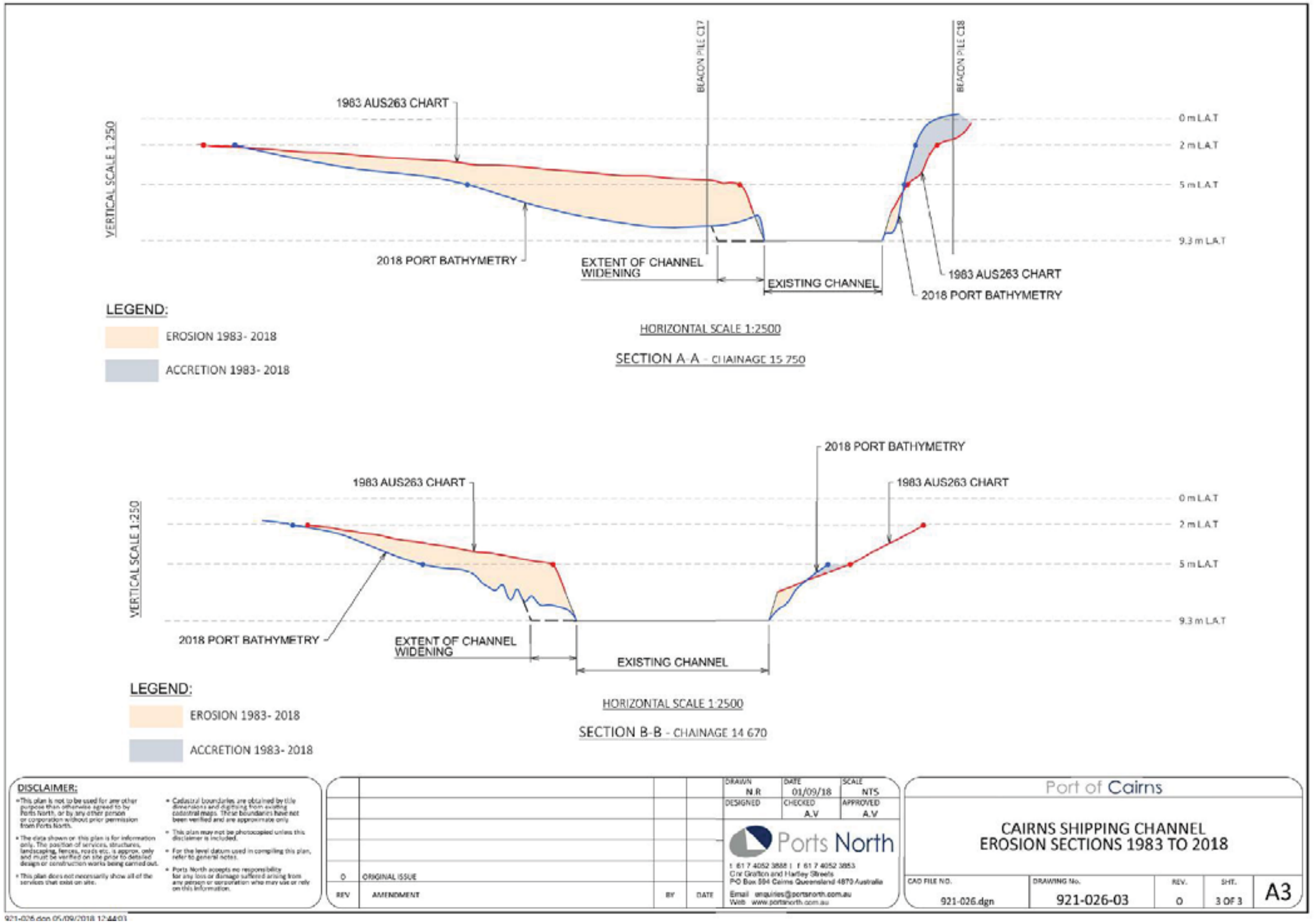
The map below depicts the natural movement of sediment in Trinity Inlet near the channel. For a distance of around 1800m, the 5m contour moved 150m between 1983 and 2001. This equates to a rough volume of 500,000m^3 of natural seabed being mobilised.



The cross section below clearly the erosion that has occurred on the western side of the channel and the accretion that has occurred on the eastern side of the channel as indicated by the contour plan above.



The longer term erosion and accretion between the 1983 contours and a recent 2018 hydrographic survey is illustrated in the cross sections below.



The above two figures have been provided in larger scale in **Appendix 5**.

The extent of channel widening as indicated by the dashed line work above is clearly within a long-term and ongoing erosion zone. It is expected that this erosion of soft material will continue until the underlying stiff material is exposed. The soft material which has been resuspended from the orange shaded erosion zones had it still been present would have formed part of the capital dredge volume. The remaining soft material still within the proposed dredging area is similarly prone to erosion and available for resuspension. This has been noted previously as referenced above in the stratigraphy cross section (**Appendix 2**) which confirm the long-term nature of this process.

4.4 Seabed Resuspension Images

The aerial photos in **Appendix 6** show that normal run-out tide currents are sufficient, when slightly amplified by eddying around the navigation beacon piles in over 8m of water, to re-suspend seabed material to the extent it is visually apparent at the water surface. Plumes of resuspended sediment can be seen clearly emanating from the piles. This represents another visual example of the high mobility of the natural seabed material.

4.5 Conclusion

Ports North consider that the CSDP will remove fine sediment material that otherwise would have been available for resuspension in Trinity Bay. Of the total maximum of one million cubic metres to be dredged, approximately 900,000m^3 is soft clay/fine sediment that is being fully removed from the marine environment, placed on land and managed to ensure it does not re-enter the marine environment with only a very minor percentage (less than 0.1%) returned through tail waters.

5 Estimate of Fine Sediment from Stiff Clay Dredging

5.1 Introduction

This section describes the steps and the detailed data acquisition, inputs and calculation of the maximum fine sediment mass available for re-suspension from the stiff clay dredging.

5.2 Stiff Clay Volume – 100,000 cubic metres

The geotechnical data gathered for this project and previous channel and port developments was utilised by our geotechnical experts (Golder Associates) and dredging consultants (JFA-BMT and Akuna Dredging Solutions) to discern the stiffer material requiring backhoe dredging. The geotechnical data set is best described in Sections 2 and 3 on pages 1 and 2 of Appendix E to the Supplementary Report – "Baseline Report – Dredged Materials." These excerpts are included as **Appendix 7** to this document. The full set includes 127 test points and 59 km of continuous seismic data. Some of these locations are shown on Figures F001, F002 and F003 in the above referenced document. These figures are included as **Appendix 8**.

Appendix E to the Supplementary Report can be found using the following link, (note that the report has been separated into seven parts on this particular webpage.) -

https://www.statedevelopment.qld.gov.au/assessments-and-approvals/projects-draft-environmental-impact-statement-documents.html

The stiff clay material locations are best illustrated in Figures F001 and F002 of Appendix J to the Revised Draft EIS document – "Assessment of Materials Proposed for Dredging Report (2016)," see weblink below. These figures are included as **Appendix 4**.

http://eisdocs.dsdip.qld.gov.au/Cairns%20Shipping%20Development/Revised%20draft%20EIS/Appendices/appendix-j-assessment-of-material-proposed-for-dredging-report.pdf

The interface level (top of stiff clay to bottom of soft clay) was then detailed in a 3D model by Golder Associates as per the Figures F003 – F012 in the above-mentioned report. In all cases (54 cross sections at 250m intervals along the channel dredging area) the stiff material is underlying a surface deposit of marine mud and more transient marine sediment. (Refer in particular Figures F006 and F008 within that set of cross sections.) Figures F003 – F012 are included as **Appendix 9**.

Golders 3D model calculated cubic metre volumes of both stiff and soft material as per Section 3.0 - Table 1 and Table 2 from the same report. These tables are included as **Appendix 10**.

Ports North also checked and verified the total dredge volume using its own Hydrographic Survey 3D model. The stiff clay material volume was therefore measured at 92,309 and rounded up to **100,000 cubic metres** to accommodate an appropriate over-dredging allowance for this type of dredging.

5.3 Density and Soil Mass – Volume to Tonnes Conversion

The Golder geotechnical report in Appendix E to the Supplementary Report – "Baseline Report – Dredged Materials," Section 6.4, page 9, (copied below) presents 1.42 to 1.72 tonnes per cubic metre as the dry density (mass of soil per unit volume) with an adopted representative average of **1.6 t/cu.m**. This summary is based on the sampling and test data provided in approximately 300 pages of appendices to that report. An extract of the applicable section of the report is included below.

> ### 6.4 Stiff Clays
> The stiff clays generally underlie the mud in the existing dredged channel and in areas where channel widening is proposed. Stiff clays are expected to be encountered within the channel widening and deepening from Ch 13,500 to 15,000. Available information indicates insitu dry densities around 1.6 t/m^3 (range 1.42 to 1.72 t/$m^{3)}$.

5.4 Percentage Fines

The particle size distribution analysis of the numerous stiff material samples was provided in Appendices A, B and C1 to Appendix E to the Supplementary Report – "Baseline Report – Dredged Materials." A sample of the data set from Appendix A1 of the above report covering the 2013 boreholes, is shown in **Appendix 11**. The stiff material is labelled "St" and the very stiff labelled "VSt". Borehole Logs 1 to 7 have been highlighted in yellow where stiff material samples were taken and the Particle Size Distribution, (PSD) test charts for these are included as **Appendix 12**.

The 10 stiff material samples have fines contents (<15.6 micron) ranging from 40% to 82% by mass, with an average of **70% fines**. This estimated average percentage of fines was determined by comparing the value of the "Percentage Finer" figure by interpolation on each PSD chart (included in Appendix 12) at the respective 15 µm "Particle Size" values.

5.5 Spill Rates Percentage by Mass

The adopted spill rate for the process of backhoe dredging of stiff material is 3% of production rate as reported in the Original Draft EIS (2015) Appendix D4 (page 116). Whilst the production rates are measured in units of in-situ cubic metres per hour, this can be directly applied to the tonnages of material being dredged. The source term of 3% was set by a dredging consultant, Pro-Dredging and Marine Consultants, based on many years of experience in planning and monitoring dredging projects. The source term as noted was intended to apply to the fines content of the stiff clay. The reference to fines in this case is based on the geotechnical definition and test method for <75 micron (commonly tested by hydrometer and reported as a single figure).

It is noted that the Pro-Dredging advice described that only 15% of this content typically remains in the water column available for passive dispersion and the remainder forming a dynamic plume on the seabed. In effect 85% of this 3% has only a very short term and localised water quality impact.

Akuna Dredging Solutions Pty Ltd has prepared a draft document – "Notes of Fine Sediment Offset," (included as **Appendix 13**) which provides further basis for the conservative estimate of **3% fine sediment spill** produced by the backhoe dredge.

Consistent with Ports Norths approach to defining fine sediments that are available and not available for resuspension, Ports North is proposing to adopt the full 3% as the source term relevant to 15.6 micron sediment. This conservatively assumes that any spilt fine dredge material that lands in the dredging area footprint is not re-dredged and may still be available for resuspension. This conservative adoption avoids the need for complicated and unreliable monitoring programs to be applied in an attempt to discern the actual fine dredge sediment left available for resuspension after the dredging.

5.6 Potential Fine Sediment Release from Stiff Clay Dredging by Backhoe

The calculated fine sediment released from Backhoe Dredging the stiff clays is defined by multiplying the relevant numbers for all of the following terms:

- Percentage fines within dredge material **(70%)**
- Fine sediment source term (spill rate) from the dredging process **(3%)**
- Dredge material dry density **(1.6 t/cu.m.)**
- Stiff clay volume to be dredged (**100,000**)

Multiplying the figures gives: 0.7 x 0.03 x 1.6 x 100,000 = **3,360 tonnes.**

Allowing a further factor of approximately 1.5 for conservatism we have suggested a maximum of **5,000** tonnes as the potential amount of fine sediment release from stiff clay backhoe dredging.

5.7 Tailwater Discharge Fine Sediment Estimate

Following is an explanation of the estimated range of tail water discharge fine sediment load. The Final Revised Draft-EIS included reclamation modelling by BMT-JFA which predicts the initial placed volume of the dredged material, its settlement rates and the corresponding surface water quality in the reclamation pond for the planned filling sequence.

Concurrent with that work BMT made assumptions on an achievable tail water quality and modelled and assessed the tail water discharge impacts based on those assumptions.

The tail water quality assumptions were;

- 50 mg/L TSS chronic threshold levels during placement and discharge (2-week average not to be exceeded)
- 100 mg/L TSS acute threshold limit during placement and discharge not to be exceeded by any 48-hour average
- a maximum daily discharge volume of 87 megalitres per day.
- a total modelled dredge priming, pumping and flushing soil and water volume of 5,534,339 cubic metres
- a total pumped soil in-situ volume of 882,650 cubic metres

The reclamation and tail water quality modelling has confirmed the design can deliver the adopted tail water quality limits.

The theoretical maximum tail water discharge volume is 4,651,689 cubic metres noting a large proportion of the soil is expected to remain fully saturated (retaining a mass of pore water at about 60%-70% of the mass of the soil). At 50mg/L this equates to **233 tonnes of fine sediment**.

For simplicity, and for the purposes of obtaining offset and fine sediment certainty prior to awarding contracts, Ports North is prepared to assume all the tail water TSS is <15.6 micron. A range of 0 - 1000 tonnes around the predicted figure of 233 tonnes was provided to DoEE as depicted in Table 1 in Section 2 of this report.

5.8 Conclusion

Appendix 1 The above analysis demonstrates the appropriateness of the range of fine sediment tonnages previously provided to DoEE (as presented in Table 2 of report) and the appropriateness of the approach proposed therein.

Appendix 1 Reference Paper – Brinkman et al 2004

Reference Paper by:

Brinkman, R., Wolanski, E., and Spagnol, S. (2004) ***Field and model studies of the nepheloid layer in coastal waters of the Great Barrier Reef, Australia.*** In: Jirka, Gerhard H., and Uijttewaal, Wim S.J., (eds.) Shallow Flows. Taylor & Francis, London, UK, pp. 225-229.

Shallow Flows – Jirka & Uijttewaal (eds)
 ISBN 90 5809 700 5

Field and model studies of the nepheloid layer in coastal waters of the Great Barrier Reef, Australia

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ABSTRACT: Field studies were undertaken of nepheloid layer dynamics in the coastal waters of the Great Barrier Reef near Cairns during the dry season in November 2001. A nepheloid layer was formed during calm weather along the coast and was advected offshore as a bottom-tagging layer. The layer spreads offshore with the ebb tidal currents and with the sediment-induced baroclinic currents. A conceptual numerical model suggests that the nepheloid layer can be modelled as a negatively buoyant plume that is deflected longshore alternatively northward and southward by the prevailing, reversing oceanic currents.

1 INTRODUCTION

An increase in human activities in river catchments adjacent to Australia's Great Barrier Reef has resulted in increased erosion and mud outflow to coastal waters (Wachenfeld et al. 1997; Wolanski & Spagnol 2000; Duke & Wolanski 2001). A portion of this mud is trapped in embayments, allowing the expansion of muddy foreshores and mangroves (Duke & Wolanski 2001). Not all that mud is retained in these embayments. Some mud is exported in a coastal boundary layer during strong winds, and some more mud is exported in calm weather in a transient, bottom-tagging, nepheloid layer described by Wolanski & Spagnol (2000) and Wolanski et al. (in press). The nepheloid layer was observed to form during calm weather; muddy water cascaded down the slope of the coastal wedge; at the base of the wedge, the nepheloid layer was advected northwards or southwards with the prevailing longshore oceanic currents.

In this paper a conceptual model of the dynamics of this nepheloid layer is developed. The baroclinic behaviour of the plume is explicitly parameterized in an advection-diffusion model, which is forced by the velocity field computed by a barotropic circulation model that includes tidal and oceanic forcing. We show that the model is able to qualitatively reproduce the general observed characteristics of the nepheloid layer. The predicted distribution of the nepheloid layer compares well with observation of sediment composition in the study area.

2 METHODS

2.1 *Field observations*

Field data on the dynamics of a nepheloid layer in the coastal waters of the Great Barrier Reef (Figure 1) were obtained from Wolanski & Spagnol (2000) and Wolanski et al. (in press). High values of up to 1000 $mg\,l^{-1}$ of suspended sediment concentration (SSC) were found in inshore waters and only during

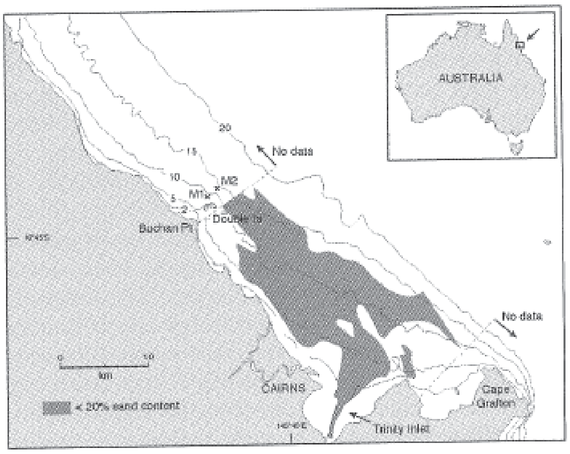

Figure 1. Locality map of the study area in the Great Barrier Reef. Also shown are bathymetric contours (m), and the mooring sites M1 and M2. Areas shaded with dark gray indicate sediment with <20% sand content (from Jones, 1985).

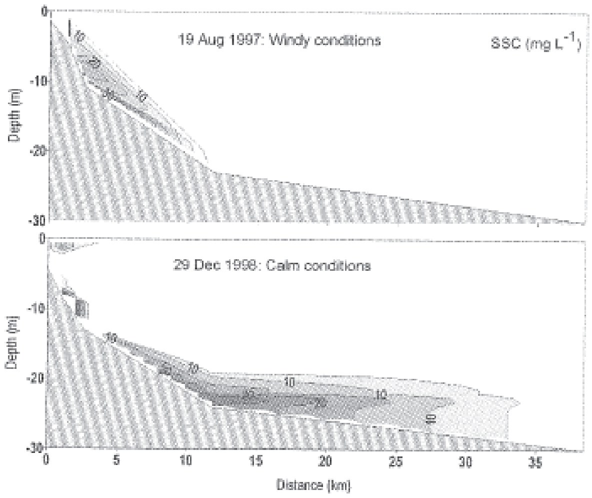

Figure 2. Cross-shore distributions of SSC during (top graph) strong winds on August 19, 1998 and (bottom graph) calm conditions on December 19, 1998. Adapted from Wolanski & Spagnol (2000).

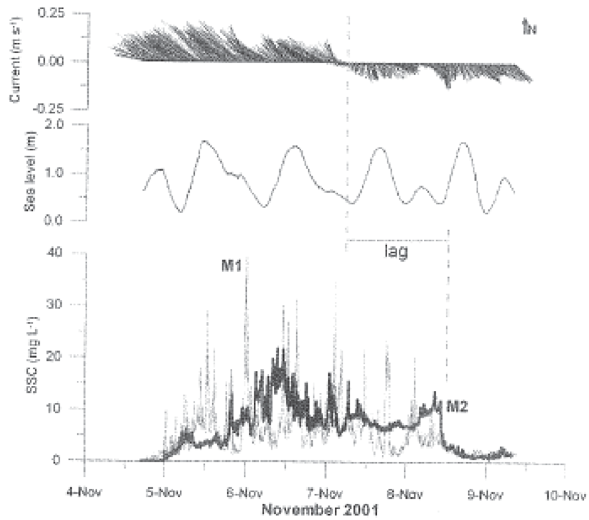

Figure 3. Time series plot of (top graph) the currents at mid-depth at site M2 shown as a stick plot, (2nd graph from the top) sea level, and (bottom graph) the suspended solid concentration (SSC) near the bottom at sites M1 (thin grey line) and M2 (thick line). The lag between longshore flow reversal (from northward to southward) and the disappearance of the nepheloid layer at site M2 is shown.

strong winds (Figure 2). During calm weather conditions, a nepheloid layer was found to extend from the slope of the coastal wedge to approximately 30 km offshore (Figure 2).

This study also indicated a high correlation between the along shore current and SSC. Coincident observations of SSC and vertical current profiles at sites M1 and M2 (shown in Figure 1) enabled four key observations of the behavior of the nepheloid layer. Firstly, the data from site M2 indicated that muddy water cascaded down the slope of the coastal wedge with a velocity of approximately 0.03 m s^{-1}. Secondly, muddy water in the nepheloid layer was found to be exported offshore from the coastal wedge during ebb tide (when the cross-shelf currents were directed offshore), with no return import of this muddy water during flood tides (when the cross-shelf currents were directed inshore). Thirdly, the data suggest that the nepheloid layer at the base of the coastal wedge was advected firstly northward, then southward by the prevailing longshore currents (Figure 3). The rapid disappearance of the plume at site M2 around mid-day on November 8, 2001 (Figure 3) suggested that the plume of muddy water that had traveled north with the prevailing currents had returned passed site M2. There was a lag of approximately 30 hours between the reversal of the longshore currents and the return of clear water at site M2 (shown in Figure 3). Fourthly, SSC concentration peaks in the nepheloid layer at site M1 occurred at times of reduced cross-shelf current near high and low water (Figure 3), an observation suggesting that the thickness of the plume is proportional to the current speed.

2.2 *Conceptual modelling*

The observations suggest that two dominant processes control the dispersion of the nepheloid plume from the nearshore region in calm weather, namely the buoyancy-induced baroclinic current of the nepheloid layer, and the general barotropic oceanic circulation.

The barotropic circulation was computed by the depth-integrated, barotropic model of Brinkman et al. (2002). The computational grid for the model was a regular mesh of 500 × 500 m spatial resolution. The grid was aligned the x-axis directed in the alongshore direction and extended northward from just south of Cape Grafton. The grid extended 27 km offshore and 75 km in the alongshore direction, encompassing the area between Trinity Inlet and north of Double Island (see Figure 1). The hydrodynamic model was forced by tides (amplitude 1.5 m, 12 h period) and the regional sea surface gradients to include the influence of remote oceanic forcing that generate longshore currents (Brinkman et al. 2002). In order to reproduce the longshore current behaviour as observed by Wolanski et al. (in press), the prescribed regional sea surface gradients were such that a northward flow with mean alongshore velocity of about 0.2 m s^{-1} prevailed for approximately 50 hours from the start of the model run. After this time the flow reversed to a southward flow, again with mean alongshore velocity of about 0.2 m s^{-1}.

The nepheloid layer was modelled as a negatively buoyant plume. Following a similar approach to Dengler & Wilde (1987), but including bottom friction, the sediment-induced baroclinic gravity current was estimated from a balance between drag, friction and the buoyancy difference between the plume and the clear water above,

$$C_d u^2 + fu = \frac{gH\Delta\rho}{\rho}\sin\theta \quad (1)$$

where u is the mean velocity of the front speed, C_d is the drag coefficient, f is the coefficient of bottom friction, g is the acceleration due to gravity, H is the thickness of the nepheloid layer, $\Delta\rho$ is the increase in density, ρ, of the nepheloid layer and θ = sea floor slope. If friction is neglected, Equation 1 reduces to,

$$u \alpha \sqrt{\frac{gH\Delta\rho}{\rho}\sin\theta} \quad (2)$$

Equation 2 is consistent with that proposed by Dengler & Wilde (1987) for turbidity currents on steep slopes. It should also be noted that for a horizontal bottom ($\theta = 0$), the mean current, u, becomes zero. This result is correct as for a horizontal bottom nepheloid layer would spread uniformly and radially away from the source of high concentration. Thus the mean velocity of the spreading plume would be zero.

For low values of the sediment-induced baroclinic gravity current ($\sim 0.03\ \mathrm{m\,s^{-1}}$ as suggested by the field data), non-linear effects are negligible and, for values of the drag coefficient, C_d, close to unity, we can assume that drag can be neglected. Equation 1 reduces to,

$$u = A\frac{gH\Delta\rho}{\rho}\sin\theta \quad (3)$$

where A is a proportionality constant. The value of A was determined from field data collected at site M2, where H, $\Delta\rho$, and u were measured. The bottom slope (θ) at site M2 was calculated from bathymetry data. It was assumed that this value of A applied everywhere in the plume.

A cross-shelf sediment-induced current described by Equation 3 was explicitly prescribed in a 2D advection-diffusion model (Oliver et al. 1992) applied on the same computational grid as the hydrodynamic model. The advection-diffusion model used a Lagrangian particle tracking technique where each particle represented a known mass of sediment. Particles were moved firstly by the prevailing barotropic currents in both the along shelf and off-shelf directions. Observations indicated that the plume was exported offshore during ebb tides, with no return import of sediment during flood tides (Wolanski et al. in press). Thus, no onshore tidal advection of the nepheloid layer was permitted. A random walk technique was then applied to simulated horizontal diffusion (Hunter 1987). Each particle was then moved offshore with a velocity, u, calculated by Equation 3. In order to determine the concentration within the simulated plume, the mean thickness of the nepheloid layer was determined in each grid cell. Following Wolanski and Spagnol (2000), bottom turbulence associated with the prevailing current was assumed to maintain the nepheloid layer in suspension. Thus, as a result of bottom-induced turbulence (Fischer et al. 1979), the thickness of the nepheloid layer was assumed proportional to the prevailing current, $H = \beta u$. The proportionality constant, β was determined from field observations at sites M1 and M2, and was assumed to be the same everywhere in the model domain. Thus the sediment concentration in the nepheloid layer in each grid cell was determined by calculating the total mass in each cell, divided by the volume of the layer in that cell (i.e. the cell area multiplied by layer thickness). The mean SSC along a cross-shelf grid transect was used in the determination of the buoyancy and the baroclinic velocity, u. Following the observations, settling and resuspension of sediment particles in the nepheloid layer was not permitted.

The advection diffusion model was run for 100 hours. Horizontal diffusion coefficient was set to $5\ \mathrm{m^2\,s^{-1}}$ over the entire domain except on the mudflats (depth <3 m) in Trinity Inlet, where it was set to $10\ \mathrm{m^2\,s^{-1}}$ to due to increased tidal mixing. Each particle represented a mass of 500 kg, and 200 particles were released instantaneously in shallow, muddy Trinity Bay. A total of 236800 particles were released, representing a total mass of 118400 tons of sediment. This density of particles was designed to simulate SSC of $1000\ \mathrm{mg\,L^{-1}}$ in cells of depth 2.0 m in Trinity Bay, a value characteristic of field observations in inshore waters of Trinity Bay during windy conditions (P. Ridd, unp. data). It is assumed that the model started at the cessation of windy conditions.

3 RESULTS

Predicted synoptic distributions of the nepheloid layer are shown in Figure 4, at 43 hours and 95 hours after the model was seeded with sediment particles in suspension. It can be seen that during a northward longshore current, the nepheloid layer separated from the coastline just north of Buchan Point, with a region of enhanced offshore transport in the vicinity of Double Island. Bathymetric contours in this region (Figure 1) show a steepening of the bottom slope in this region. The nepheloid layer also extended far offshore from Trinity Inlet. The nepheloid layer was advected northwards for 50 hours before reversing with the southward current. At 95 hours after release, the nepheloid layer was almost entirely south of Double Island (Figure 4),

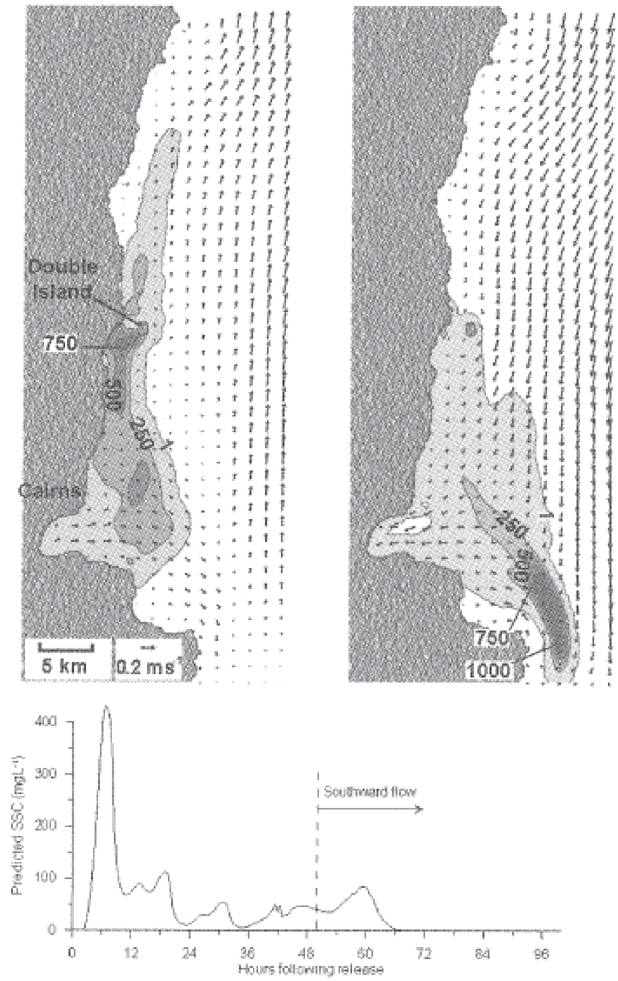

Figure 4. Synoptic views of the predicted nepheloid layer distribution and SSC (left) 43 hours and (right) 93 hours after the start of the model run. Flow reversal occurred 50 hours into the run. Synoptic distributions of barotropic currents are also shown. Bottom plot shows a time series of predicted SSC near site M2.

with the majority of the plume offshore from Trinity Inlet and sweeping south around Cape Grafton.

Predicted SSC near site M2 is shown in Figure 4. A large peak in SSC is evident within 10 hours of seeding, with subsequent smaller SSC peaks as time progressed. The predicted SSC decreases rapidly to zero, approximately 17 hours after the reversal of the alongshore current.

4 DISCUSSION

Recent field data revealed the existence of a transient nepheloid layer in the shallow coastal waters of the Great Barrier Reef. The nepheloid layer exhibited the following dynamics: the layer was observed to form during neap tides and calm weather; muddy water cascaded offshore down the costal wedge during ebb tides; there was no return onshore flow of the nepheloid layer during flood tides; at the base of the coastal wedge, the layer was advected with the prevailing longshore currents. There was a lag of 30 hours between the reversal of the longshore current and the disappearance of the nepheloid layer; the SSC in the nepheloid layer varied at tidal frequency.

A conceptual model of the dynamics of this nepheloid layer was developed. The internal dynamics of the nepheloid plume were explicitly parameterized in an advection-diffusion model. A barotropic circulation model computed the velocity field.

The model presented here was intended only to reproduce the major features observed in the field, however the results provide valuable insight into the behavior of the nepheloid plume. The model was able to reproduce and confirm much of the observed plume dynamics. The predicted distribution of the nepheloid layer and the predicted time series of SSC at site M2 (Figure 4) indicate that the plume was advected offshore. The distance of offshore transport is of the same order of magnitude as that reported in Wolanski & Spagnol (2000). Predicted baroclinic velocities (not shown) were similar to those observed by Wolanski et al. (in press). The model relies on the field observations that the nepheloid layer is advected offshore during ebb tides and does not return onshore during flood tides. This assumption is fundamental to the model. Indeed, results (not shown) from a model run which permitted onshore advection showed a negligible offshore spread of the nepheloid layer because tidally driven offshore transport during ebb tides was balanced by a similar onshore transport during flood tides. Thus the model suggests that for the nepheloid layer to realistically spread offshore, at flood tide the cross-shelf tidal motion "slides" over the top of the nepheloid layer, which is unable to climb, up-slope. This was indeed observed in the field. The predicted distribution of the nepheloid plume (Figure 4) showed that at the foot of the coastal wedge, the plume moved firstly northwards, then southward, as the longshore current reversed, in agreement with observations. A schematic representation of this is sketched in Figure 5. Under prevailing northward currents, the nepheloid layer was found to extend northward from its source area (Trinity Bay) as a negatively buoyant plume that separated from the coastline in an area of large bottom slope. Time-series plots of predicted SSC near site M2 (Figure 4) indicated that as the plume reversed with the longshore currents, clean water was advected passed site M2. Predicted peaks in SSC appeared at the frequency of the tidal forcing (12 h), further supporting the field observations that the plume is pumped offshore by ebbing tides with no return during flood tides.

Whilst no synoptic observations of the distribution of the nepheloid layer are available for comparison

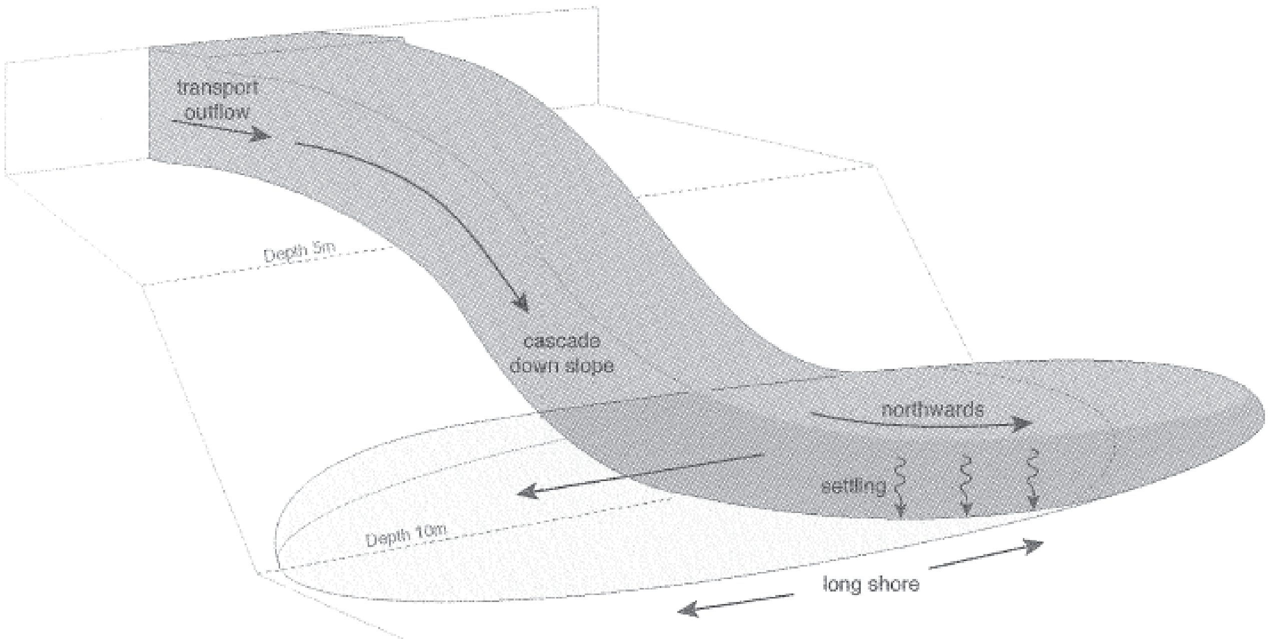

Figure 5. Schematic diagram showing the dynamics of the nepheloid layer.

with our predicted plume distribution, observations of coastal sediment composition (Jones 1985) show an area offshore between Trinity Inlet and Double Island where the sediment is predominantly muddy and contains <20% sand (see Figure 1). This region coincides with the area predicted to be consistently covered by the nepheloid layer.

5 CONCLUSIONS

At present, field studies of the dynamics of the nepheloid layer in the shallow coastal waters of the Great Barrier Reef are limited to the dry season. No field data are available on the export of sediments from the Trinity Inlet region during river floods associated with the tropical wet season.

The conceptual model presented here furthers our understanding of the dynamics of the nepheloid layer during the dry season. However, further studies, both modelling and in the field, are essential to understand the cross-shelf sediment transport mechanisms during the tropical wet season.

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Appendix 2 Reference Paper – Carter et al 2002

"*Applied Sedimentology of Trinity Bay" 2002,* Carter, R.M., Larcombe, P., Liu, K., Dickens, J., Heron, M.L., Prytz, A., Purdon, R. and Ridd, P.

Chapter 7 - Sediment Transport

SUMMARY

Water motions, and therefore sediment transport, within the Cairns coastal region are strongly influenced by:

Southeasterly trade winds in winter
Variable north and northeasterly winds during summer
A daily easterly coastal sea-breeze
Diurnal tidal currents (southeast flood; northwest ebb)
Intermittent tropical cyclones

In combination, these processes are responsible for the generally high background turbidity which is present in Cairns' coastal waters (20-200 mg/l), which is caused by the resuspension of mud from the seabed. They also individually, or in combination, drive the following flows, which are often strong enough (>20 cm/s) to move sand at the seabed:

Northward long-shelf flow (stronger offshore)
Coastal setup, and return bottom flow
Tidal jetting (Trinity Inlet)
River mouth jetting (Barron River in flood)
Northerly longshore drift (Northern Beaches; Cape Grafton)
Southerly longshore drift (Ellie Point-Esplanade)

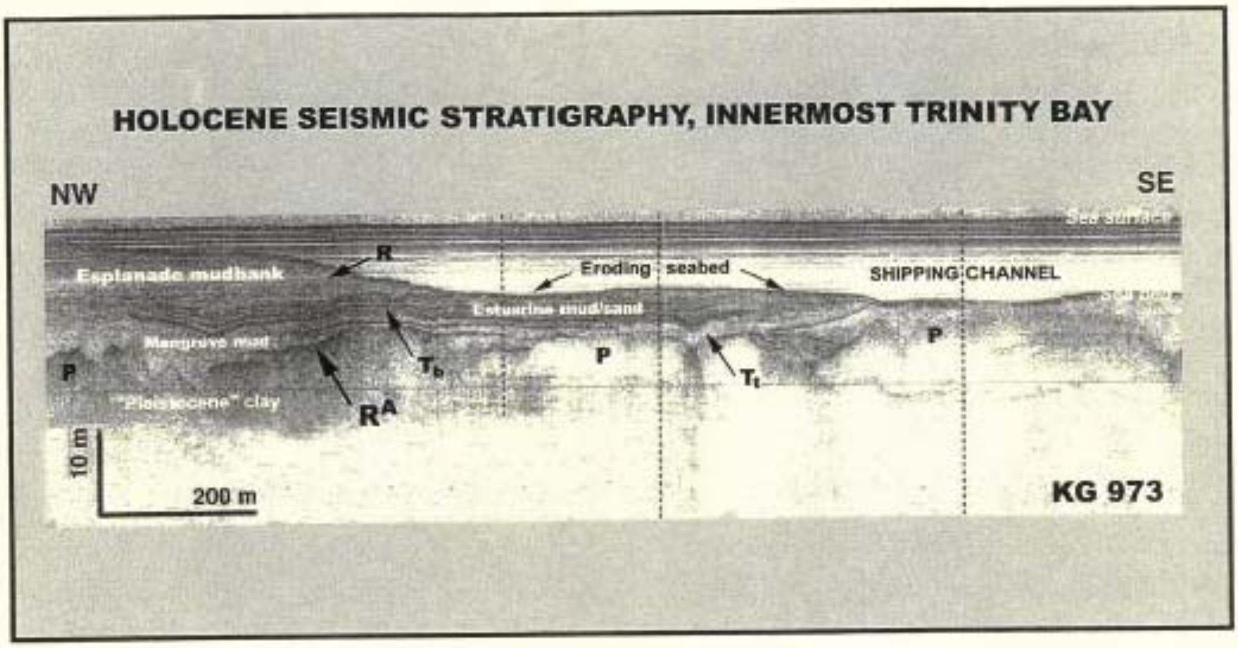
Accordingly, sediments within Trinity Bay are strongly partitioned. Coarser grainsizes concentrate at the Barron River mouth, along beaches, and within tidal inlet channels. In contrast, mud is bypassed either into mangrove swamps by high-tide flooding, or offshore where it settles in the bay centre.

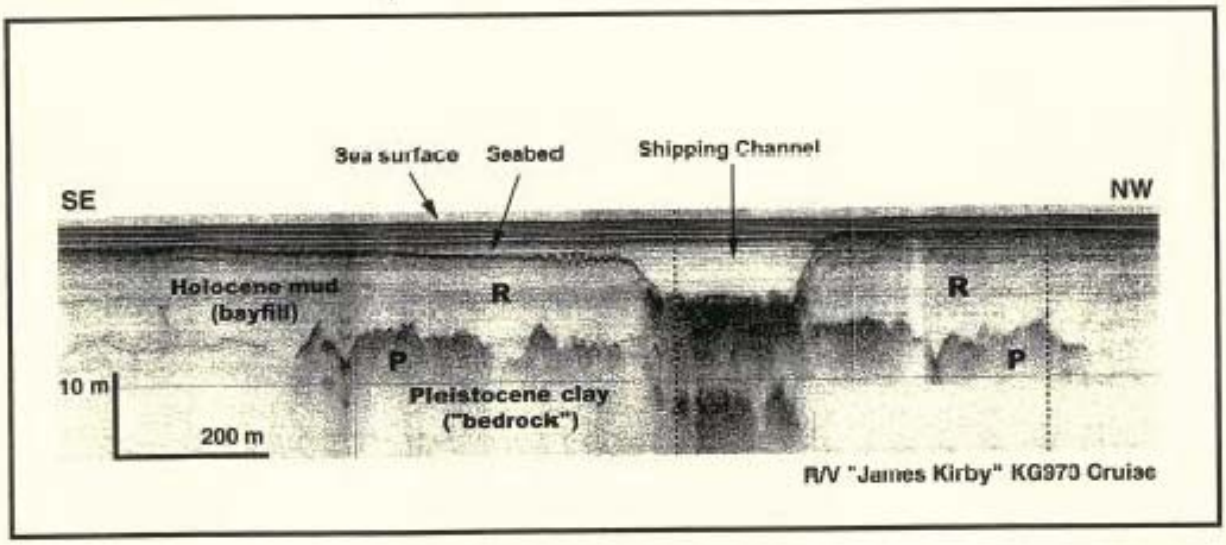
Computer modelling studies on geological time scales of several thousand years replicate this general pattern, and suggests that the major sediment depocentre should lie in the southeastern part of Trinity Bay. This prediction is confirmed by seismic data.

In summary, mineralogic, textural, process and modelling studies suggest that the following natural sediment transport paths operate in the Trinity Inlet-Trinity Bay area:

Sand and gravel transport	
Cyclone unmixing	Shellbeds and cheniers, Trinity Bay shorelines
Sand transport	
Longshore drift	North along the Northern Beaches
(from Barron mouth)	South and west around Ellie Point
(from King Beach)	West around Cape Grafton
Seaward-directed jets	Northeast into bay, mouth of Trinity Inlet
	North into bay, Barron River mouth
Mud transport	
Tidal channel flow	Overbank into mangrove swamps
River flood plumes	Offshore into Trinity Bay
Turbid underflows	Offshore into Trinity Bay
Cyclone-induced advection	Clinoform accretion, sourced from the mid-shelf

Extract of Chapter 5 – Stratigraphy





Figs. 5.2, 5.3 3.5 kHz profiles across Cairns Port shipping channel near marker beacon C17. Note the major reflectors at the seabed and at the base of the Holocene bay fill (reflector A), between which occur seismic units P, T, and R.

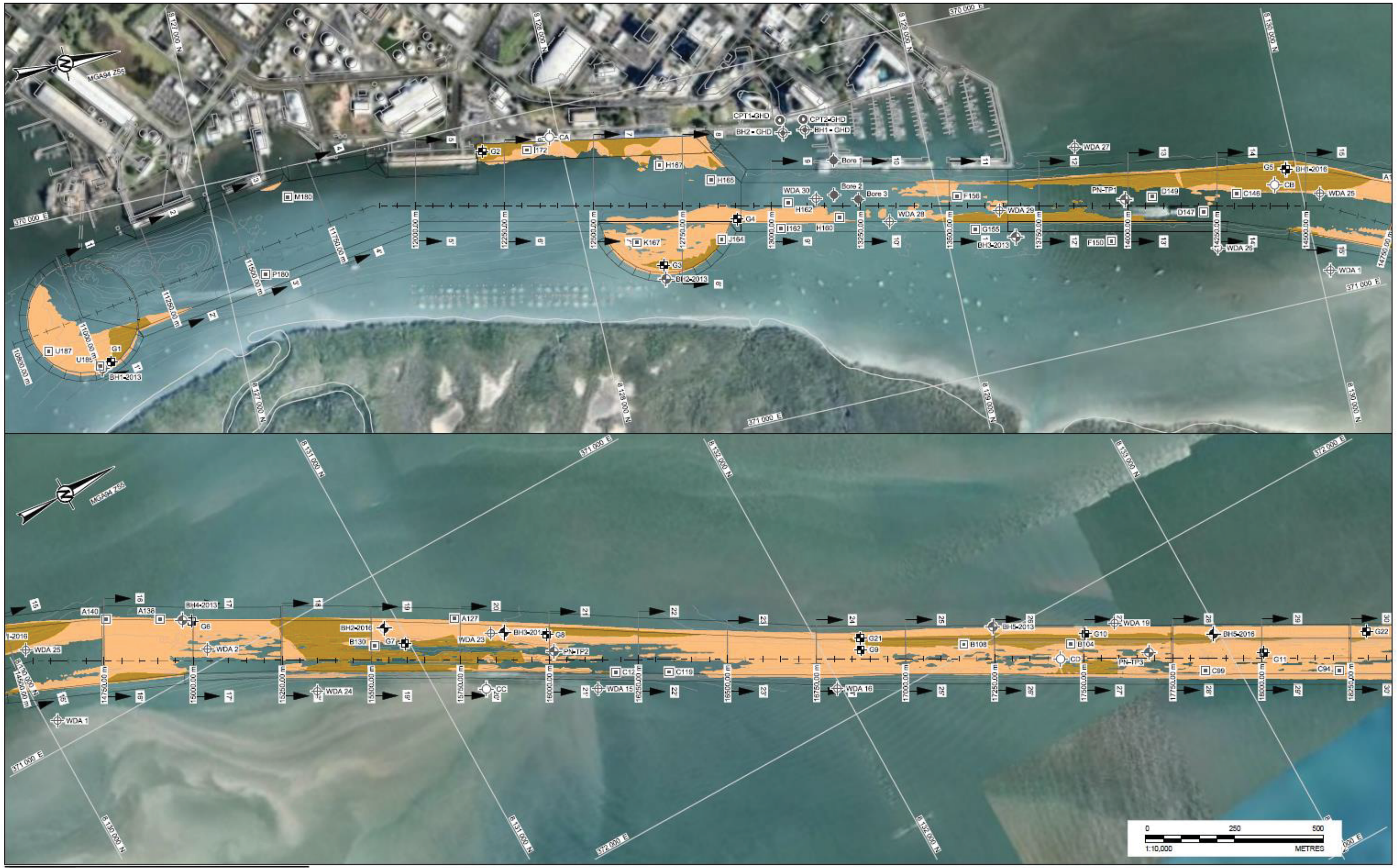
Appendix 3 Dredge Material Type Images

Stiff Clay Sample Image

Soft Clay Sample Image

Appendix 4 Soft Clay and Stiff Clay Location Maps

Ports North



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- GRAB SAMPLE GOLDER ASSOCIATES (CURRENT INVESTIGATION)
- BORE HOLE GOLDER ASSOCIATES (PREVIOUS INVESTIGATION)
- BORE HOLE GHD (PREVIOUS INVESTIGATION)
- BORE HOLE DOUGLAS PARTNERS (PREVIOUS INVESTIGATION)
- BORE HOLE WDA (PREVIOUS INVESTIGATION)
- BORE HOLE CH (PREVIOUS INVESTIGATION)
- BORE HOLE BMT-WBM (PREVIOUS INVESTIGATION)
- CPT GHD (PREVIOUS INVESTIGATION)
- SOFT CLAY (CAPITAL DREDGING)
- STIFF CLAY (CAPITAL DREDGING)

CLIENT
FLANAGAN CONSULTING GROUP

CONSULTANT
Golder Associates

YYYY-MM-DD	2016-08-25
DESIGNED	PB
PREPARED	GPG
REVIEWED	MC
APPROVED	MC

PROJECT
CAIRNS SHIPPING DEVELOPMENT PROJECT

TITLE
INVESTIGATION LOCATION PLAN - SHEET 1

PROJECT NO.	DOCUMENT No	REV.	FIGURE
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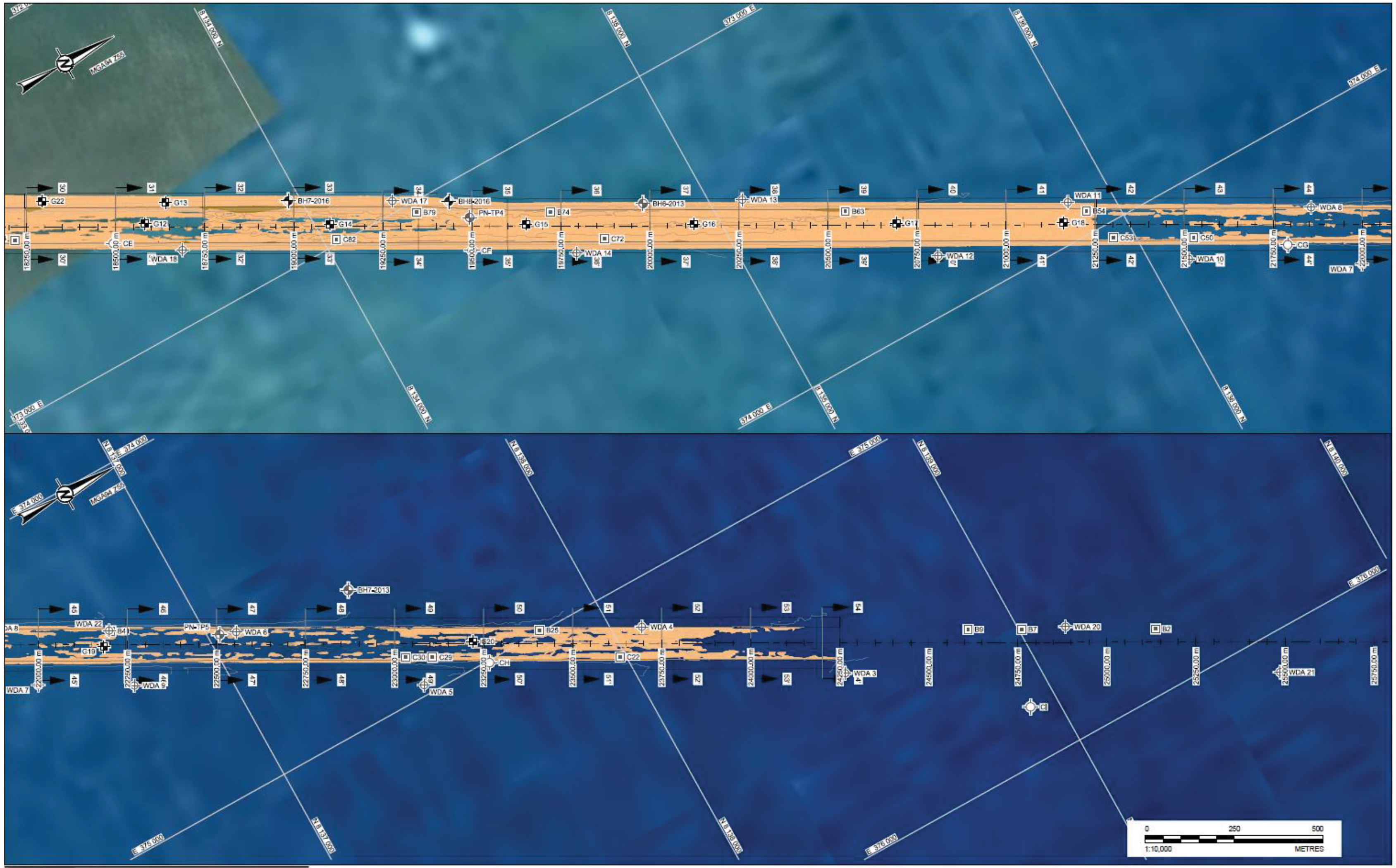
Ports North



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GRAB SAMPLE GOLDER ASSOCIATES (CURRENT INVESTIGATION)	BORE HOLE BMT-WBM (PREVIOUS INVESTIGATION)
BORE HOLE GOLDER ASSOCIATES (PREVIOUS INVESTIGATION)	CPT GHD (PREVIOUS INVESTIGATION)
BORE HOLE GHD (PREVIOUS INVESTIGATION)	SOFT CLAY (CAPITAL DREDGING)
BORE HOLE DOUGLAS PARTNERS (PREVIOUS INVESTIGATION)	STIFF CLAY (CAPITAL DREDGING)
BORE HOLE WDA (PREVIOUS INVESTIGATION)	

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PROJECT
CAIRNS SHIPPING DEVELOPMENT PROJECT

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Golder Associates

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TITLE
INVESTIGATION LOCATION PLAN - SHEET 2

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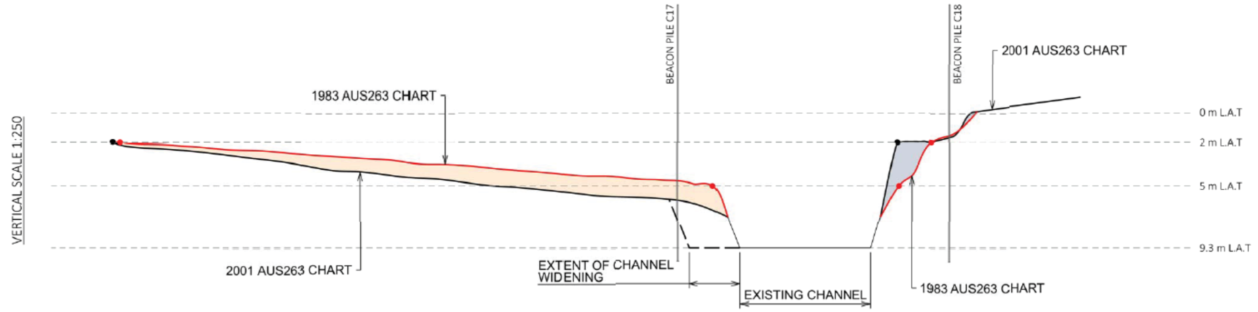
Appendix 5 Seabed Erosion Profiles



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SECTION A-A - CHAINAGE 15 750

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HORIZONTAL SCALE 1:2500

SECTION B-B - CHAINAGE 14 670

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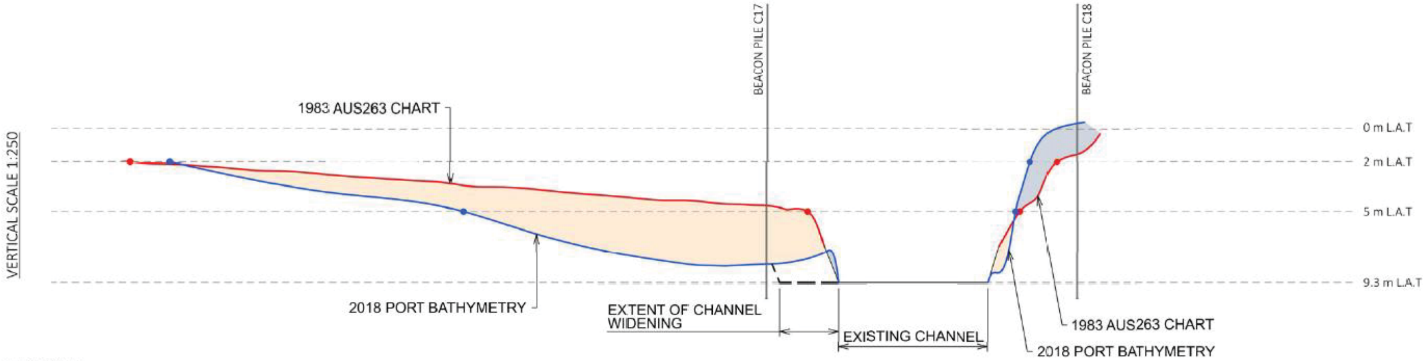

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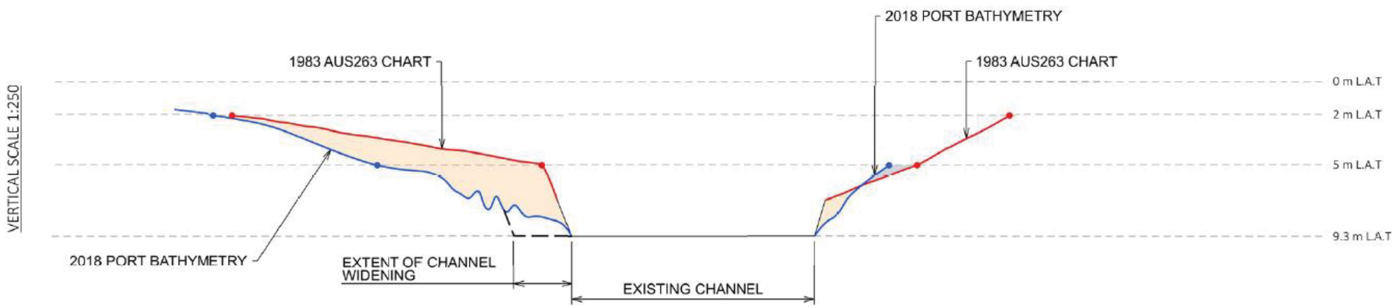

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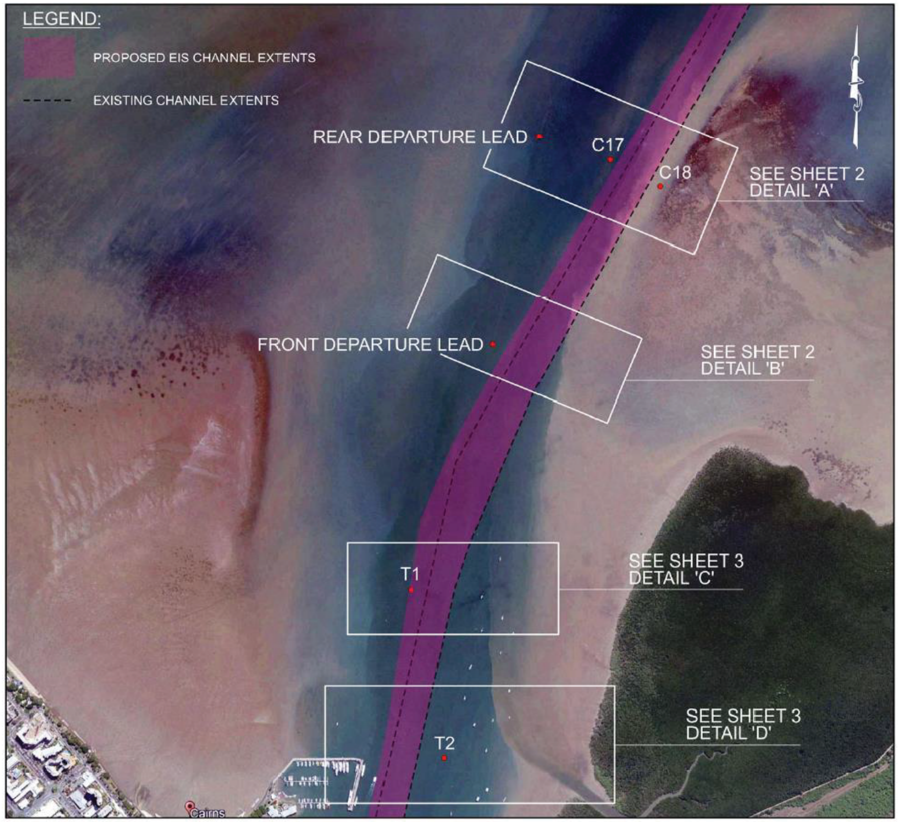
Appendix 6 Seabed Resuspension Images



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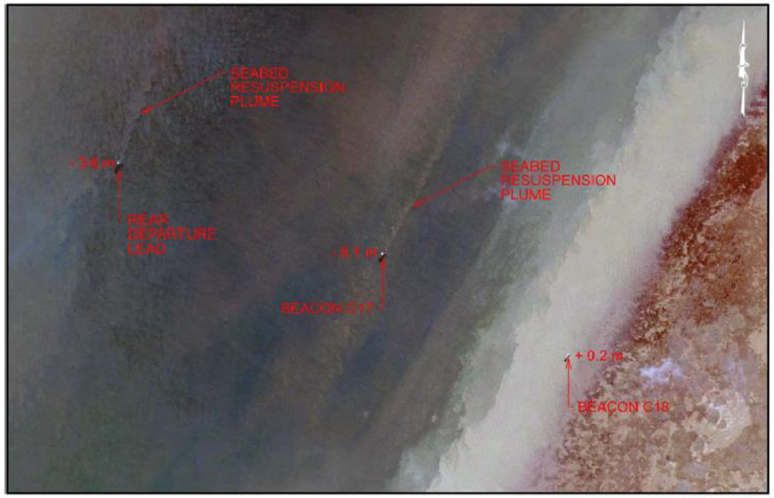

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Appendix 7 Extract of “Baseline Report – Dredged Materials.” Golder, 2016

Exerpt of “Sections 2 and 3 on pages 1 and 2 of Appendix E to the Supplementary Report – “Baseline Report – Dredged Materials.” Golder, 2016

1.0 INTRODUCTION

Flanagan Consulting Group (FCG) commissioned Golder Associates Pty Ltd (Golder) to provide geotechnical advice as part of the Revised Draft Environmental Impact Statement for the Cairns Shipping Development (CSD) Project. Geotechnical input related to the assessment of the values and constraints associated with the dredge material includes the following:

- Further assessment of subsurface conditions likely to be encountered in the proposed dredging;
- Further assessment of the geotechnical properties of the dredged materials;
- Further assessment of the ASS properties of the dredged materials.
- Preparation of a 3D model of ground conditions relevant to the proposed

dredging. This report presents the results of the studies.

2.0 PREVIOUS INVESTIGATIONS

2.1 Golder Investigations

Of the documents prepared by Golder for the Draft EIS, the information considered to be most relevant to assessment of the dredged materials is presented in the following reports:

- Golder report reference 117672052-001-Rev0, dated November 2011. This report presented information on subsurface conditions based on a review of available documents from Ports North and information from previous Golder projects in the general area of the port.
- Golder report reference 107672522-008-Rev1, dated June 2012. This report presented information on subsurface conditions based on the results of test pitting at five locations along the channel and subsequent laboratory testing.
- Golder report reference 137632122-001-Rev0, dated September 2013. This report presented further information on subsurface conditions based on the results of drilling at seven locations along the channel and subsequent laboratory testing.

Copies of relevant information from these reports is presented in Appendix A1.

2.2 Other Available Information

Available documents from Ports North containing information relevant to assessment of the dredged materials includes the following:

- Dept of Harbours and Marine Qld - Seven boreholes (BH CA to BH CG) drilled along the channel in 1964.
- Westminster Dredging Australia – Thirty boreholes (WDA1 to WDA30) drilled along the channel in 1965.
- Douglas Partners – Three boreholes drilled for the Marlin Marina in 1993.
- GHD - Two boreholes drilled for the Marlin Marina in 2001.
- BMT WBM – Fifty-five sampling locations for EIS in 2014.

Copies of relevant information from these documents is presented in Appendix A2.

3.0 CURRENT INVESTIGATIONS

3.1 Rationale for Proposed Fieldwork and Laboratory Testing

The rationale for the proposed fieldwork and laboratory testing for the current investigations is summarised below:

- Geotechnical boreholes – Boreholes were proposed at 8 locations within the proposed channel widening, with the aim of recovering “undisturbed” samples for assessment of undrained shear strength (by hand vane/penetrometer) plus geotechnical laboratory testing (i.e. Moisture Content, Bulk Density, Atterberg Limits and Particle Size Distribution). The boreholes were also aimed at recovering soil core for ASS testing (i.e. field screening and Chromium Suite testing). With regard to ASS sampling and testing, it is noted that the main channel widening covers areas of about 4 hectares and 8 sampling locations across these areas provides compliance with QASSIT guidelines.

- Grab sampling (with Ports North dredging equipment) – Grab sampling was proposed at 20 locations to ~0.8m depth in areas proposed for channel deepening (i.e. 16 locations in "sediments"), channel widening/deepening (i.e. 2 locations in "stiff clays"), and channel widening (i.e. 2 locations in "mud"). The aim of this work was recover "undisturbed" samples for further assessment of undrained shear strength plus for geotechnical laboratory testing (as outlined above), plus to recover additional samples for ASS testing (as outlined above), The grab sampling was also aimed at recovering bulk samples of soils and seawater required for specialised laboratory testing by BMT JFA.

- Geophysics – ~52km of longitudinal lines and traverse lines were proposed with the aim of assessing the depth to the soft clay/stiff clay interface within the areas proposed for dredging, particularly in areas where stiff clays are expected to be encountered within the depth of proposed dredging. The results of the survey were to be calibrated with the ground conditions encountered in previous and proposed boreholes.

The fieldwork and laboratory testing are discussed further in the following sections.

3.2 Geophysics

The geophysical survey was completed between 16 and 17 August 2016 and covered an area approximately 200 m wide and 12 km in length. Four longitudinal lines and 27 transverse lines were carried out totalling about 59 km. The survey methodology and results are presented in Section 4.0

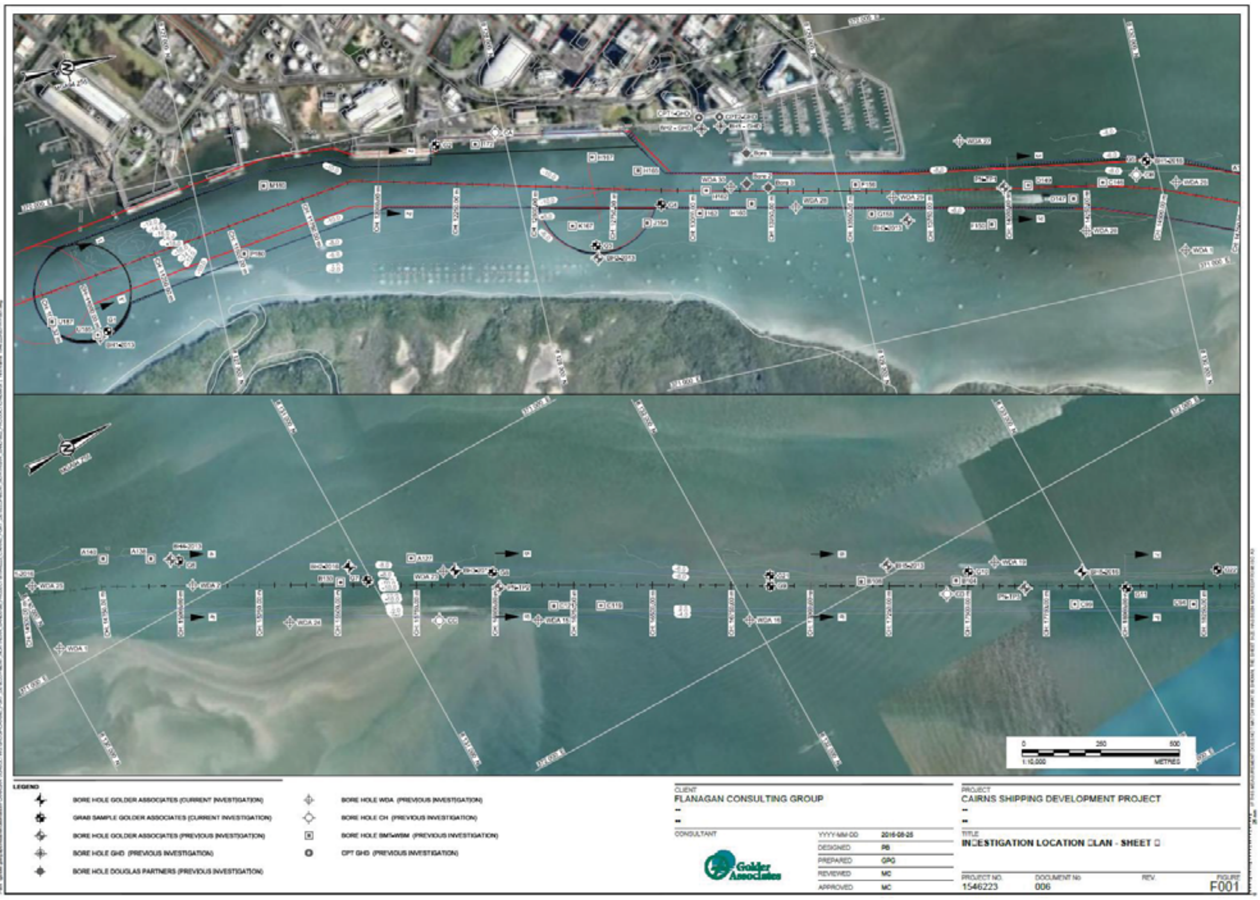
3.3 Boreholes and Grab Sampling

The boreholes (namely BH1 to 3, BH5 and BH7 to 8) were drilled to depths ranging from 2.5 m to 9.5 m. proposed boreholes BH4 and BH6 could not be drilled due to the adverse weather and sea conditions at the time of the drilling programme. The geotechnical samples were recovered using wash boring methods with undisturbed (U75) tubes. The ASS samples were generally recovered using piston tube sampling, however where the depth of water did not allow this type of sampling the samples were recovered using wash boring methods with undisturbed (U75) tubes.

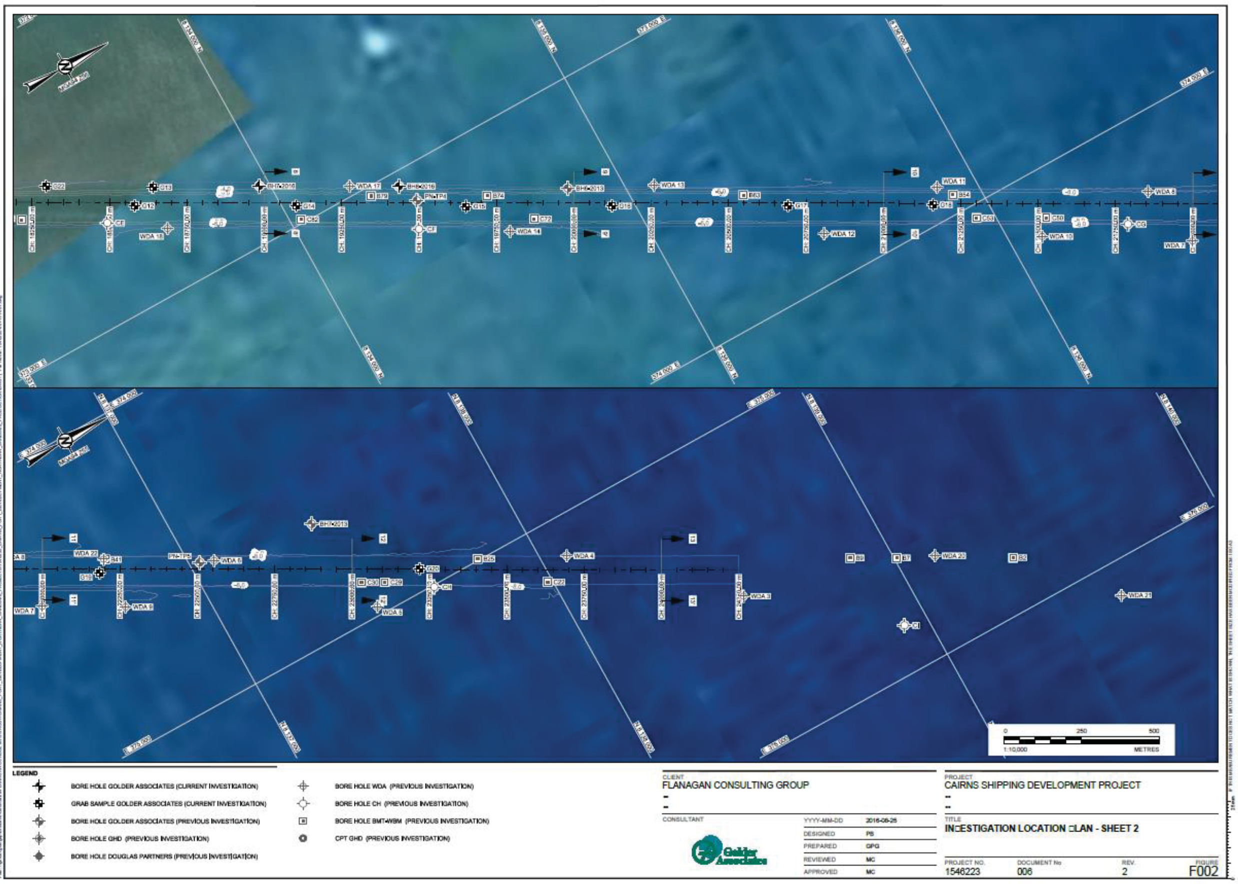
Grab sampling was carried out at twenty locations (namely GS1 to GS20). Additional sampling (namely GS21 and GS22) was carried out at the proposed locations of boreholes BH4 and BH6.

The locations of the boreholes and the grab sampling are shown on Figures F001 and F002, and the reports are presented in Appendix B1 and B2 respectively. Photographs of materials collected during the grab sampling are also presented in Appendix B2.

Appendix 8 Geotechnical Investigation Locations

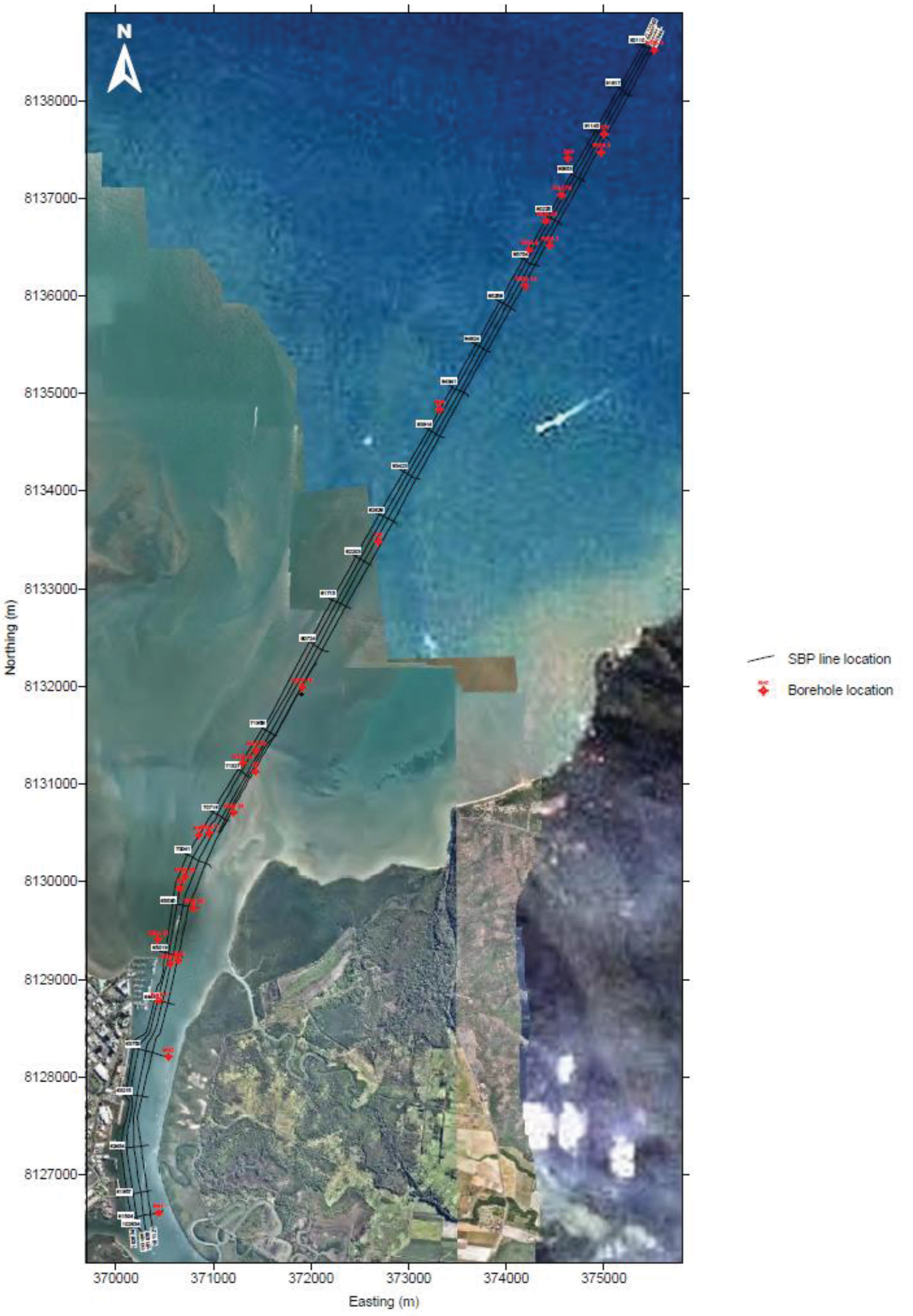


LEGEND
BORE HOLE GOLDER ASSOCIATES (CURRENT INVESTIGATION)
GRAB SAMPLE GOLDER ASSOCIATES (CURRENT INVESTIGATION)
BORE HOLE GOLDER ASSOCIATES (PREVIOUS INVESTIGATION)
BORE HOLE GHD (PREVIOUS INVESTIGATION)
BORE HOLE DOUGLAS PARTNERS (PREVIOUS INVESTIGATION)
BORE HOLE WDA (PREVIOUS INVESTIGATION)
BORE HOLE CH (PREVIOUS INVESTIGATION)
BORE HOLE BMT-WBM (PREVIOUS INVESTIGATION)
CPT GHD (PREVIOUS INVESTIGATION)
0 250 500
1:10,000 METRES
CLIENT
FLANAGAN CONSULTING GROUP
CONSULTANT
Golder Associates
YYYY-MM-DD 2016-08-25
DESIGNED PB
PREPARED GPG
REVIEWED MC
APPROVED MC
PROJECT
CAIRNS SHIPPING DEVELOPMENT PROJECT
TITLE
INVESTIGATION LOCATION PLAN - SHEET 1
PROJECT NO. 1546223
DOCUMENT No 006
REV.
FIGURE F001



LEGEND
BORE HOLE GOLDER ASSOCIATES (CURRENT INVESTIGATION)
GRAB SAMPLE GOLDER ASSOCIATES (CURRENT INVESTIGATION)
BORE HOLE GOLDER ASSOCIATES (PREVIOUS INVESTIGATION)
BORE HOLE GHD (PREVIOUS INVESTIGATION)
BORE HOLE DOUGLAS PARTNERS (PREVIOUS INVESTIGATION)
BORE HOLE WDA (PREVIOUS INVESTIGATION)
BORE HOLE CH (PREVIOUS INVESTIGATION)
BORE HOLE BMT-WBM (PREVIOUS INVESTIGATION)
CPT GHD (PREVIOUS INVESTIGATION)
0 250 500
1:10,000 METRES
CLIENT
FLANAGAN CONSULTING GROUP
CONSULTANT
Golder Associates
YYYY-MM-DD 2016-08-25
DESIGNED PB
PREPARED GPG
REVIEWED MC
APPROVED MC
PROJECT
CAIRNS SHIPPING DEVELOPMENT PROJECT
TITLE
INVESTIGATION LOCATION PLAN - SHEET 2
PROJECT NO. 1546223
DOCUMENT No 006
REV. 2
FIGURE F002

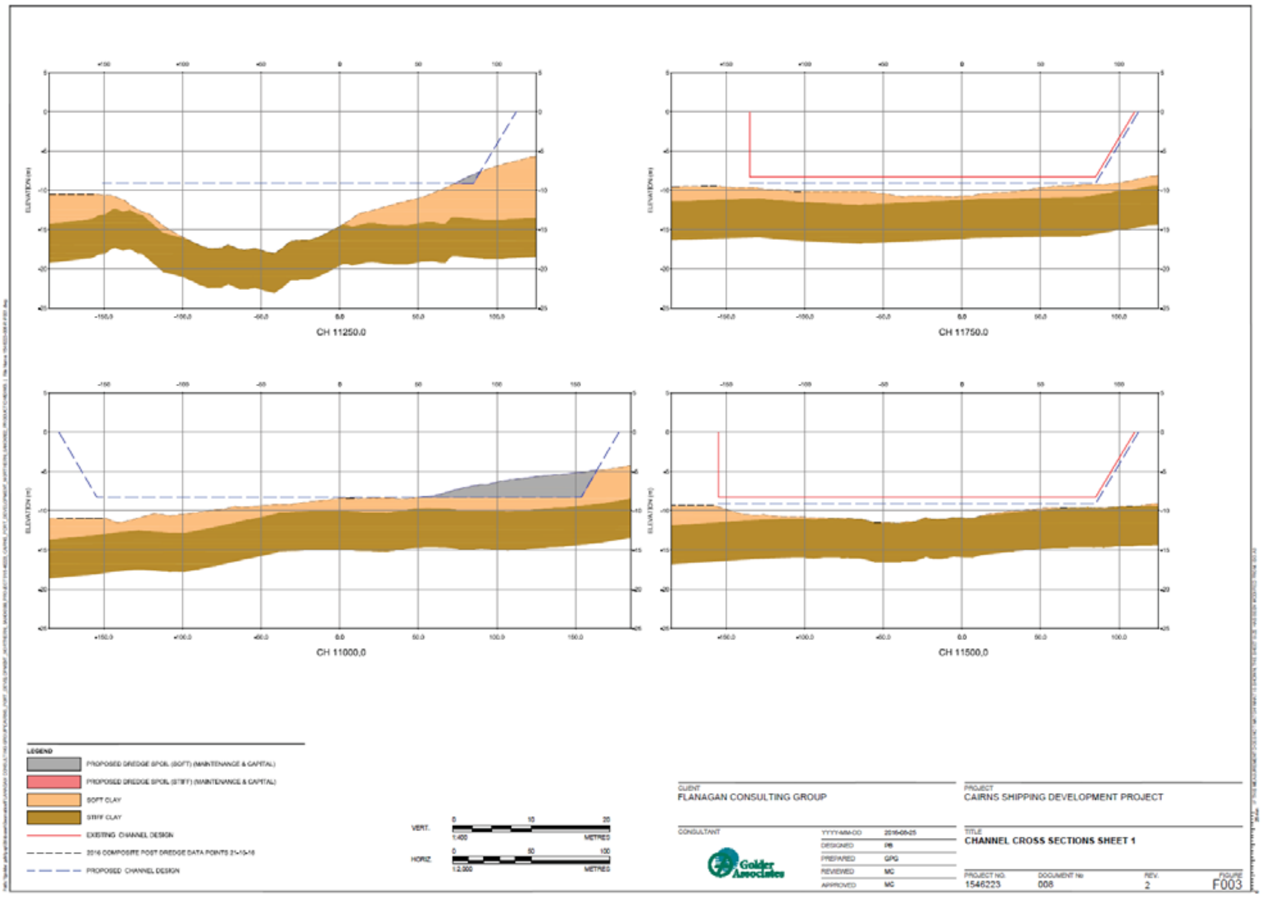
Ports North



CLIENT	PROJECT
FLANAGAN CONSULTING GROUP	CAIRNS SHIPPING DEVELOPMENT PROJECT

CONSULTANT			TITLE			
Golder Associates	YYYY-MM-DD	2016-09-14	GEOPHYSICS SURVEY LOCATION PLAN			
	DESIGNED	RR				
	PREPARED	RR				
	REVIEWED	TR	PROJECT NO.	DOCUMENT No.	REV.	FIGURE
	APPROVED	TR	1546223	006	2	F003

Appendix 9 Channel Cross Sections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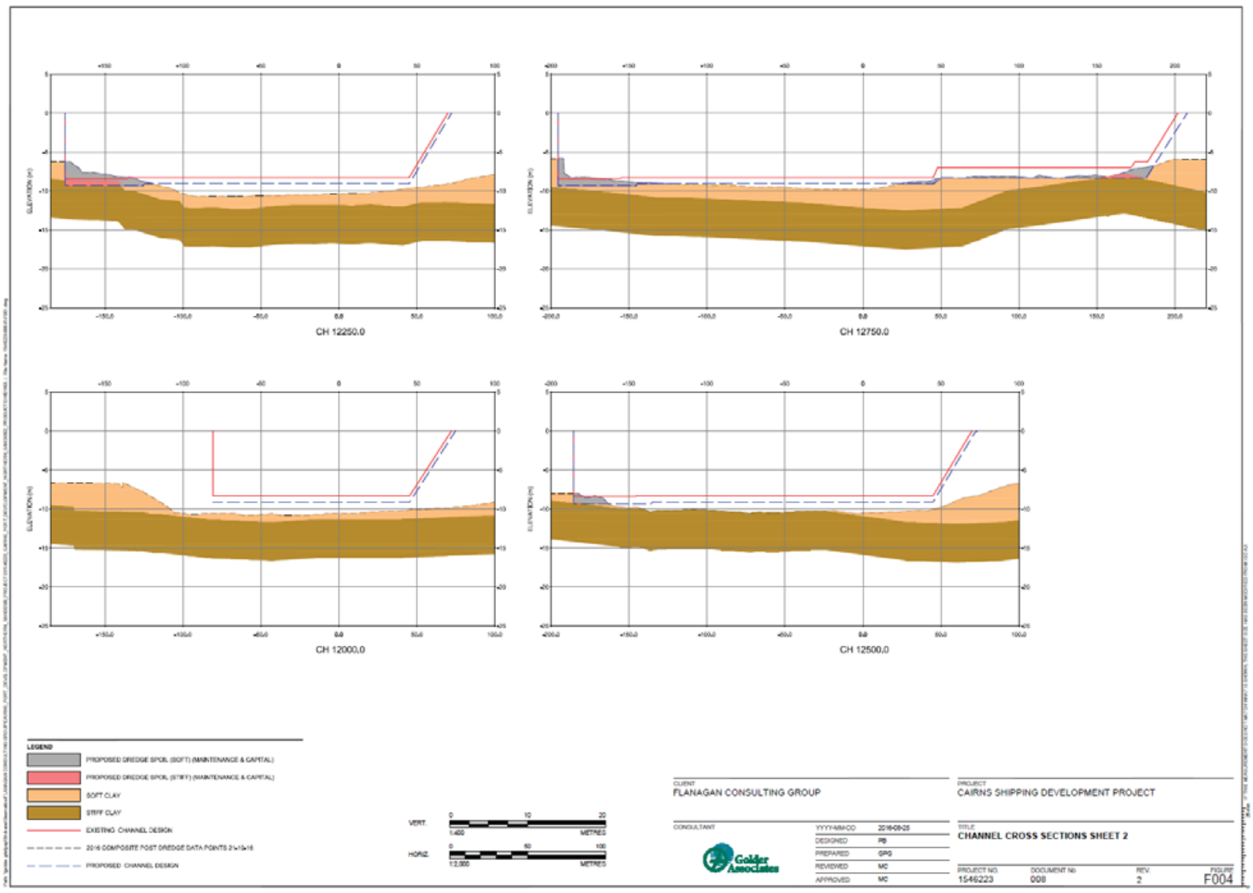
CH 11750,0
CH 11000,0
CH 11500,0
ELEVATION (m)
LEGEND
PROPOSED DREDGE SPOIL (SOFT) (MAINTENANCE & CAPITAL)
PROPOSED DREDGE SPOIL (STIFF) (MAINTENANCE & CAPITAL)
SOFT CLAY
STIFF CLAY
EXISTING CHANNEL DESIGN
2016 COMPOSITE POST DREDGE DATA POINTS 21-10-16
PROPOSED CHANNEL DESIGN
VERT. 1:400 METRES
HORIZ. 1:2,000 METRES
CLIENT
FLANAGAN CONSULTING GROUP
PROJECT
CAIRNS SHIPPING DEVELOPMENT PROJECT
CONSULTANT
Golder Associates
YYYY-MM-DD 2016-08-25
DESIGNED PB
PREPARED GPG
REVIEWED MC
APPROVED MC
TITLE
CHANNEL CROSS SECTIONS SHEET 1
PROJECT NO. 1546223
DOCUMENT No 008
REV. 2
FIGURE F003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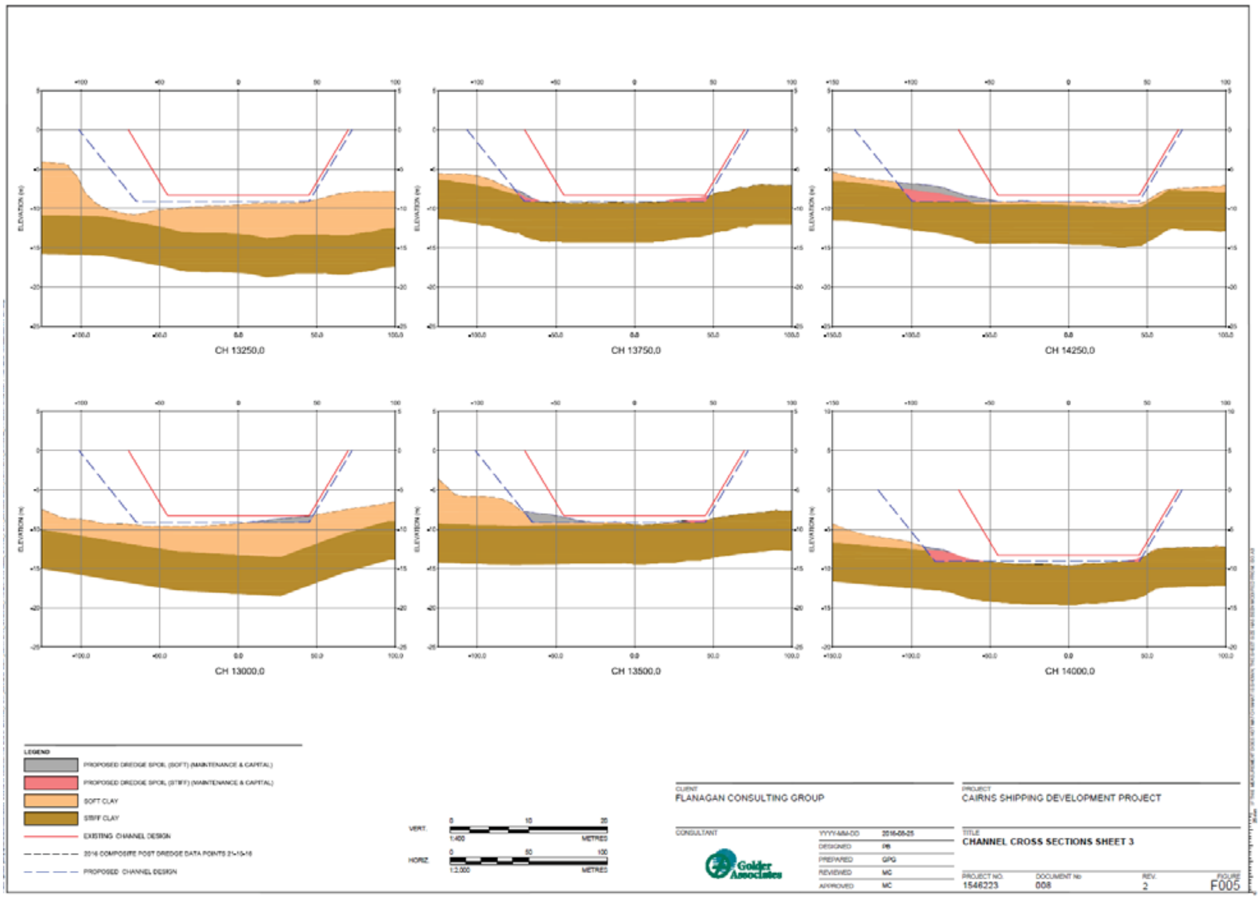
CH 12750,0
CH 12000,0
CH 12500,0
ELEVATION (m)
LEGEND
PROPOSED DREDGE SPOIL (SOFT) (MAINTENANCE & CAPITAL)
PROPOSED DREDGE SPOIL (STIFF) (MAINTENANCE & CAPITAL)
SOFT CLAY
STIFF CLAY
EXISTING CHANNEL DESIGN
2016 COMPOSITE POST DREDGE DATA POINTS 21-10-16
PROPOSED CHANNEL DESIGN
VERT. 1:400 METRES
HORIZ. 1:2,000 METRES
CLIENT
FLANAGAN CONSULTING GROUP
PROJECT
CAIRNS SHIPPING DEVELOPMENT PROJECT
CONSULTANT
Golder Associates
YYYY-MM-DD 2016-08-25
DESIGNED PB
PREPARED GPG
REVIEWED MC
APPROVED MC
TITLE
CHANNEL CROSS SECTIONS SHEET 2
PROJECT NO. 1546223
DOCUMENT No 008
REV. 2
FIGURE F004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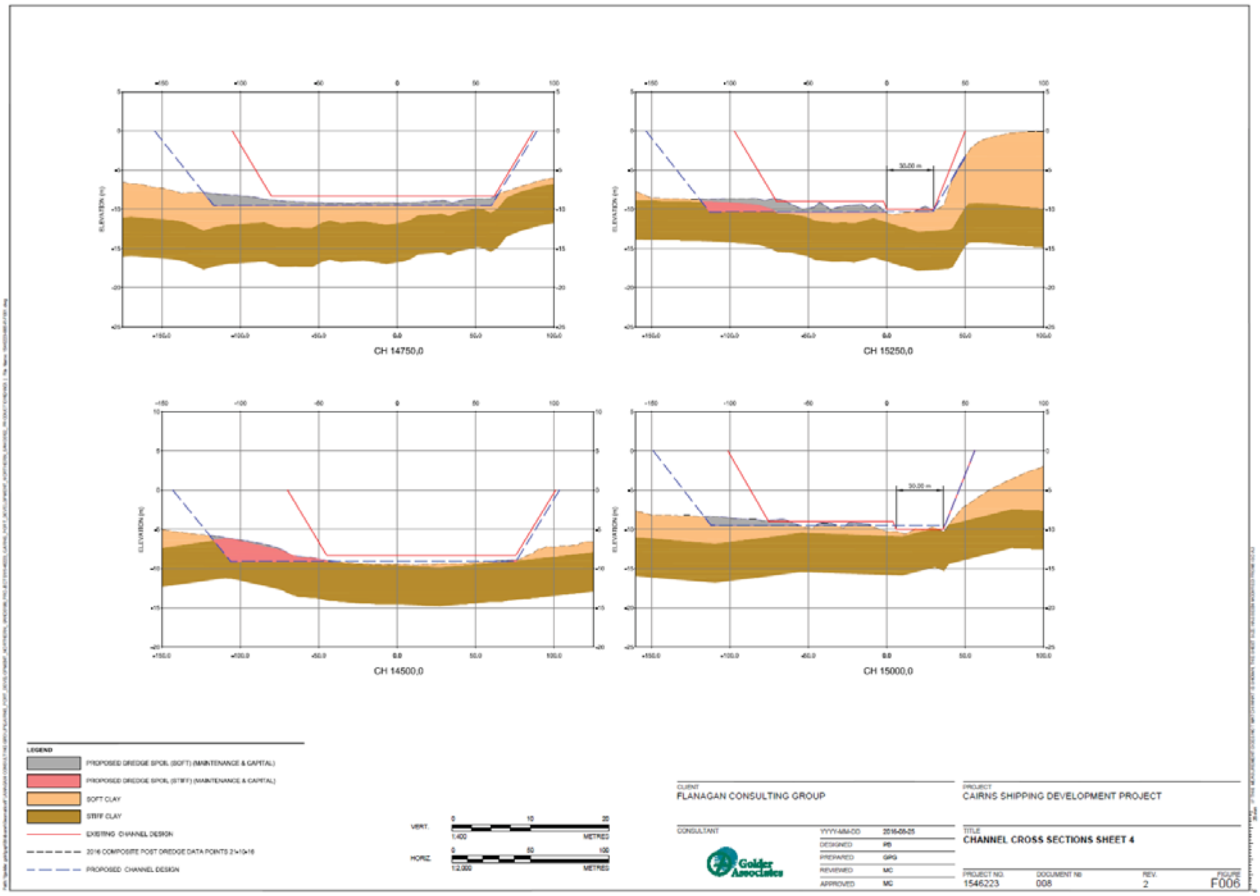
CH 13750,0
CH 14250,0
CH 13000,0
CH 13500,0
CH 14000,0
LEGEND
PROPOSED DREDGE SPOIL (SOFT) (MAINTENANCE & CAPITAL)
PROPOSED DREDGE SPOIL (STIFF) (MAINTENANCE & CAPITAL)
SOFT CLAY
STIFF CLAY
EXISTING CHANNEL DESIGN
2016 COMPOSITE POST DREDGE DATA POINTS 21-10-16
PROPOSED CHANNEL DESIGN
VERT.
1:400
METRES
HORIZ.
1:2,000
METRES
CLIENT
FLANAGAN CONSULTING GROUP
CONSULTANT
Golder Associates
YYYY-MM-DD 2016-05-25
DESIGNED PB
PREPARED GPG
REVIEWED MC
APPROVED MC
PROJECT
CAIRNS SHIPPING DEVELOPMENT PROJECT
TITLE
CHANNEL CROSS SECTIONS SHEET 3
PROJECT NO. 1546223
DOCUMENT No. 008
REV. 2
FIGURE F005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CH 15250,0
CH 14500,0
CH 15000,0
30.00 m
LEGEND
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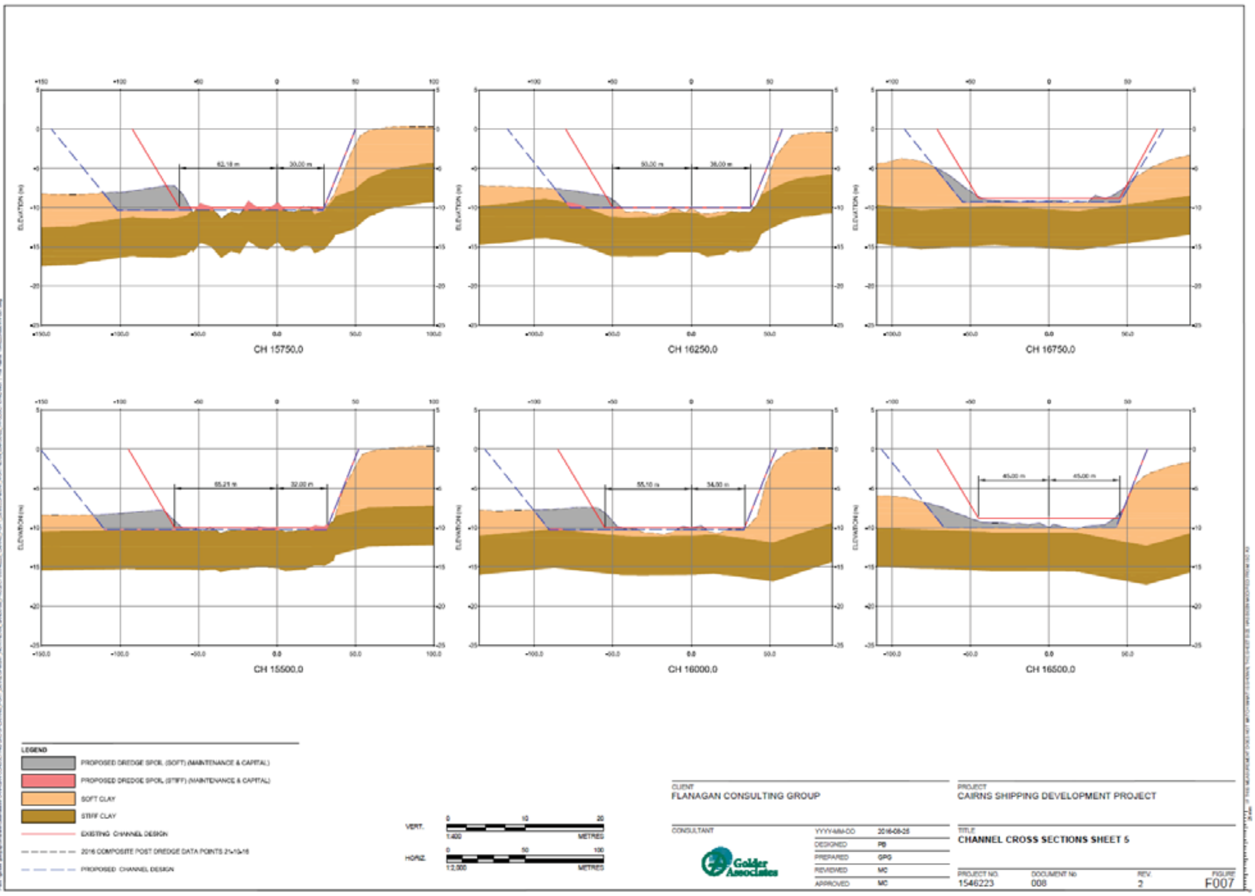
PROPOSED DREDGE SPOIL (STIFF) (MAINTENANCE & CAPITAL)
SOFT CLAY
STIFF CLAY
EXISTING CHANNEL DESIGN
2016 COMPOSITE POST DREDGE DATA POINTS 21-10-16
PROPOSED CHANNEL DESIGN
VERT.
1:400
METRES
HORIZ.
1:2,000
METRES
CLIENT
FLANAGAN CONSULTING GROUP
CONSULTANT
Golder Associates
YYYY-MM-DD 2016-05-25
DESIGNED PB
PREPARED GPG
REVIEWED MC
APPROVED MC
PROJECT
CAIRNS SHIPPING DEVELOPMENT PROJECT
TITLE
CHANNEL CROSS SECTIONS SHEET 4
PROJECT NO. 1546223
DOCUMENT No. 008
REV. 2
FIGURE F006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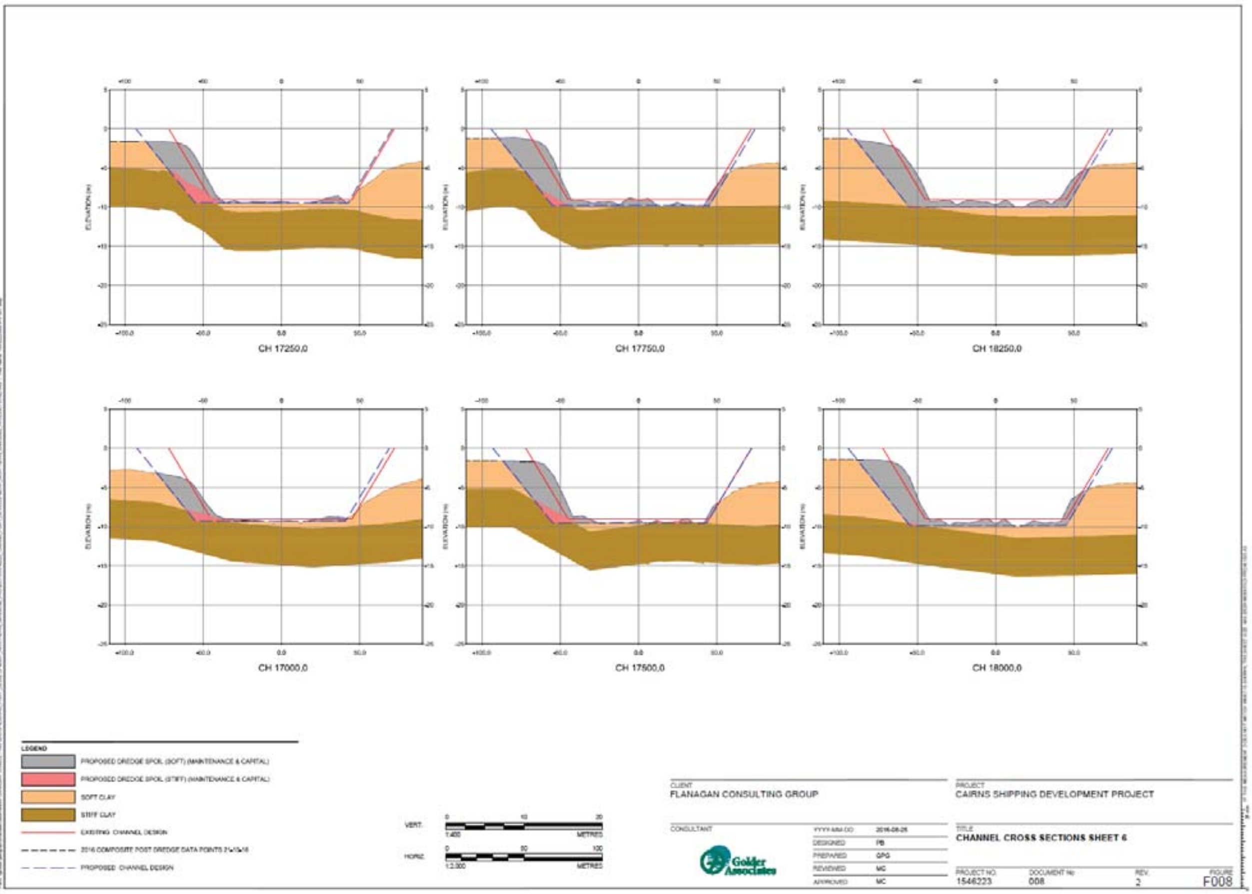
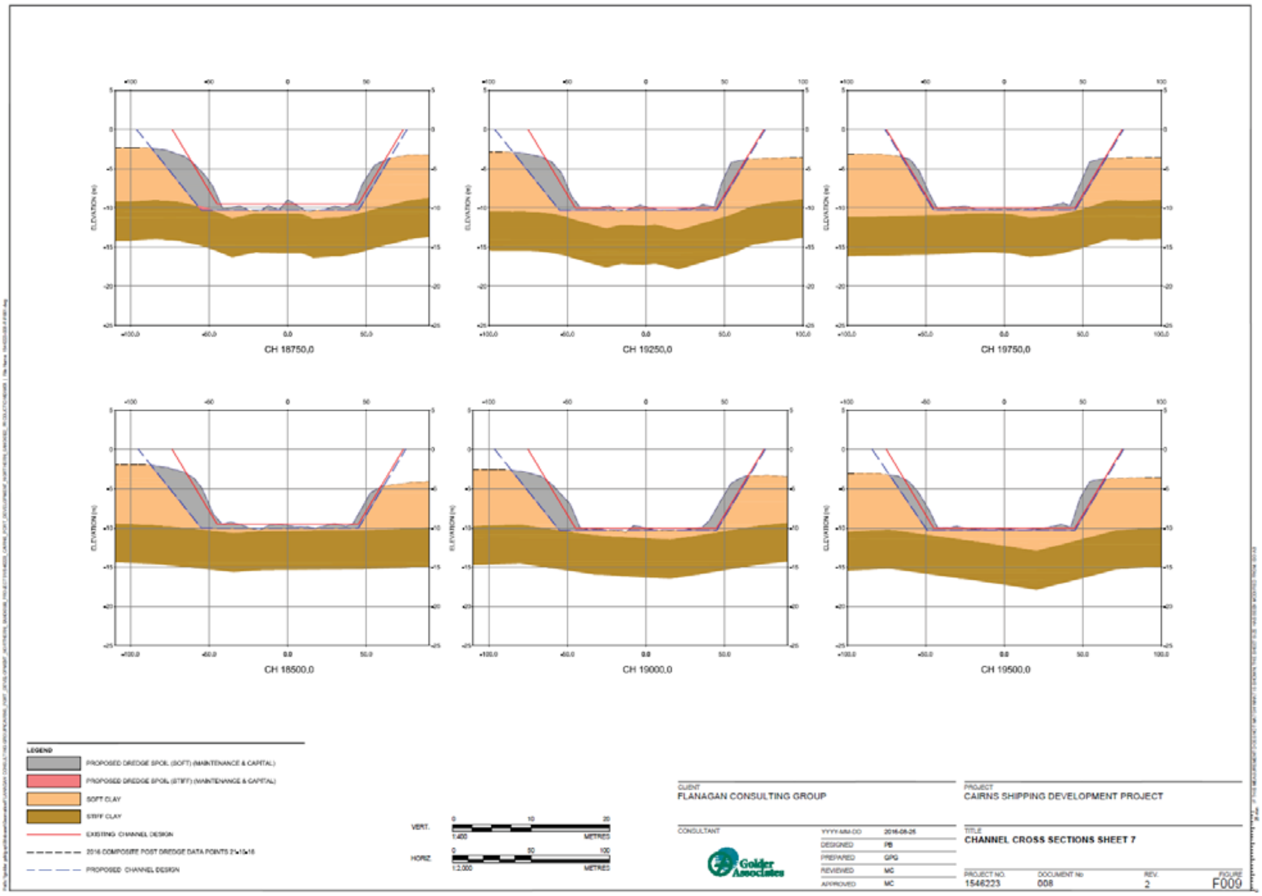
CH 16250.0
CH 16750.0
CH 15500.0
CH 16000.0
CH 16500.0
LEGEND
PROPOSED DREDGE SPOIL (SOFT) (MAINTENANCE & CAPITAL)
PROPOSED DREDGE SPOIL (STIFF) (MAINTENANCE & CAPITAL)
SOFT CLAY
STIFF CLAY
EXISTING CHANNEL DESIGN
2016 COMPOSITE POST DREDGE DATA POINTS 21-10-16
PROPOSED CHANNEL DESIGN
CLIENT
FLANAGAN CONSULTING GROUP
PROJECT
CAIRNS SHIPPING DEVELOPMENT PROJECT
TITLE
CHANNEL CROSS SECTIONS SHEET 5
PROJECT NO. 1546223
DOCUMENT No. 008
REV. 2
FIGURE F007


CH 17250.0
CH 17750.0
CH 18250.0
CH 17000.0
CH 17500.0
CH 18000.0
LEGEND
PROPOSED DREDGE SPOIL (SOFT) (MAINTENANCE & CAPITAL)
PROPOSED DREDGE SPOIL (STIFF) (MAINTENANCE & CAPITAL)
SOFT CLAY
STIFF CLAY
EXISTING CHANNEL DESIGN
2016 COMPOSITE POST DREDGE DATA POINTS 21-10-16
PROPOSED CHANNEL DESIGN
CLIENT
FLANAGAN CONSULTING GROUP
PROJECT
CAIRNS SHIPPING DEVELOPMENT PROJECT
TITLE
CHANNEL CROSS SECTIONS SHEET 6
PROJECT NO. 1546223
DOCUMENT No. 008
REV. 2
FIGURE F008

Ports North


CH 18750,0
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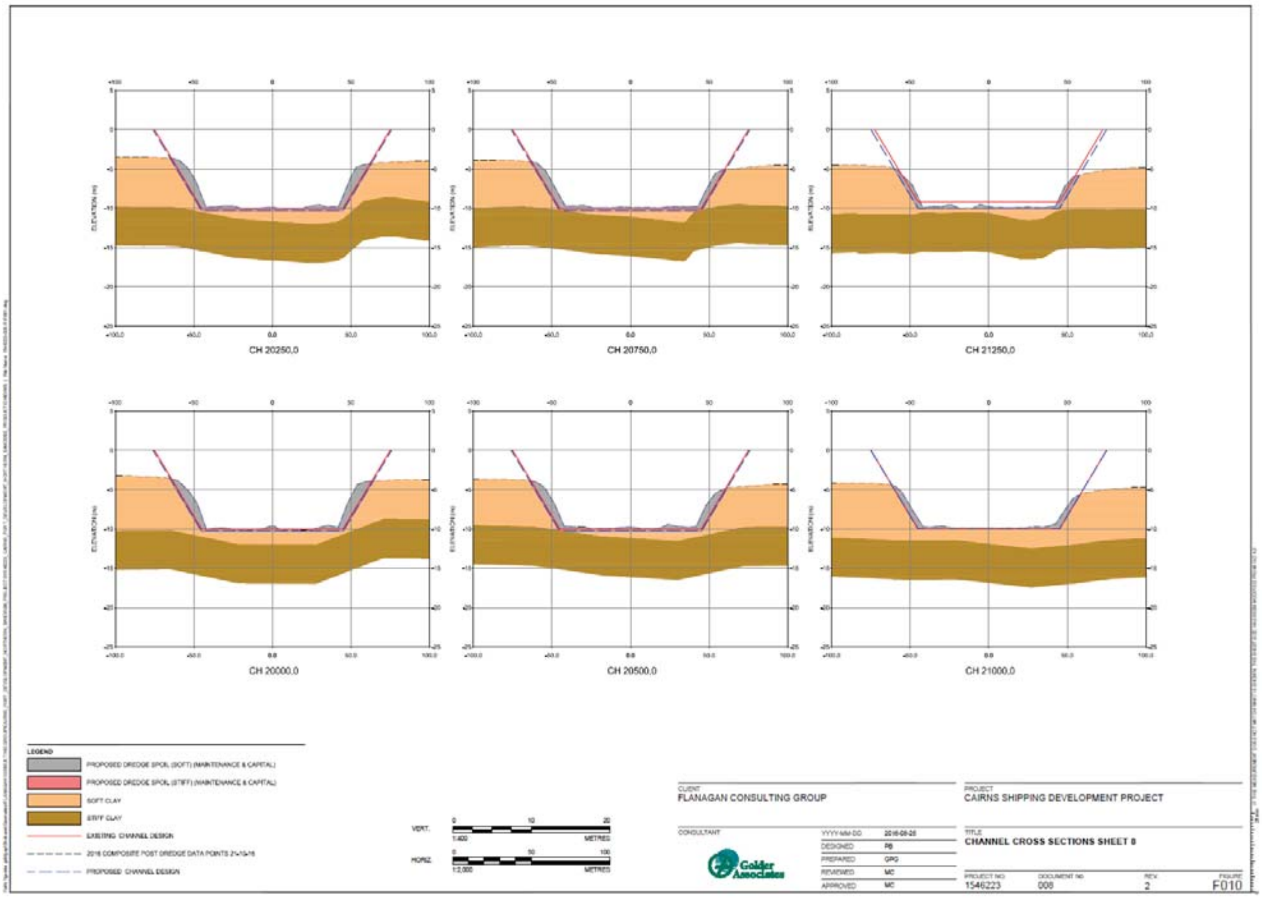
CH 18500,0
CH 19000,0
CH 19500,0
ELEVATION (m)
LEGEND
PROPOSED DREDGE SPOIL (SOFT) (MAINTENANCE & CAPITAL)
PROPOSED DREDGE SPOIL (STIFF) (MAINTENANCE & CAPITAL)
SOFT CLAY
STIFF CLAY
EXISTING CHANNEL DESIGN
2016 COMPOSITE POST DREDGE DATA POINTS
PROPOSED CHANNEL DESIGN
VERT. 1:400 METRES
HORIZ. 1:2,000 METRES
CLIENT
FLANAGAN CONSULTING GROUP
PROJECT
CAIRNS SHIPPING DEVELOPMENT PROJECT
CONSULTANT
Golder Associates
YYYY-MM-DD 2016-08-25
DESIGNED PB
PREPARED GPG
REVIEWED MC
APPROVED MC
TITLE
CHANNEL CROSS SECTIONS SHEET 7
PROJECT NO. 1546223
DOCUMENT No. 008
REV. 2
FIGURE F009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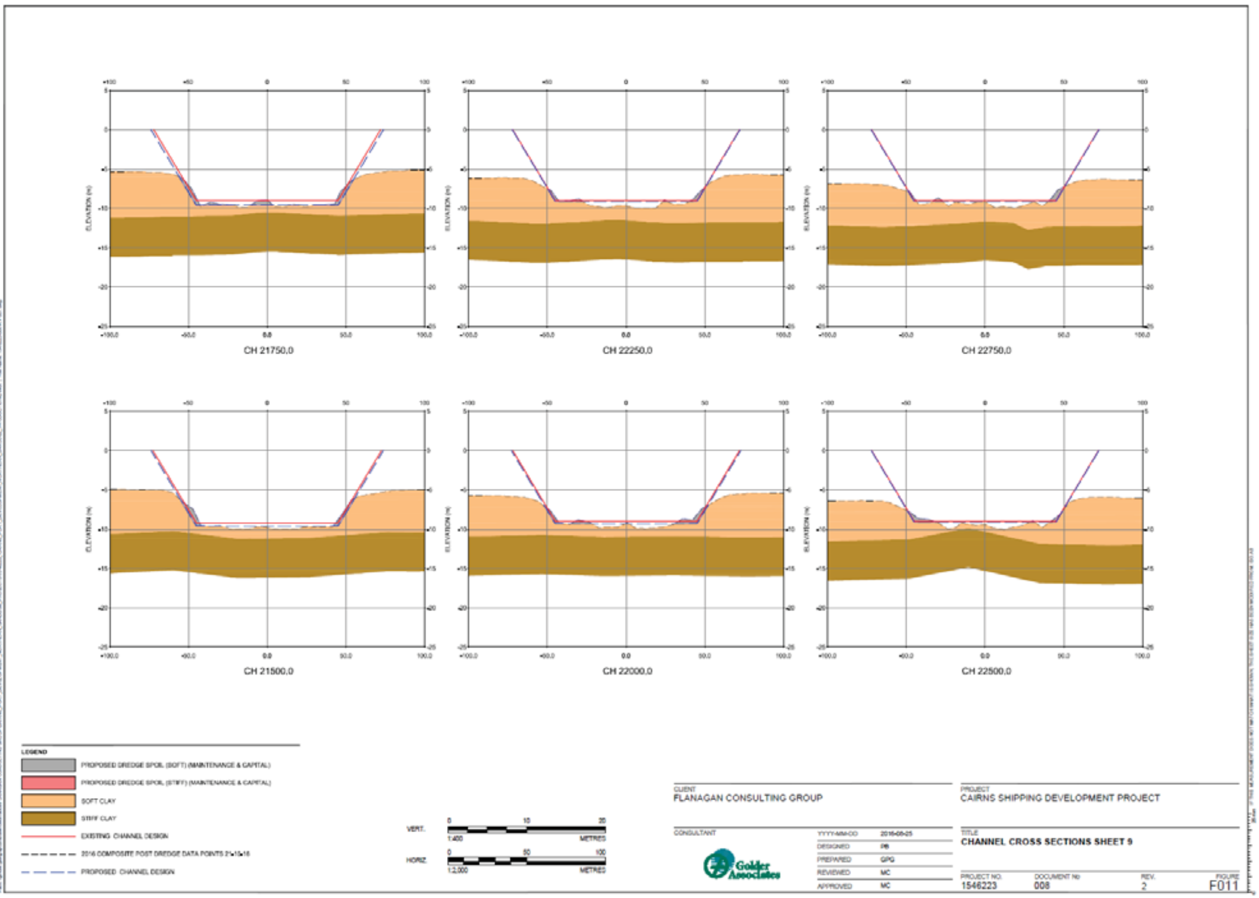
CH 20000,0
CH 20500,0
CH 21000,0
ELEVATION (m)
LEGEND
PROPOSED DREDGE SPOIL (SOFT) (MAINTENANCE & CAPITAL)
PROPOSED DREDGE SPOIL (STIFF) (MAINTENANCE & CAPITAL)
SOFT CLAY
STIFF CLAY
EXISTING CHANNEL DESIGN
2016 COMPOSITE POST DREDGE DATA POINTS
PROPOSED CHANNEL DESIGN
VERT. 1:400 METRES
HORIZ. 1:2,000 METRES
CLIENT
FLANAGAN CONSULTING GROUP
PROJECT
CAIRNS SHIPPING DEVELOPMENT PROJECT
CONSULTANT
Golder Associates
YYYY-MM-DD 2016-08-25
DESIGNED PB
PREPARED GPG
REVIEWED MC
APPROVED MC
TITLE
CHANNEL CROSS SECTIONS SHEET 8
PROJECT NO. 1546223
DOCUMENT No. 008
REV. 2
FIGURE F010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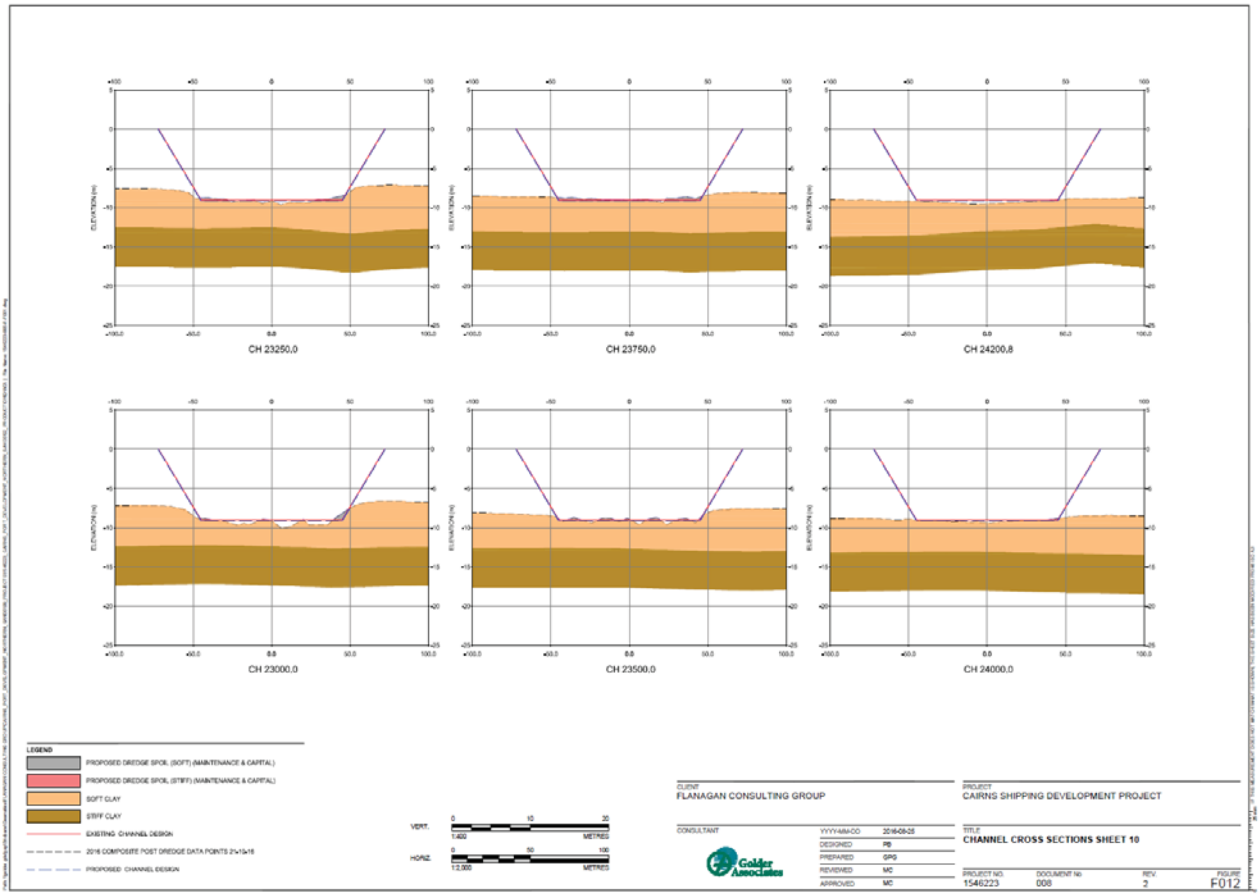
CH 22750,0
CH 21500,0
CH 22000,0
CH 22500,0
LEGEND
PROPOSED DREDGE SPOIL (SOFT) (MAINTENANCE & CAPITAL)
PROPOSED DREDGE SPOIL (STIFF) (MAINTENANCE & CAPITAL)
SOFT CLAY
STIFF CLAY
EXISTING CHANNEL DESIGN
2016 COMPOSITE POST DREDGE DATA POINTS
PROPOSED CHANNEL DESIGN
VERT. 1:400 METRES
HORIZ. 1:2,000 METRES
CLIENT
FLANAGAN CONSULTING GROUP
PROJECT
CAIRNS SHIPPING DEVELOPMENT PROJECT
CONSULTANT
YYYY-MM-DD 2016-08-25
DESIGNED PB
PREPARED GPG
REVIEWED MC
APPROVED MC
TITLE
CHANNEL CROSS SECTIONS SHEET 9
PROJECT NO. 1546223
DOCUMENT No 008
REV. 2
FIGURE F011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CH 23000,0
CH 23500,0
CH 24000,0
LEGEND
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PROPOSED DREDGE SPOIL (STIFF) (MAINTENANCE & CAPITAL)
SOFT CLAY
STIFF CLAY
EXISTING CHANNEL DESIGN
2016 COMPOSITE POST DREDGE DATA POINTS
PROPOSED CHANNEL DESIGN
VERT. 1:400 METRES
HORIZ. 1:2,000 METRES
CLIENT
FLANAGAN CONSULTING GROUP
PROJECT
CAIRNS SHIPPING DEVELOPMENT PROJECT
CONSULTANT
YYYY-MM-DD 2016-08-25
DESIGNED PB
PREPARED GPG
REVIEWED MC
APPROVED MC
TITLE
CHANNEL CROSS SECTIONS SHEET 10
PROJECT NO. 1546223
DOCUMENT No 008
REV. 2
FIGURE F012

Appendix 10 Dredge Material Volumes

3.0 VOLUMES AND DISTRIBUTION OF MATERIALS

Based on the revised model the re-calculated volumes of materials to be dredged are summarised below.

Table 1: Volumes of Materials to be Dredged

Material Type	Volume (m^3)
Soft clays	698,755
Stiff clays	92,309
Total	**791,064**

The distribution of materials within the capital dredging was also calculated by chainage and is summarised below.

Table 2: Distribution of Materials to be Dredged by Chainage

Chainage	Volume of Soft Clays (m^3)	Volume of Stiff Clays (m^3)	Total Volume (m^3)
11000-11500	42558	2783	45340
11500-12000	356	0	356
12000-12500	880	2316	3196
12500-13000	21346	2160	23506
13000-13500	13812	579	14391
13500-14000	3337	1923	5260
14000-14500	6419	9541	15960
14500-15000	12923	30687	43610
15000-15500	31136	1280	32416
15500-16000	44424	15965	60390
16000-16500	47187	2997	50184
16500-17000	34641	380	35021
17000-17500	43571	6213	49784
17500-18000	57749	12499	70248
18000-18500	89979	2382	92361
18500-19000	77999	43	78041
19000-19500	71070	485	71555
19500-20000	34862	1	34863
20000-20500	16182	16	16198
20500-21000	18504	57	18562
21000-21500	10539	2	10541
21500-22000	8018	0	8018
22000-22500	4516	0	4516
22500-23000	1192	0	1192
23000-23500	1478	0	1478
23500-24000	3007	0	3007
24000-24500	1071	0	1071
Totals	**698755**	**92309**	**791064**

Appendix 11 Sample Bore Logs – Stiff Material Locations

Ports North

REPORT OF BOREHOLE: BH1

CLIENT: Ports North	COORDS: S 16° 56.4406' E 145° 46.9976'	SHEET: 1 OF 1	
PROJECT: Cairns Shipping Development Project (EIS)	SURFACE RL: -5.10 m DATUM: LAT	DRILL RIG: HYDRA SCT	
LOCATION: Trinity Inlet, Cairns	INCLINATION: -90° DIRECTION: 000°	CONTRACTOR: Geo Investigate	
JOB NO: 137632122	HOLE DEPTH: 5.15 m	LOGGED: JKW	DATE: 5/8/13
		CHECKED: JJP	DATE: 8/8/13

Drilling					Sampling		Field Material Description					
METHOD	PENETRATION RESISTANCE	WATER	DEPTH (metres)	DEPTH RL	SAMPLE OR FIELD TEST	RECOVERED	GRAPHIC LOG	USCS SYMBOL	SOIL/ROCK MATERIAL DESCRIPTION	MOISTURE CONDITION	CONSISTENCY DENSITY	STRUCTURE AND ADDITIONAL OBSERVATIONS
RD	L		0	-5.10	BH1-001 U75 0.10-0.50 m Rec = 400/400 mm PP = <0.1 kg/cm^2 Sv = <0.1 kg/cm^2			CH	Silty CLAY high plasticity, grey, with some shells		VS	Inner Harbour
			1		BH1-002 U75 1.10-1.50 m Rec = 400/400 mm PP = 0.2 kg/cm^2 Sv = < 0.1 kg/cm^2							
			2	2.10 -7.20	BH1-003 U75 2.10-2.50 m Rec = 400/400 mm Insitu Shear Vane at 2.5m Sv = 10 kPa				trace organics			
			3		BH1-004 U75 3.10-3.50 m Rec = 400/400 mm PP = 0.6-0.8 kg/cm^2 Sv = 0.2 kg/cm^2 Insitu Shear Vane at 3.5m Sv = 15 kPa						F	
			4	4.00 -9.10	BH1-005 U75 4.10-4.50 m Rec = 400/400 mm PP = 2.0-2.3 kg/cm^2 Sv = 0.65 kg/cm^2				grey and brown, with some shells, trace organics			
			5		BH1-006 Rec = 450/450 mm SPT 4.70-5.15 m 3, 3, 6 N=9						St	
				-10.25					END OF BOREHOLE @ 5.15 m TARGET DEPTH DRILLED OVER WATER			
			6									
			7									

This report of borehole must be read in conjunction with accompanying notes and abbreviations. It has been prepared for geotechnical purposes only, without attempt to assess possible contamination. Any references to potential contamination are for information only and do not necessarily indicate the presence or absence of soil or groundwater contamination.

GAP gINT FN. F01a RL3

GAP 8_37.13 LIB.GLB Log GAP NON-CORED FULL PAGE 137632122.GPJ <<DrawingFile>> 23/09/2013 13:07 8.30.003 Datgel Tools

Appendix 12 Particle Size Distributions

Golder Associates

BRISBANE LABORATORY

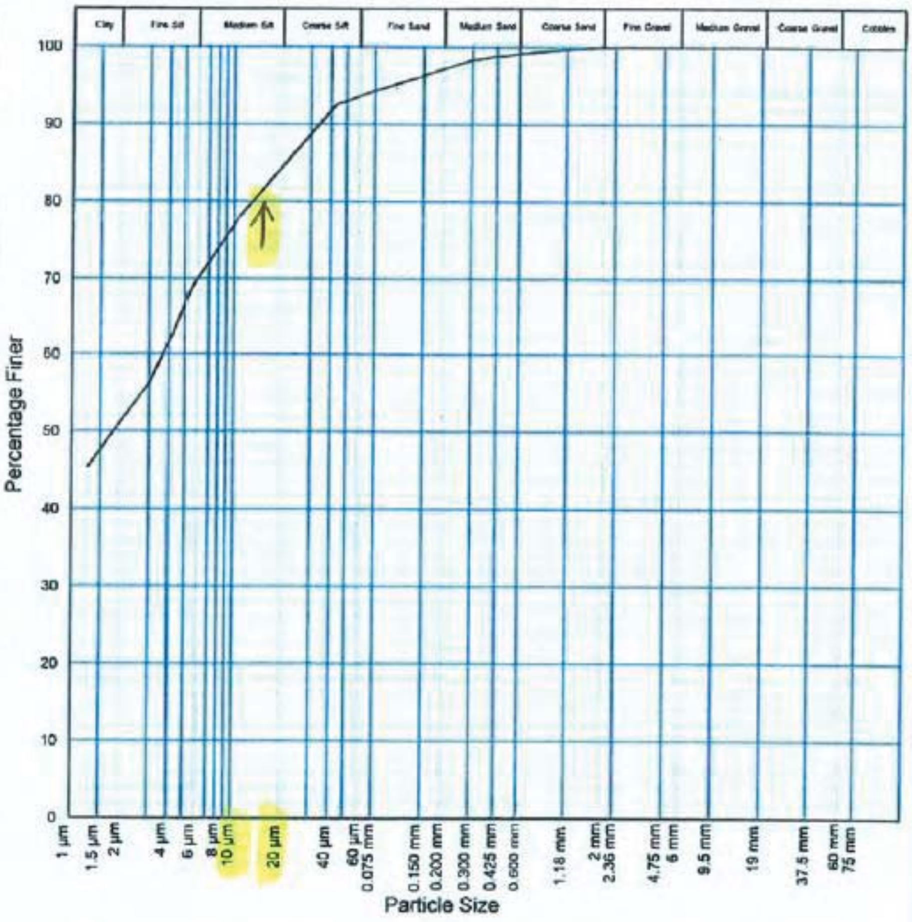
ABN 64 006 107 857
28 Bank Street, West End QLD 4101
PO Box 3427 Sth Brisbane BC QLD 4101
Phone : (07) 3840 9500
Email : bnelab@golder.com.au

PARTICLE SIZE DISTRIBUTION BY HYDROMETER

Client :	Ports North	Report No. :	R16142
Address :	Cnr Grafton & Hartley Streets, Cairns	Job No. :	137632122-4000
Project :	Cairns Shipping Development Project EIS	Reg'n No. :	13303495
Location/Sample ID :	BH1 005 (4.10 - 4.50m)	Senders No. :	
	Stiff	Date Received :	12/08/2013
		Sampled By :	Golder

SIZE FRACTIONS AS PER AUSTRALIAN STANDARDS AS 1726

Particle Size (mm)	Percent Passing
150	
75	
37.5	
19.0	
9.5	
4.75	
2.36	100.0
1.18	99.7
0.600	99.1
0.425	98.8
0.300	98.4
0.150	96.4
0.075	94.4
Particle Size (Microns)	**Percent Passing**
42.5	92.5
30.4	88.9
21.8	85.4
11.1	78.3
7.9	73.9
5.7	69.4
4.1	62.3
3.0	56.1
1.3	45.5



Pretreatment	Tested as received	Soil Particle Density (assumed)	2.70 t/m³
Loss in Pretreatment (%)	-	Type of Hydrometer	ASTM E100
Method of Dispersion	Mixer		
Test Procedure : AS 1289.3.6.3	- Variations to test method a)assumed particle density used b) testing up to 24 hours		
Prepared by : NF		Checked by : GH	

This document is issued in accordance with NATA's accreditation requirements.

NATA

26/8/13

Nick Farrer
Approved Signatory

Senior Technical Officer
NATA Accred. No. : 1961

Add

Appendix 13 Akuna Dredging Solutions – Notes on Fine Sediment Offset

Notes on fine sediment offset.

Backhoe Dredger scope.

Cairns Shipping Development Project
Queensland

Ports North

Akuna Dredging Solutions Pty Ltd

Camp Mountain,
August 2018

Appendix B Peer Reviewer CV

Appendix C Peer Review Report (in full)

BMT has a proven record in addressing today's engineering and environmental issues.

Our dedication to developing innovative approaches and solutions enhances our ability to meet our client's most challenging needs.

BMT

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Fax +61 3 8620 6105
Email melbourne@bmtglobal.com

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Broadmeadow New South Wales 2292
PO Box 266 Broadmeadow
New South Wales 2292
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Fax +61 2 4940 8887
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Email sydney@bmtglobal.com

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Email wa@bmtglobal.com

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Tel +44 (0) 20 8090 1566
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Tel: +44 (0) 113 328 2366
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