Port of Gladstone
Gatcombe and Golding Cutting
Channel Duplication Project

Environmental Impact Statement

Appendix E1
Channel Duplication Project – Final Geotechnical Report

aurecon

Port of Gladstone
Gatcombe and Golding Cutting Channel Duplication Project

Final Geotechnical Report

Gladstone Ports Corporation

19 August 2015
Revision: 2
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Executive summary

Objectives

The purpose of this report is to detail the geotechnical conditions and present the subsurface materials including soil and rock encountered during this investigation for the proposed Channel Duplication footprint. The objectives of the geotechnical investigation were to:

- Undertake tests on the composition of the submarine soils to determine the percentage of clay, silt, sand and gravel based on boreholes completed
- Provide an understanding of the behavioural characteristics of the proposed material to be dredged as defined by density, water content and Atterberg limits
- Determine material strength, in particular classification of any cohesive soils with undrained shear strengths greater than 200 kPa
- Determine the likelihood of encountering rock within the proposed dredging footprint, and characterising the rock in terms of strength and abrasivity

Methodology

A detailed site investigation was carried out in the proposed dredging footprint by Aurecon in accordance with the Geotechnical and Geochemical Investigations for the Port of Gladstone. The geotechnical fieldwork was undertaken between 13 February and 19 May 2015.

A total of twenty three (23) boreholes were drilled to explore the areas requiring deepening as part of the duplication of the Gatcombe and Golding Cutting Channels to a target drilling depth of approximately -20 m LAT.

Aurecon engaged geotechnical drilling contractor J&S Drilling to supply all plant and personnel to perform the physical works. Borehole drilling was undertaken over water from a jack-up barge Ocean Driller II. The barge was manoeuvred to pre-determined borehole locations by means of RTK DGPS on the barge and other GPS instruments using a tug. Constant communication between the barge Master, Aurecon staff, MSQ and the Harbour Master/Deputy Harbour Master was undertaken to ensure all works were performed safely and with minimal disruption to shipping movements.

Aurecon geotechnical and geological engineers supervised the geotechnical drilling full time, logging all soils and rock arising from beneath the seabed and overseeing in situ testing in accordance with Australian Standards.

During drilling in situ Standard Penetration Tests (SPTs) were performed to characterise the submarine soils. In addition, hand shear vane and pocket penetrometer tests were performed on cohesive soil samples retrieved during the drilling process.

After logging and photographing the soil and rock core, samples were selected and scheduled for laboratory testing at a NATA accredited laboratory. Testing included but was not limited to moisture content tests, Atterberg limits and particle size distribution tests.

Results

As expected from review of the available literature and previous reports, unconsolidated soils and sediments were encountered during the site investigation above -20 m LAT. Whilst the submarine soils would have likely been deposited in horizontal layers over time, the complex depositional and erosional environment of the Port of Gladstone has resulted in an extremely complex and convoluted soil profile which does not provide a clear geological model, as can be seen in the geologic sections (Appendix E).

In general, sands overlying gravels were encountered within the Gatcombe Channel.

A significant deposit of gravel, likely containing cobbles and boulders, was identified between the Gatcombe and Golding Cutting Channels in the area of borehole GG12.

Cohesive material was recorded within the Golding Cutting Channel beneath the seafloor. This layer is medium to high plasticity and stiff to very stiff in consistency. Sand and gravel layers underlie this cohesive layer.

“Bedrock” was not encountered during the geotechnical investigation within the Golding and Gatcombe Cutting Channels although the presence of rock cannot be ruled out of the proposed dredging profile completely.

There is a 5 m “step” feature of the seabed in the vicinity of borehole GG15. This may be due to the complex underlying geological structures of the area, which is known to comprise a series of horst and graben structures and later sedimentary deposits.

Conclusions

The geotechnical investigation has confirmed that unconsolidated soils are present within the area of the proposed area to be dredged for the channel duplication. These soils are primarily granular near the coast, becoming fine grained and cohesive away from the coast.

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1 Introduction

1.1 Background

Gladstone Ports Corporation (GPC) is responsible for the control and management of port infrastructure and cargo handling operations for coal and other products at the Port of Gladstone, Port of Rockhampton and Port of Bundaberg. GPC provides and maintains vital shipping channels within the Port. The Port of Gladstone is located along the Capricorn Coast of Central Queensland, approximately 525 km north of Brisbane.

The Port of Gladstone is Queensland's largest multi-commodity port, with RG Tanna Coal Terminal in the 2013/14 reporting period being the world's fourth largest coal export terminal (by throughput). Cumulatively, the Port handles the export of mineral resources from Central Queensland and products from local industries, and the import of raw materials from national and international sources (GPC 2014).

The Port of Gladstone is also one of the busiest ports in Australia, vital to the local, state and national economies. Major exports from the Port include coal, alumina, cement, petroleum, aluminium and agricultural resources.

GPC has identified the need to improve the Port of Gladstone's operational and safety efficiencies, and to mitigate an existing and increasing potential shipping incident risk as the Port throughput increases.

The duplication of the existing Gatcombe and Golding Cutting shipping channels will facilitate improved flexibility for vessel passing within the Port, which will address the above mentioned need.

1.2 Environmental impact statement

The proposed Gatcombe and Golding Cutting Channel Duplication Project (herein referred to as 'the Project') was declared a 'coordinated project' by the Queensland Coordinator-General (CG) under the *State Development and Public Works Organisation Act 1971* (SDPWO Act) on 25 September 2012. The Project was also determined to be a 'controlled action' requiring an Environmental Impact Statement (EIS) by the Commonwealth Minister for the Environment under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) on 23 October 2012.

GPC is currently proceeding with the EIS phase of the Project. The EIS will be submitted for assessment to both the Queensland State Government under the SDPWO Act and the Commonwealth Department of the Environment (DoE) under the EPBC Act.

The dredging component of the Project involves deepening and widening the existing Gatcombe and Golding Cutting bypass channels to provide a duplicate channel parallel to the main shipping channel promoting a two-way passage.

The proposed duplicate channel will be approximately 15.23 km long and dredging is proposed to be undertaken to an ultimate depth of -16.1 m LAT (Stage 1 to -13.5 m LAT, Stage 2 to -16.1 m LAT), with a channel width (toe to toe) of 200 m (refer Figure 1). The channel footprint is approximately 382 ha, however, due to the existing bathymetry in the Port of Gladstone, the total area requiring dredging (ie above -16.1 m LAT maximum dredge depth) is less, being 247.8 ha. The estimated volume to be dredged is 12.6 Mm^3. The dredged material is proposed to be disposed in the approved dredged material placement area (DMPA).

1.3 Purpose of this report

The geotechnical investigations carried out in the proposed Gatcombe and Golding duplicate channels will allow GPC to characterise the geotechnical and geological conditions, and geochemical status of the subsurface material to be incorporated in the ongoing project Environmental Impact Statement (EIS).

1.4 Objectives

The primary objectives of the Geotechnical and Geochemical Investigation are to:

- Provide sufficient geotechnical information to feed into the EIS for Port of Gladstone Gatcombe and Golding Channel Duplication Project
- Provide sufficient information to adequately inform the Dredging Contractor during the tendering process and undertaking the dredging and dredge material placement activities. This includes the Stage 1 (-13.5 m LAT) and Stage 2 (-16.1 m LAT) dredging components

1.5 Layout of this report

This report is a factual account of the geotechnical investigation designed and commissioned by GPC, and implemented by Aurecon. The report includes:

- A detailed account of the scope of work
- A description of the site details, including expected geological conditions
- A review of productivity of the investigation
- The investigation methodology
- Schedule of laboratory testing
- Discussion of the findings of the proposed area to be dredged and a simplified geological model of the Gatcombe and Golding Cutting Channels
- A list of conclusions
- List of references
- Limitations to the report

Appended to this report are:

- Appendix A Borehole location plans
- Appendix B Explanatory notes
- Appendix C Borehole logs, core photos, and SPT photos
- Appendix D Geotechnical laboratory testing
- Appendix E Geological long section

2 Scope of work

2.1 Background

Aurecon engaged J&S Drilling supported by Fodico marine to undertake the physical geotechnical borehole drilling using the Ocean Driller II jack-up barge (JUB).

The fieldwork was carried out between 13 February 2015 and 19 May 2015.

2.2 Borehole drilling

Investigation works in the proposed dredging footprint were scheduled to comprise the drilling of twenty three (23) boreholes to nominal depths ranging from 4 to 12.5 m depth below the existing seabed surface, with all boreholes being advanced to a minimum of -20.1 m LAT (4 m below the proposed dredging depth). Details of the design locations of these boreholes are provided in Table 1.

Table 1 Coordinates of geotechnical borehole design locations and estimated drill depths (GPC 2014)

Name	Easting (GDA 1994)	Northing (GDA 1994)	Estimated seabed level (m LAT)	Estimated drill depth (m)
GG01	329929	7361167	-15.9	4.2
GG02	330073	7360496	-14.5	5.6
GG03	330518	7360728	-15.3	4.8
GG04	330851	7359830	-15.2	4.9
GG05	331632	7359107	-15.7	4.4
GG06	331815	7358850	-14.1	6.0
GG07	331983	7359235	-15.6	4.5
GG08	332058	7358663	-15.1	5.0
GG09	332214	7359111	-15.7	4.4
GG10	332794	7357964	-15.6	4.5
GG11	333016	7357650	-15.8	4.3
GG12	333675	7357111	-12.5	7.6
GG13	334776	7356451	-14.7	5.4
GG14	335216	7356010	-14.4	5.7
GG15	335655	7355917	-10.7	9.4
GG16	336016	7355503	-9.5	10.6
GG17	336758	7355239	-11.4	8.7

Name	Easting (GDA 1994)	Northing (GDA 1994)	Estimated seabed level (m LAT)	Estimated drill depth (m)
GG18	337248	7354767	-8.8	11.3
GG19	337859	7354579	-9.9	10.2
GG20	338299	7354138	-7.6	12.5
GG21	339400	7353588	-8.2	11.9
GG22	340171	7352927	-8.5	11.6
GG23	340832	7352707	-9.4	10.7

The investigation methodology is provided in Section 4 of this report.

Boreholes were required within the dredge footprint to provide information on the classification and strength of the subsurface materials.

2.3 Geotechnical testing

Geotechnical laboratory testing was undertaken on selected samples retrieved from drilling primarily to provide data for sediment characterisation, excavatability and wear and tear. The laboratory testing provided information on the following:

- Composition of the material (ie percentage of clay, silt, sand and gravel)
- Behavioural characteristics of the material to be dredged as defined by density, water content and Atterberg limits
- Identification of deposits of calcium carbonate and other materials that may impede dredging production rates
- Excavatability and abrasiveness on dredging equipment
- Material strength, in particular classification of soils with undrained shear strengths greater than 200 kPa

More detail on the geotechnical laboratory testing undertaken is provided in Section 5 of this report.

The design locations of the boreholes were compiled following a review of the bathymetry (ie high spots to be dredged) combined with interpretation of existing seismic data. The seismic survey report completed by Marine & Earth Sciences (October 2011) contained sections with interpretations of possible rock levels or other materials potentially difficult to dredge based on seismic velocity within the material established from the geophysical data. Borehole locations were selected to test and confirm the inferred material types from this geophysical survey.

3 Site details

3.1 Port of Gladstone

The Port of Gladstone is situated approximately 525 km north of Brisbane. The proposed deepening and duplication of the existing Gatcombe and Golding Cutting Channels (Figure 1), is part of the GPC's strategy to facilitate the potential increase in port throughput into the future and to mitigate the risks caused by additional vessels utilising the port's shipping channels.

The duplicate channel is to be developed adjacent to the existing shipping channel, providing a two-way passage from the outer harbour, around East Banks, to the western side of Facing Island.

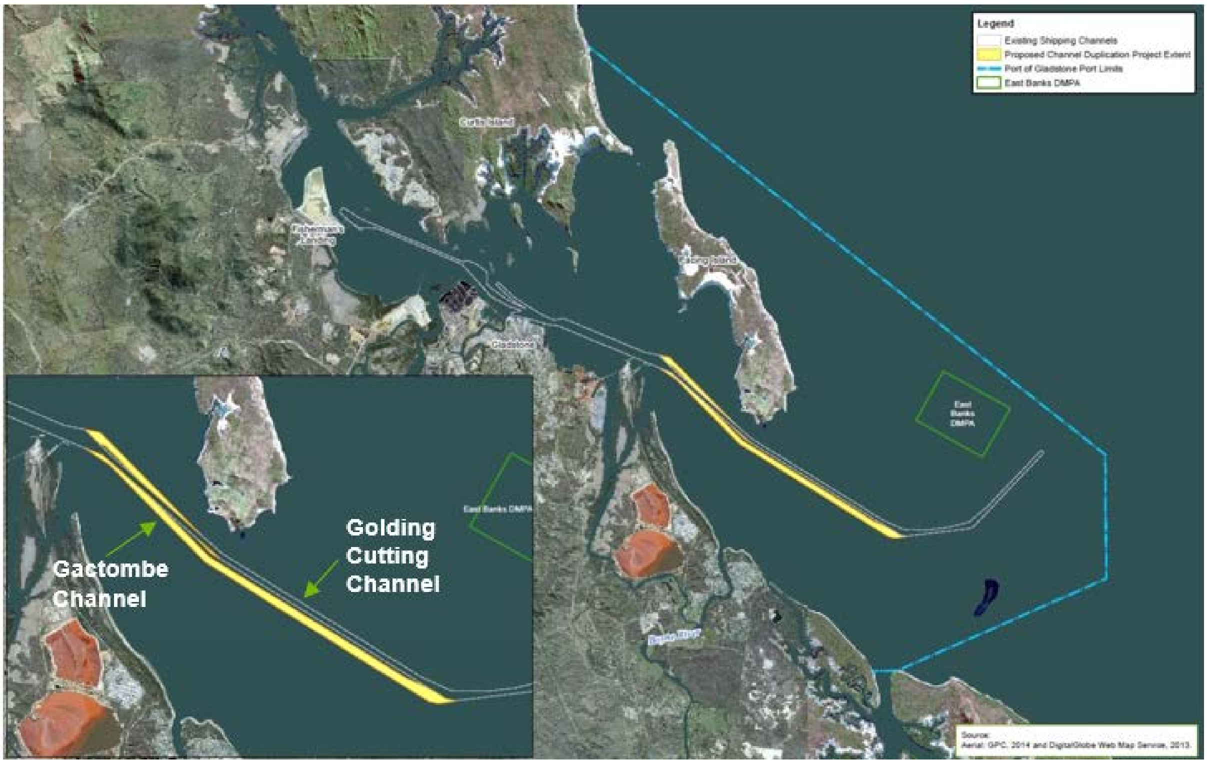

Figure 1 **Location of the proposed Gatcombe and Golding Cutting duplicate channels**

3.2 Gatcombe Head tidal planes

Tidal planes for Gatcombe Head are given in Table 2. The close proximity of the geotechnical investigation area to Gatcombe Head, which is located on the southern tip of Facing Island, is considered most appropriate for this project due to its close proximity to the site.

Table 2 2014 Semidiurnal Tidal Planes Gatcombe Head (GPC 2014)

Tidal Plane	Tidal level (m LAT)
Highest Astronomical Tide (HAT)	4.29
Mean High Water Springs (MHWS)	3.45
Mean High Water Neaps (MHWN)	2.71
Australian Height Datum (AHD)	2.21
Mean Low Water Neaps (MLWN)	1.37
Mean Low Water Springs (MLWS)	0.56
Lowest Astronomical Tide (LAT)	0.00

3.3 Expected geological conditions

3.3.1 Published geology

The offshore geology of the Port of Gladstone is not presented on published geological maps (Figure 2 and Figure 3).

The 1:100,000 scale geological map for Gladstone (Queensland Government Department of Natural Resources and Mines, Sheet 9150 and part 9151, March 2006) indicates that bedrock for the onshore areas adjacent to the region under investigation generally comprises Late Devonian-Early Carboniferous rocks of the Curtis Island Group; specifically the Wandilla Formation and the Shoalwater Formation.

The rocks of the Curtis Island Group were locally subjected to amphibolite grade metamorphism and are structurally complex moderately to steep dipping beds, tight folds and slaty and crenulation cleavage (State of Queensland (SoQ) 2013).

According to Geoscience Australia (2015), the Wandilla Formation comprises mudstone, lithic sandstone, siltstone, jasper, chert, slate and local schist. SoQ (2013) describe the Wandilla Formation as being dominated by rhythmically interbedded mudstone and graded sandstone derived from intermediate to felsic volcanics. Large chert lenses within this Formation form prominent ridges, particularly on Curtis Island. Sandstone beds within the Formation show soft-sediment deformation and in the middle of the unit is an interval with calcareous or silicified ooids (rounded particles).

The Shoalwater Formation is the easternmost Formation of the Curtis Island Group and is likely to represent “bedrock” for the majority of the area to be dredged. The Formation comprises quartzose sandstone beds up to 3 m thick alternating with thinner mudstone beds and rare bands of chert and felsic tuff forming strike ridges. Geoscience Australia (2015) describes this Formation as quartzose sandstone, mudstone, local quartz-muscovite-biotite schist and strongly foliated metasediments.

From geological interpretation of the material, overlying bedrock will comprise a combination of unconsolidated Quaternary (Holocene and Pleistocene) aged marine and fluvial sediments.

The tectonic history of the Gladstone area is complex and involves three major north-northwest-trending structural belts; the Coastal Block, the Rockhampton Block and the Eungella-Cracow Mobile Belt (Bureau of Mineral Resources, Geology and Geophysics 1975).

The Coastal Block comprises Palaeozoic sedimentary rock (Curtis Island Group) that have probably undergone repeated tectonism and were finally deformed and metamorphosed in the Early Permian before being uplifted in the Late Permian. Strike and dip of the bedding trends from north to northwest and dips steeply to the east.

The results from the geophysical investigation carried out by Marine and Earth Sciences in 2011 for GPC reflect the geological structure of the area as described above.

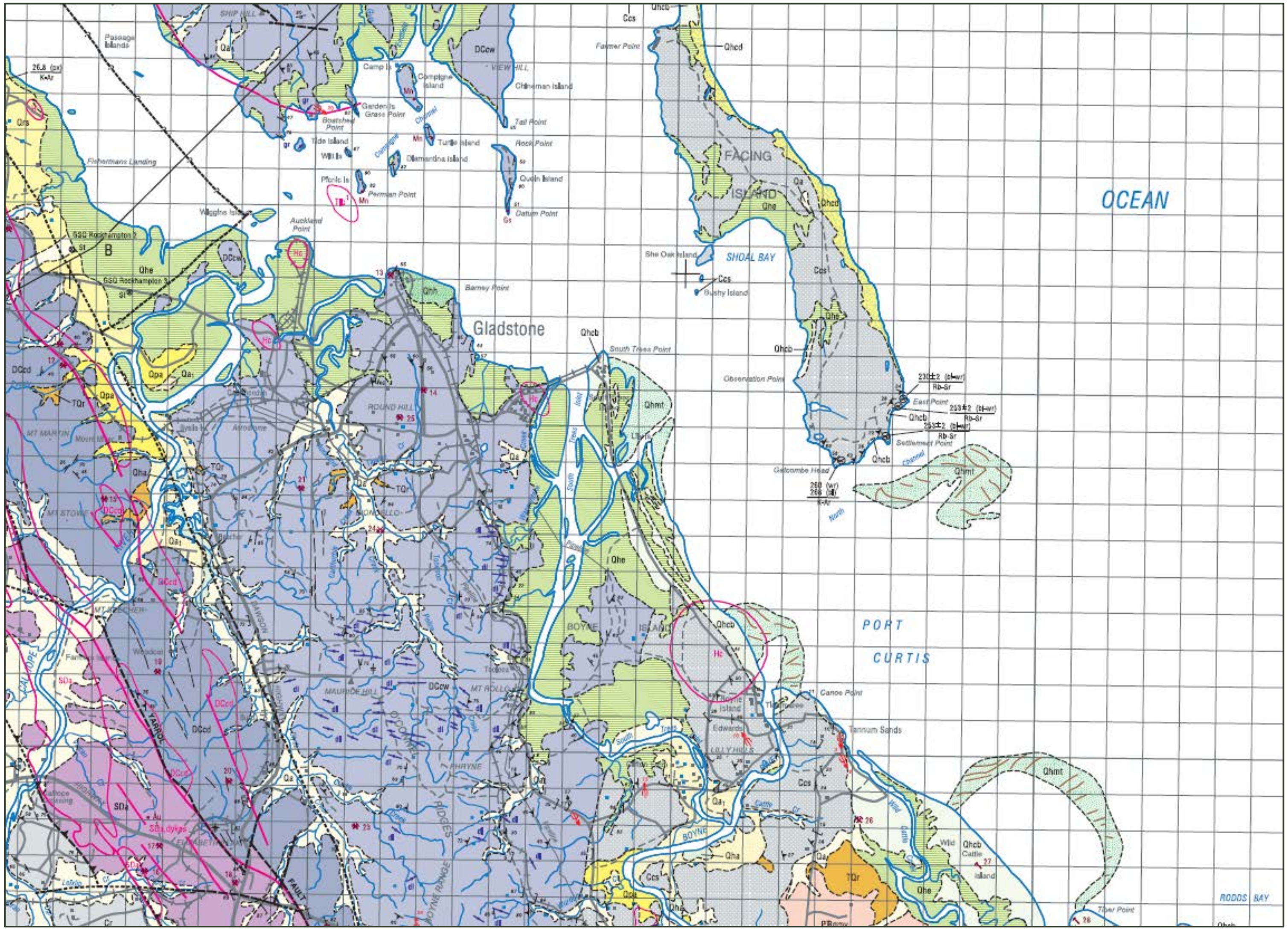

Figure 2 **Excerpt from the 1:100,000 scale geological map Gladstone Special (sheet 9150 and part 9151) (Queensland Government Department of Natural Resources and Mines 2006)**

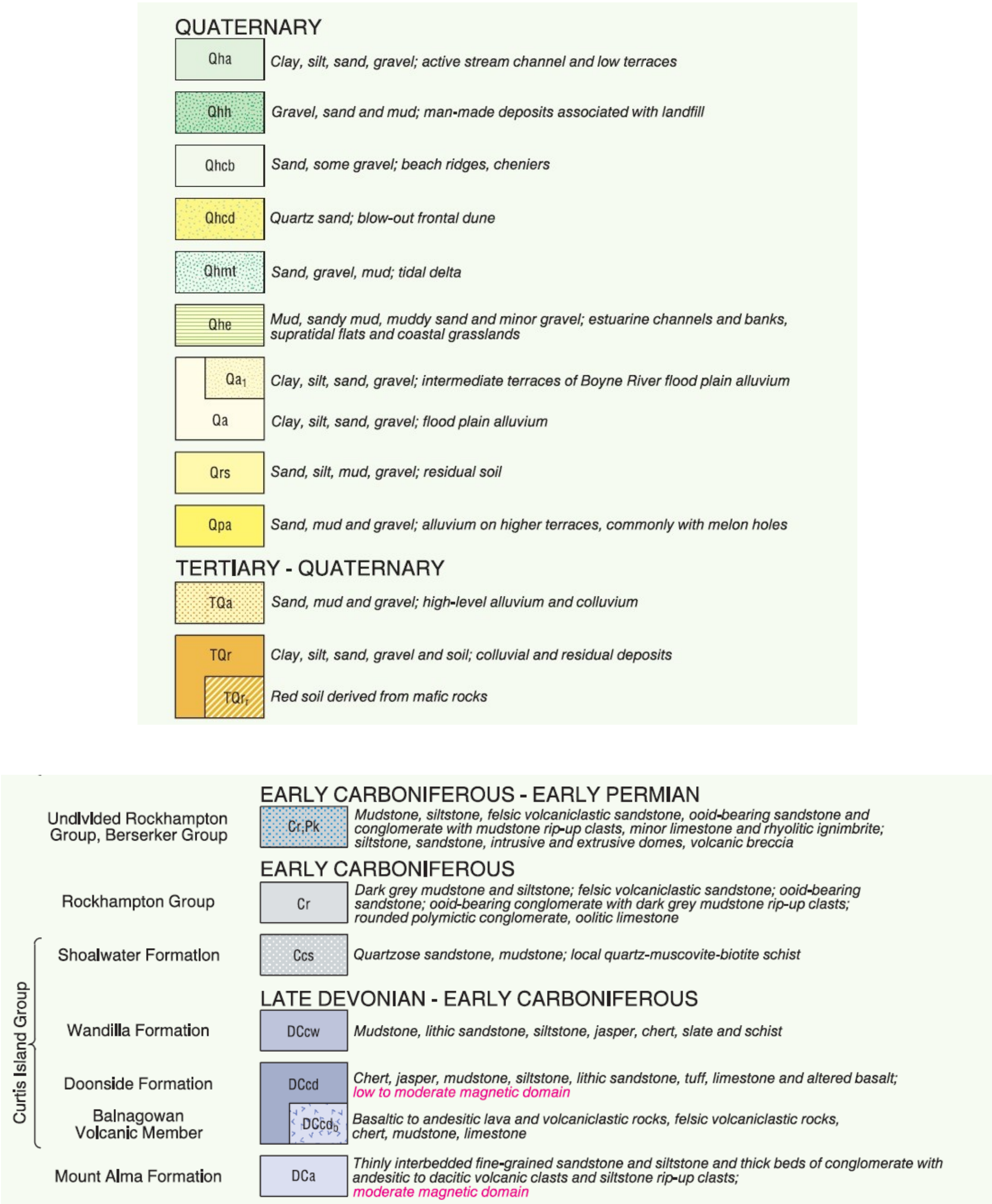

Figure 3 **Selected Geological Legend from 1:100,000 scale geological map Gladstone (Queensland Government Department of Natural Resources and Mines Special 2006 (sheet 9150 and part 9151)**

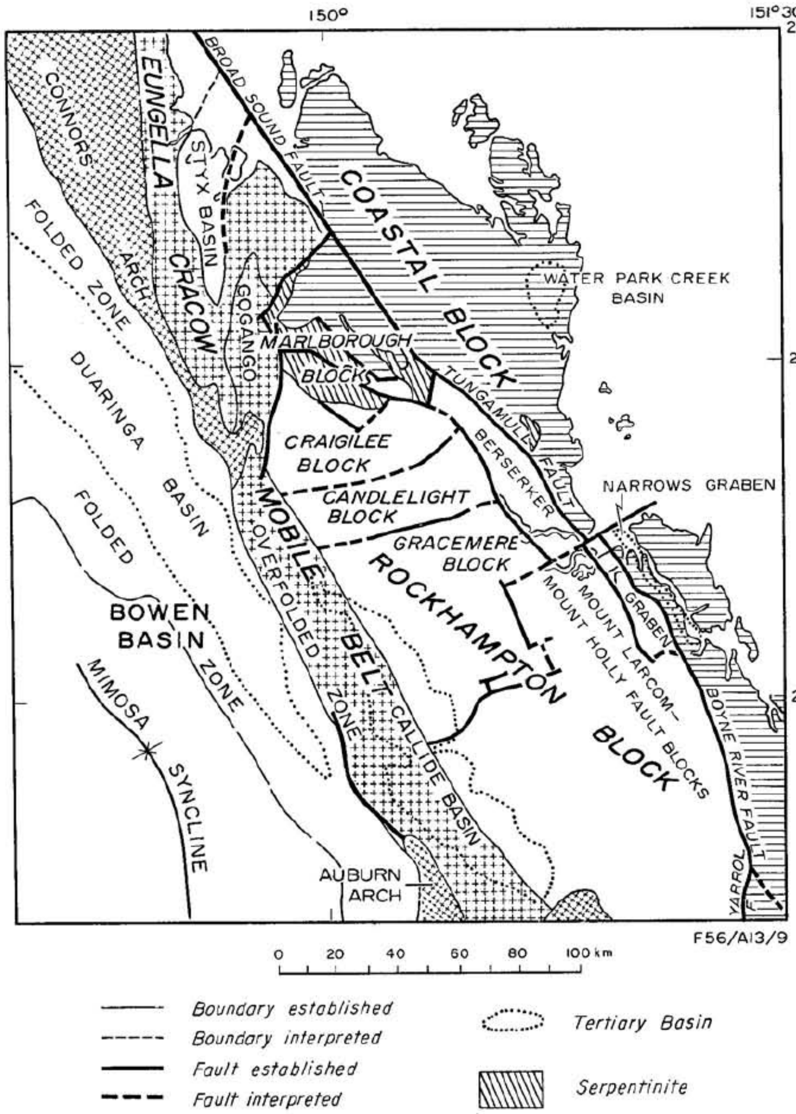

Figure 4 **Structural elements of the Rockhampton/Gladstone area (Bureau of Mineral Resources, Geology and Geophysics 1975)**

3.3.2 Previous reports

A number of ground investigations have been undertaken previously in the vicinity of the proposed area to be dredged. This report uses the following previous investigations as background information:

- Blain Bremner &Williams, March 1980 – A Study of the Sub-surface materials for dredging in the approach channels to the Port of Gladstone
- Blain Bremner & Williams, 1981 – Approach Channel Dredging Study
- Macdonald Wagner, (1987) Offshore Drilling – Clinton Wharf Extensions Gladstone Harbour
- Connell Hatch, (2005) Wiggins Island Coal Terminal: Initial Advice Statement
- Coffey Geotechnics, (2007) Marine Seismic Survey Channel Dredging Study Port of Gladstone
- Connell Wagner, (2008) Gladstone Liquefied Natural Gas Plant Curtis Island –Offshore Geotechnical Investigations – Offshore Structures
- Seismic Survey by Marine & Earth Science (2011)

- Aurecon, (2012) Clinton Bypass Channel Investigation, Gladstone Ports Corporation
- Aurecon Hatch, (2013) WICET Expansion Phase 1 – WEXP1

All of the above geotechnical investigations indicate a mixture of soil types present within the soil profile to be dredged. Quaternary Alluvial deposits comprising clays, sands, gravels and mixtures of all of the above soil types (eg Gravelly Sand) occur.

3.3.3 Quaternary (Holocene) sediments

Typically, the Quaternary aged soils comprise unconsolidated marine/intertidal sediments over older coarse and fine grained soils being marine or fluvial in their deposition. It is likely that the fluvial deposits were carried down by the action of large river systems such as the Boyne River. The undifferentiated fluvial material typically comprises a mixture of clay, silt, sand and gravel. Intertidal sediments carried by strong tidal currents may also be encountered throughout the Port Curtis area and are shown on the geological map.

Previous investigations have shown the presence of a thin layer of Holocene-aged estuarine clay and recently deposited marine sediments in the Port Curtis area. The Holocene-aged material is typically 0.5 m tick to approximately 5 m tick in un-dredged areas, and is described as soft clay and loose sand/gravel with shell fragments. However, in areas where seabed topography is variable, pockets of thicker sediment can be anticipated.

This young Holocene-aged alluvium is typically underlain by residual soils, comprising sandy clay, clayey sand, gravelly sand and clay.

3.3.4 Quaternary (Pleistocene) sediments

Below the softer surface marine and alluvial sediments, the area is typically underlain by dense or stiff consolidated sediments interpreted as being Pleistocene in age 11,700 years ago to 2.5 million years ago. These sediments are typically composed of stiff to very stiff high plasticity clays as well as dense sands.

Coarse gravel layers with clasts up to boulder size, possibly deposited during the uplift of the Mount Larcom and Curtis blocks, are known to exist in the Port Curtis area. These gravels are typically comprised of quartz, chert and metasediments.

3.3.5 Bedrock

Variability in the level of rock head is known to exist throughout the Port Curtis area due to the existence of numerous faults and the nature of the resistant zones known to exist in the Wandilla and Shoalwater Formations. Any bedrock encountered would potentially be comprised of medium to high strength metasediments.

3.3.6 Structure

From the published geological maps it is also apparent that extensive faulting exists within the area of the proposed channel to be dredged. These faults are not thought to be active at the present time, however their existence can produce large variations in the underlying geology. This may introduce changes in rock type that potentially produce significant changes to rock head level. Known seabed topography in the area supports the presence of complex underlying structures in the geology which will in turn impact on the depositional relationships.

3.4 Work progress

Figure 6 demonstrates the actual drilling progress, showing metres drilled per day over the duration of the fieldwork program. Following completion of the CPT testing approximately 16% of the total 94 days of fieldwork were lost to standby, including the disruption caused by TC Marcia. Despite isolated poor weather such as TC Marcia, and associated residual large swells, the program progressed smoothly with few delays beyond shipping movements and waiting for tidal currents. The average drilling production rate for the entire program was 6.45 m/shift.

During the course of the investigation, stand-by time was incurred, due to inclement weather and at times "severe" weather conditions, tides and currents. In general, unsafe weather conditions were defined as winds in excess of 20-25 knots and waves in excess of 1.5 m. Due to the complex combination of sea conditions, including many variables other than just wind speed and wave height, the final decision to board the barge was determined onsite by the Barge Master.

In addition, Tropical Cyclone (TC) Marcia, a Category 5 severe tropical cyclone, made landfall at its peak strength over central Queensland, near Shoalwater Bay on 20 February 2015 (Williams B. 2015). The cyclone went on to severely affect various areas, including Yeppoon and Rockhampton (Figure 5).

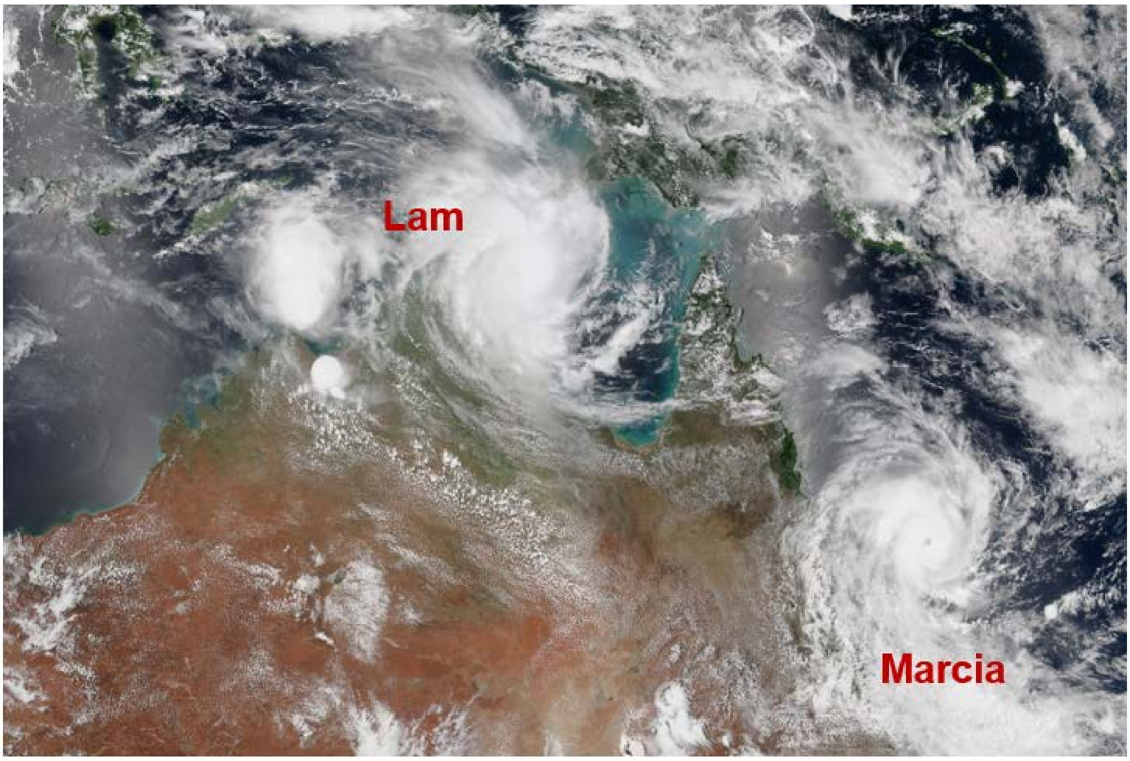

Figure 5 "Cyclones Lam and Marcia" (Sunomi NPP Satellite, February 2015)

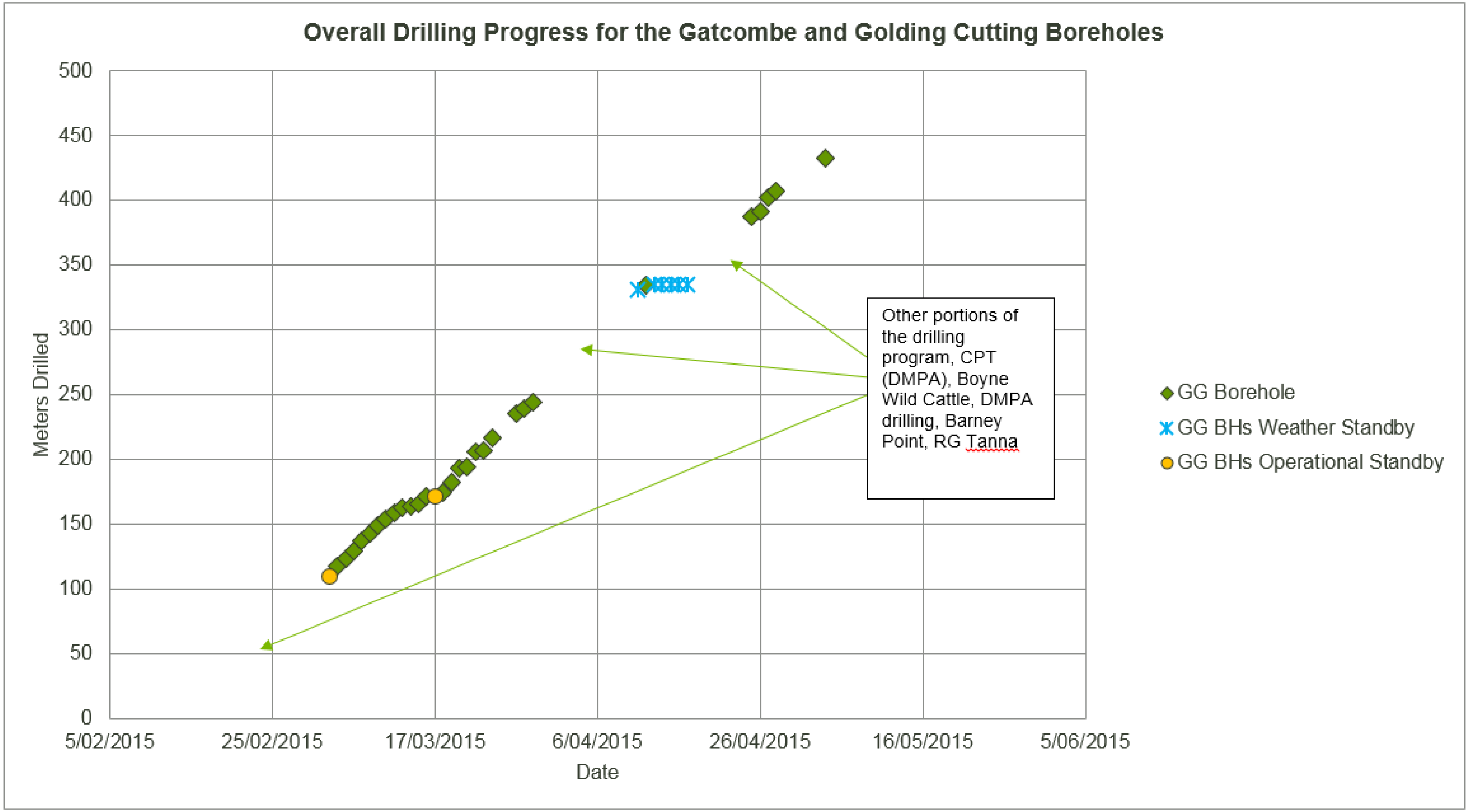

Figure 6 **Overall drilling progress for the program of work within the Gatcombe and Golding Cutting Channels**

4 Investigation methodology

4.1 General

Aurecon engaged J&S Drilling to perform the offshore drilling investigation, with Aurecon site staff being present throughout and responsible for detailed logging of the recovering of soil and drill core, recording in situ testing and sampling, boxing of recovered drill core and core photography. In addition, the Aurecon site engineers supervised and operational procedures, including positioning of the barge.

A total of twenty three (23) boreholes were completed as part of the Gatcombe and Golding Cutting Channels investigation as per the proposed schedule.

The as constructed borehole locations as executed on site are presented in Table 3. Borehole coordinates were adjusted from the design locations for the following reasons:

- Undulated seabed terrain creating difficulty in positioning the barge in equilibrium

Borehole locations were typically drilled within 5 m of the design locations.

The target depth for boreholes within the area to be dredged was approximately – 20.1 m LAT, which corresponds to a depth of approximately 4.0 m below the design dredging elevation of -16.1 m LAT.

Table 3 “As Constructed” borehole locations and depths

Hole	Date Start	Date End	Easting	Northing	Seabed elevation (m LAT)	Drill length (m)	Terminated Elevation (m LAT)
GG01	10/03/2015	10/03/2015	329925	7361168	-15.88	5.45	-21.33
GG02	9/03/2015	9/03/2015	330075	7360493	-14.68	5.45	-20.13
GG03	11/03/2015	11/03/2015	330515	7360727	-15.82	4.45	-20.27
GG04	12/03/2015	12/03/2015	330849	7359825	-15.78	5.00	-20.78
GG05	28/03/2015	28/03/2015	331634	7359105	-15.83	4.40	-20.23
GG06	12/04/2015	12/04/2015	331817	7358848	-16.60	4.10	-20.7
GG07	13/03/2015	13/03/2015	331983	7359234	-15.51	4.45	-19.96
GG08	29/03/2015	29/03/2015	332059	7358667	-15.32	5.00	-20.32
GG09	27/03/2015	27/03/2015	332210	7359111	-16.24	4.00	-20.24
GG10	15/03/2015	15/03/2015	332794	7357961	-15.67	3.45	-19.12
GG11	14/03/2015	15/03/2015	333014	7357653	-15.85	3.45	-19.3
GG12	4/03/2015	5/03/2015	333676	7357110	-12.48	8.00	-20.48

Hole	Date Start	Date End	Easting	Northing	Seabed elevation (m LAT)	Drill length (m)	Terminated Elevation (m LAT)
GG13	6/03/2015	6/03/2015	334779	7356449	-14.48	6.00	-20.48
GG14	7/03/2015	7/03/2015	335215	7356006	-14.29	6.00	-20.29
GG15	8/03/2015	8/03/2015	335651	7355914	-12.40	8.00	-20.4
GG16	18/03/2015	19/03/2015	336014	7355503	-9.37	11.00	-20.37
GG17	6/04/2015	6/04/2015	336754	7355240	-11.16	9.13	-20.29
GG18	20/03/2015	20/03/2015	337247	7354771	-9.07	11.00	-20.07
GG19	3/05/2015	4/05/2015	337860	7354580	-9.90	9.34	-19.24
GG20	27/04/2015	28/04/2015	338299	7354135	-7.53	12.45	-19.98
GG21	21/03/2015	21/03/2015	339397	7353591	-8.19	12.00	-20.19
GG22	25/04/2015	26/04/2015	340172	7352923	-8.59	12.00	-20.59
GG23	23/03/2015	24/03/2015	340829	7352705	-9.01	11.45	-20.46

A borehole location plan is provided in Appendix A of this report.

4.2 Jack-up barge and drilling program

The geotechnical investigation comprised a series of boreholes all drilled within the Port of Gladstone from a Jack Up Barge (JUB). A series of in situ tests comprising Standard Penetration Tests (SPTs) were carried out at regular intervals. Samples were recovered from the SPT testing and from drilling. Samples were strategically selected for geotechnical laboratory testing and transported to a NATA accredited laboratory in Brisbane.

Personnel were transferred to the barge from Gladstone Marina by the support vessel MV Alkira operated by Fodico and subcontracted to J&S Drilling to undertake the support duties for the drilling program. The MV Alkira was also subcontracted to J&S Drilling to tow the JUB to each borehole location.

The overall field investigation commenced on Friday 13 February 2015 and comprised forty four (44) boreholes and 12 cone penetration tests (CPT). The fieldwork was completed on Tuesday 19 May 2015. This report details the 23 boreholes completed for the Gatcombe and Golding Cutting Channel portion of the drilling program.

The J&S JUB is a modular 4 legged jack-up platform with a total deck load capacity of approximately 44 tonnes. Once in position over a borehole, the barge is jacked up to its operational height above sea level. Operational height is determined by tides and prevailing sea state conditions. In general, the barge is jacked up to have a 1 m air gap during high tide to account for waves. This relatively small air gap was chosen due to the sheltered harbour location, although the barge could be jacked higher during stormy conditions to account for prevailing sea state and surge conditions when necessary. The JUB was equipped with an Edson 3000 G rotary drilling rig, along with portable storage facilities for equipment and consumables. A photograph of the Ocean Driller 2 JUB is presented below in Photograph 1. Select photographs from the investigation, including JUB and location, are provided in Appendix D.

Photograph 1 **View of the J&S Jack up barge "Ocean Driller II"**

4.3 JUB positioning and reduced level determination

The predetermined coordinates for each borehole position were input into a Real Time Kinetic (RTK) Global Positioning System (GPS) on the barge, into a handheld stored GPS operated by the skipper of the accompanying tug boat, and into a smaller handheld GPS controlled by the Barge Master. When moving to a new borehole location, the tug towed the barge toward the borehole location using the GPS to maintain the correct heading. During this process, the Barge Master was in constant radio contact with the tug, verifying the movement with his handheld GPS. Once over the borehole position, the JUB legs were lowered from the barge and the barge is then jacked-up just above the buoyancy level.

The position was verified through the Barge Master's GPS and the on-board RTK GPS. The ability to close in on the required location was heavily dependent on the weather conditions, the tug captain's skill and tug's capabilities. The majority of the borehole positions were within 5 m of the proposed location.

Once all measurements were recorded, the seabed level could be calculated. This was achieved by subtracting the recorded table height and deck to seabed measurements, from the RTK GPS height. The RTK GPS value is given in Australian Height Datum (AHD) and therefore the calculated value had to be converted into Lowest Astronomical Tide (LAT). The elevation of AHD above the LAT varies depending on site location and the value of 2.21 m was adopted for this conversion. Depths to seabed and deck to water were measured with a lead line lowered inside the placed drill casing.

Figure 7 presents a depiction of the relevant measurements required to determine the seabed RL during the offshore investigation.

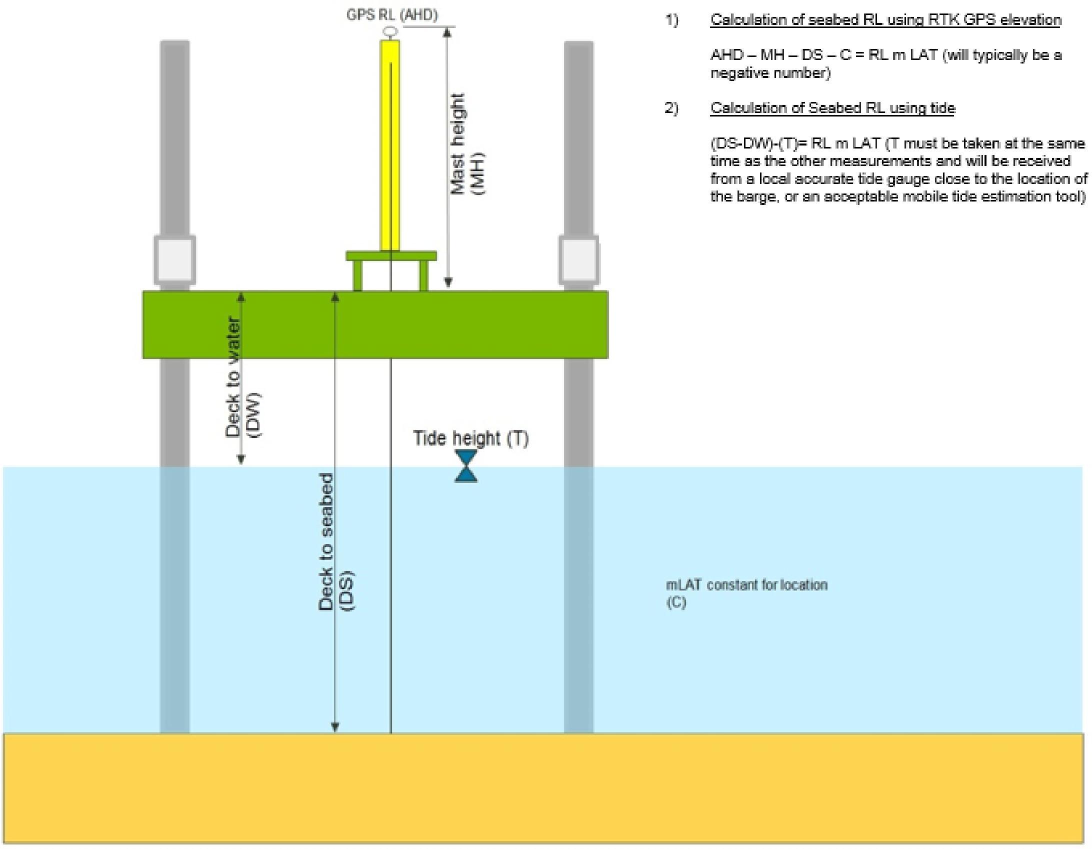

Figure 7 **Description of required levels to determine seabed RL during overwater drilling**

4.4 Drilling methodology

Drilling consisted of lowering 150 mm outside diameter casing on to the seabed and drilling through the casing with a PQ3 (140 mm) size bit. The large diameter outer casing was pushed into the loose surface sediments and generally sunk under its own weight until firmer material was encountered. The inner and outer PQ3 casing, armed with a diamond drill bit was lowered to the seabed after an initial SPT test was taken at seabed level. The coring used water circulation to lubricate the cutting surface of the bit which tended to wash away any soft / loose material collected in the outer casing.

The inner core barrel was lowered to the bottom of the PQ3 casing where it was mechanically locked in place. The PQ3 casing was advanced an additional distance until just above where the next SPT test was taken which equates to the total length of the inner core barrel. Following the 1.0 m run, the core barrel was retrieved from the bottom of the PQ3 casing using a wire line winch system. PQ3 drill bits produce rock core with a diameter of 83.6 mm. The core collected on the previous run was only extruded from the barrel with water pressure from the on board water pump when rock was encountered, otherwise soils were gently removed from the splits and processed (ie logged, photographed, wrapped and stored).

Core recovery in marine sediments was variable and dependent on the nature of the sediment encountered. Where fine-grained sediment was present, recovery was typically good but in coarser sand and gravelly material, recovery tended to be poor. Core recovery in weathered rock was again variable due to the presence of weak layers and fractured rock. Recovery generally improved with depth.

Intact soil and rock core was logged, photographed, wrapped in plastic, sealed in core boxes and transferred to the tug boat and brought ashore for storage. Hand written logs were produced at the time of drilling, recording all relevant details, including:

- Drilling methods, elevation referenced to LAT
- Details of colour, plasticity or particle characteristic and consistency
- Comments on sampling and in situ testing
- Rock descriptions including: weathering, colour strength, jointing and structure
- Estimation of rock strength, Rock Quality Designation (RQD) and defect spacing
- Defect description including depth, type, angle, roughness and infill

4.5 In situ testing and undisturbed sampling

Standard Penetration Tests (SPTs) were undertaken in accordance with AS 1289.6.3.1 within the marine sediments, typically at seabed level and at 0.5 to 1.0 m intervals thereafter. SPT samples recovered from the test spilt spoon were sealed in airtight bags, labelled and stored on board the JUB before transfer to storage or the geotechnical laboratory.

Undisturbed tube (U63) or piston tube samples were taken when suitable sediments were encountered, and where this sampling technique was successful, samples were scheduled for subsequent laboratory testing.

Borehole logs and core photographs are provided in Appendix B of this report.

5 Laboratory testing

5.1 Introduction

Geotechnical laboratory testing was scheduled on selected samples of sediment retrieved from the boreholes throughout the drilling operation by Aurecon Engineers, following logging and photographing the core boxes. The selected samples were shipped to a NATA accredited geotechnical testing laboratory (Tri Labs) in Brisbane. The laboratory testing certificates as well as summary plots of the test results for the Gatcombe and Golding Cutting boreholes are presented in Appendix D of this report. A discussion of the results of the testing is included in Section 6.

The following tests were undertaken on sediment samples:

- In situ moisture content
- Atterberg limits
- Linear shrinkage
- Particle Size Distribution or Grading (both sieved and hydrometer)
- Particle density
- Triaxial Testing (UU)

Details of the type, Australian Standard used, and number of samples for each geotechnical laboratory test is presented in Table 4.

Table 4 Laboratory testing summary

Laboratory Test	Australian Standard	Number of Tests Scheduled
Moisture content	AS 1289.2.1.1	74
Atterberg limits	AS 1289 3.1.1, 3.1.2, 3.2.1, 3.3.1	28
Linear shrinkage	AS 12893.3.4.1	28
Particle size distribution (wet sieve method)	AS 1289.3.6.3, 3.5.1, 6.6.1	47
Particle size distribution (hydrometer method)	AS 1289.3.6.3,3.5.1	11
Particle density	AS 1289.3.5.1	11
Triaxial Test	AS1289.6.4.1	7

In addition to the laboratory tests, in situ testing in the form of Standard Penetration Tests (SPTs) were performed in accordance with AS1289.6.3.1 at regular intervals within each borehole. Where predominantly cohesive material was encountered, undisturbed U63 tube samples were retrieved instead of performing SPT tests. Pocket penetrometer testing was undertaken within the base of each U63 tube to provide an indication of shear strength of the sample.

5.2 Geotechnical laboratory testing results

This section summarise the finding of the geotechnical results.

All test certificates are provided in Appendix E.

5.2.1 Atterberg limits and linear shrinkage

Atterberg Limit tests are used to assist in classification of cohesive (silt and clay) materials. The classification and behaviour of the tested sample has been used to assist in the generation of the generalised geological model of the site area to be dredge.

The results of the Atterberg Limits tests are presented in Table 5.

Table 5 Atterberg limits summary

Borehole Number	Depth (m LAT)	Material (as described in logs)	Atterberg Limits (%)			Linear Shrinkage%	USC Classification of tested sample
			LL	PL	PI		
GG-03	-17.82	Clayey SAND	26	18	8	3.5	CL
GG-06	-18.10	Sandy CLAY	38	15	23	10.5	CI
GG-07	-17.51	Silty CLAY	37	18	19	11.5	CI
GG-09	-18.24	Silty CLAY	36	16	20	9.5	CI
GG-11	-15.85	Silty CLAY	47	18	29	13	CI
GG-14	-15.29	Silty CLAY	49	21	28	15.5	CI
GG-14	-17.29	Silty CLAY	61	23	38	17.5	CH
GG-15	-17.40	Clayey SAND	38	16	22	9.5	SC
GG-16	-11.37	Silty CLAY	32	17	15	6.5	CL
GG-16	-14.32	Silty CLAY	42	15	27	11	CI
GG-17	-12.16	Silty CLAY	60	20	40	17.5	CH
GG-17	-13.16	Silty CLAY	63	20	43	18.5	CH
GG-17	-14.16	Silty CLAY	42	16	26	-	CI
GG-18	-11.07	Silty CLAY	52	22	30	15.5	CH
GG-18	-13.07	Silty CLAY	69	23	46	19.5	CH
GG-18	-15.07	Silty CLAY	65	21	44	20	CH
GG-18	-19.07	Silty CLAY	22	14	8	4	CL
GG-19	-10.90	Silty CLAY	47	18	29	17.5	CI
GG-19	-13.90	Silty CLAY	48	20	28	15	CI
GG-20	-7.53	Silty CLAY	37	18	19	11.0	CL
GG-20	-11.53	Silty CLAY	38	16	22	10.5	CI
GG-20	-14.53	Silty CLAY	36	17	19	11.5	CI

Borehole Number	Depth (m LAT)	Material (as described in logs)	Atterberg Limits (%)			Linear Shrinkage%	USC Classification of tested sample
			LL	PL	PI		
GG-21	-10.19	Silty CLAY	48	19	29	14	CI
GG-21	-14.19	Silty CLAY	54	22	32	15.5	CH
GG-22	-10.59	Silty CLAY	40	16	24	12.5	CI
GG-22	-12.59	Silty CLAY	41	16	22	11.5	CI
GG-22	-14.59	Silty CLAY	38	16	22	11	CI
GG-23	-16.01	Silty CLAY	32	17	15	8	CL

The Atterberg test results indicate that the majority of the cohesive material encountered within the Gatcombe and Golding Cutting Channels boreholes are composed of low to medium plasticity clays. High plasticity clay was observed in only seven samples of the 28 cohesive samples tested. These high plasticity clays observed within the proposed dredging depth and were isolated to only three boreholes (ie GG17, GG18 and GG21).

The overall plasticity of cohesive materials varied greatly between the Gatcombe and Golding Cutting Channels are to be dredged, with the Gatcombe Channel footprint having minor amounts of cohesive material which was typically low to medium plasticity. The Golding Cutting Channel area to be dredged contained a much larger percentage of cohesive material which ranged from low to high plasticity associated with "Layer 1".

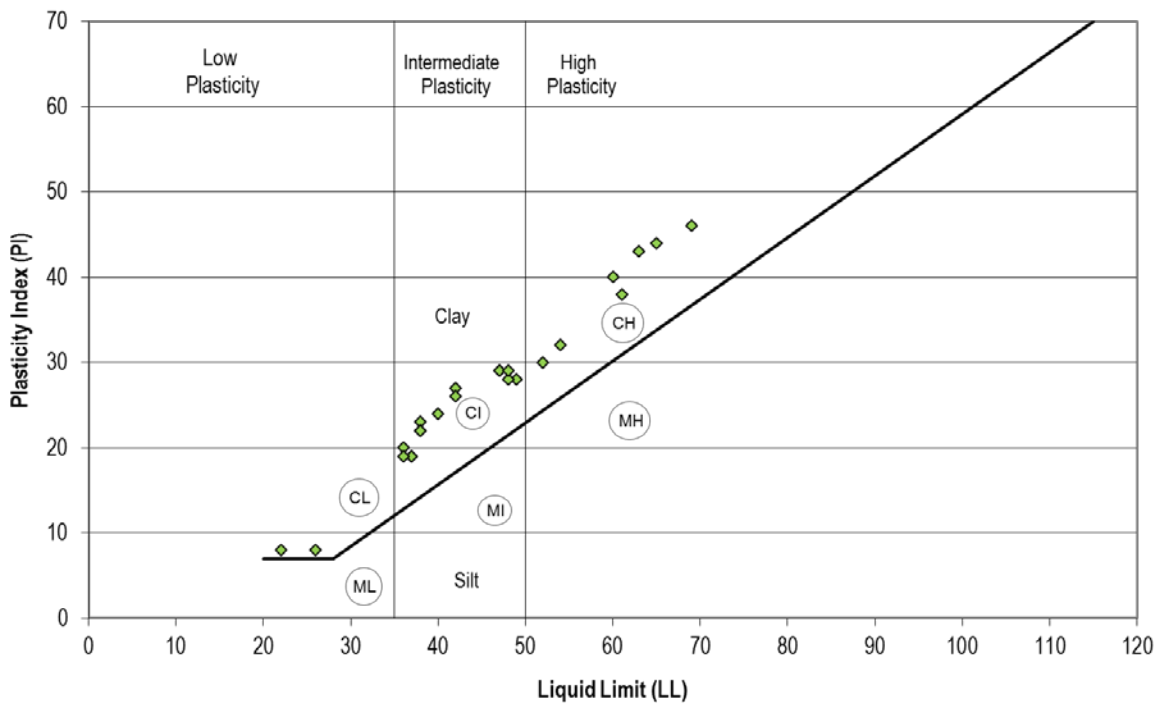

Figure 8 **Combined Atterberg limits results from Gatcombe and Golding cutting channels**

Figure 8 to Figure 10 present the Atterberg results split between the two channels that require dredging, and a combined plot showing all of the results. Fewer tests were sampled for Atterberg testing in the Gatcombe Channel due to the high percentage of non-cohesive material encountered.

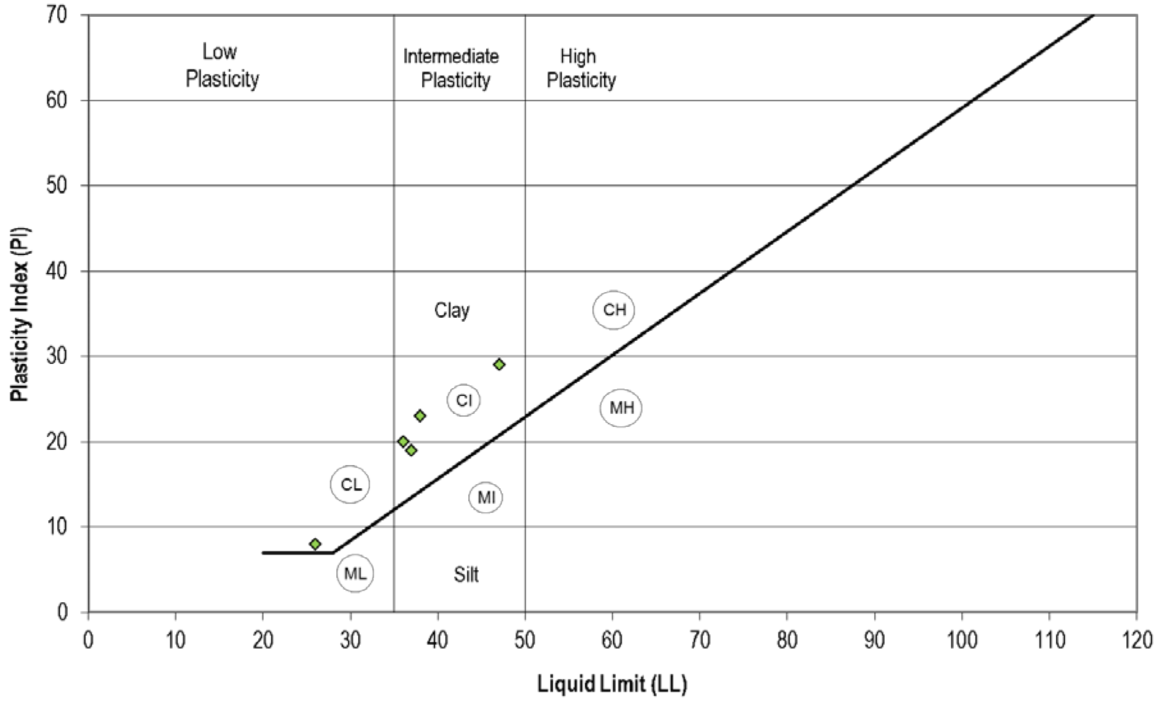

Figure 9 Atterberg results from the Gatcombe Channel

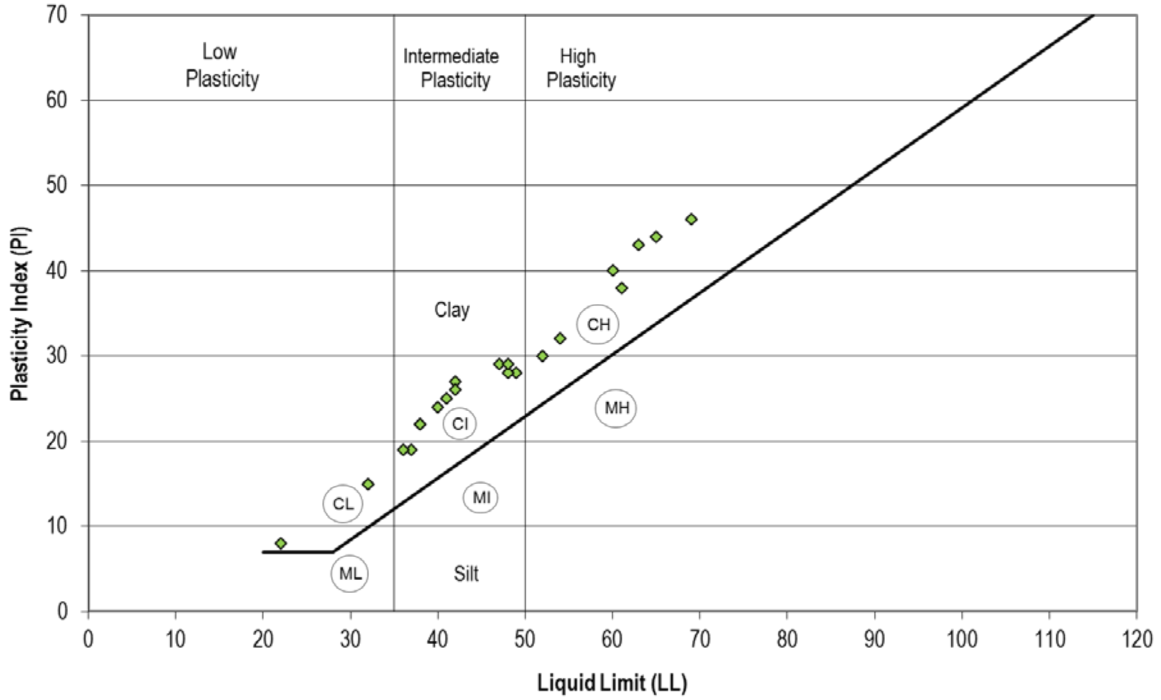

Figure 10 Atterberg results from the Golding Cutting Channel

It should be noted that the majority of the high plasticity results were obtained from only three boreholes (ie GG17. GG18 and GG21) indicating an isolated zone of highly plastic clay.

5.2.2 Particle size distribution

Particle Size Distribution (PSD) tests were used to assist with the classification of cohesive and non-cohesive materials. PSD tests were performed on SPT, core and "undisturbed" U63 samples typically using the wet sieve method. Where the fines content of a sample was judged to be sufficiently high, hydrometer tests were performed.

The section below summarises the results of the PSD testing with respect to the Gatcombe and Golding Cutting Channel. Test certificates are provided in Appendix D.

5.2.2.1 Gatcombe Channel

Figure 11 shows the grading results from two samples of cohesive material taken from within the Gatcombe Channels. The results clearly demonstrate that clays and silts are present within the soil profile in this area.

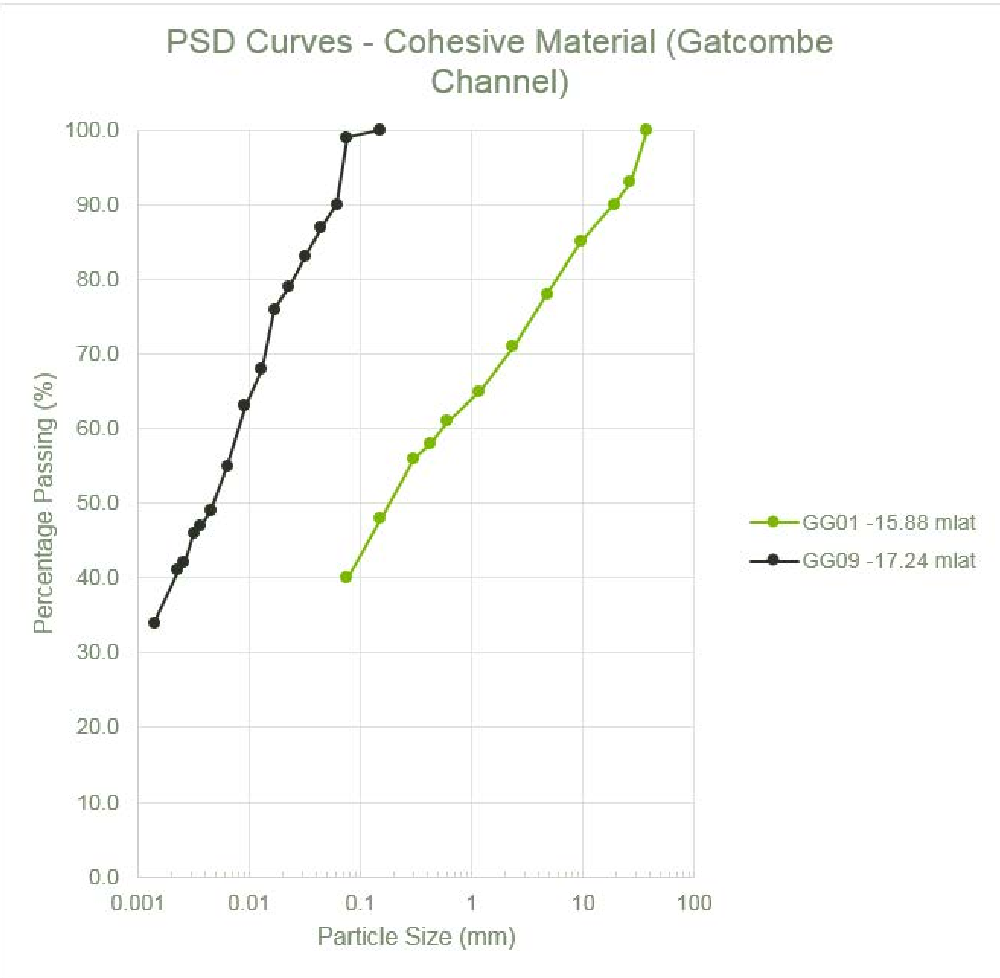

Figure 11 PSD graph of cohesive material tested within the Gatcombe Channel

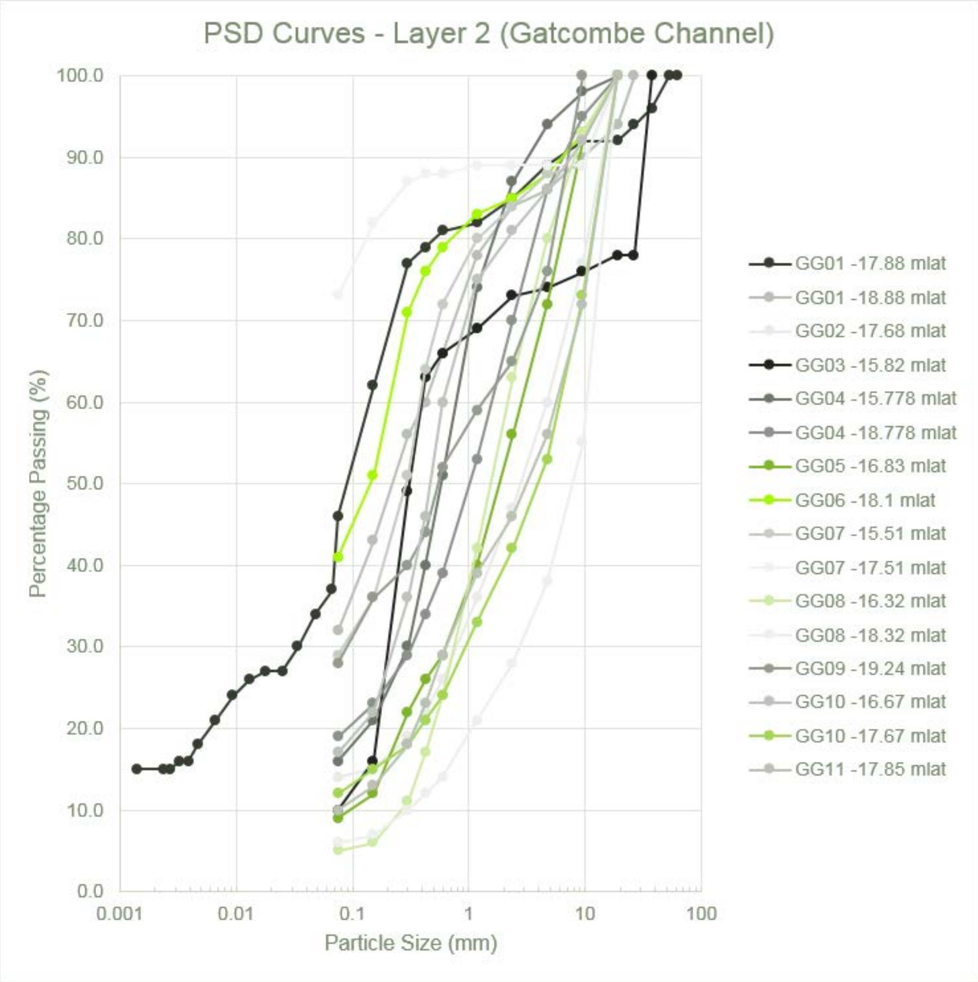

Figure 12 PSD graph showing the particle size variations in Layer 2, principally sand, within the Gatcombe Channel

For the Gatcombe Channel, the PSD results indicate that Layer 2 predominantly consists of sand, with a notable gravel content varying on average between 20 to 40% (Figure 11). Increases in gravel content are generally noted with samples recovered at a lower depth, such as at GG10 and GG11. This may be due to the material transition at the interface of Layer 3.

Some grading results, such as GG07 which is represented on Figure 12 by hollow squares, show a significant fines content. Such results demonstrate the variable nature of the deposits tested and that careful interpretation of the geological model from the borehole is required.

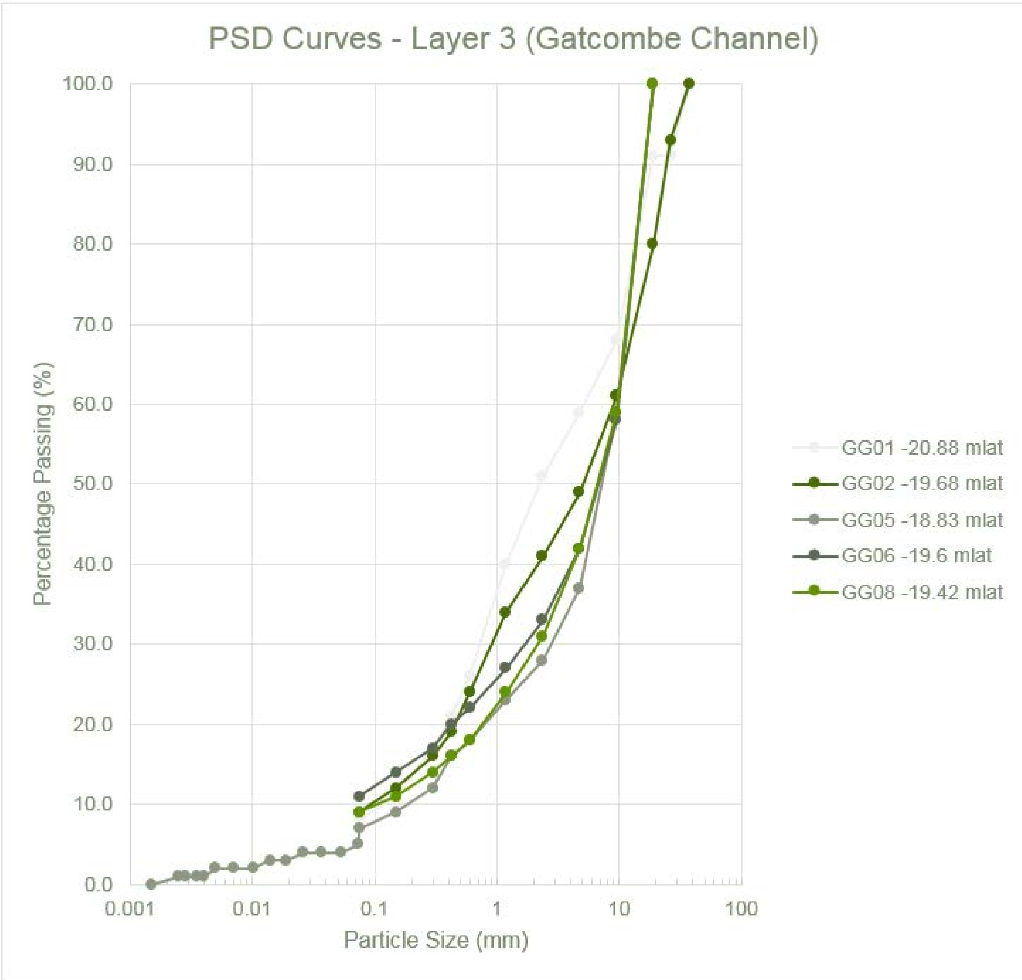

Figure 13 **PSD graph showing the particle size variations in Layer 3, principally gravel, within the Gatcombe Channel**

The results of samples tested from Layer 3 in the Gatcombe Channel show reasonably consistent sandy gravel, with a high gravel content comprising of approximately 50 – 70% of the recovered material (Figure 13).

Similarly, the three PSD tests undertaken in the area of the gravel deposit around borehole position GG12 show good agreement and depict a sandy gravel with some fines (Figure 14).

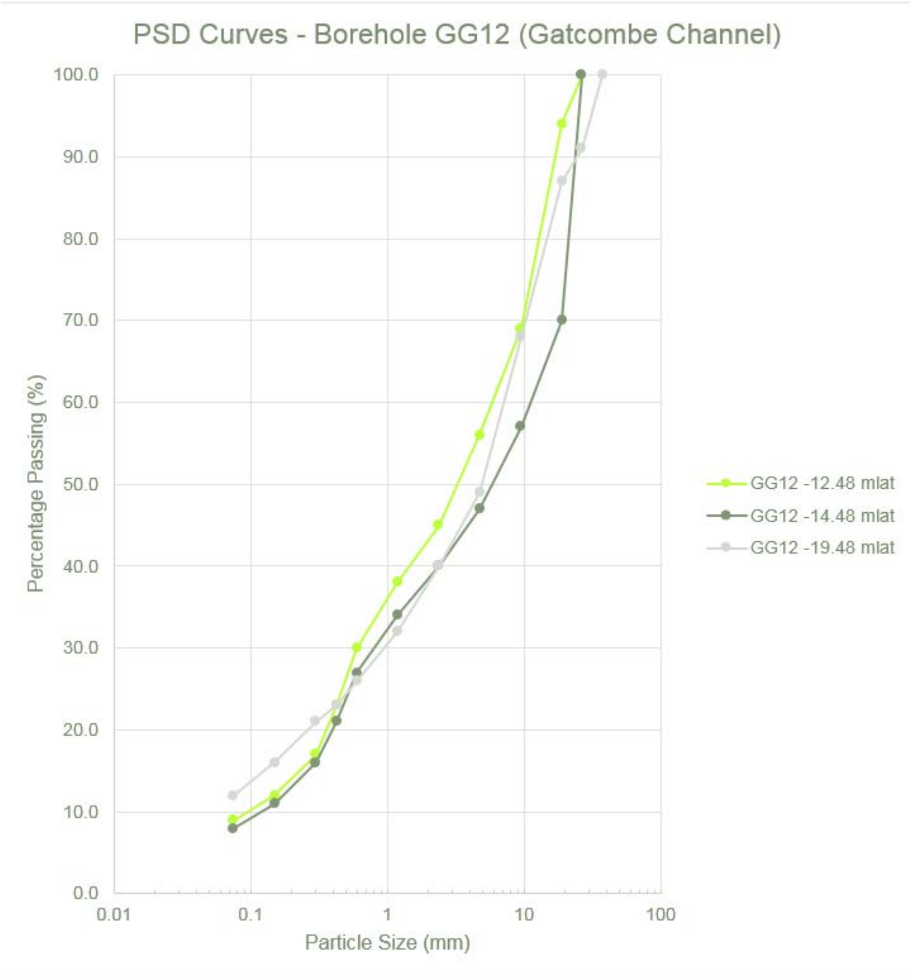

Figure 14 PSD graph showing the particle distribution curves for the gravel deposit at GG12

5.2.2.2 Golding cutting channel

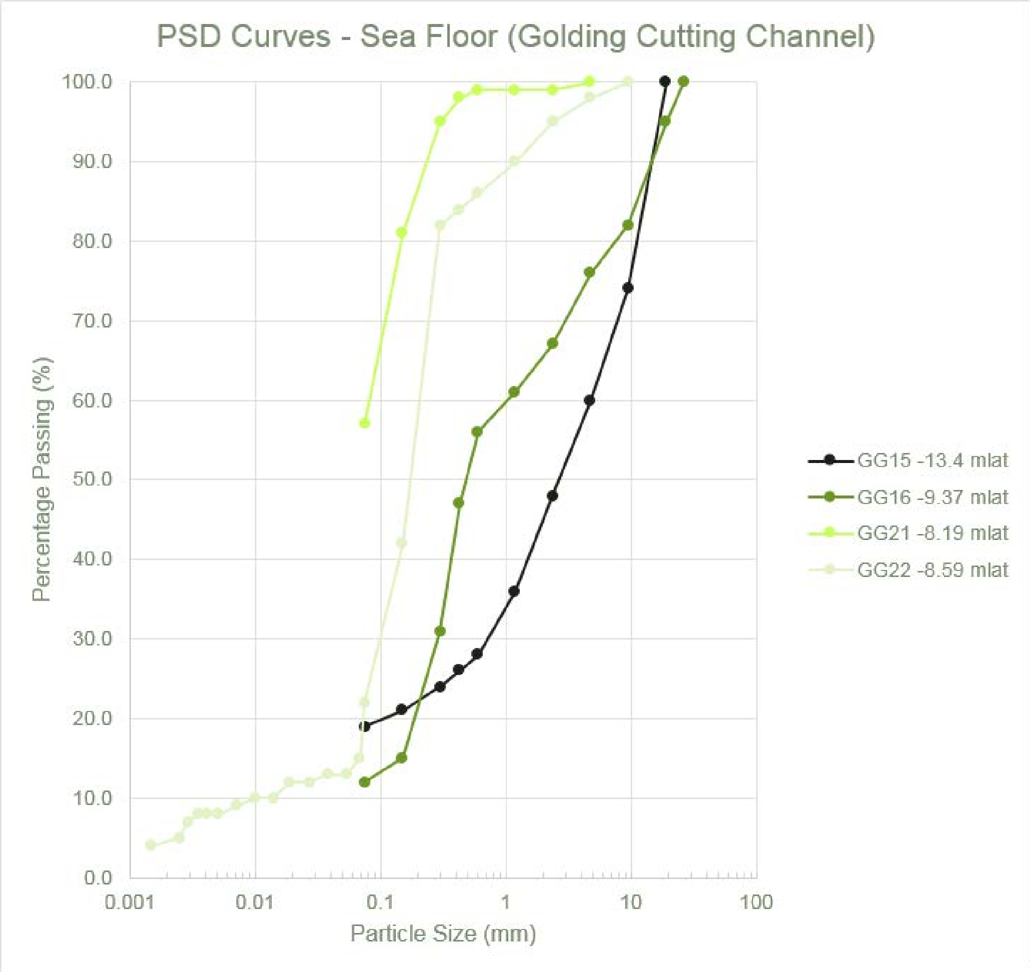

Figure 15 **PSD graph showing the particle distribution curves for the seafloor material within the Golding Cutting Channel**

For both the Gatcombe and Golding Cutting Channels, the PSD results attributed to the surficial seafloor layer (Figure 15) and Layer 1 (Figure 16) show the greatest variation. It is expected this is in part due to sampling bias, with samples collected in the cohesive materials undergoing Atterberg Limits testing, as opposed to PSD testing. Also, increased diversity in material type may be found in the upper layers due to tidal action and the ongoing movement of surficial sediments.

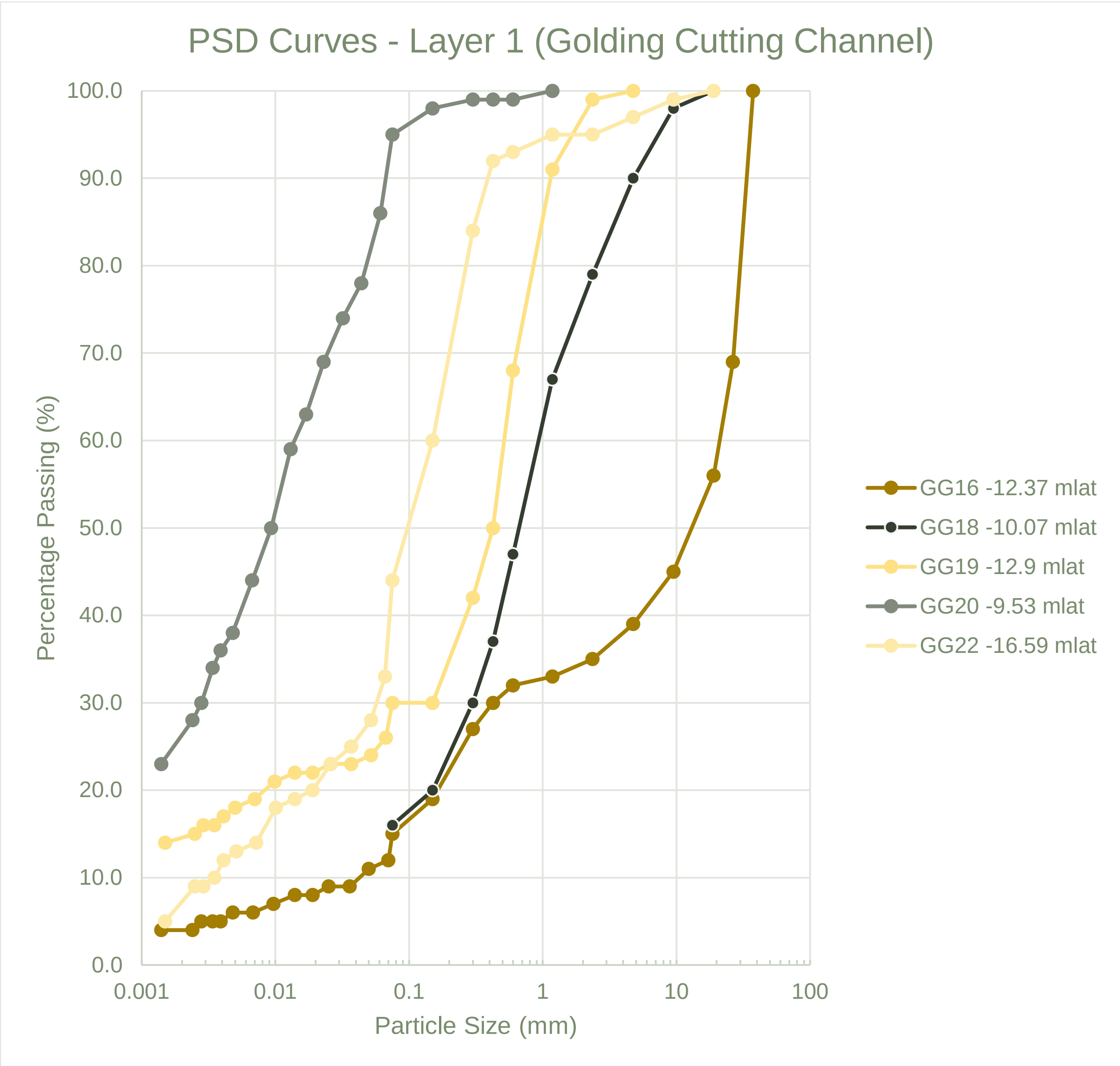

Figure 16 **PSD graph showing the particle distribution curves for Layer 1 within the Golding Cutting Channel**

In terms of the Golding Cutting Channel, the Layer 2 PSD graphs prove that in general this material comprises sand (Figure 17). The gravel content in the Golding Cutting Channel is, however, found to be reduced when compared to the results from the Gatcombe Channel.

A notable outlier in the Golding Layer 2 results is observed at GG18 (-18.07 m LAT). This is due to a zone of sandy clay observed within the stratigraphy at that location.

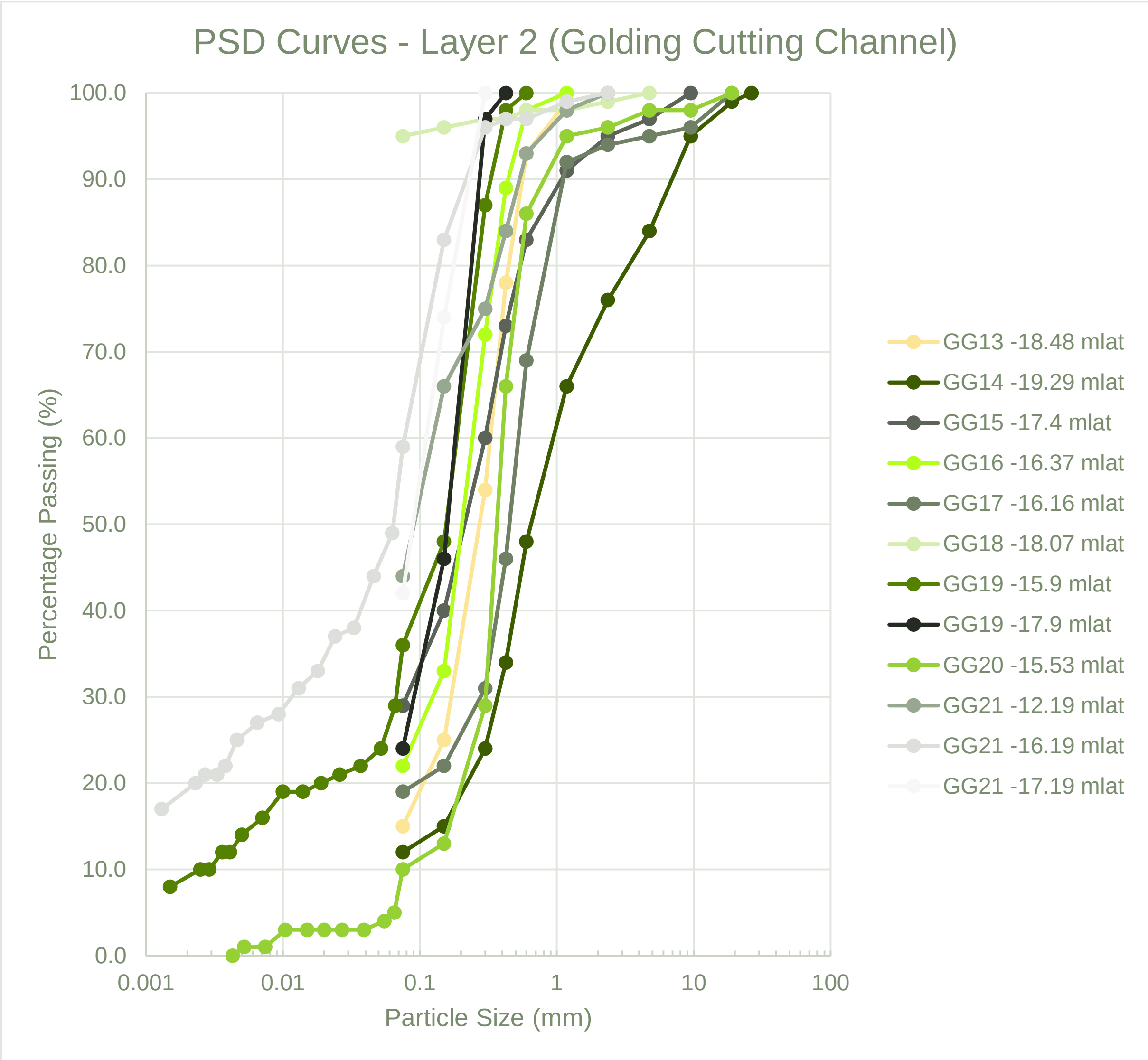

Figure 17 **PSD graph showing the particle distribution curves for Layer 2 within the Golding Cutting Channel**

Layer 3 within the Golding Cutting Channel, while still considered to be predominantly gravel, also demonstrates a similar reduction in gravel content and a higher percentage of both sand and fines (Figure 18).

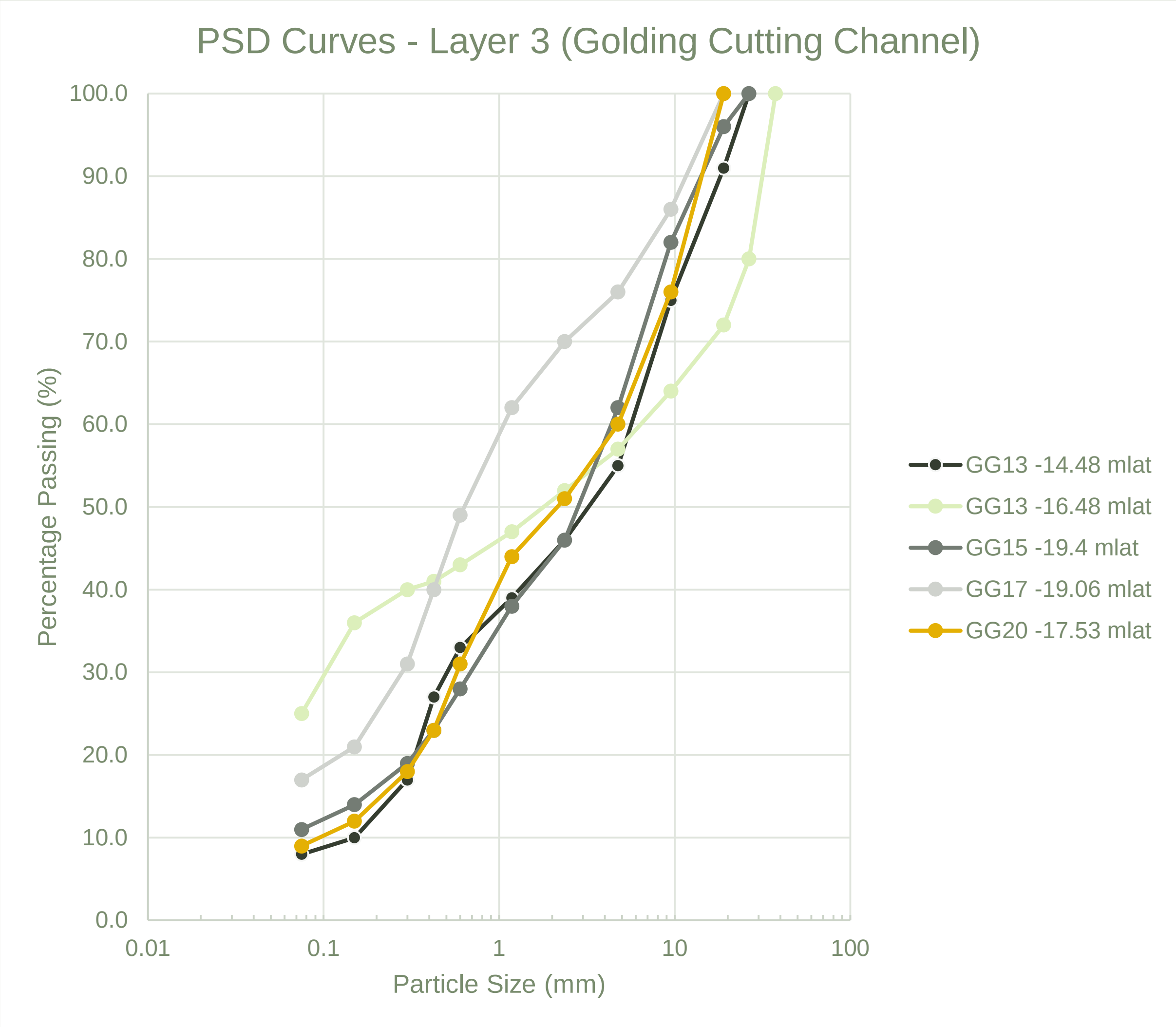

Figure 18 **PSD graph showing the particle distribution curves for Layer 3 within the Golding Cutting Channel**

On the basis of this analysis, the results of the PSD results in the Gatcombe and Golding Channels is therefore shown to correspond with the interpreted geological section.

5.2.2.3 Triaxial testing (UU)

Triaxial testing is used to estimate the in situ strength of silts and clays. Triaxial testing was done in the form of single stage, unconsolidated undrained (UU) tests. The results of these triaxial tests are presented in Table 6.

Table 6 **Triaxial unconsolidated undrained (UU) test results.**

BH ID	Elevation (m LAT)	Material Type/Description		Moisture Content (%)	Dry Density (t/m3)	Confining Pressure (kPa)	Deviator Stress at Failure (kPa)	Strain at Failure (%)
GG-14	-16.29	Silty CLAY	Mottled grey/brown	22.6	1.67	120	339	3.51
GG-16	-12.37	Sandy Silty CLAY	Dark grey	37.3	1.33	120	66	3.88
GG-18	-14.07	Silty CLAY	Mottled grey-brown	24.1	1.63	120	257	5.63

BH ID	Elevation (m LAT)	Material Type/Description		Moisture Content (%)	Dry Density (t/m3)	Confining Pressure (kPa)	Deviator Stress at Failure (kPa)	Strain at Failure (%)
GG-18	-16.07	Silty CLAY	Brown/grey	20.6	1.75	120	405	6.97
GG-19	-11.90	Sandy Silty CLAY	Mottled grey brown, orange/yellow	17.9	1.81	120	408	14.69
GG-21	-11.19	Silty Sandy CLAY	Mottled grey brown/orange	16.9	1.84	120	339	11.03
GG-21	-15.19	Sandy Silty CLAY	Mottled grey/brown	20.9	1.72	120	296	5.49

5.3 In situ testing results

5.3.1 Standard penetration tests

A total of 162 SPTs were undertaken within the boreholes at typically 1.0 m vertical depth intervals as part of the offshore drilling investigation. The plots shown in Figure 19 to Figure 20 present the SPT "N" value results with respect to depth (m LAT) for the various materials encountered during the investigation.

Figure 19 presents the SPT "N" values for Layer 1 (principally cohesive soils). The test results generally indicate slightly increasing SPT "N" values with depth with results indicating clay consistency to be between very soft (N=<2 blows) and very stiff (N=20 to 40 blows).

Low SPT "N" values of 3, 0 and 0 blows were recorded in borehole GG16 between -11.3 m LAT and 15.3 m LAT. The reason for the presence of this very soft medium plasticity clay is not immediately obvious.

A representative SPT "N" value of between 15 to 25 blows for the Layer 1 material relates to a stiff to very stiff consistency.

Two SPT values greater than 40 blows, representing hard clay or silt (>200 kPa) are also shown on the graph. Of particular significance is SPT result N=52 blows at -13.96 m LAT within GG17. This material was logged as a high plasticity sandy clay, with fine to coarse subangular to subrounded gravel encountered just below the end of the SPT test. This material occurs below the proposed Stage 1 design dredging but will be within the Stage 2 design dredging depth of -16.1 m LAT.

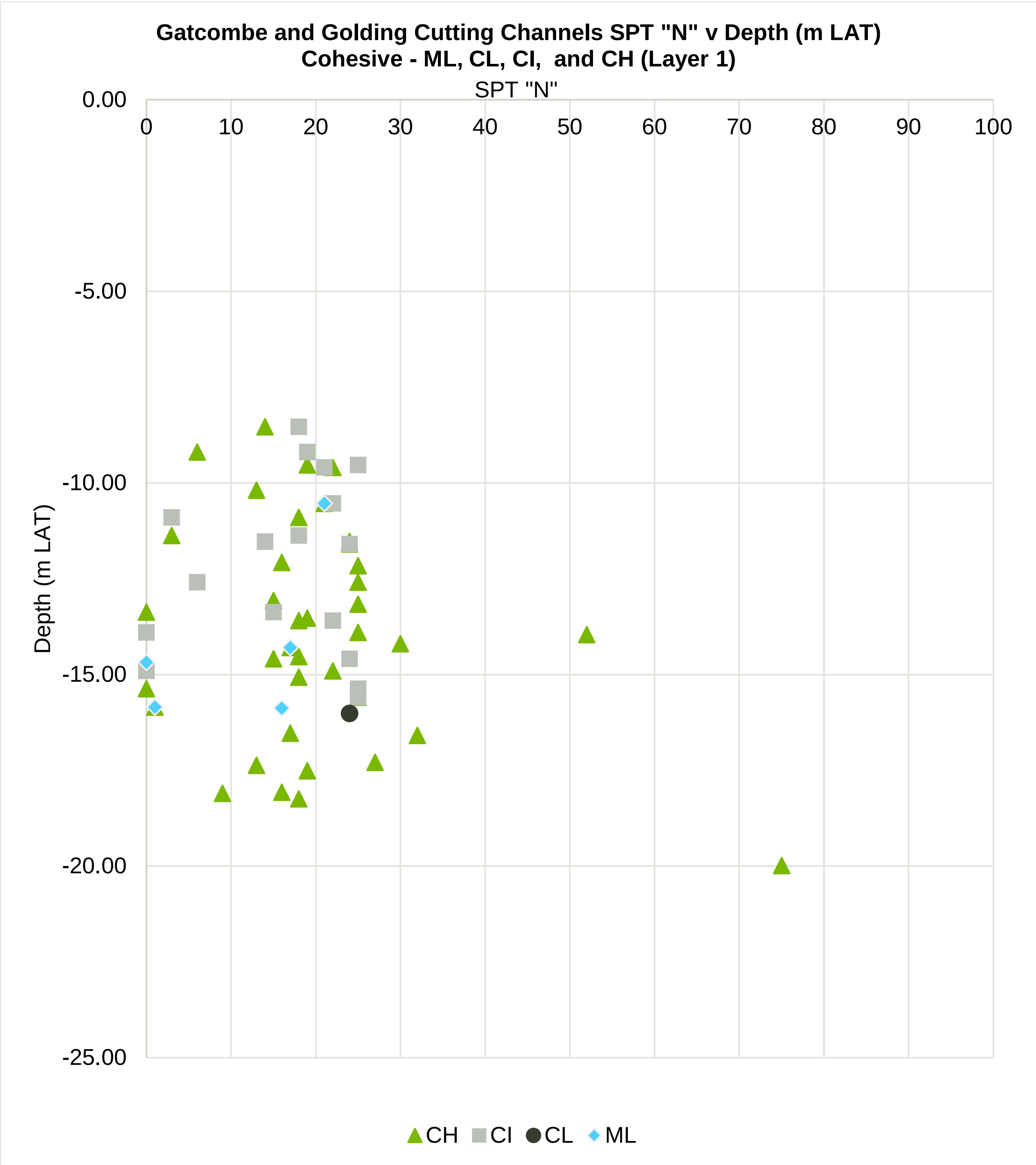

Figure 19 Cohesive soils (Layer 1) SPT “N” v m LAT

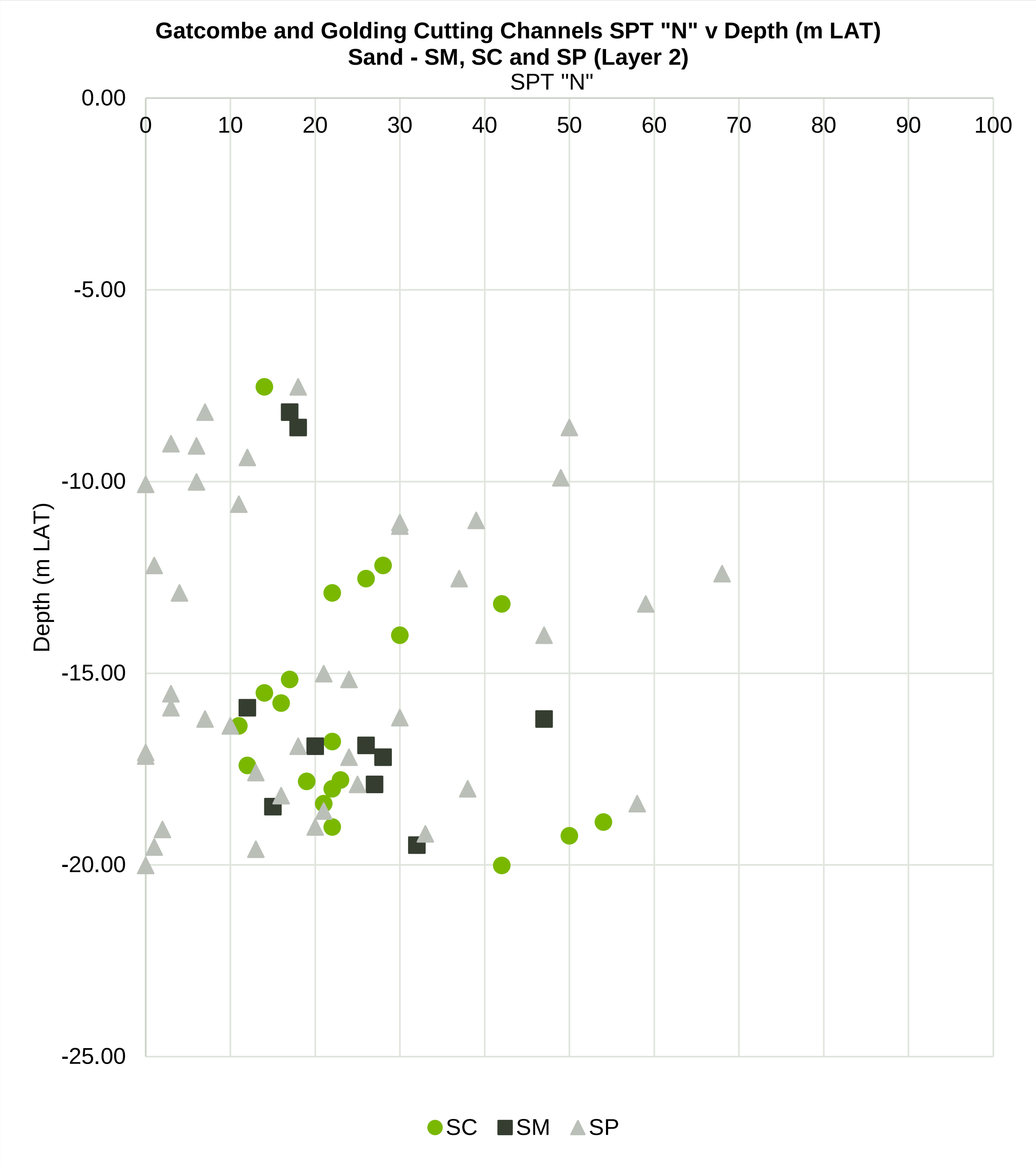

Figure 20 Sand soils (Layer 2) SPT "N" v m LAT

The SPT test results for the predominantly sand Layer 2 material (Figure 20) show that material density generally improves with depth, though a significant proportion of the SP (poorly sorted sand) material was found to be very loose between -15 m LAT and -20 m LAT. The majority "N" values were found within the 10 to 30 blows range (medium dense). The next largest grouping was between 30 and 50 blows (dense).

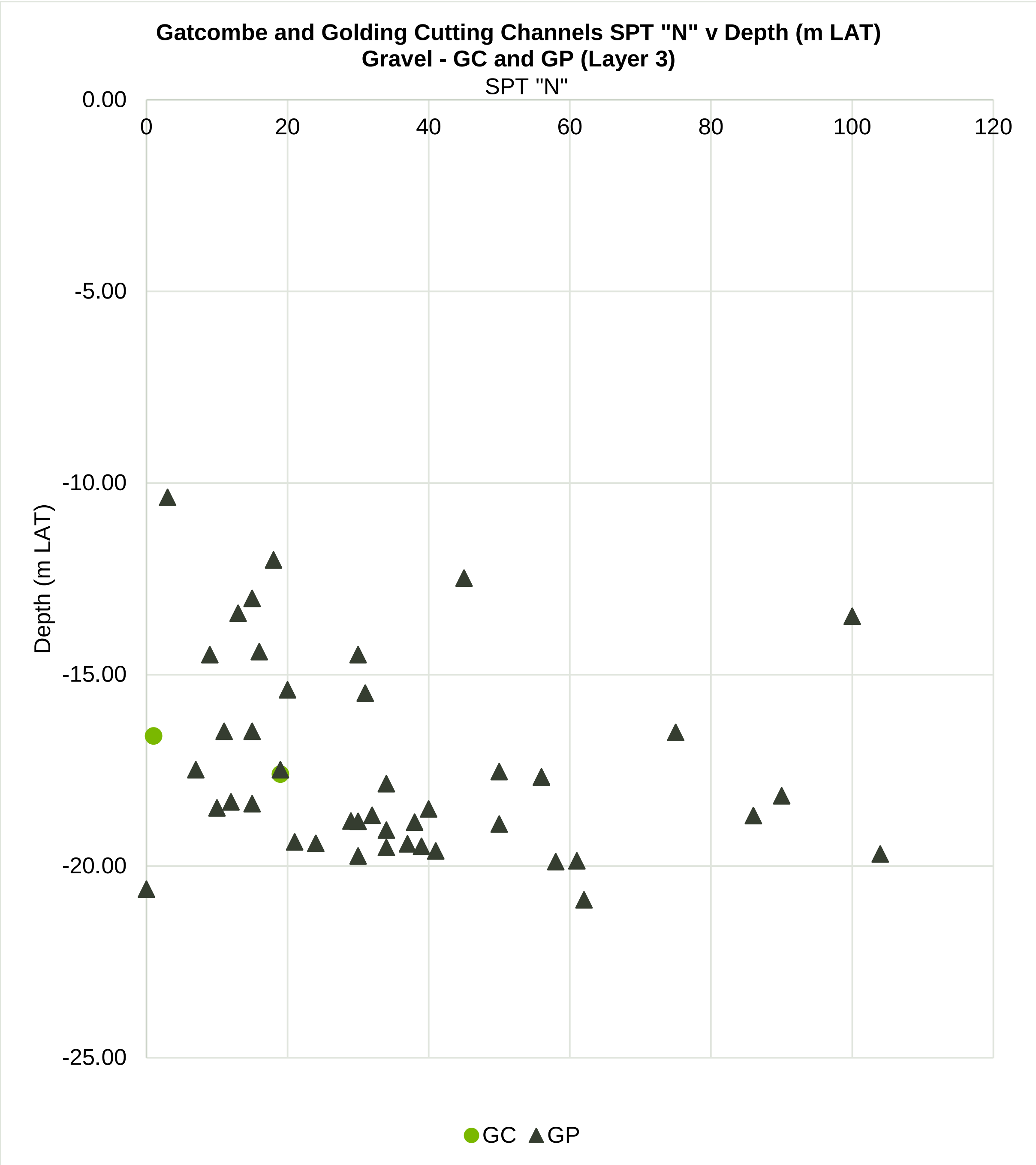

Figure 21 **Gravel soils (Layer 3) SPT "N" v m LAT**

Figure 21 shows that above -17.5 m LAT, the SPT "N" values for the gravel material (Layer 3) were found to be typically medium dense (between 10 and 30 blows), whereas below -17.5 m LAT, the gravel was found to be dense (between 30 and 50 blows) and even very dense (>50 blows).

Several outlying SPT "N" values in excess of 60 blows are likely to be the result of testing a large cobble or boulder and may not truly be representative of the in situ density.

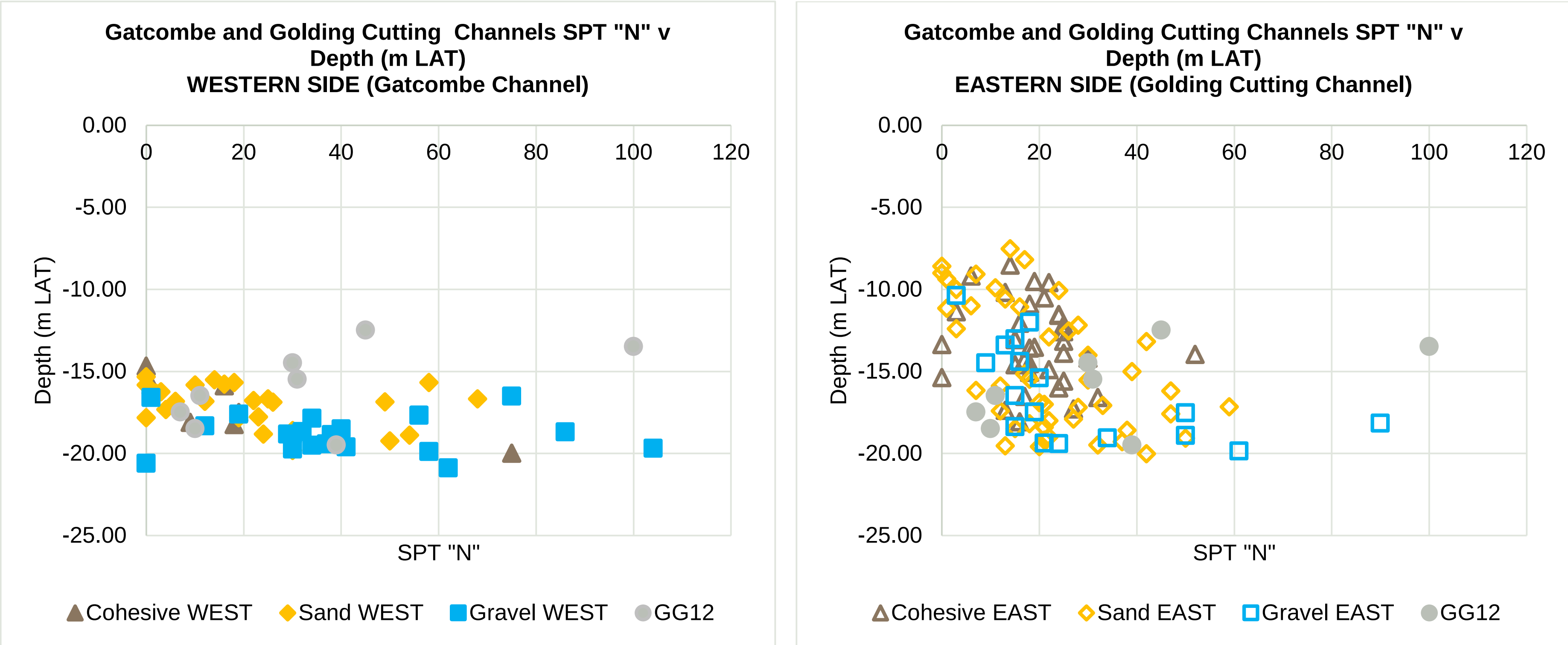

Figure 22 **Gatcombe and Golding Cutting Channels SPT Results v depth (m LAT)**

The above figures compare the SPT “N” values for all material types for both the Gatcombe Channel and the Golding Cutting Channel and the gravel deposit at GG12 (Figure 22). As the sea floor occurs at around -15 m LAT in the Gatcombe Channel, there are no SPT results available. For the Golding Cutting Channel, the sands and clays are typically medium dense and stiff to very stiff, respectively. Results below circa -15 m LAT within each channel are very similar.

5.3.2 Pocket penetrometer tests

Pocket penetrometer tests were conducted in cohesive soils where undisturbed tube samples (U63) or piston samples were taken. The pocket penetrometer test can be used to estimate shear strength of cohesive soils and the results are presented in Figure 23 .

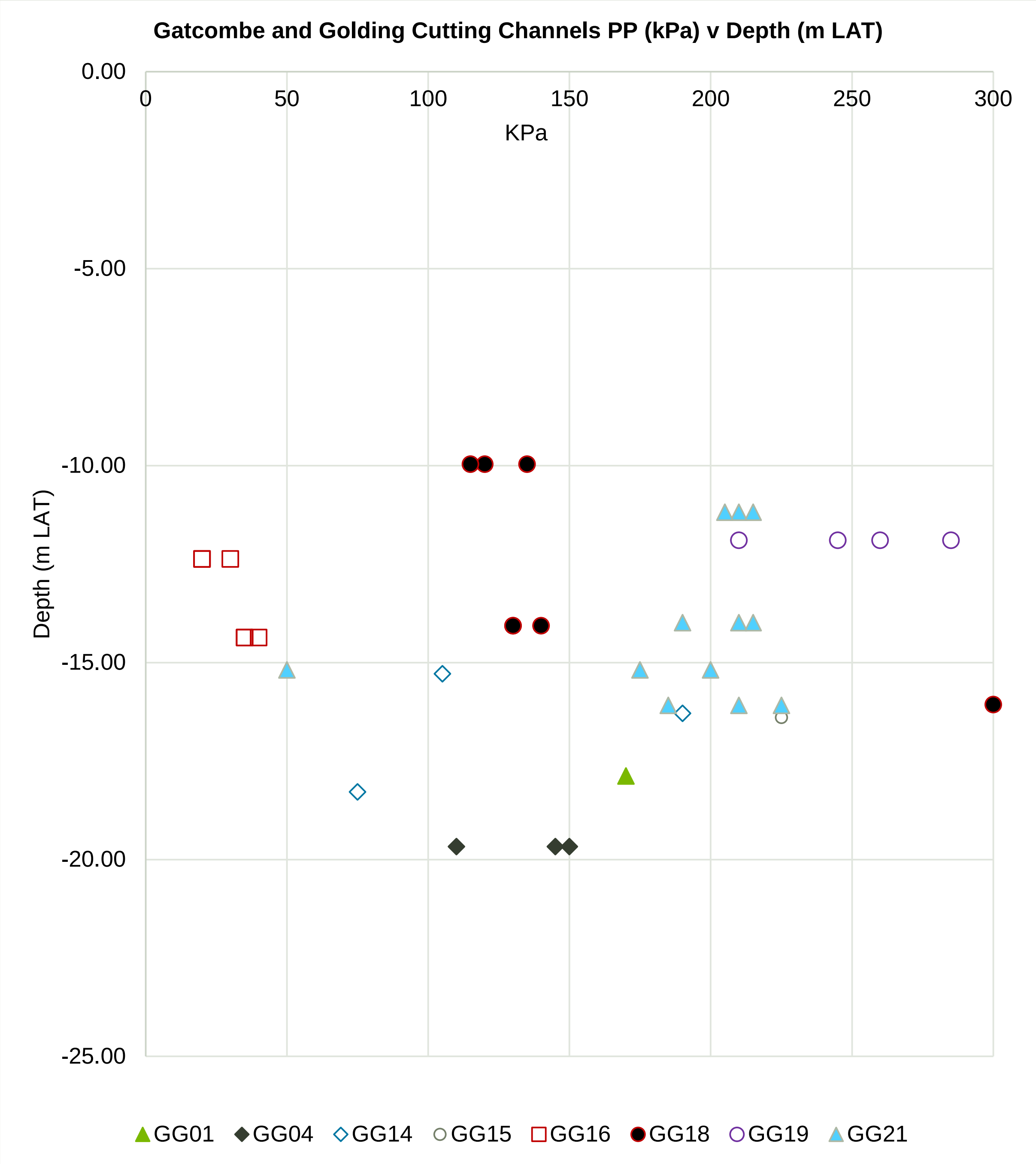

Figure 23 Pocket penetrometer results

The pocket penetrometer results range from 20 kPa within GG16, to 300 kPa in GG18. Whilst being of some value, pocket penetrometer results may be susceptible to influence from sand or gravel particles within the confined tube and should be treated with a degree of caution.

6 Discussion of findings

6.1 Geological model

In general, the results of the intrusive geotechnical fieldwork were consistent with the expected conditions as interpreted from the geological map and the previous reports, that is:

- Holocene soils
- Pleistocene soils
- Bedrock (not encountered in this investigation, but expected at depth)

The Port of Gladstone's dynamic natural fluvial and marine erosional and depositional environment, has resulted in a complex soil profile which makes clear vertical and horizontal delineation, based on soil type, extremely difficult.

An attempt to separate Holocene and Pleistocene soils based on SPT "N" values proved equally difficult as values in excess of 50 blows were encountered at seabed level in some areas, and low values were also reported at depth. That notwithstanding, the majority of SPT "N" values increased with depth.

For the purposes of this report, it is considered that the soils encountered during the investigation are Pleistocene in age, with only the very soft or very loose thin layer of seabed material representing soils of Holocene age.

Despite the complex soil profile, a series of generalised geological sections were produced based on the results of the boreholes, including.

- Section through Gatcombe Channel (north) (1 of 4)
- Section through Gatcombe Channel (south) (2 of 4)
- Section through Golding Cutting Channel (3 of 4)
- Section through Gatcombe and Golding Cutting Channels (4 of 4)

Scaled sections are provided in Appendix E.

6.1.1 Gatcombe channel

Two sections were drawn from the boreholes within this channel, as depicted in (Figure 24) for both northern and southern sections. This was undertaken as several of the boreholes were offset and a single section proved difficult to produce.

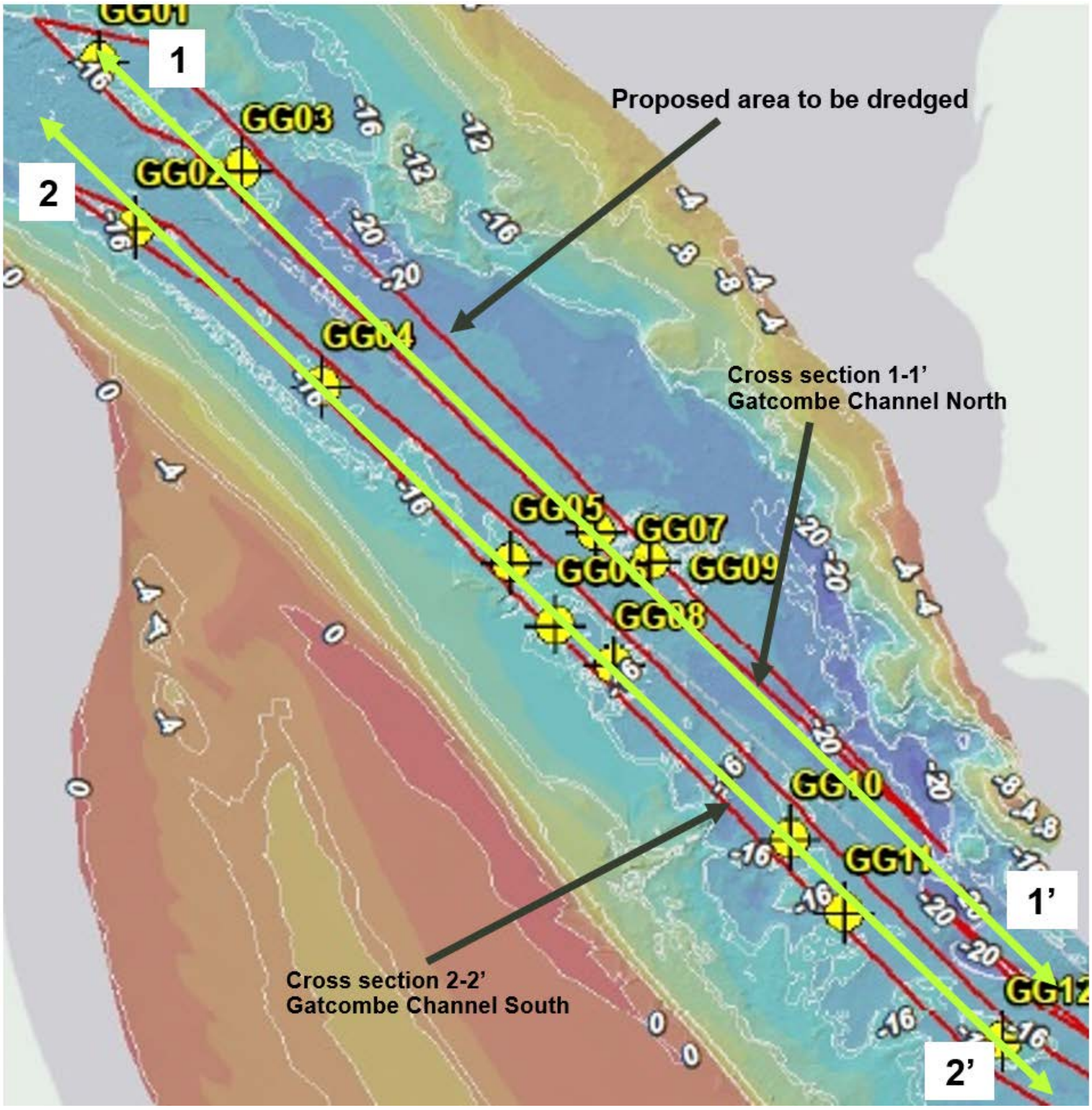

Figure 24 **Plan showing location of sections within the Gatcombe Channel (NTS). Sea floor contours are in m LAT and based on bathymetric data provided by GPC**

The north section includes four boreholes (GG01, GG03, GG07 and GG09) and demonstrates the innate geological variability with respect to clear stratum delineation based on soil type as described earlier. A different soil type was recorded on the seafloor at each borehole location, though the principal constituent of the seafloor in this area was recorded as sand. High plasticity clay and silt was recorded in both GG07 and GG09 from approximately -16.8 m LAT, but these materials were not recorded in GG01 and GG03. Principally, gravelly soil was recorded at the base of the boreholes from -18 m LAT, except for borehole GG03 which comprised sand and clayey sand from seafloor to the base of the borehole at -20.2 m LAT.

Similar to the north section, the south section does not provide clear stratum delineation based on soil type (Figure 25). However it is considered that the eight boreholes (GG02, GG04, GG05, GG06, GG08, GG10, GG11 and GG12) do provide *some* pattern with respect to layering. Typically the sea floor material comprises poorly graded sand, though low plasticity silt was recorded at borehole location GG02 and GG11 and poorly graded gravel recorded at GG06 and GG12. Beneath this top layer, variably dense (loose to very dense), poorly graded sand dominates the profile to a maximum depth of -19.6 m LAT. This sand layer is typically underlain by medium dense to very dense, clayey and poorly graded gravel. Exceptions to this were observed within borehole GG04 where high plasticity clay was recorded circa -19 m LAT between the sand and the gravel, and within borehole GG12 which encountered only loose to very dense poorly graded gravel from to sea bed (-18 m LAT) to borehole termination (circa -20.5 m LAT).

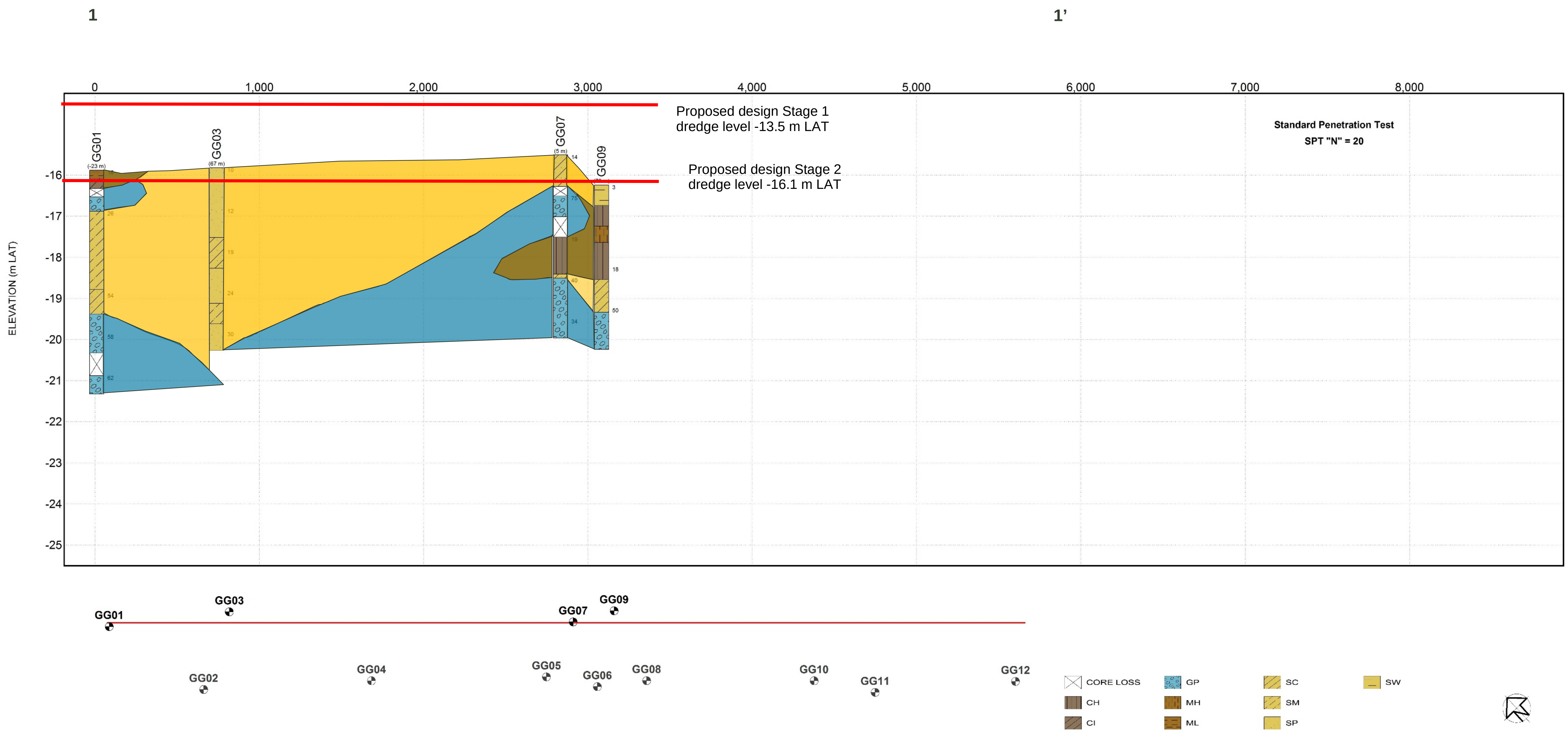

Figure 25 Sketch of the interpreted geological section for the Gatcombe Channel (north) (NTS)

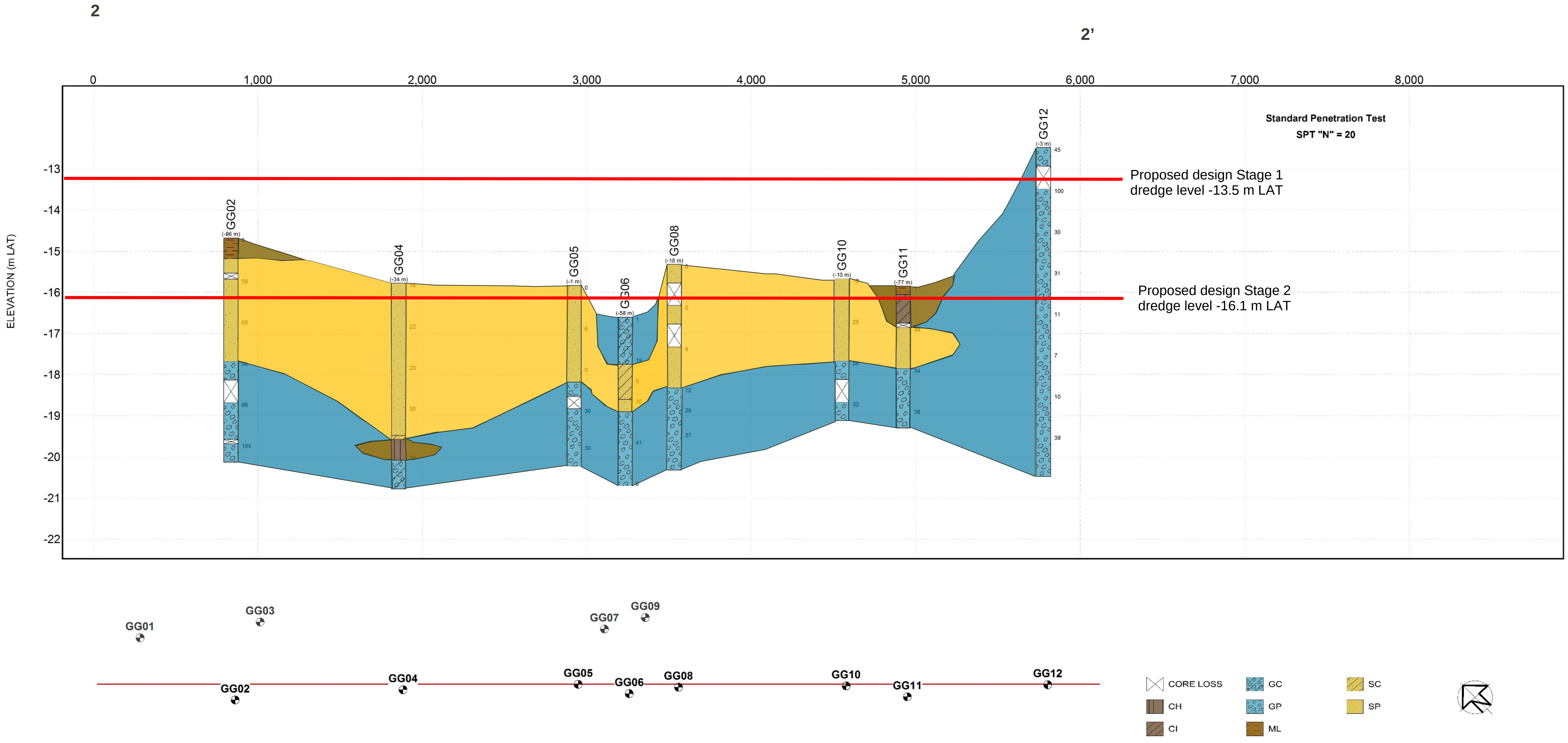

Figure 26 Sketch of the interpreted geological section for Gatcombe Channel (south) (NTS)

6.1.2 Golding cutting channel

The Golding Cutting Channel section comprises eleven (11) boreholes (GG13 to GG23) with seafloor materials described as being loose to medium dense, poorly graded gravel, clayey and poorly graded sand (Figure 27 and Figure 28). As with the Gatcombe Channel sections, the boreholes undertaken for the Golding Cutting Channel do not clearly portray a definitive geological patterns based on soil type. However, unlike the Gatcombe boreholes, the Golding Cutting section contains a significant amount of cohesive material between approximate levels -7.53 m LAT (GG20) and -18.3 m LAT (GG14). This cohesive layer comprises low to high plasticity silt and low, medium and high plasticity clay. The cohesive material ranges in consistency from very soft to very stiff.

Beneath the cohesive layer, soil described as principally sand (clayey sand, poorly graded sand etc) was recorded, and beneath the sand, a layer of principally gravel was recognised. The complex depositional history of the area can be seen from the geological sketch Figure 28, where the interpreted cohesive layer contains several sand lenses, and the interpreted sand layer contains several cohesive layers. A layer of loose to medium dense gravel was interpreted between GG15 and GG16 between circa -12 m LAT and -16 m LAT.

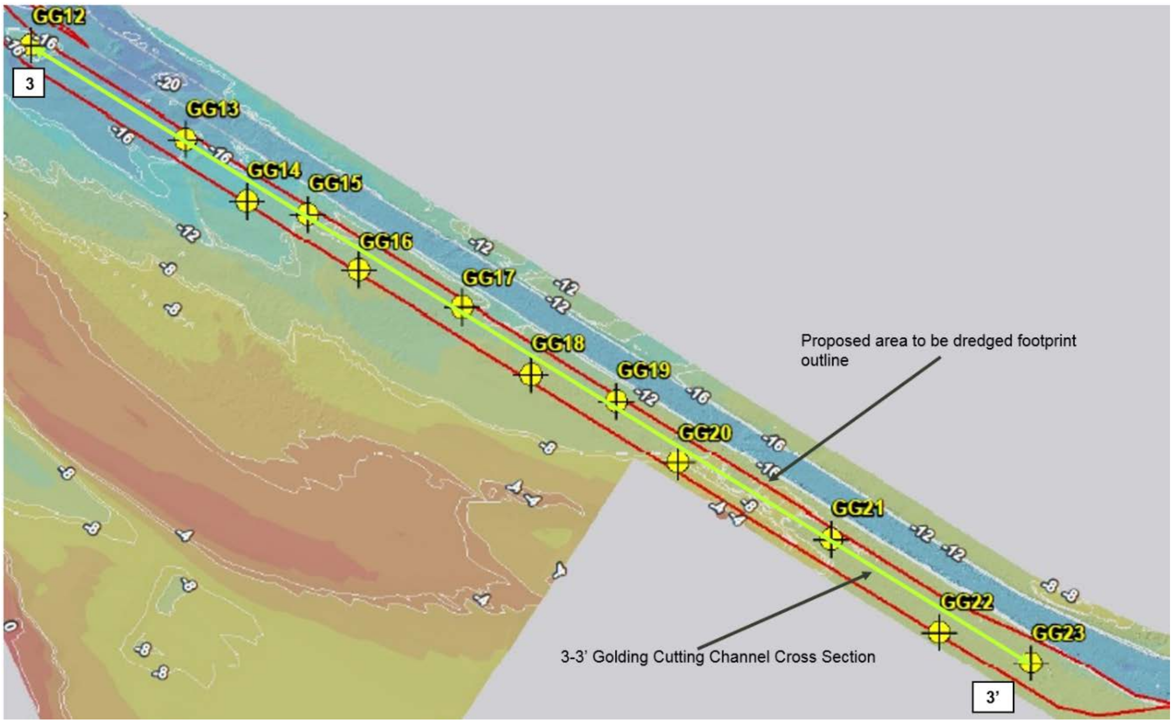

Figure 27 Plan showing location of section within the Golding Cutting Channel (NTS). Seafloor contours are in m LAT and based on bathymetric data provided by GPC

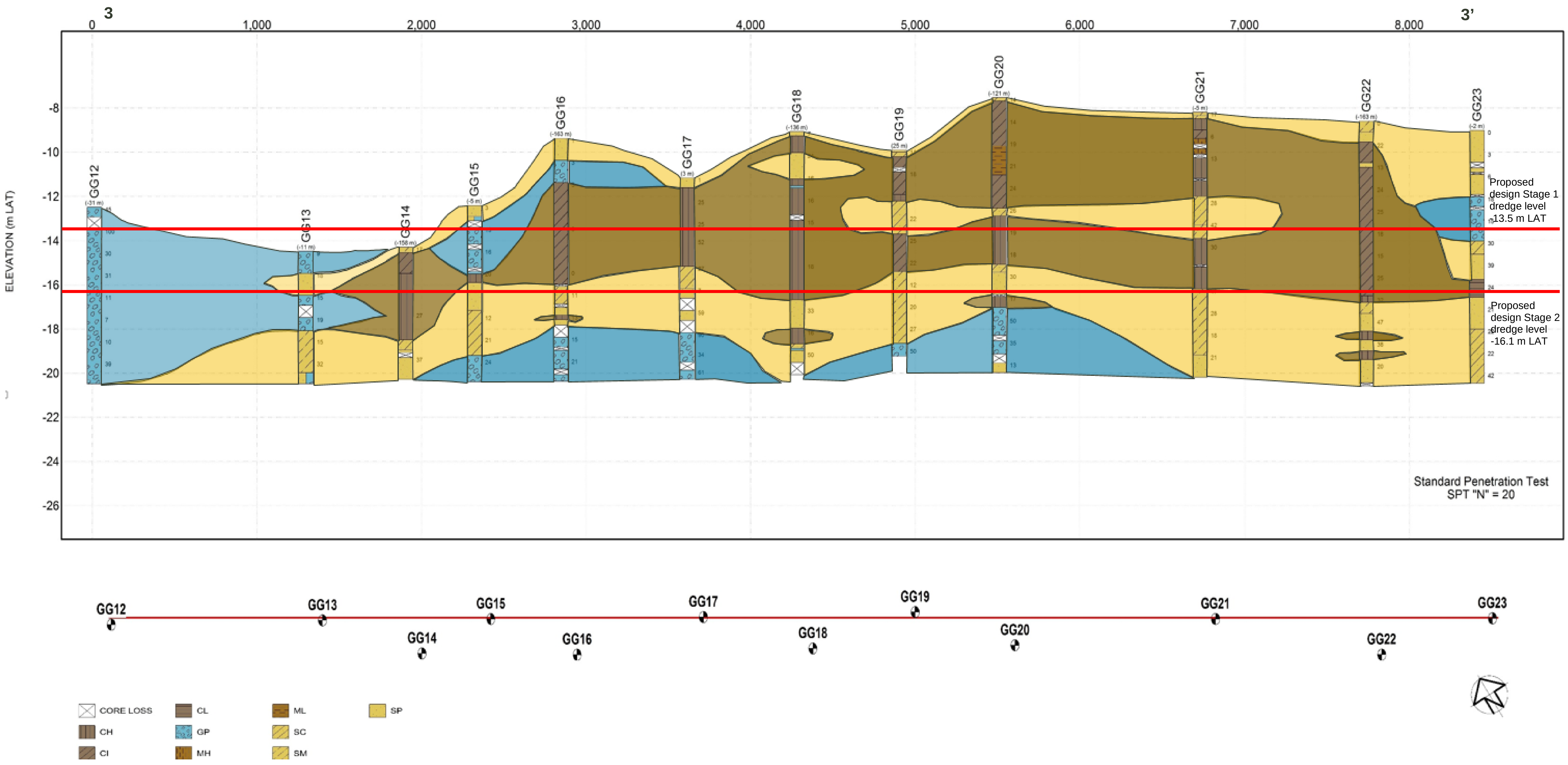

Figure 28 Sketch of the interpreted geological section for Golding Cutting Channel (NTS)

6.1.3 Gatcombe and Golding Cutting Channels combined

From the combined geological sketch (Figure 30), it is clear that seabed level increases from west to east at borehole location GG12 and in the area between borehole GG15 and GG16.

The bathymetric plans provided by GPC and produced by Marine and Earth Sciences clearly show that GG12 is located on a relative “high spot”. The reason for this high spot, which is not shown to be in an area of particularly high level rock according to the geophysical survey, is not clear but is likely associated with high energy fluvial deposition from the Boyne River which is located to the south. The presence of gravel – and likely cobbles and boulders in the vicinity of borehole 12 is well known, and the presence of an accumulation of gravel (and likely cobbles and boulders that could not be identified during borehole drilling) near position GG12 is in keeping with Aurecon’s understanding of the general area.

This general rise in seabed level in the vicinity of borehole GG15 is a change of roughly 5 m and is considered to have been formed by a combination of the complex underlying geological structures of the area, which is known to comprise a series of buried or partially buried horst and graben structures.

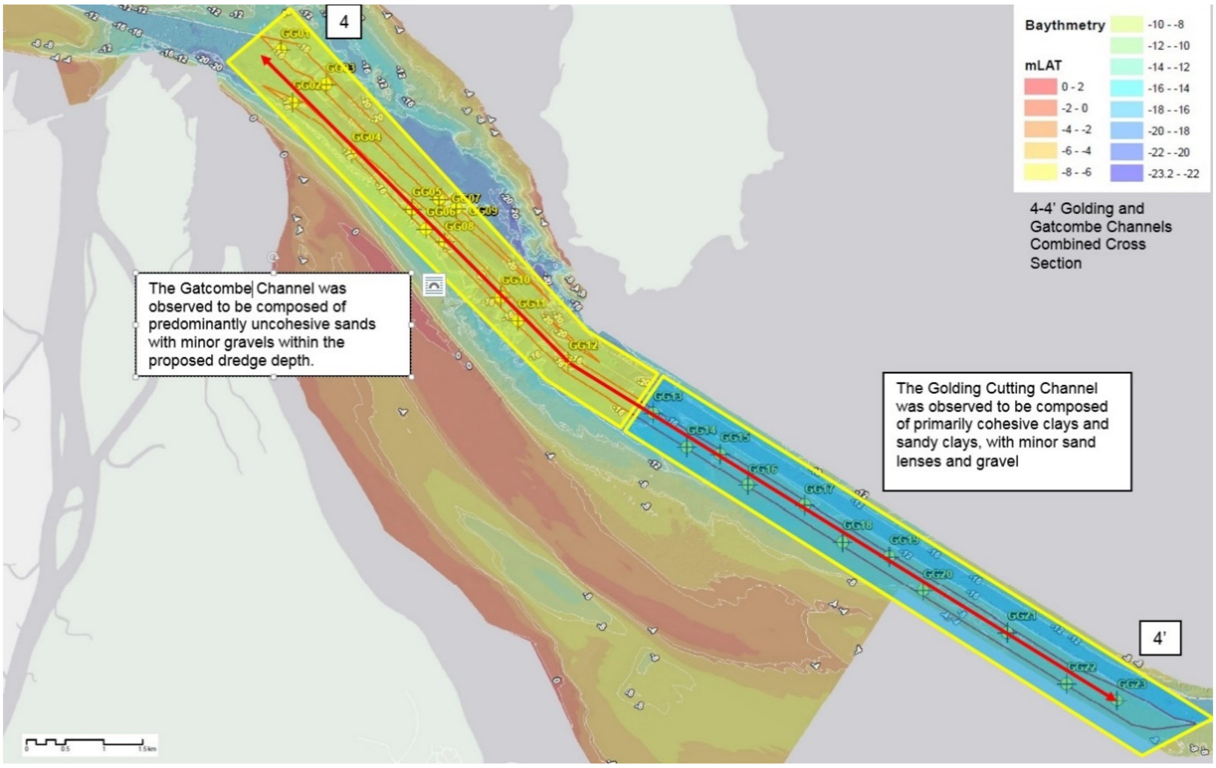

Figure 29 **Plan showing the section line for the combined Gatcombe and Golding Cutting Channels (NTS) and the general distribution of materials within the two channels. Seafloor contours are in m LAT and based on bathymetric data provided by GPC**

A second observation of the combined section is that “rock”, whether extremely weathered or better, was not encountered during the borehole investigation. This observation corresponds with the geophysical surveys performed over the Gatcombe and Golding Cutting channel areas. The existing surveys indicate that rock is typically located below -26 m LAT though some high level reflectors were observed in the vicinity of GG01 to GG03 and between GG13 and GG18. Based on the drilling performed in these areas, the higher level reflector at these locations was composed primarily of coarse grained gravel lenses likely deposited by the adjacent Boyne River. No bedrock was observed in these borehole locations within the proposed dredging depth. Rock, in the form of sediments and metasediments of the Curtis Island Group, is expected at greater depths. The presence of rock cannot however, be ruled out of the proposed dredging.

As a summary, the soil profile within the Gatcombe and Golding Cutting Channels generally comprises granular soils (sands and gravels) to the west (near the coast), with increasing amounts of cohesive material (silts and clays) deposited to the east (away from the coast) (Figure 29). This pattern represents the classic theory of fluvial deposition where sediment in rivers, such as the Boyne or Calliope Rivers, are transported as bed load (coarse fragments) or suspended load (fine fragments) and deposited when the velocity drops to a level where the particles cannot be carried any further.

From the model, three general layers were identified as summarised in Table 7 and Figure 30:

Table 7 Summary of interpreted layers from the geological section

Layer 1	**Generally Cohesive:** This layer incorporates material recorded as principally silt (ML and MH) and clay (CL, CI and CH). From Figure 8 it can be seen that this layer located to the east of the area to be dredged and contains sand lenses.
Layer 2	**Generally Sand:** This layer underlies Layer 1 and comprises material recorded as sand (SC, SM and SP). Layer 2 is present beneath the seafloor to the west and was recorded on both the west and east sides.
Layer 3	**Generally Gravel:** Layer 3 underlies the sand layer and comprises GC and GP materials.

The complex depositional and erosional environment through the geological history for the Port of Gladstone has resulted in a complex and convoluted soil profile which may not follow the general depositional pattern and generalised geological model described in Table 7.

Figure 30 also indicates the proposed Stage 1 and Stage 2 dredging depths for this Project, with depths being -13.5 m LAT and -16.1 m LAT respectively.

It can be seen that minimal dredging would be required within the Gatcombe Channel during Stage 1 dredging, with only dense gravel in the area of GG12 being above -13.5 m LAT. Dredging of the Golding Cutting Channel will require removal of the principally cohesive layer (Layer 1), as well as gravels and sand materials.

For the Stage 2 dredging, removal of Layer 2 (principally sand) will be required from the Gatcombe Channel above -16.1 m LAT, with more gravel from the deposit around GG12 requiring removal. Both Layer 1 and Layer 2 will require dredging as part of the Stage 2 dredging program.

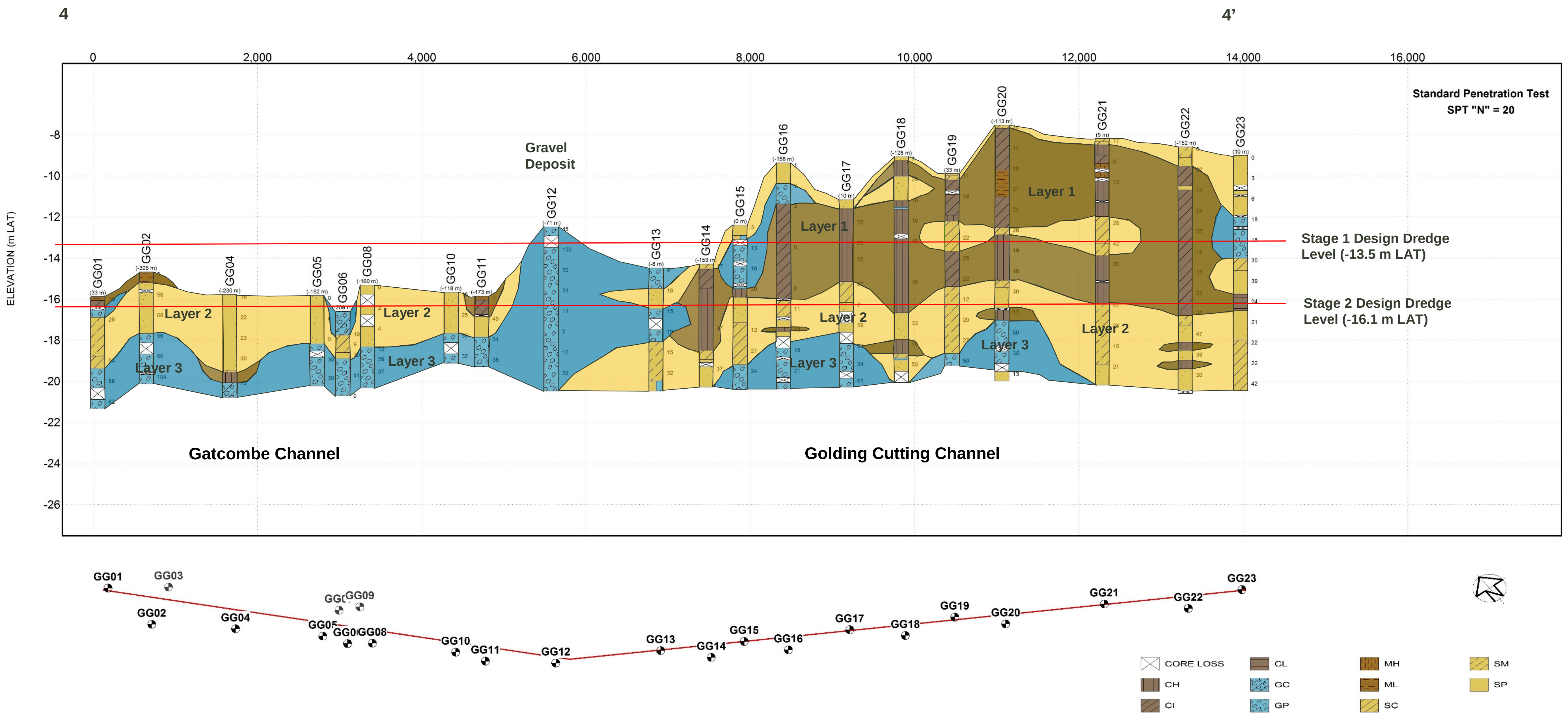

Figure 30 Sketch of the interpreted geological section for the combined Gatcombe and Golden Cutting channel (NTS)

Layer 1	**Generally Cohesive:** This layer incorporates material recorded as principally silt (ML and MH) and clay (CL, CI and CH). From Figure 8 it can be seen that this layer located to the east of the area to be dredged and contains sand lenses.
Layer 2	**Generally Sand:** This layer underlies Layer 1 and comprises material recorded as sand (SC, SM and SP). Layer 2 is present beneath the seafloor to the west and was recorded on both the west and east sides.
Layer 3	**Generally Gravel:** Layer 3 underlies the sand layer and comprises GC and GP materials.

6.2 Description of materials

6.2.1 Cohesive

- The cohesive clay and silt materials were encountered mainly within the Golding Cutting Channel beneath a thin layer of sand and an impersistent gravel (Layer 1). Several sand lenses were noted within this layer especially within GG19, GG20 and GG21
- Some cohesive material was observed within the Gatcombe Channel in discreet lenses
- From Atterberg Limit tests the clay material was typically medium plasticity with a zone of high plasticity observed in GG17, GG18 and GG21 at approximately -13 m LAT. Both the clay and silt layers contained varying amounts of sand and gravel
- The cohesive materials were found to be typically stiff to very stiff in consistency (approximately between 50 kPa and 200 kPa), however SPT records shows the medium plasticity clay to be very soft to soft in borehole GG16

6.2.2 Sand

- Sand material was encountered on the seafloor in the Gatcombe Channel and the Golding Cutting Channel. However, in the Golding Cutting Channel, the majority of sand was beneath the cohesive layer (Layer 1) as described above
- The sand was typically poorly sorted, containing some shells on the seafloor. The majority of the sand was quartzitic
- The grading tests indicated that the sand contained a notable gravel content in the Gatcombe Channel, with an average of 20% to 40%. The gravel content was found to be reduced within the Golding Cutting Channel, whilst the sand layer was predominantly found to be clayey sand
- The sand density generally improved with depth with the majority of SPT tests indicating medium dense to very dense sand

6.2.3 Gravel

- Gravel (Layer 3) was recorded on the seafloor at GG06 and beneath a sand layer within GG15 and GG16, but was generally encountered beneath the sand layer (Layer 2) as demonstrated on the geological model (Figure 30)
- In general terms, the gravel encountered and recorded by the supervising engineer during drilling was poorly sorted and comprised chert, sandstone, siltstone, quartz, quartzite, metasediments and calcarenite (probably coral)
- The grading results shows that material logged as gravel comprised 50 to 70% gravel-sized fragments with typically 10 to 15% fines
- The density of the gravel varied from very loose to very dense but was generally medium dense above -17.5 m LAT and dense to very dense below -17.5 m LAT. SPT “N” values in excess of 60 blows in this material are likely the result of testing upon large cobble or boulder. Whilst the recovery of cobbles and boulders was not possible from the borehole drilling, such particle sizes are likely to be present within the gravel material
- Calcium carbonate, in the form of coral or calcrete gravel, was recorded on the borehole logs during drilling at some locations. Calcrete in the form of lenses or reefs that may impede dredging production rates were not recorded during the investigation. However, their presence between boreholes cannot be discounted

- A gravel deposit, which coincided with a “high spot” on the seafloor, was observed in the area of GG12. This feature is likely to be a fluvial deposit originating from the Boyne River. It is understood that such gravel, cobble and boulder deposits are well known in that area
- The gravel materials and to a lesser extent the sands are abrasive. Much of the coarse gravel observed is chert or silica rich and is likely to have a significant effect on dredging equipment in terms of wear and tear

6.2.4 Abrasivity and angularity

A review of the soils descriptions of the borehole logs as well as the SPT photographs was completed as part of this this report. The soils represented in the borehole logs comprise clays, sands and gravels and mixtures of all three components. This review concentrates on the sand and gravel particles only.

Gravels

Where present, gravels are typically sub rounded to sub angular in nature (Figure 31). Most of the gravels comprise cherts from the remnants of weathered Wandilla Formation in particular and from other sources. Cherts are silica rich and form very hard resistant gravel particles. Some of these particles will be well rounded then broken to angular particles during depositional processes giving a range of expected angularity. The largest continuous deposit of gravels was located around borehole GG12 and GG13. Gravels comprised of chert are hard and resistant with a Moh hardness value of approximately 7.

Gravels are also present as minor components of other soils such as sands or clays. Gravels retrieved from these deposits exhibit similar ranges of angularity and abrasivity as observed in the predominantly gravel soils which occur in specific areas. A visual assessment of the angularity of the gravel particles can be carried out by inspecting SPT photographs which are presented in Appendix C of this report along with borehole logs and core photographs. Gravels are likely to be extremely abrasive and consideration should be taken to carry out further sampling and testing of soil materials recovered and now stored in a GPC facility. Testing of these materials will inform interested parties of the likely wear and tear on dredging equipment.

Sands

Sand recovered from the drilling comprises quartz and shell fragments. Particles are predominantly quartzose in composition. Grains range from sub rounded to sub angular and are fine to course grained. Sands form part of the majority of the soils types found during the site investigations including sandy clays and sandy gravel as well as predominantly sand mixtures with clays, gravels or both. Sands are likely to be abrasive and consideration should be taken to carry out further sampling and testing of soil materials recovered and now stored in a GPC facility. Testing of these materials will inform interested parties of the likely wear and tear on dredging equipment.

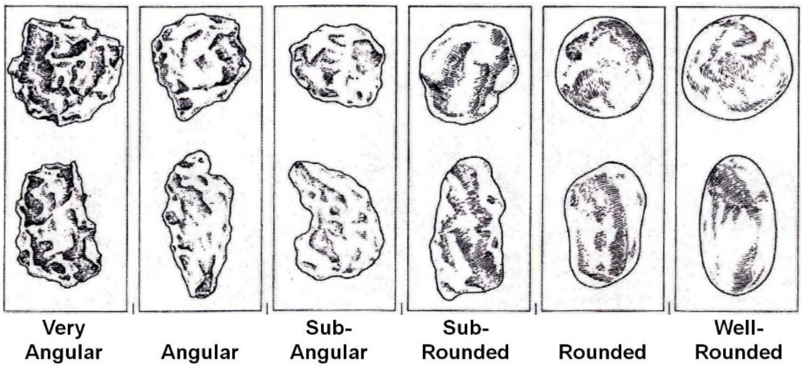

Figure 31 Example of particle angularity for soil particles

6.2.5 Comparison between Blain, Bremner and Williams, 1980 and Aurecon 2015 findings

A review of the Blain, Bremner and Williams report (*A study of the sub-surface materials for dredging in the approach channels to the Port of Gladstone, March 1980*) was conducted to compare the findings of the historic site investigation with the recently completed Aurecon work (2015). Each site investigation covered similar areas of the port with Blain, Bremner and Williams 1980 boreholes located from just west of the existing Wiggins Island Coal Exporting Terminal (WICET) to the eastern section of the Wild Cattle Channel.

This review compared the 17 boreholes drilled in 1980 by Blain, Bremner and Williams to the 23 Golding Cutting Channels only. Both sets of borehole logs provide a similar assessment of the prevailing ground conditions as follows:

- The eastern portion of the Golding Cutting Channel (Boreholes GG23 to GG16 and Bh79/32 to Bh79/27) indicate the presence of predominantly clay soils
- The central and western part of the Golding Cutting Channel at BH GG15 to GG12 contain elevated levels of gravel which match the soils description in boreholes Bh79/33 and Bh79/34
- The Gatcombe Channel is predominantly sandy in nature as seen in boreholes GG10 to GG01 which are similar to soils descriptions in Bh79/39 to Bh79/46
- The only significant difference is observed in Bh79/38 and Bh79/38A where a Quartz Mica Schist is described from approximately -16.8 m LAT and –14.5 m LAT respectively. These boreholes are in the vicinity of GG11 and GG10. The description of shallow rock in the area could indicate a localised fault which has brought rock closer to the surface than the surrounding areas

7 Conclusions

In general, the subsurface conditions encountered through the area to be dredged within the Gatcombe and Golding Cutting Channels were similar to the previous investigations results and are consistent with recent seismic surveys of the channels. No high-level bedrock was observed within the proposed area to be dredged. Rock however may still be present above the proposed design dredging depth at the Gatcombe and Golding Cutting Channel areas (see Blain, Bremner and Williams 1980).

The sediments were described as cohesive (clays and silts), sands and gravels with variable mixtures and isolated lenses of all soil types recorded.

The following key points describe the main observations made during the investigation:

- The sedimentary deposits observed during the site investigation were comparative to materials encountered in previous investigations being composed primarily of clays, sands and significant gravel deposits
- There is a 5 m rise of the seabed in the vicinity of borehole GG15. This may have been formed by a combination of the complex underlying geological structures of the area, which is known to comprise a series of horst and graben structures and the fluvial action of the Boyne River
- “Bedrock” was not encountered during this geotechnical investigation within the Gatcombe and Golding Cutting Channels although the presence of rock cannot be ruled out of the proposed dredging profile completely as the Blain, Bremner and Williams investigation (1980) intersected “rock” in two boreholes
- Three general layers were observed from the borehole section; clay/silt (Layer 1), sand (Layer 2) and gravel (Layer 3)
- For the Gatcombe Channel, Layer 1 was absent though discreet lenses of clay and silt were identified from the borehole logs. A layer of sand (Layer 2) overlying gravel (Layer 3) was identified within this area
- For the Golding Cutting Channel a significant layer of clay/silt material (Layer 1) overlies the sand (Layer 2) and gravel (Layer 3)
- A significant gravel deposit was identified in the region of borehole GG12. SPT results and historic data suggests the likely presence of cobbles and boulders in this deposit, which was probably formed by the Boyne River
- For Stage 1 dredging (to a depth -13.5 m LAT), the vast majority of the seabed of the Gatcombe Channel is below the proposed design dredging depth. A small area of gravel has been observed above the dredging depth at GG12
- For the Golding Cutting Channel significant amounts of variably stiff to very stiff and medium to high plasticity clay, with impersistent sand lenses, will occur above the Stage 1 design dredging depth and will require removal

- For the Stage 2 dredging (-16.1 m LAT) variably medium dense sand and gravel occurs above the design dredging depth within the Gatcombe Channel
- The Stage 2 dredging for the Golding Cutting Channel will generally encounter medium to high plasticity, stiff to very stiff cohesive material. In addition, pockets of low strength cohesive material will also be encountered around borehole GG16. Below this, a layer of generally medium dense to dense sand is present

8 References

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9 Limitations

This report has been prepared in accordance with the brief, where provided. The contents of the report are for the sole use of the client (GPC) and no responsibility or liability will be accepted to any third party. Data or opinions contained within this report may not be used in other contexts or for any other purposes without our prior review and agreement.

The findings and conclusions in this report are based on data collected at specific locations and by using suitable investigation techniques. Only a finite amount of information has been collected to meet the specific financial and technical requirements of the client's brief and this draft report does not purport to completely describe all the site characteristics and properties.

Subsurface conditions relevant to construction works should be assessed by contractors who can make their own interpretation of the factual data provided. They should perform any additional tests as necessary for their own purposes. It is strongly recommended that any plans and specifications prepared by others and relating to the content of this report, or any amendments to the original plans and specifications, are reviewed by Aurecon to verify that the intent of our findings and conclusions are properly reflected in the design. During construction we request the opportunity to review our interpretations if the exposed site conditions are significantly different from those inferred in this report.

There are always some variations in sub-surface conditions across a site that cannot be defined even by exhaustive investigation. Hence it is unlikely that the measurements and values obtained from sampling and testing during the investigation will represent the extremes of conditions which exist within the site.

Subsurface conditions can change over time. This should be borne in mind, particularly if this report is used after a protracted delay.

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Appendices

Appendix A
Borehole location plan

Gladstone Ports Corporation
Growth, Prosperity, Community.

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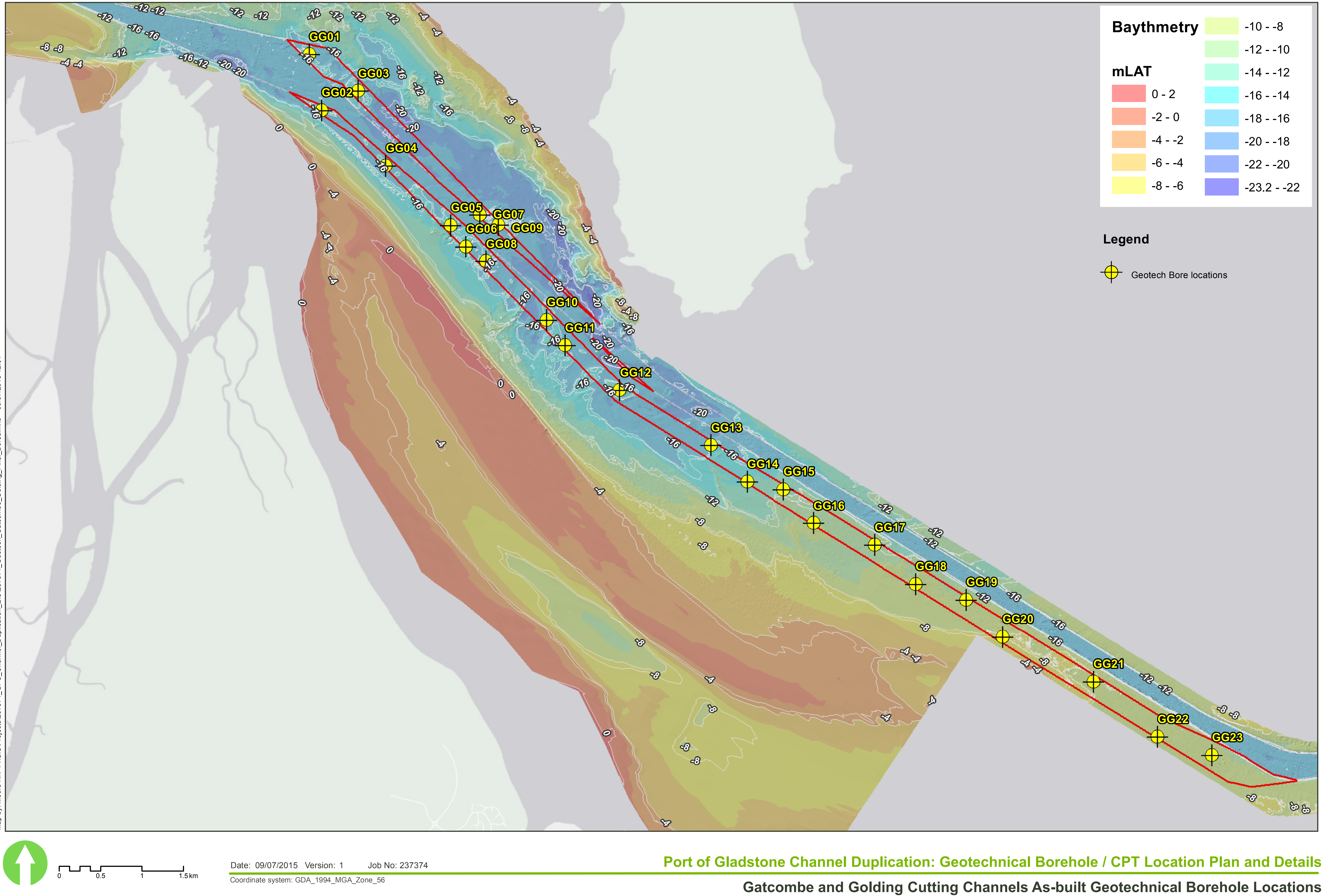

Map by: Moore NK P:\GIS\Projects\237374_GPC_Channel_Duplication_EIS\237374_Geotech_Gatcombe_Golding_Final_Bores.mxd 09/07/2015 12:01

Date: 09/07/2015 Version: 1 Job No: 237374

Coordinate system: GDA_1994_MGA_Zone_56

Port of Gladstone Channel Duplication: Geotechnical Borehole / CPT Location Plan and Details

Gatcombe and Golding Cutting Channels As-built Geotechnical Borehole Locations

Appendix B
Explanatory notes

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EXPLANATORY NOTES AND ABBREVIATIONS

The following information provides the terms and abbreviations used in Aurecon geotechnical borelogs and reports. Description of soil and rock are generally in accordance with the Unified Soil Classification System and Australian Standard AS1726-1993, Geotechnical Site Investigations. Soil and rock descriptions using established field techniques have been recorded independent of any laboratory test results. As far as is practicable the data contained on the log sheets is factual. Some interpretation is inevitable in the assessment of conditions between samples and of the origin of the materials. Standard colour charts have not been used.

Assessment of potential site contamination does not form part of this geotechnical report. Any reference to potential contaminants is for information only, and does not necessarily indicate the presence or absence of soil or groundwater contamination.

Soil Description

Soils are generally described in the borelog using the following sequence of terms:

[Drilling Information]; [USC Symbol]; [Soil Type, Colour, Plasticity/Particle Description, Structure]; [Moisture Condition]; [Consistency]

Unified Soil Classification Group Symbols

Typical Names	USC Symbol
Well graded gravels	GW
Poorly graded gravels	GP
Silty gravels	GM
Clayey gravels	GC
Inorganic silts of low plasticity.	ML
Inorganic silts of high plasticity	MH
Organic silts of low plasticity	OL
Organic clays of high plasticity	OH

Typical Names	USC Symbol
Well graded sands	SW
Poorly graded sands	SP
Silty sands	SM
Clayey sands	SC
Inorganic clay of low plasticity	CL
Inorganic clay of medium plasticity	CI
Inorganic clays of high plasticity	CH
Peat and other highly organic soils	Pt

Soil Type and Particle Size

Major Divisions		Symbols	Subdivision	Particle Size
Coarse Grained Soils (more than half of material is larger than 0.075mm)	Boulders			> 200 mm
	Cobbles			63 mm – 200 mm
	Gravels (more than half of coarse fraction is larger than 2.36mm)	G	Coarse	20 mm – 63 mm
			Medium	6 mm – 20 mm
			Fine	2.36 mm – 6 mm
	Sands (more than half of coarse fraction is smaller than 2.36mm)	S	Coarse	0.6 mm – 2.36 mm
			Medium	0.2 mm – 0.6 mm
			Fine	75 μm – 0.2 mm
Fine Grained Soils (more than half of material is smaller than 0.075mm)	Silts	M		< 75 μm
	Clays	C		
	Organic	O		

Soil Plasticity

Term	Symbol	Field Assessment	
Low Plasticity	L	Cannot be rolled into threads when moist	
Medium Plasticity	I ; L / H	Can be rolled into threads when moist.	Shows some shrinkage on drying
High Plasticity	H		Considerable shrinkage on drying. Greasy to touch. Cracks in dry material

Moisture Content

Term	Symbol	Field Assessment	
		Cohesive Soils	Granular Soils
Dry	D	Hard and friable or powdery	Runs freely through hands.
Moist	M	Feels cool, darkened in colour	
		Can be moulded	Tend to cohere.
Wet	W	Feels cool, darkened in colour	
		Free water forms on hands when handling	Tend to cohere

Consistency of Cohesive Soil

Term	Symbol	Field Assessment	Undrained Shear Strength (kPa)
Very Soft	VS	Exudes between fingers when squeezed.	< 12
Soft	S	Can be moulded by light finger pressure.	12 – 25
Firm	F	Can be moulded by strong finger pressure.	25 – 50
Stiff	St	Cannot be moulded by fingers. Can be indented by thumb pressure.	50 – 100
Very Stiff	VSt	Can be indented by thumb nail.	100 – 200
Hard	H	Difficult to indented by thumb nail.	> 200

Consistency of Non-cohesive Soil

Term	Symbol	Field Assessment	SPT N – Value	Density Index (%)
Very Loose	VL	Foot Imprints easily.	< 4	< 15
Loose	L	Can be excavated with spade. 50mm peg easily driven	4 – 10	15 –35
Medium Dense	MD	Shovelling difficult	10 – 30	35 – 65
Dense	D	Needs pick for excavation. 50mm peg hard to drive.	30 – 50	65 – 85
Very Dense	VD	Picking difficult	> 50	> 85
Cemented	C	Cemented, indurated or large size particles	> 50	N / A

Rock Description

Rocks are generally described in the borelog using the following sequence of terms:

[Drilling Information]; [Weathering]; [Rock Type, Colour, Structure]; [Rock Quality Designation]; [Strength]; [Defects]

Rock Weathering Classification

Term	Symbol	Field Assessment
Residual Soil	RS	Soil developed on extremely weathered rock; the mass structure and substance fabric are no longer evident; there is a large change in volume but the soil has not been significantly transported.
Extremely Weathered	XW	Soil is weathered to such an extend that it has 'soil' properties ie it either disintegrates or can be remoulded, in water.
Distinctly Weathered	DW	Rock strength usually changed by weathering. The rock may be highly discoloured, usually by ironstaining. Porosity may be increased by leaching, or may be decreased due to deposition of weathering products in spores.
Slightly Weathered	SW	Rock is slightly discoloured but shows little or no change of strength from fresh rock.
Fresh	FR	Rock shows no sign of decomposition or staining.

Rock Strength

Strength	Symbol	Field Assessment		Point Load Index $I_s(50)$ (MPa)
		By Hand	Hammer with Hand Held Specimen	
Extremely Low	EL	Easily remoulded to a material with soil properties.		< 0.03
Very Low	VL	Easily crumbled in 1 hand.		0.03 – 0.1
Low	L	Broken into pieces in 1 hand.		0.1 – 0.3
Medium	M	Broken with difficulty in 2 hands.	Easily broken with light blow (thud).	0.3 – 1.0
High	H		1 firm blow to break (rings).	1.0 – 3.0
Very High	VH		> 1 blow to break (rings)	3.0 – 10
Extremely High	EH		Many blows to break (rings).	> 10

Notes on rock strength

1. These items refer to the strength of the rock material and not to the strength of the rock mass which may be considerably weaker due to the effect of rock defects.
2. Anisotropy of rock material samples may affect the field assessment of strength
3. The unconfined compressive strength is typically about 20 x I_s (50), but the multiplier may vary widely for different rock types.

Rock Defects

Defects are generally described using the following sequence of terms: *[Defect Spacing]; [Depth (metres from surface), Defect Type, Defect Angle (degrees from horizontal), Surface roughness, Infill, Defect thickness (mm)]*

Defect Spacing

Description	Spacing
Extremely closely spaced	< 20mm
Very closely spaced	20mm to 60mm
Closely spaced	60mm to 200mm
Medium spaced	0.2m to 0.6m
Widely spaced	0.6m to 2.0m
Very widely spaced	2.0m to 6.0m
Extremely widely spaced	> 6.0m

Defect Description

Defect Type	Surface Roughness		Coating or Infill
	Macro-surface geometry	Micro- surface geometry	
Bp – Bedding Parting	St – Stepped	Ro – Rough	cn – clean
Fp – Foliation Parting	Cu – Curved	Sm – Smooth	sn – stained
Jo – Joint	Un – Undulating	Sl – Slickensided	vn – veneer
Sh – Sheared Zone	Ir – Irregular		cg – coating
Cs – Crushed Seam	Pl – Planar		
Ds – Decomposed seam			
Is – Infilled Seam			

Water

▼	Measurement standing water level and date
▽	Water Noted
▶	Water inflow
◀	Water / drilling fluid loss

Method

BH EX	Backhoe bucket (rubber tyred machine) Excavator bucket (tracked machine)
HA	Hand Auger
AV	Auger drilling with steel "V" bit
AT	Auger drilling with Tungsten Carbide (TC) bit
HOA	Hollow Auger

Support

C	Casing
M	Mud
W	Water
 RA RM RC	Rotary drilling with flushing of cuttings using - air circulation - bentonite or polymer mud circulation - water circulation
NMLC	Coring using an NMLC core barrel
RR	Tricone (Rock Roller) Bit
DB	Drag(Blade) Bit

Field Sampling and Testing

Symbol	Sample or Test
W	Water Sample
D	Disturbed Sample
B	Bulk Disturbed Sample
SPT	Standard Penetration Test
- 7, 11, 12 (eg)	Example of blows per 150mm penetration
- N = 23 (eg)	Penetration Resistance (blows for 300mm penetration following 150mm seating drived, Example of 11 + 12 = 23
- 25/20mm (eg)	Partial Penetration, example of blow for the measured penetration
- N*	Inferred SPT Value

Symbol	Sample or Test
- RW	Rod Weight only causing penetration (N < I)
- HW	Hammer and rod weight only causing full penetration (N < I)
- HB	Hammer Bouncing (N* > 50)
U (50)	Undisturbed Sample (50mm diameter tube)
PP	Pocket Penetrometer Test (kPa)
FV	Field Shear Vane (kPa)
RQD	Rock Quality Designation expressed as : <u>Sum of lengths of sound core pieces > 100mm</u> Total Length of core section considered
DCP	Dynamic Cone Penetrometer measured in blows / 100mm