REPORT

Hay Point Disposal Site Analysis

Hay Point Disposal Site

Client: North Queensland Bulk Ports Corporation

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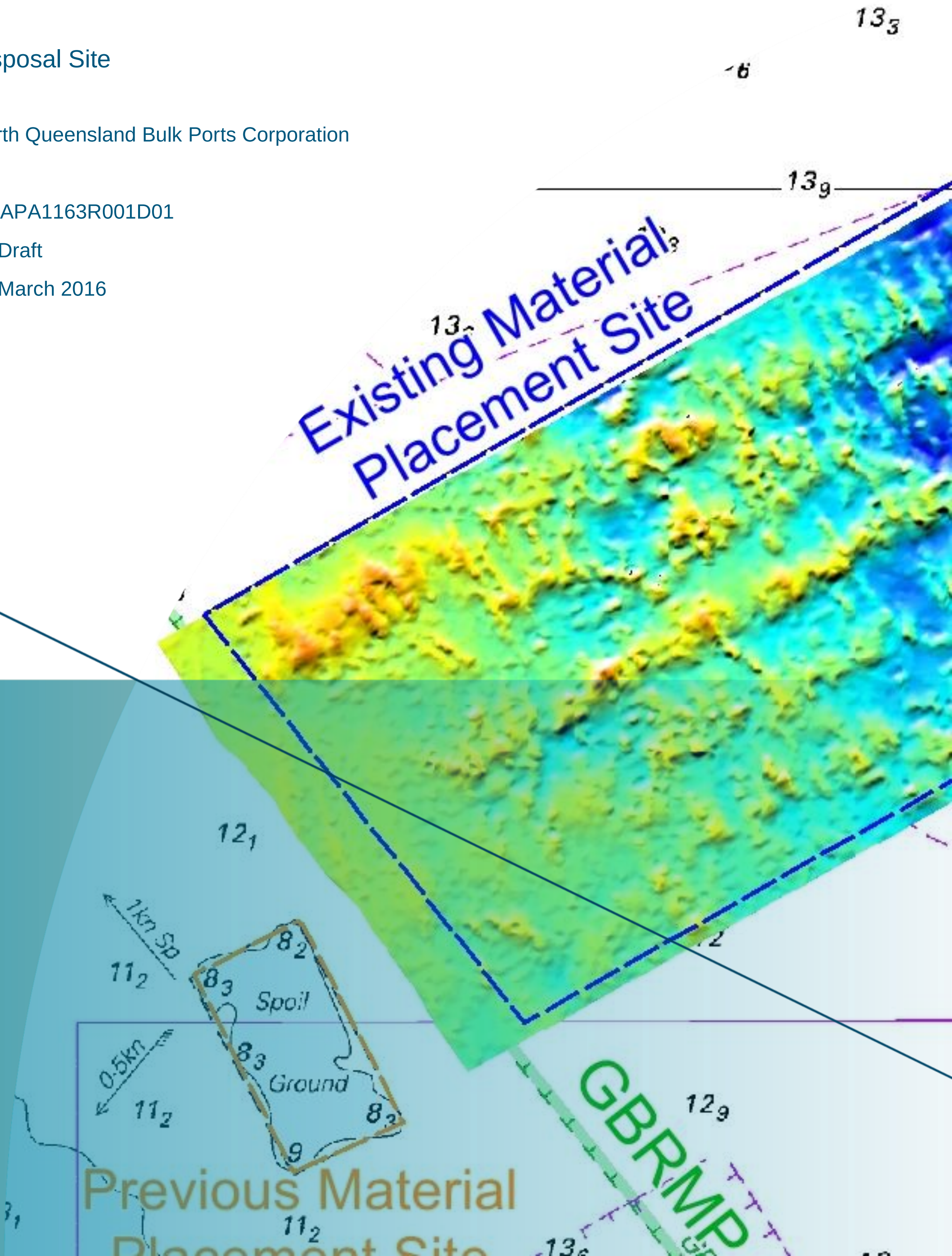

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Executive Summary

North Queensland Bulk Ports Corporation (NQBP) commissioned Royal HaskoningDHV (RHDHV) to undertake a study to better understand both the existing and previous dredged material placement sites at the Port of Hay Point. This study forms part of a larger investigation being undertaken by NQBP which focuses on sustainable sediment management at the port.

This report is aimed at:

1. providing quantitative changes in bathymetry at the existing and previous dredged material placement sites;
2. assessing the volume of material retained at the sites following the placement of dredged material. At the existing placement site this includes a large capital dredging campaign in 2006, and a subsequent smaller capital campaign for the HPCT Berth 3 in 2011; and
3. determining if the sites are predominantly retentive or dispersive.

Based on the bathymetric data available, the volume of sediment on the seabed has increased at both material placement sites due to the placement of sediment from dredging. Both placement sites are considered to be retentive.

The existing placement site has retained 64% of the sediment from capital and maintenance dredging over the eight years after the main capital dredging campaign. This period has included two tropical cyclones, one of which resulted in significant erosion in the Port of Hay Point apron and departure channel.

The bathymetric surveys indicate that the previous placement site was almost completely retentive. However, this is thought to be a result of the timing of the surveys (immediately after cessation of dredging) along with bulking of the fine grained sediment dredged. As such, based on the bathymetric data available it is not possible to accurately calculate the percentage of sediment which has been retained within the placement site but the site is considered to be retentive.

1 Introduction

North Queensland Bulk Ports Corporation (NQBP) commissioned Royal HaskoningDHV (RHDHV) to undertake a study to better understand both the existing and previous dredged material placement sites at the Port of Hay Point. This study forms part of a larger investigation being undertaken by NQBP which focuses on sustainable sediment management at the port.

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3. determining if the sites are predominantly retentive or dispersive.

1.1 Project Background

In October 2006 NQBP completed the development of a departure path and apron area for shipping at the Port of Hay Point. The capital works involved dredging sediment from the seabed in the order of 9 million m^3 and placing the material at a dredged material placement site located to the north of the port (herein referred to as the existing placement site). Since the capital dredging in 2006 there has also been a smaller capital dredging campaign to create the HPCT Berth 3, this involved the removal of 275,000m^3 of sediment which was also placed at the existing material placement site.

Maintenance dredging has also periodically been undertaken at the Port of Hay Point, with two campaigns since the 2006 capital dredging of the channel and apron (**Table 1**). The sediment removed as part of these maintenance dredging campaigns was also placed at the existing material placement site. Since 2012 it has not been possible to undertake any additional maintenance dredging due to a delay in the approval of the dredging permit and a subsequent appeal lodged on the approval.

Prior to 2006 another material placement site was used for all capital and maintenance dredging, this was located to the north-west of the port (herein referred to as the previous placement site). As such, the sediment from the maintenance dredging in 2004 and capital dredging in 2005, as detailed in **Table 1**, were placed at the previous placement site. The capital dredging of 400,000m^3 undertaken in 2005 was to create DBCT Berth 4.

Table 1. Historic in-situ dredging volumes (m^3) at the Port of Hay Point since 2006.

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

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

1.2 Port of Hay Point

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

The existing placement site is located approximately 2km north of the northern end of the apron, while the previous site was located just to the west of this. The existing placement site is located within the GBRMP, while the previous site was located outside the GBRMP (**Figure 1**). Details of the placement sites are as follows:

- previous material placement site - area of 1.27km^2, with existing bathymetric depths of up to 8.2m below LAT within the site and 11.2m below LAT outside of the site (based on the depths shown in the chart in **Figure 1)**; and

- existing material placement site - area of 18.4km^2, with bathymetric depths within the site ranging from 10.2m below LAT to 14.7m below LAT and between 10.3 to 15.4m below LAT outside of the site (based on the depths shown in the chart in **Figure 1)**.

As the chart shows that the bathymetry within the existing placement site is similar in depth to that outside the site we can infer that the site has additional capacity. This could indicate that the site is dispersive, although the size of the site means that it could easily accommodate the volume of capital material without a significant change in depth. In contrast, the chart shows that the previous placement site is at least partially retentive as the site is approximately 3m shallower than the surrounding seabed.

1.3 Report Structure

The report herein is set out as follows:

- a brief overview of the coastal processes is provided in **Section 2** along with a summary of the sediment properties from the capital dredging;
- a review of the bathymetric data is provided in **Section 3**; and
- a summary of the findings is provided in **Section 4**.

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

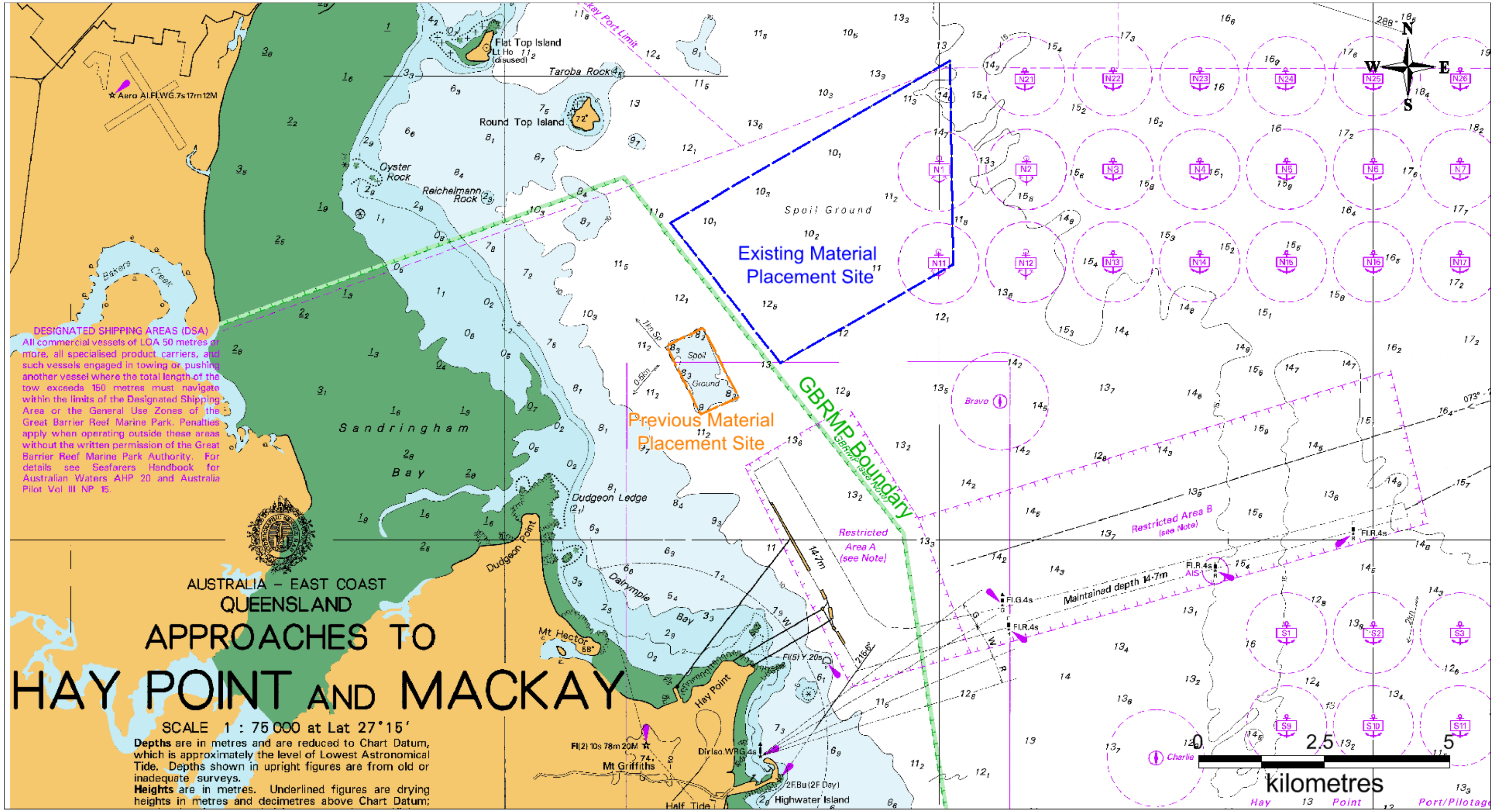


Figure 1. Location of the existing and previous placement sites relative to the GBRMP.

2 Coastal Processes

This section provides details of available hydrodynamic, meteorological, water quality and sedimentological data. A summary of the data which has been used in the study is provided in **Table 2**.

Table 2. Overview of available data at the study site.

Data Type	Location	Description
Rainfall	Mackay	BoM meteorological station at Mackay Meteorological Office (Dec 2000 – Nov 2015)
Wind	Hay Point	BoM meteorological station at Hay Point (Nov 2005 – Sep 2015)
Waves	Hay Point	Waverider buoy (WRB) managed by DSITI, located in 10m water depth (non-directional March 1977 - Aug 2008, directional Aug 2008 – Nov 2015).
Water Level	Mackay Outer Harbour	Storm tide gauge managed by DSITI, located in the Mackay Outer Harbour on Pier No.1 (Jan 2007 – Dec 2014).
Currents	Hay Point	Data collected as part of the recent Dudgeon Point Coal Terminals Project EIS, data available includes two ADCP deployments (September 2011 and November 2011) at a location approximately 1 km north-west of the DBCT berths.
Deposition	Hay Reef	Data from ongoing ambient marine water quality monitoring (June 2014 – July 2015).
Water Quality	Hay Reef	Data from ongoing ambient marine water quality monitoring (June 2014 – July 2015).
Climate Variability	Pacific Region, GBR	BoM determination of Southern Oscillation Index (Jan 05 – Oct 2015)

2.1 Tides

Hay Point is located in the area of the Queensland coast which experiences the highest tidal range, with mixed semi-diurnal tides with a peak tidal range of 7.14 m and a mean spring tidal range of 4.88 m. The tidal planes for Hay Point are shown in **Table 3**. The large tidal range at Hay Point is primarily due to local tidal amplification at Broad Sound. The tidal amplitude at Hay Point results in relatively strong tidal currents experienced at the port (further discussed in **Section 2.5**).

Table 3. Hay Point tidal planes (MSQ, 2015).

Tidal Level	Height above LAT
HAT	7.14m
MHWS	5.80m
MHWN	4.48m
MSL	3.37m
MLWN	2.25m
MLWS	0.94m
AHD	3.34m

2.2 Rainfall

Hay Point experiences a tropical climate with a distinct monsoonal rainfall trend. In this study, rainfall data recorded at the Mackay Meteorological Office (Mackay M.O, 1959 - 2015) has been analysed. On average Mackay receives 1595 mm of rainfall each year. Average monthly rainfall measurements are shown in **Figure 2**. Rainfall in the region can be summarised as:

- the wet season occurs between January and March and sees a significant proportion of the annual rainfall falling;
- the dry season occurs between June and October; and
- the months of April to May and November to December are the transition periods between the wet and dry seasons.

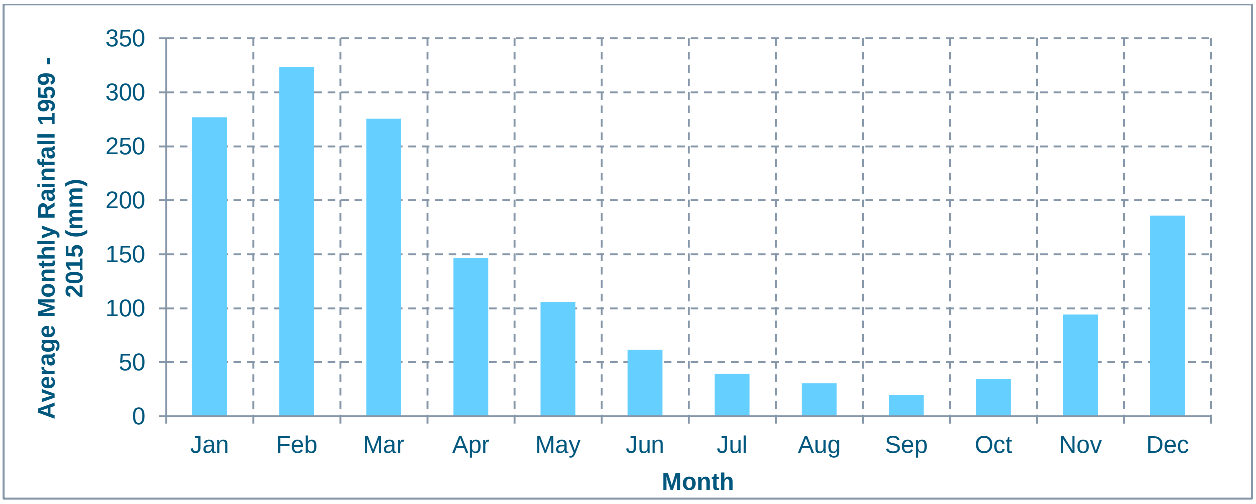


Figure 2. Mackay average monthly rainfall.

Rainfall and the associated catchment runoff is one of the key drivers responsible for the input of new terrigenous sediment to the inner shelf of the GBR. During the wet season, cyclones and periods of high rainfall can result in large volumes of sediment being input into the waters of the Great Barrier Reef (GBR) via local river systems and their associated catchment areas. Local catchments which discharge close to the port are further described in **Section 2.6**.

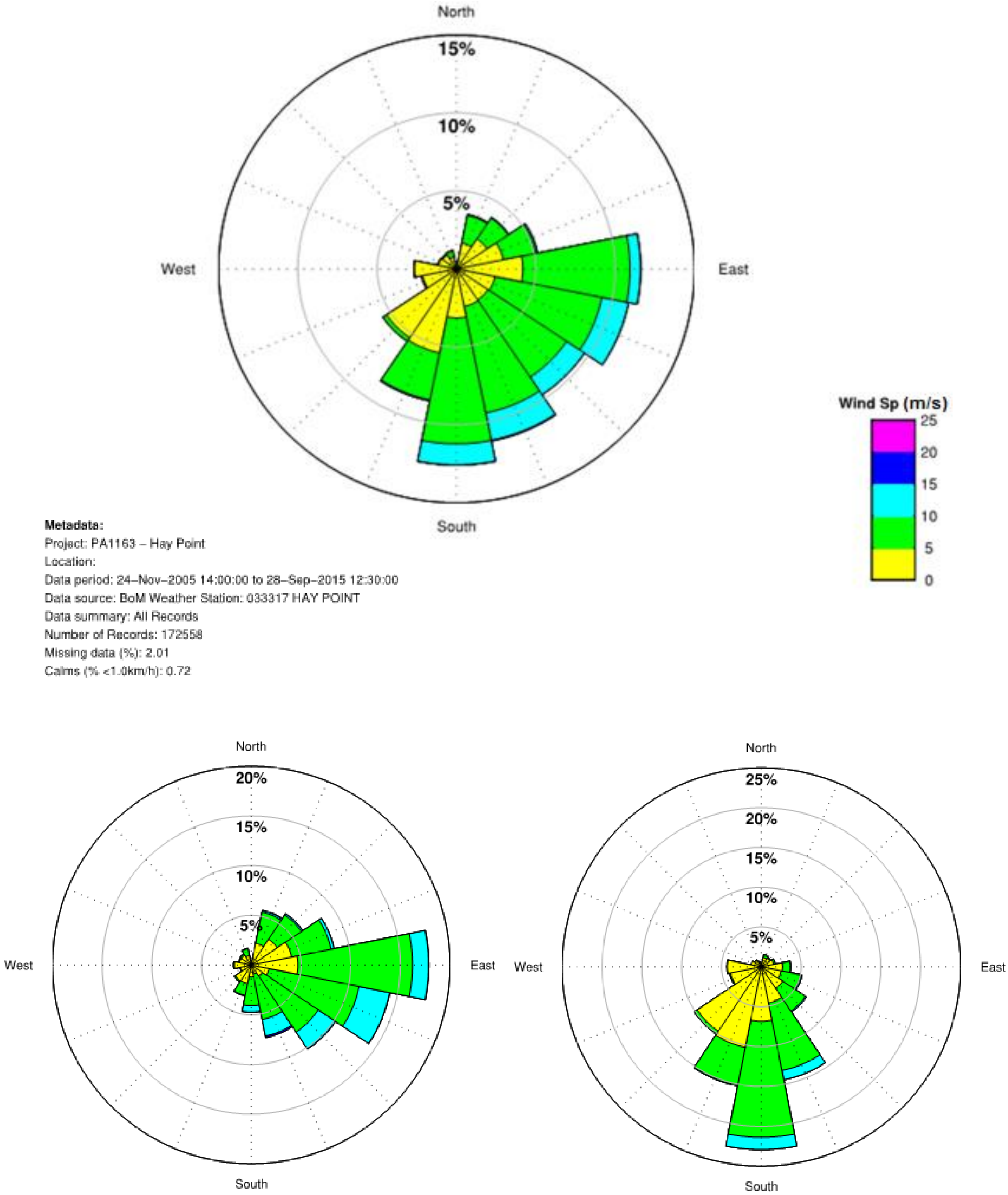
2.3 Wind Climate

Hay Point lies in the trade wind belt for most of the year resulting in the local wind climate being governed by east to south-easterly winds. **Figure 3** presents wind data measured by the BoM at Hay Point and includes data recorded between 2005 and 2015. **Figure 3** highlights the prevalence of the east to south-easterly trade winds.

It is also evident from **Figure 3** that during the summer months, wind conditions tend to be stronger and are predominantly from the east, with lighter north-easterly sea breezes common during the afternoon. During the winter months the wind direction is more prominent from the south with lighter land breezes from the south–west also occurring.

The higher wind speeds recoded at Hay Point are a result of tropical cyclones which can influence the area. The associated speed and direction of these winds are a result of the cyclones intensity and path.

Local wind conditions are an important driver for locally generated waves and to a lesser extent currents at Hay Point.



Summer Months **Winter Months**

Figure 3. Wind roses - Hay Point (2005 – 2015).

2.4 Wave Climate

Wave data made available from the DSITI waverider buoy (WRB) deployed at Hay Point has been reviewed for the purpose of this study. The data is from 1977 and extends to November 2015, however

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directional wave data is only available from 2008. The directional wave data has been analysed and is shown in **Figure 4** and **Figure 5**.

The GBR and adjacent Islands located offshore of Hay Point blocks, and/or significantly attenuates, long period swell waves from reaching the port. However, occasionally large wave events generated inshore of the reef (within the GBR Lagoon) do occur due to tropical cyclones and storm events. Accordingly, the wave climate at Hay Point can be described as relatively variable.

Figure 4 presents wave rose plots which illustrate the directional variability of waves at the site. **Figure 4** shows that the dominant wave direction is from the east-south-east. This is a result of a large open fetch from the south east combined with predominant south easterly trade winds which dominate the local wind climate. The large fetch which extends towards the south-east between the GBR and the coastline is known as the Capricorn Channel and is responsible for the larger more developed waves from the east and east-south-easterly sectors.

Figure 4 also shows that higher energy wave conditions generally occur during the summer months which is consistent with the stronger wind speeds and cyclonic conditions experienced during these months. Similarly, waves from the east-north-east are more prevalent during summer when winds tend to be from a more east and north-easterly direction.

Figure 5 presents the relationship between significant wave height (Hs) and peak wave period (Tp). It is evident that the port is exposed to both sea and swell (attenuated) waves, with spectral peak periods ranging from 2 to 18 seconds. Locally generated sea waves dominate at a period of 3 to 7 seconds while swell waves tend to be lower in height and vary in peak period from 7 to 18 seconds. The dominant short period waves experienced at the port are a result of sea waves generated by local winds within the GBR Lagoon.

Cyclones passing nearby to Hay Point are responsible for the largest waves recorded at the site. Notable recent waves measured include a maximum wave height of 7 m associated with tropical cyclone (TC) Dylan (January 2014) and maximum wave height of 6.3 m associated with TC Ului (March 2010). Both cyclones made landfall to the north of Hay Pont and both resulted in significant wave heights in excess of 1.5m from a south-easterly direction for a number of days prior to the cyclones passing. It is important to note that both of these cyclones passed well to the north of Hay Point and were of only intermediate intensity (TC Dylan was a category 2 and TC Ului was a category 3 (out of 5)). If a higher intensity cyclone was to pass closer to Hay Point in the future, it is likely that higher energy waves (larger wave heights and longer wave periods) would be experienced.

Local wave conditions can play an important role in the suspension of bed sediments. The degree to which waves suspend sediment is directly related to the relationship between the shear stress which is exerted by the wave and critical bed shear stress of the bed sediment. The strength of bed shear stress imposed by waves is a result of the oscillatory wave induced currents which are dependent on the wave conditions and local water depth. It is important to note that waves are a key driver in the suspension of bed sediments, however they are essentially ineffective at transporting sediment outside of the breaker zone where longshore drift occurs, and it is only under the simultaneous presence of even a weak tidal or wind induced current that net sediment transport occurs.

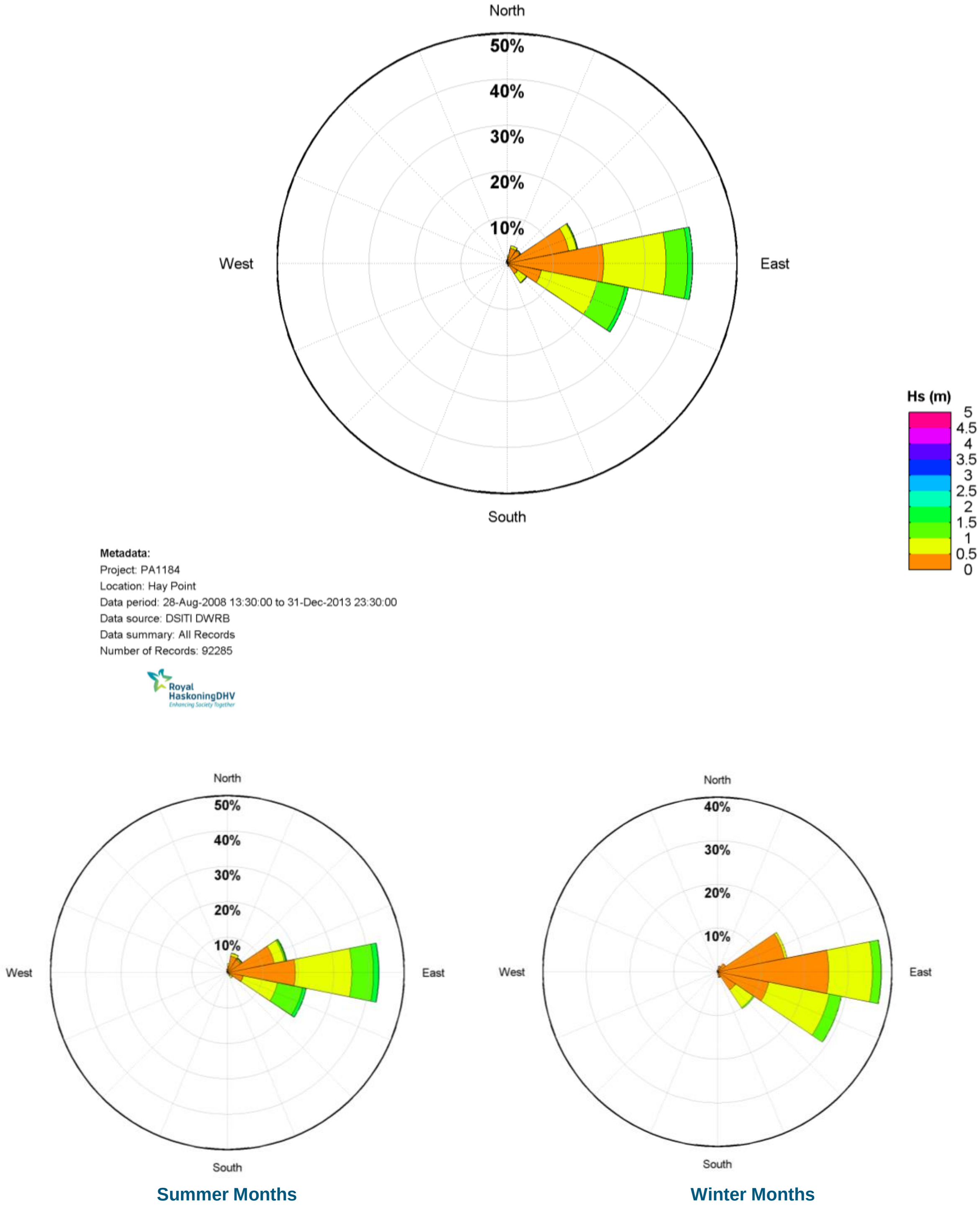

Figure 4. Wave roses - Hay Point waverider buoy (2008 – 2014).

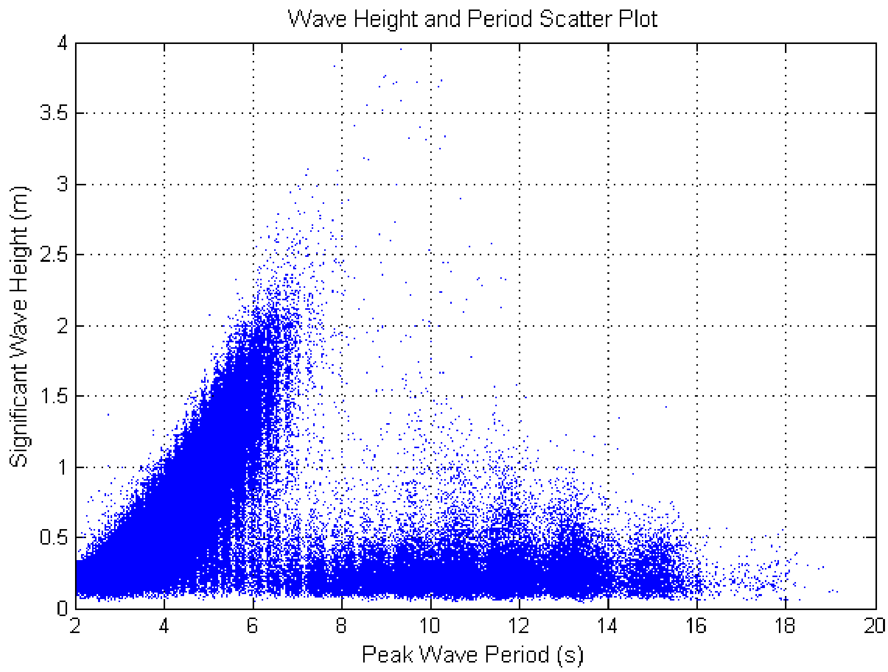

Figure 5. Wave height and period scatter plot - Hay Point waverider buoy (2008 – 2014).

2.5 Currents

Current data collected as part of the Dudgeon Point Coal Terminals Project EIS has been reviewed as part of this study. The available current data includes data collected from two ADCP deployments (September 2011 and November 2011) at a location approximately 1 km north-west of the DBCT berths (21.235° S, 149.291° E) (WorleyParsons, 2012).

Data from the deployments are shown in **Figure 6** and **Figure 7**. **Figure 6** shows current roses at three different depths through the water column while **Figure 7** presents a time series of the near bed current speed and direction over both spring and neap tides.

The data shows the depth averaged current speeds vary between 0.2 m/s and 0.5 m/s (0.3 – 0.35 m/s at the seabed) during spring and neap tides respectively. This is consistent with data described by GHD (2005) which also showed current speeds varying between 0.2 m/s (neap) and 0.5 m/s (spring).

It is evident from **Figure 6** that the tidal induced currents flow parallel to the coastline, with flood currents to the south-southeast (170˚) and ebb currents to the north-north west (340˚). Previous current measurements collected near Mackay Harbour (approximately 18 km north) showed that the ebb tidal current to the north is slightly stronger and flows for slightly longer than the flood tidal current to the south (Connell Wagner, 1991).

Wind can exert a frictional drag on the surface of the ocean which can in turn transfer momentum to the surface water and subsequently to the water column below. Wind induced currents are a prominent feature along most of the GBR coastline, partially due to the regional south-easterly trade winds. **Figure 7** presents a time series of near bed current speed and direction along with wind data measured at Hay Point. From **Figure 7** It is evident that during periods of prolonged south easterly winds (3/9/15 – 5/9/15) the typical current direction at Hay Point becomes slightly rotated and the south-easterly directed flood current becoming shorter in duration. Furthermore, the already dominant ebb tidal current is reinforced, resulting in a more pronounced net residual current in a north-westerly direction.

Additionally, cyclones can result in increased current speeds and changes to current direction as a result of the associated strong winds. The predominant east to west track of cyclones across the Great Barrier Reef lagoon generally results in cyclonic wind induced currents directed to the north west.

As well as tide and wind induced currents, regional scale circulation currents can occur in the GBR Lagoon. These regional scale currents are dynamic and intermittent as they are primarily driven by a complex interaction between oceanic inflows caused by the North Vanuatu Jet and local wind driven circulation (Andutta et al., 2013). Although these regional scale ocean circulation processes have the potential to intermittently influence current regimes at the Port of Hay Point, their impacts are considered minor relative to tidal and wind induced currents.

As previously noted in **Section 2.4**, both currents and waves play an important role in driving sediment transport and sedimentation. As with waves, bed currents can be responsible for the suspension of sediment from the seabed. Furthermore, currents can drive advection of suspended sediments. The stronger the current speeds, the higher the associated bed shear stresses and the more potential for sediment transport. The relatively high tidal currents experienced at Hay Point could potentially result in regular resuspension, transport and deposition of bed sediment.

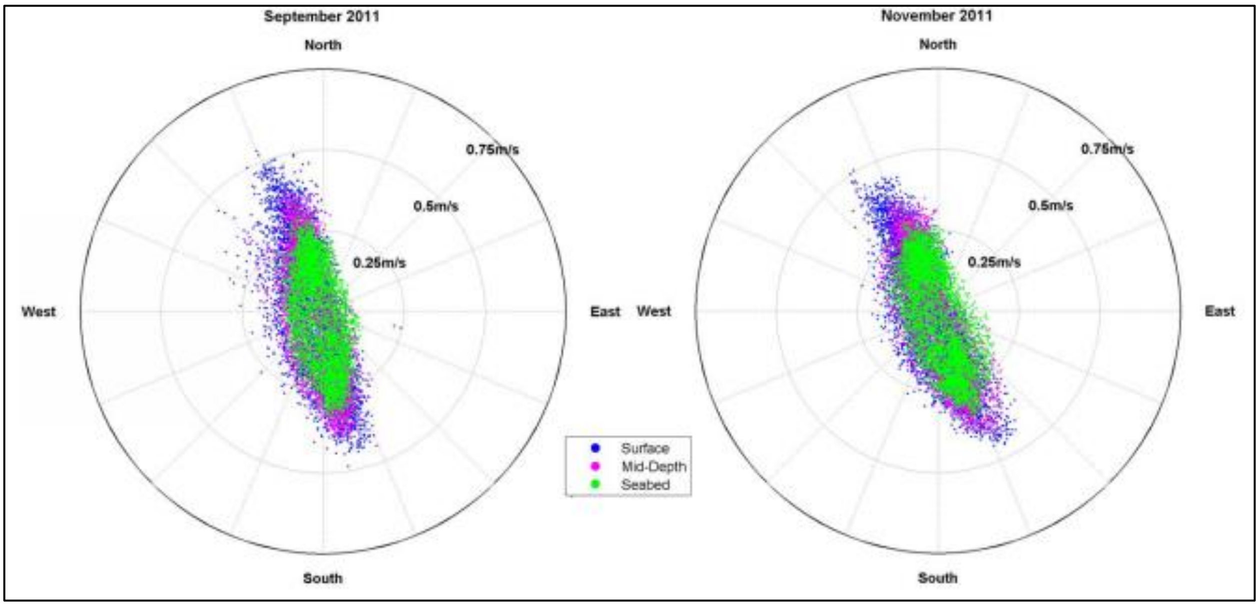

Figure 6. Current data approximately 1 km north-west of the DBCT berths (WorleyParsons, 2012).

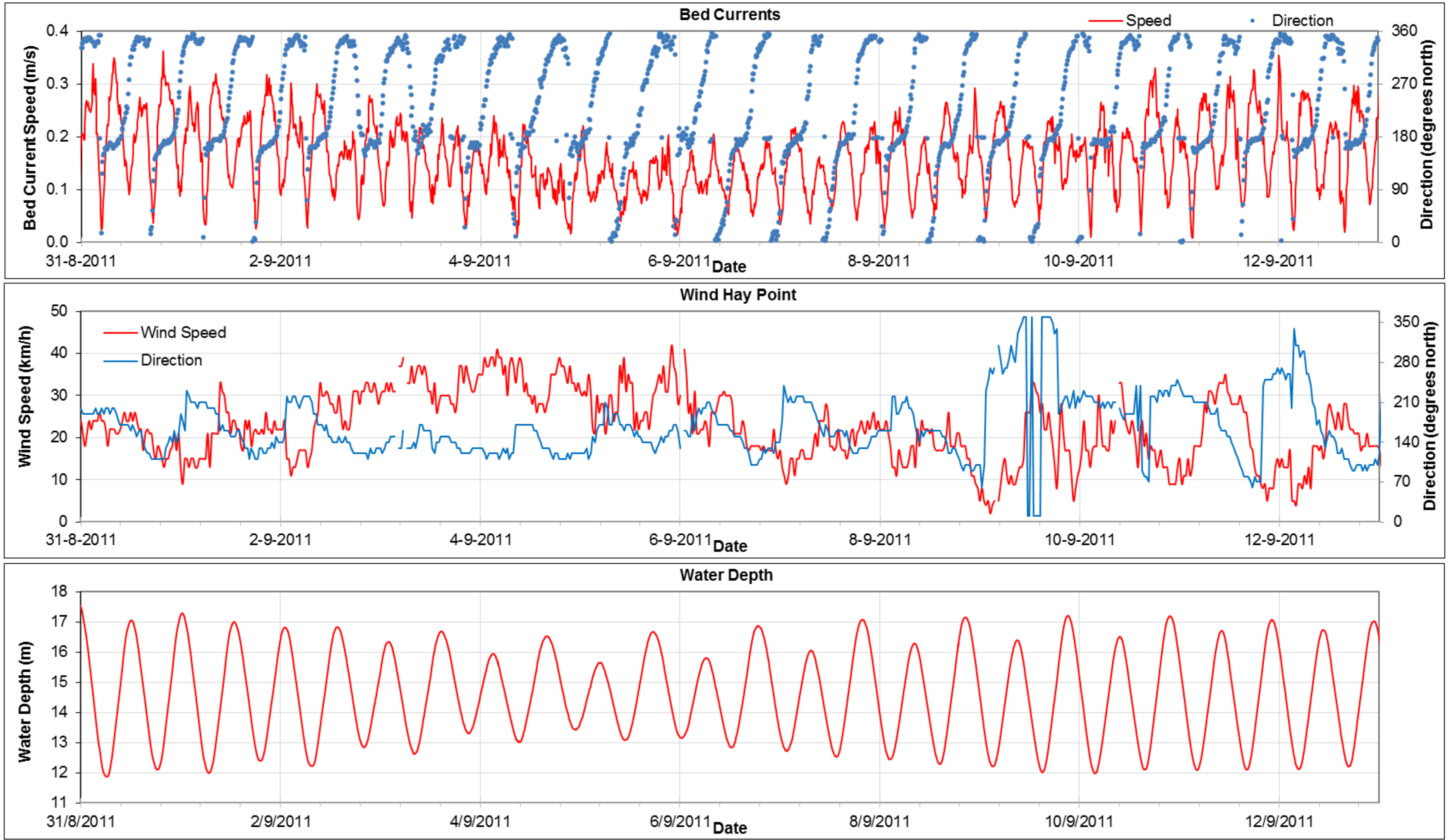

Figure 7. Current, wind and water level data approximately 1 km north-west of the DBCT berths (WorleyParsons, 2012).

2.6 Fluvial Discharge

As previously noted in **Section 2.2**, Hay Point experiences a tropical climate with a distinct monsoonal rainfall season. During this wet season it is not uncommon for cyclones and significant flood events to result in local river catchments delivering the majority of their annual river discharge and associated sediment load within a number of days or weeks.

The major catchment areas discharging nearby to Hay Point include the Pioneer River located approximately 17 km to the north-west and Plane Creek located approximately 14 km to the south. Estimates of the current (2012) annual suspended sediment load discharged from these catchments are presented in **Table 4**. Both of these systems play an important role in the delivery of new terrigenous sediments to the inner Hay Point region.

Table 4. Estimates of suspended sediment discharge load from river basins nearby to the Port of Hay Point (Kroon et. al, 2012).

Basin	Estimated Load (ktonnes/year)
Pioneer River	52
Plane Creek	550

2.7 Tropical Cyclones

Hay Point is vulnerable to the effects of severe tropical cyclones during the summer months (wet season). Since 1906, 24 cyclones have passed within 100 km of Hay Point (BoM, 2015). Recent notable cyclones which have affected the port include TC Ului (March 2010) and TC Dylan (January 2014). Wave and wind data collected during the passing of both of these cyclones is summarised in **Table 5**.

Table 5. Recent cyclone induced wind and wave recorded at Hay Point.

Cyclone	Maximum Recorded Wind Speed (km/hr)	Peak H_s (m)	Peak H_{max} (m)
TC Ului (March 2010)	94	3.95	6.3
TC Dylan (January 2014)	80	3.55	7

Tropical cyclones have the potential to drive significant sediment transport/sedimentation events by generating large waves, strong currents and increased river discharge. Due to the typical east to west projection of cyclones making landfall along the GBR coastline, passing cyclones generally result in the development of strong north-westerly longshore currents as well as large waves from the south-east to north-east. These higher energy wave and current events have the potential to mobilise bed sediments in deep water, areas which would not normally be subject to bed sediment mobilisation under ambient conditions. Research conducted by Carter & Larcombe (2009) showed that wave generated bed shear stresses from an intense cyclone can suspend sediments at depths of up to 30-60m.

Cyclone induced waves and currents are also important in the supply of new sediment to the inner-shelf of the GBR through the erosion and advection of sediments from the mid-shelf of the GBR. Studies undertaken by Gagan et. al. (1990) and further investigated by Orphin & Ridd (2012) suggest that the cyclone induced high energy wave and current conditions can result in erosion of Pleistocene clay substrates present in the deeper mid-shelf of the GBR. The suspended mid-shelf sediments are subsequently transported both along the shelf in a northerly direction and in a shoreward direction towards the inner shelf, this is known as cyclone pumping. The sediments eroded from the mid-shelf and transported shoreward may settle out directly in dredged areas of the port or they may subsequently be resuspended and transported to these areas at a later time under ambient conditions.

2.8 Water Quality

Suspended sediment concentrations (SSC) in waters adjacent to Hay Point are predominantly the result of existing bed sediments being suspended through current and wave action. A number of studies have been undertaken at Hay Point to monitor and understand the variability in water quality adjacent to the Port. Most of these studies have been typically associated with development projects at the port. SSC data collected through these previous monitoring programs (GHD 2006, BMA 2011a, BMA 2011b and BMA 2012, BMA 2013, WorleyParsons 2010) have been summarised by WorleyParsons (2014) and are presented in **Table 6**.

Table 6. Summary of background SSC measurements (Hay Reef 2004 -2012).

Season	Sample Number	Median (mg/l)	80th percentile (mg/l)	90th percentile (mg/l)	95th percentile (mg/l)
Summer (October – March)	23549	16.2	71.9	128.8	208.5
Winter (April – September)	32743	6.6	26.6	57	101

The data presented in **Table 6** provides a summary of background SSC measurements collected at Hay Reef between 2004 and 2012. Hay Reef is located approximately 1 km inshore of the Hay Point berths and represents the closest monitoring location to the port.

The data shows that during the summer months the medium SSC (16.6 mg/l) is higher compared to the winter months (6.6 mg/l). Similarly, the upper bounds are further elevated during summer. This is due to stronger winds during the summer months resulting in increased wave conditions during the summer months which promote suspension of bed sediments. In addition, cyclones and significant storm events occur in the summer months and can result in significant increases in wind and waves and SSC.

As part of this study, water quality data collected by James Cook University (JCU) at Hay Reef between 2014 and 2015 has been analysed. In this area the wave induced bed shear stresses are the primary driver responsible for elevated SSC concentrations as the data clearly shows that elevated periods of significant SSC concentrations correlate directly to periods of increased wave activity.

It should also be noted that to a lesser extent, tidal currents also play a role in both the daily and weekly variability in SSC concentrations. Variations in spring and neap current speeds directly correlate to variability in SSC concentrations at a similar temporal pattern. Under limited wave conditions, spring tidal currents result in SSC readings to 7-8 mg/l while neap tides generally result in SSC readings of 1-2 mg/l (Hay Reef). This is a result of stronger currents during times of spring tides suspending greater amounts of bed material.

2.9 Deposition

As part of the ongoing ambient water quality monitoring at Hay Point by JCU (2014-2015), sediment deposition has been recorded nearby to Hay Reef. A sample of concurrent deposition, SSC and wave data is presented in **Figure 8**. **Figure 8** shows that there is a notable trend between wave activity, SSC and deposition. During periods of higher wave energy, wave induced bed shear stresses act to suspend sediment and in turn increase the SSC concentration. It is during these periods of elevated SSC that peaks in deposition also occur. These peaks can be attributed to periods of slack water when suspended sediments have the opportunity to settle out of the water column. The trend which exists between SSC and deposition indicates that SSC concentrations could be used as a proxy for the amount of sediment potentially settling in the dredged areas of the Port of Hay Point.

The major limitation in using the recorded deposition data to estimate siltation at the port arises through the way in which the data is measured. The recorded deposition data is recorded using an optical backscatter sensor with a self-cleaning wiper (Ridd, 2001), this method does not account for any erosion as the sensor only measures the volume of sediment which settles on the sensor face over a particular interval. It is not possible to derive net sedimentation (siltation) rates without knowing the amount of sediment suspended (eroded) in the first place (i.e. the instrument may record zero deposition over a period where extensive erosion has actually occurred).

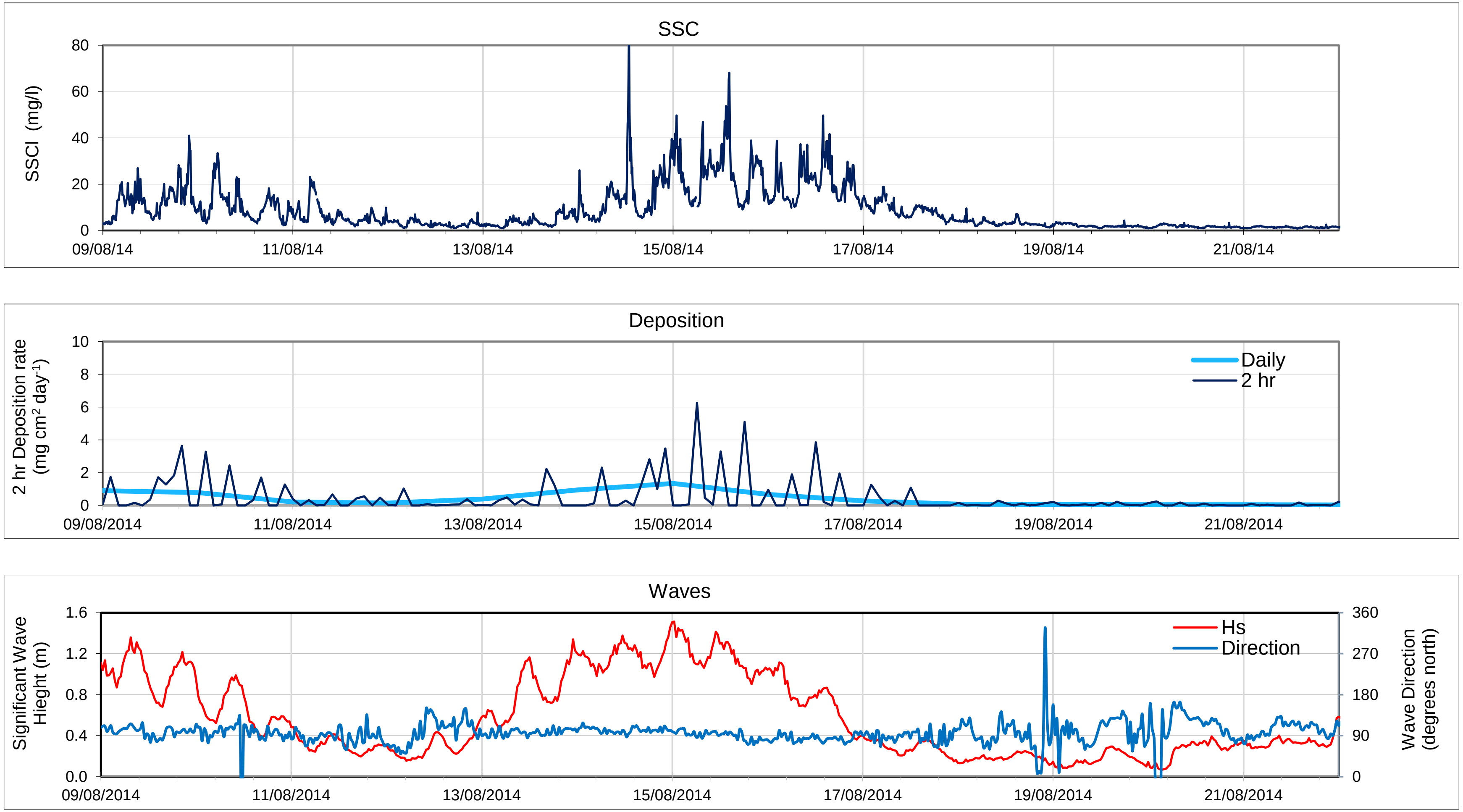

Figure 8. Wave, SSC and deposition data recorded at Hay Point.

2.10 Sediment Properties

Sediment sampling was undertaken prior to the capital dredging in 2006 as summarised in **Table 7**. The results from the sampling and particle size analysis can be summarised as:

- on average, bed sediments were generally comprised of predominantly sand fractions;
- the majority of the 9Mm^3 of sediment dredged was gravelly muddy sand (i.e. predominantly sand, with silt/clay and some gravel);
- the apron area exhibits a higher proportion of fines (silts and clays) compared to the departure channel. The amount of clay remains relatively similar in both areas, but the amount of silt is significantly lower in the departure channel;
- there is some gravel present throughout the areas.

The presence of some fine grained silts and clays (up to 40% composition) in the 9Mm^3 of sediment which was removed as part of the capital dredging in 2006 indicates that there is the potential for some consolidation of the sediment following relocation to the placement site. Consolidation occurs over time as pore water is forced out of the spaces between fine grained particles of silts and clays due to the influence of gravity forces, resulting in a compaction of the sediment (i.e. reduction in bed thickness) and an increase in the strength of the bed material. The influence of consolidation on the volumes of the dredged material is further discussed in **Section 3.4**.

Table 7. Physical characteristics of sediment from 2006 capital dredging (from GHD, 2005).

Location	Percent Passing			
	Gravel	Sand	Silt	Clay
Apron (A2)	14.7	46.1	18.9	20.3
Departure Channel (DP2)	9.1	66.8	6.2	17.9

2.11 Summary

Coastal processes and site conditions at the Port of Hay Point can be summarised as:

Tides:

- the port is located in an area of the Queensland coast which experiences very high tidal ranges, with semi-diurnal tides and a peak tidal range of 7.14 m (MSQ, 2015).

Wind Climate:

- the local wind climate is governed by the east to south east trade winds, with lighter land breezes from the south-west sector during the winter months and lighter north-easterly afternoon sea breezes common during summer afternoons.

Wave Climate:

- the port is largely protected from swell waves as a result of the GBR and adjacent islands;
- the large open fetch to the south east and predominant south easterly trade winds dominate the local wave direction; and
- the dominant waves at the port are short period sea waves which are generated by local winds within the GBR Lagoon.

Current Regimes:

- current forcing at Hay Point is predominantly driven by the large astronomical tides with tidal currents in excess of 0.5 m/s measured adjacent to the berths;
- measured data at the port suggests that the ebb tidal currents to the north-west are slightly stronger than the flood currents to the south-east; and
- the predominant south easterly trade winds act to reinforce the net northerly residual tidal current.

Rainfall/Fluvial Influences:

- the major catchment areas discharging nearby to the port include the Pioneer River (located approximately 17 km to the north-west) and Plane Creek (located approximately 14 km to the south) with both playing an important role in the delivery of new terrigenous sediments to the region.

Cyclones:

- Hay Point is susceptible to cyclonic activity and has seen 24 cyclones pass within 100km of the port between 1906 and 2007 (BoM, 2015); and
- recent notable cyclones which have affected the Port include TC Ului (March 2010) and TC Dylan (January 2014).

Water Quality:

- concentrations of SSC in waters adjacent to the Port are predominantly driven by bed sediments being suspended through both current and wave action; and
- during the summer months higher SSC concentrations occur compared to the winter months (16.6 mg/l compared to 6.6 mg/l) as a result of stronger winds and the increased occurrence of higher energy waves from cyclones and storm events.

Deposition:

- it is evident from data collected nearby to Hay Point (JCU, 2014-2015) that periods of elevated SSC result in subsequent peaks in deposition;
- the data shows that deposition at Hay Reef does not occur regularly over time, rather it is an event driven process; and
- Hay Point is not an accretional environment, with deposition typically only occurring following resuspension of existing bed sediment during specific events.

Sediment Properties:

- on average, bed sediments in the dredged areas of the port are comprised of predominantly sands fractions; and
- the apron has a higher percentage of fine sediment (silt and clay) relative to the departure channel.

3 Bathymetric Analysis

Hydrographic survey data of the Port of Hay Point existing and previous placement sites collected by Maritime Safety Queensland (MSQ) have been made available for this project. Survey data from February 2004 to June 2014 have been provided to allow analysis of the bathymetric changes at the placement sites.

Details of the survey data, analysis method and results are provided in this section of the report.

3.1 Hydrographic Surveys

Details of the hydrographic survey data available for the placement sites are provided in **Table 8**. The spatial extent of the surveys varies depending on the purpose of the survey. For example, some of the surveys were pre and post dredging surveys for targeted maintenance works and so only the areas where placement occurred was surveyed.

All surveys have been undertaken by MSQ and despite changes in technology over this period the surveys have been undertaken using similar equipment and to similar levels of accuracy, as summarised below:

- the surveys have been carried out to MSQ Class C standards with a vertical uncertainty of between 0.15 – 0.2m; and

- Kongsberg EM3002D or R2Sonic 2022 multi-beam echo sounders have been adopted for the surveys.

It is important to consider the vertical uncertainty of the surveys when analysing the hydrographic surveys and interpreting any changes in the bathymetry. To put the vertical uncertainty into context, the total area of the existing material placement site at the Port of Hay Point is approximately 18.4km^2. If a survey uncertainty of 0.15m is assumed throughout, the total volumetric error is approximately 2.76 million m^3. This is a large potential change in volume considering that the total volume of the capital dredging was 9 million m^3. The relative confidence which can be placed in the surveys will be assessed through interpretation of the volumetric and sectional changes and any potential issues will be discussed.

Table 8. Details of the material placement sites bathymetric surveys.

Plan Number	End Date	Description	Coverage
G290060	29/02/2004	Previous placement site and possible extension areas	All of previous material placement site as well as the western half of the existing material placement site
G290068	9/09/2004	Previous placement site pre-dredge	All of previous material placement site
G290070	16/10/2004	Previous placement site post dredge	All of previous material placement site
G290071	12/12/2005	Previous placement site pre-bed levelling	All of previous material placement site
G290072	13/12/2005	Previous placement site post-bed levelling	All of previous material placement site
G290085	22/08/2008	Existing placement site	South-eastern corner of existing material placement site
G290099	4/06/2010	Existing placement site pre-dredge	All of existing material placement site
G290103	30/10/2010	Existing placement site post-dredge	All of existing material placement site
G290114	24/06/2014	Existing placement site	All of existing material placement site

3.2 Analysis

The hydrographic survey data was used to create high resolution (10m) gridded Digital Elevation Models (DEMs) for each of the surveys provided. The DEMs were then analysed and processed to determine how the bathymetry has changed over time. The following analyses have been undertaken and are discussed in the following section:

- **Spatial**: to understand the spatial variability in erosion and siltation (due to dredged material placement) at the existing and previous placement sites at the Port of Hay Point, map plots of the differences between the DEMs have been produced. Differences have been calculated between subsequent surveys.

- **Volumetric**: volumetric changes have been calculated to quantify any erosion and siltation (due to dredged material placement) which has occurred in the placement sites. The volumetric changes have been calculated between subsequent surveys.

- **Sectional**: plots showing the bathymetry from the DEMs have been extracted at specific sections (long and cross) in the existing placement site (**Figure 13**) to show how the bathymetry has changed over time.

3.3 Results

The results from the bathymetric analyses are discussed in this section. When interpreting the results it is important to take historic dredging and subsequent material placement quantities (both maintenance and capital works) into consideration to determine how the volumetric changes between surveys relate to how much sediment has been retained or lost from the placement sites.

3.3.1 Spatial Changes

The bathymetry prior to the 9Mm^3 capital dredging in 2006 is shown in **Figure 9**. The figure shows:

- the bathymetry appears to be relatively flat and uniform. There are some shallower features in the north-eastern corner, based on the plot it is thought that these are rock outcrops;
- based on the western half of the existing material placement site which was surveyed, the existing site had a gradual slope in a north-easterly direction with depths reducing from approximately 12.5 to 14m below LAT; and
- the previous placement site shows evidence of historic dredged material having been retained within its boundaries with elevations of approximately 10 below LAT within the site and more than 12m below LAT outside of the site boundaries.

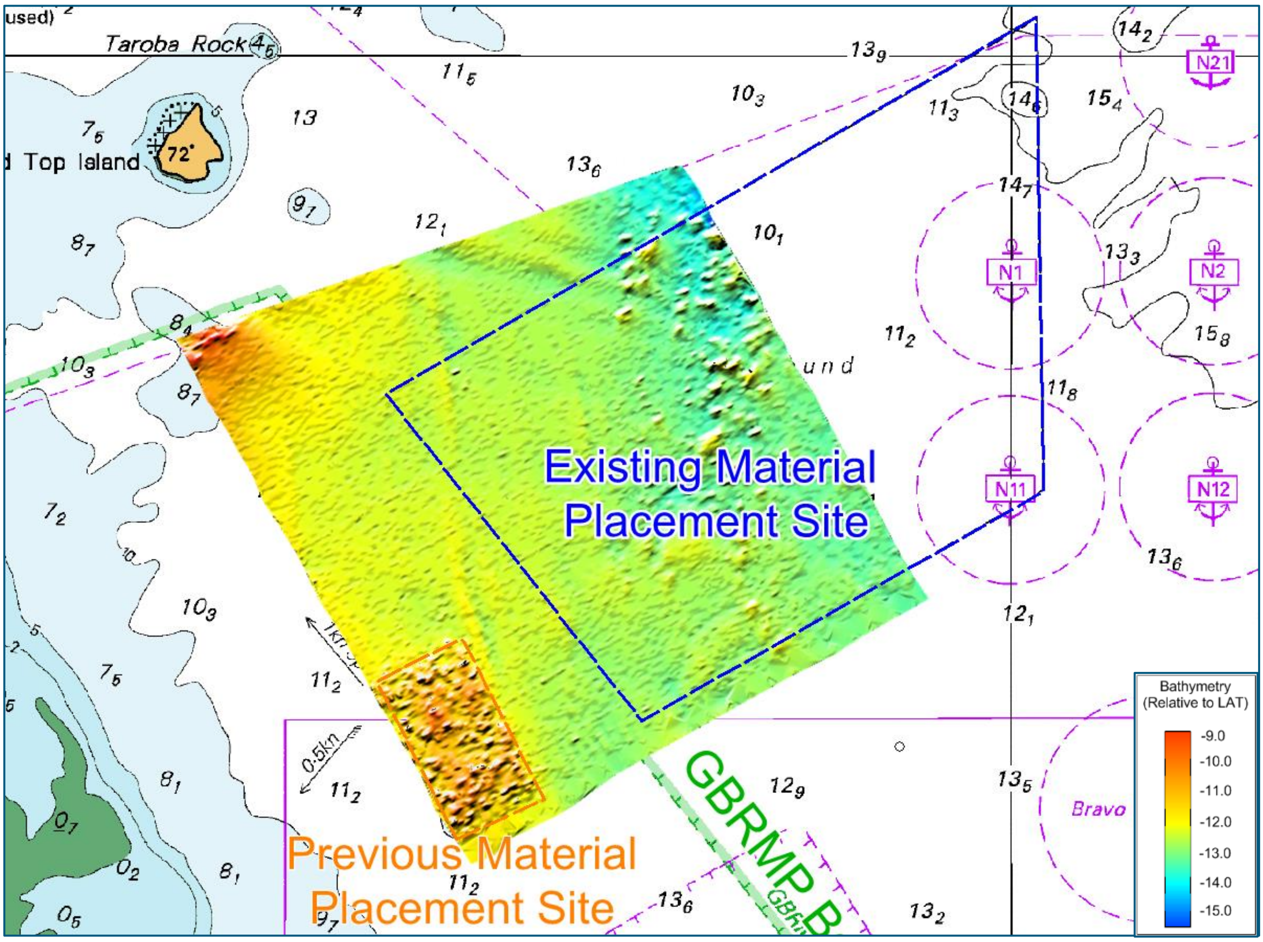

Figure 9. Bathymetric Survey Plan G290060 – 29/02/2004. Note: the survey did not extend to the eastern half of the existing placement site.

The bathymetry approximately four years after the 9Mm^3 of sediment was relocated to the existing placement site is shown in **Figure 10**. The figure shows:

- there has been a change in the morphology of the seabed in the existing placement site, with five ridges of shallower sediment (orientated southwest to northeast) present through the placement site. The ridges are a result of the material placement, it is thought that the dredger released the sediment in a way which has resulted in the formation of the ridges ;
- the shallowest depth observed on the ridges is 10.4m below LAT; and
- the deepest depth observed within the placement site on the ridges is in the north-eastern corner with depths of 16.9m below LAT.

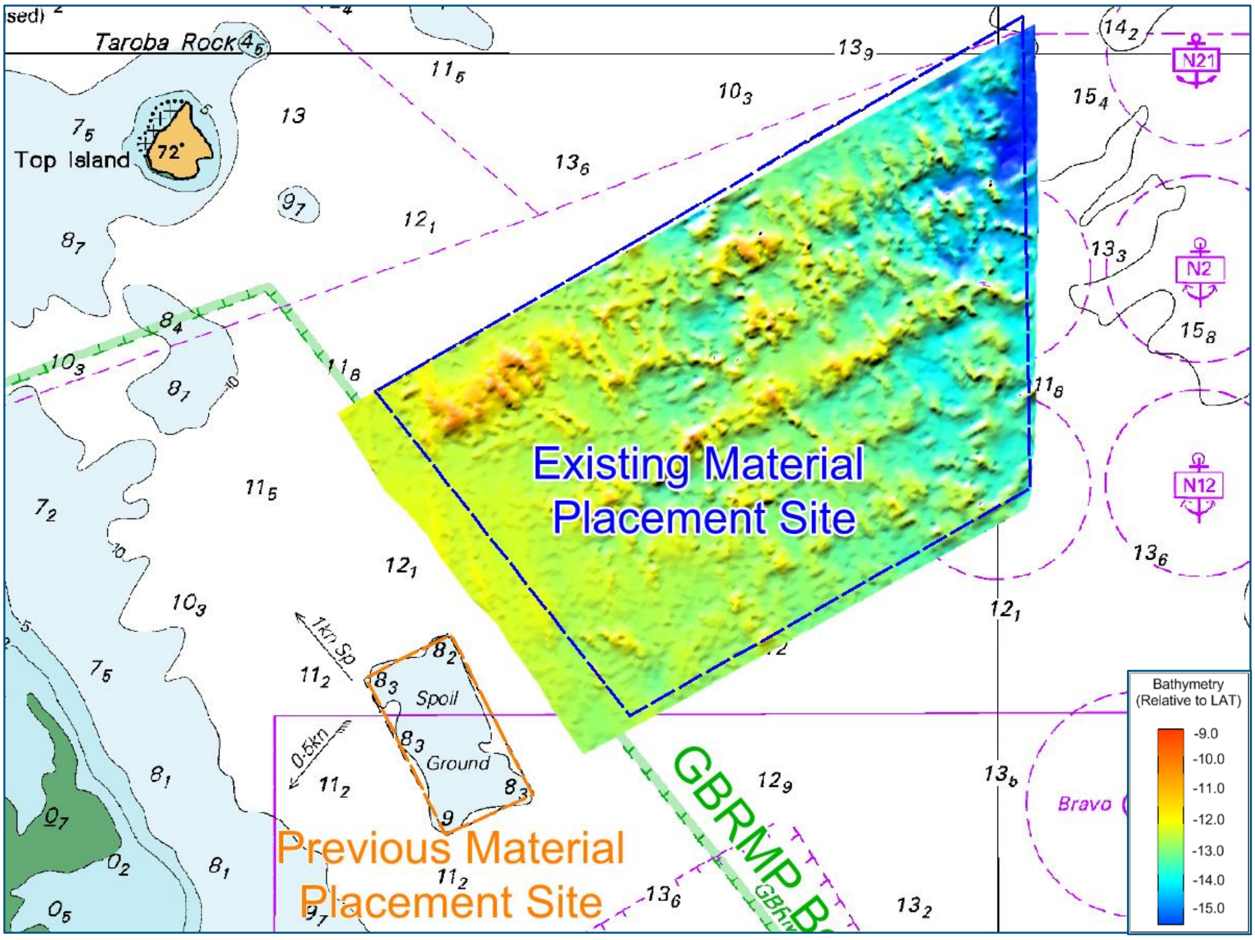

Figure 10. Bathymetric Survey Plan G290099 – 04/06/2010

The changes in bathymetry at the existing placement site are shown in **Figure 11**. The changes are detailed below:

- February 2004 to June 2010 - there was a significant increase in the bed elevation throughout the placement site, this occurred in the form of a series of ridges orientated southwest to northeast. The material is thought to be primarily from the relocation of 9Mm^3 of sediment during the capital dredging work in 2006, although maintenance dredging of 192,294m^3 in 2008 also occurred over this period. In March 2010 TC Ului impacted the Mackay region, with large waves and strong winds occurring at Hay Point. Despite this event the bathymetric surveys shows that significant material from the material relocation in 2006 remained within the existing material relocation site;

- August 2008 to June 2010 - the August 2008 survey only covered the south-east corner of the site, as such it is assumed that the survey was a post maintenance dredging survey with the 192,294m^3 of material dredging in 2008 relocated to this area of the site. The difference plot only shows relatively small differences, with slightly more siltation occurring compared to erosion;

- June 2010 to October 2010 - the surveys cover the entire existing material relocation site and show both erosion and siltation has occurred over the period, with an area of defined siltation in the north-eastern corner of the site. The area of defined siltation is assumed to be where the 216,070m^3 of sediment from maintenance dredging in 2010 was placed;

- October 2010 to June 2014 - the changes over this period indicate little overall change in volume over the existing material placement site, with localised areas of erosion and siltation. The main areas where erosion has occurred are along the centres of the ridges (the shallowest areas), while siltation has occurred along the sides of the ridges (the deepest areas). This indicates that some erosion of the higher areas of the ridges has occurred and that this material has then been transported to the sides of the ridges which are deeper and more conducive to siltation. Over this period TC Dylan impacted the region with the cyclone resulting in an estimated 300,000 to 725,000m^3 of erosion in the apron and departure channel at Hay Point. However, the changes over this period show that the event did not result in widespread erosion of the existing placement site; and

- February 2004 to June 2014 - the changes over this 10.5 year period show that a significant increase in volume has occurred due to the placement of dredged material. This indicates that the site is retaining sediment from the dredging and subsequent material placement.

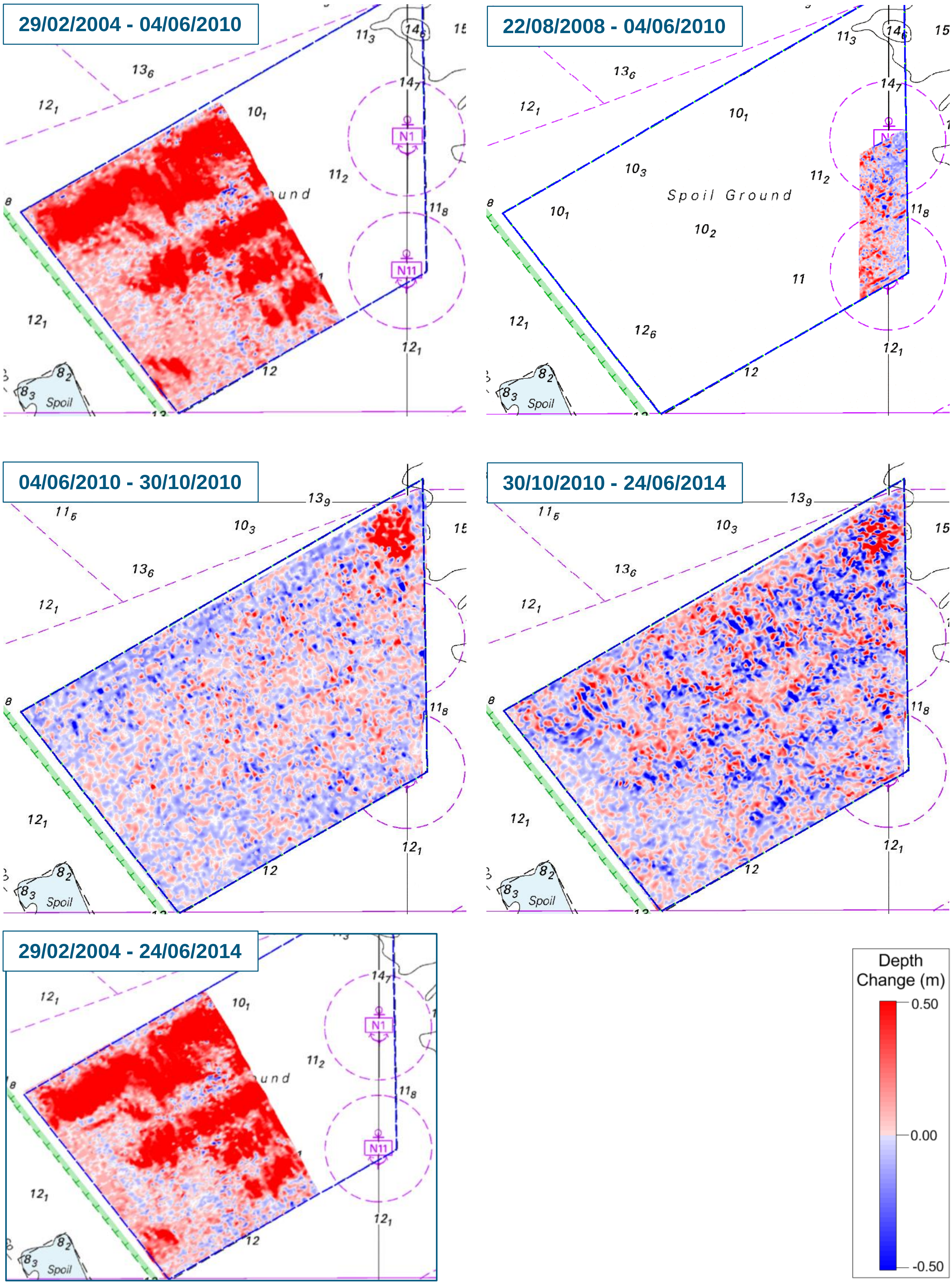

Figure 11. Volumetric differences between successive surveys – Existing Placement Site

The changes in bathymetry at the previous placement site are shown in **Figure 12**. The changes are detailed below:

- September 2004 to October 2004 - these surveys were pre and post maintenance dredging of 98,900m^3 of sediment and as expected the changes show an increase in volume over this one month period. The changes show that material was placed over the entire site, with more of the sediment being placed on the west side of the site;

- October 2004 to December 2005 - between these surveys 400,000m^3 of sediment was placed at the site as part of a capital dredging campaign. The change in bathymetry shows that sediment has primarily been placed around the edge of the site; and

- 12th December 2005 to 13th December 2005 - there are some very small localised changes due to bed levelling activity at the south-eastern corner of the previous placement site.

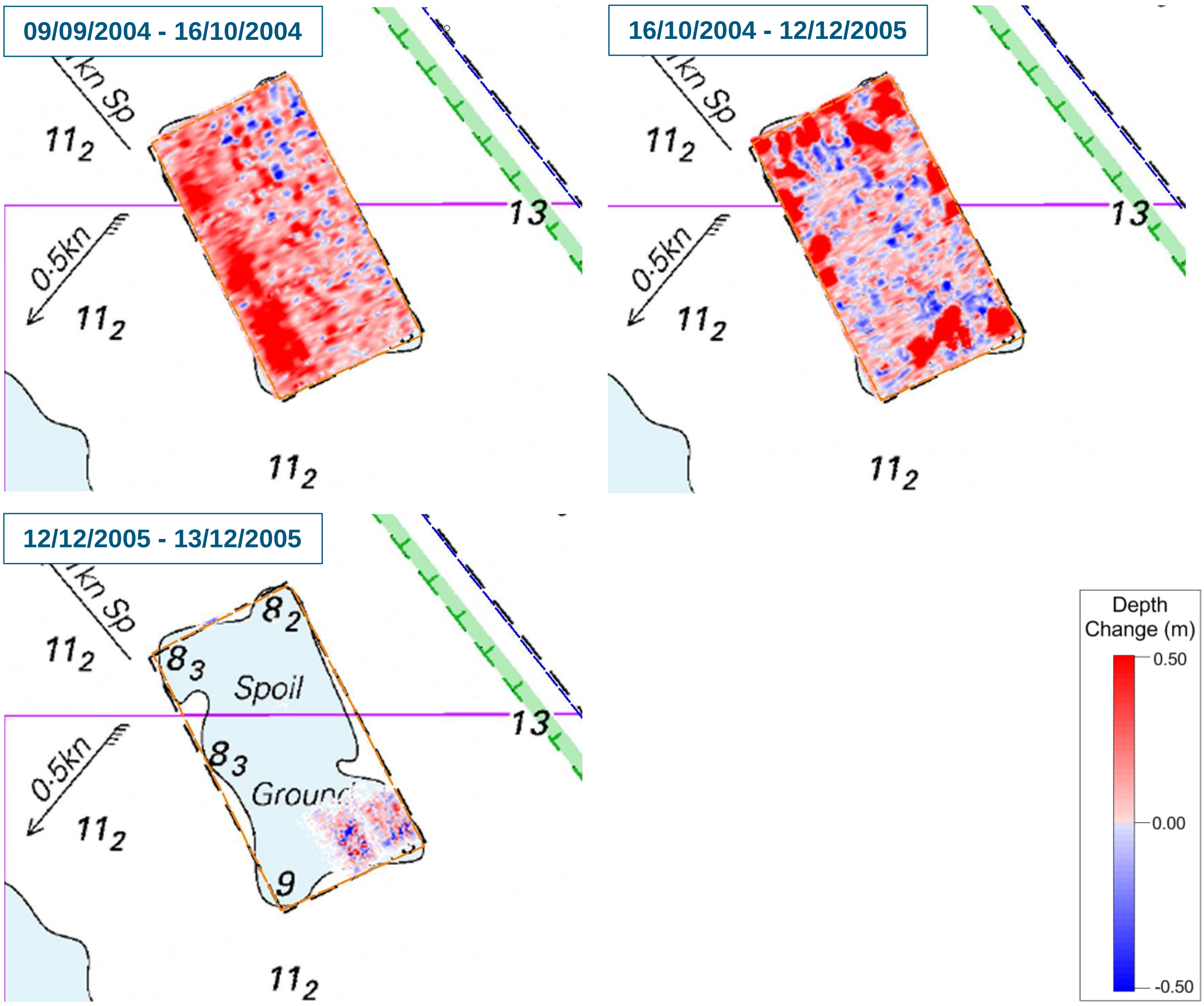

Figure 12. Volumetric differences between successive surveys – Previous Placement Site

3.3.2 Volumetric

The spatially varying positive, negative changes and the net volume change between the February 2004 and October 2014 surveys are tabulated in **Table 9** for the existing placement site and in **Table 10** for the previous placement site.

Table 9 shows that the existing material placement site has been subject to both increases and decreases in volume (varying spatially) over all the periods. The increase in volume in areas which were subject to siltation which has occurred over the period from February 2004 to June 2014 is just over 3,566,758m^3. The decrease in volume in areas which were subject to erosion over the period was just over 93,270m^3. The net change in volume was therefore an increase of 3,473,488m^3 (noting that the February 2004 survey only covered approximately half of the site and so this volume requires scaling, this is further discussed later in this section).

Table 9. Change in volume at Existing Placement Site

Period	Description of Coverage for Volumetric Assessment	Change in Volume		
		Siltation Areas (m^3)	Erosion Areas (m^3)	Net Change (m^3)
29/02/2004 - 04/06/2010	Change in western half of existing material placement site (9Mm^3 + 192,294m^3 dredged)	3,886,396	-60,573	+3,825,823 (+6,842,694[1])
22/08/2008 – 04/06/2010	Change in south-eastern strip of existing material placement site (192,294m^3 dredged)	106,902	-67,769	39,133
04/06/2010 - 30/10/2010	Change in whole of existing material placement site post dredge exercise (216,070m^3 dredged)	689,429	-837,656	-148,227[2]
30/10/2010 - 24/06/2014	Change in whole of existing material placement site (275,000m^3 dredged)	1,047,815	-1,322,762	-274,947[3]
19/06/2013 - 24/06/2014	Change in south-west corner of existing material placement site 1 year following dredge exercise	9,842	-231	+9,611
29/02/2004 - 24/06/2014	Change in western half of existing material placement site over 10 years (Total)	3,566,758	-93,270	+3,473,488 (+6,213,723[1])

1. scaled to approximate change in volume over entire placement area.
2. there was an increase in volume of 167,676m^3 in the north-eastern corner of the placement site over this period.
3. there was an increase in volume of 27,228m^3 in the north-eastern corner of the placement site over this period.

Table 10 shows that the previous material placement site has also been subject to increases and decreases in volume (varying spatially) over all periods. The increase in volume in areas which were subject to siltation which has occurred over the total period of surveys from February 2004 to December 2005 is 633,141m^3. The decrease in volume in areas which were subject to erosion over the period was just over 140,204m^3. The net change in in volume was therefore an increase of 492,937m^3.

Table 10. Change in volume at Previous Placement Site

Period	Description of Coverage for Volumetric Assessment	Change in Volume		
		Siltation Areas (m^3)	Erosion Areas (m^3)	Net Change (m^3)
29/02/2004 - 09/09/2004	Change in whole of previous material placement site[1]	41,287	-72,740	-31,453
09/09/2004 - 16/10/2004	Change in whole of previous material placement site post dredge[1] (likely the 98, 900m^3 maintenance dredging)	252,572	-16,454	236,118
16/10/2004-12/12/2005	Change in whole of previous material placement site[#] (400,000m^3 of capital dredging)	331,632	-44,522	287,110
12/12/2005 - 13/12/2005	Change in whole of previous material placement site immediately following bed-levelling exercise	7,650	-6,488	1,162
29/02/2004 - 13/12/2005	Change in whole of previous material placement site over 21.5 months (Total)	633,141	-140,204	492,937

1. It is understood that 2 campaigns in 2004 (98, 900m^3) and 2005 (400,000m^3) were placed at this site.

A summary of the changes in volume is provided below:

- between the surveys in February 2004 and June 2010 approximately 9Mm^3 (in-situ volume, the actual volume placed will be slightly larger due to bulking of any fine grained sediment) of sediment from the 2006 capital dredging campaign and 192,294m^3 from the 2008 maintenance dredging campaign was placed in the **existing material placement site**. Unfortunately, the February 2004 survey only partially covers the placement site (just over half of the total area (55.9%)). As the June 2010 survey shows that the ridge patterns extend across the entire length of the site a scaling of the net accretion observed should provide a reasonable representation of the total change in volume for the entire site. As such, the total increase in volume over the 4 year period is estimated to be 6,844,048m^3, indicating that of the 9,192,294m^3 placed at the site over this period approximately 75% has been retained. This shows that over this period the existing material placement site has been retentive for sediment from capital dredging;

- a comparison of the 2014 survey versus the 2004 survey shows that over the 8 year period since the capital dredging the **existing material placement site** has retained much of the total material placed there. Considering the scaling detailed above, this equates to an approximate total increase in volume over the 10 year period of 6,213,723m^3, indicating that of the 9,683,364m^3 deposited from the two capital dredging campaigns and two maintenance dredging campaigns (see **Table 1**) approximately 64% has been retained in the placement site. This also indicates that between June 2010 and June 2014 approximately 630,000m^3 of sediment was eroded from the existing placement site. This coincided with an extended period of strong La Nina conditions, which typically result in stronger winds and larger waves and therefore increased erosion potential. In addition, TC Dylan also occurred over this period, and resulted in between 300,000 and 725,000m^3 of erosion in the apron and departure channel. As such, the loss of 630,000m^3 may not represent the typical loss over this period, rather the loss due to an extreme event;

- of the 216,070m^3 of material that was dredged during the 2010 maintenance campaign, 167,700m^3 of the sediment remained within the north-eastern corner of the **existing material**

placement site in the post dredging survey, this equates to 77%. The following survey four years later (in 2014) showed that although there had been some reworking of the sediment in this area, with erosion of the higher spots and deposition in the lower areas, the overall volume of sediment in this area increased by over 27,000m^3. This indicates that the existing placement site is retentive for sediment from maintenance dredging. In addition, the fact that the volume has not decreased over time indicates that the material was predominantly sands, with limited fine grained material; and

- the volume changes indicate that almost all of the material placed at the **previous material placement site** between February 2004 and December 2005 has remained at the site (99%). Based on this it appears that the previous material placement site is retentive in nature, although some bulking of the fine grained sediment could influence the volumes, this is further considered in **Section 3.4**.

3.3.3 Sectional

To show how the bed elevation has changed since February 2004, a series of sections (long and cross) have been extracted from the DEMs at specific locations as shown in **Figure 13**. It is important to note that the sections only show a single transect through the DEMs and so may not show isolated areas of erosion or siltation which are visible in the two dimensional difference plots. The sections are shown in **Figure 14** to **Figure 19**, with a summary of the changes detailed below:

- the 3 long sections (**Figure 14** to **Figure 16**) show that sediment deposits with heights of up to 2m are present following the capital dredge campaign in 2006;
- all sections indicate that following the 2006 dredging the site has mainly been retentive, with erosion limited to the shallowest areas of the ridges where in some cases up to half a metre of erosion has occurred; and
- **Figure 19** (cross-section) shows that since 2008 the south-eastern area of the site has been stable.

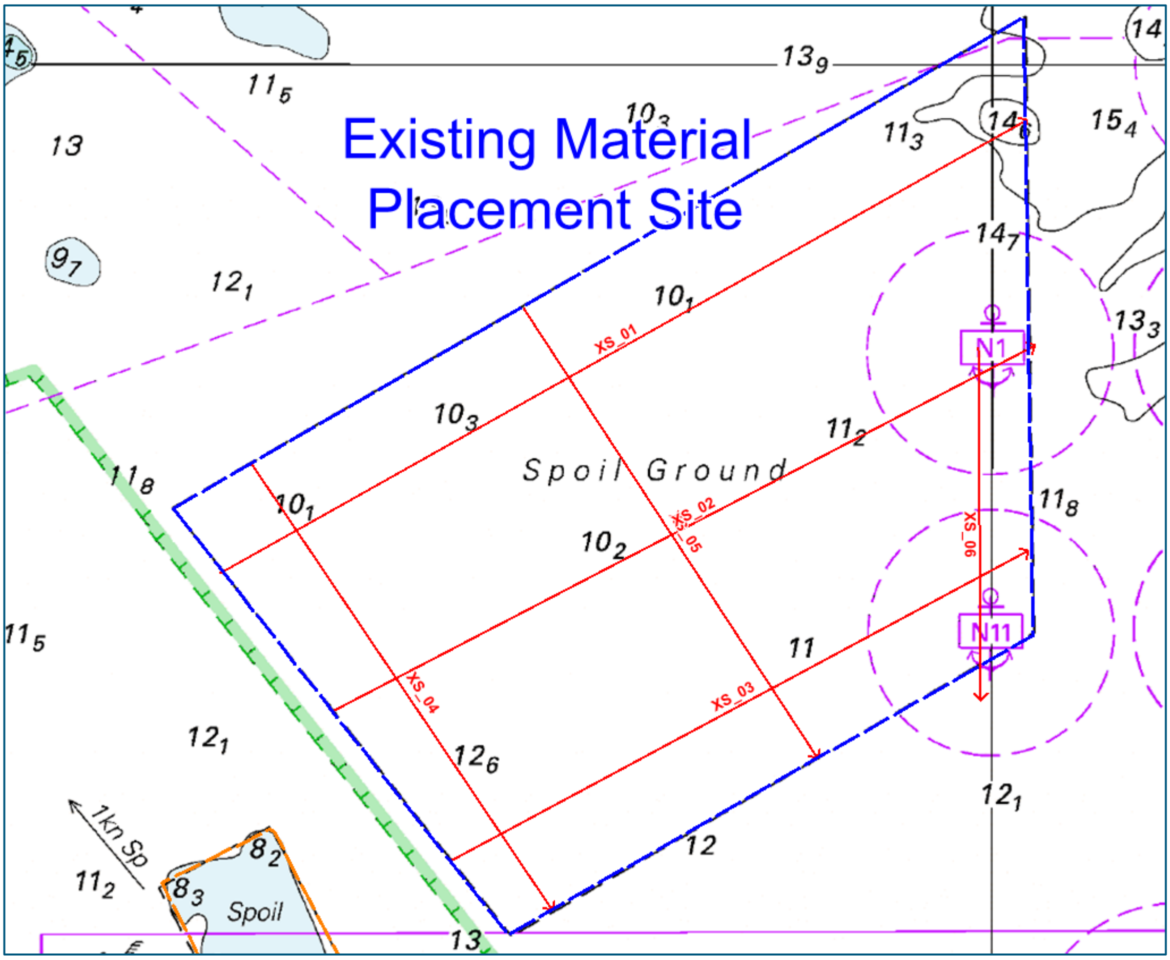

Figure 13. Cross-section Locations

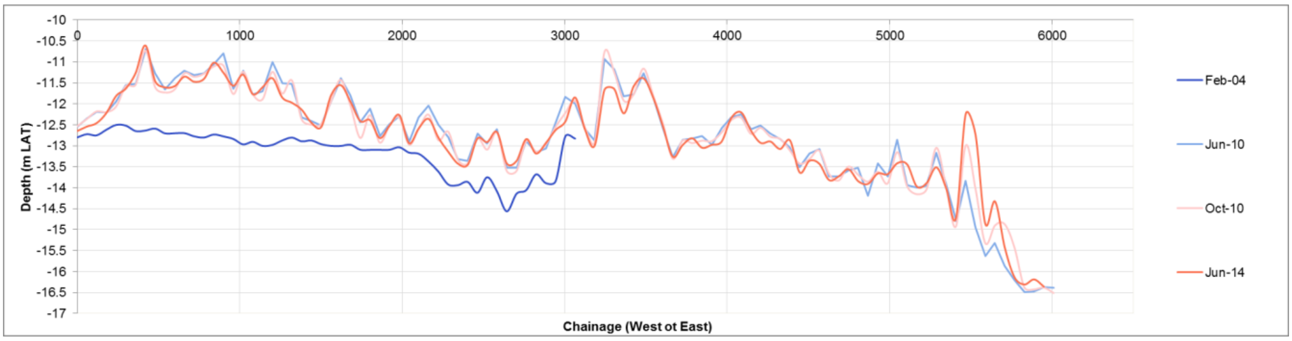

Figure 14. Long-sections showing change in bed elevation - Section 1 in Figure 13

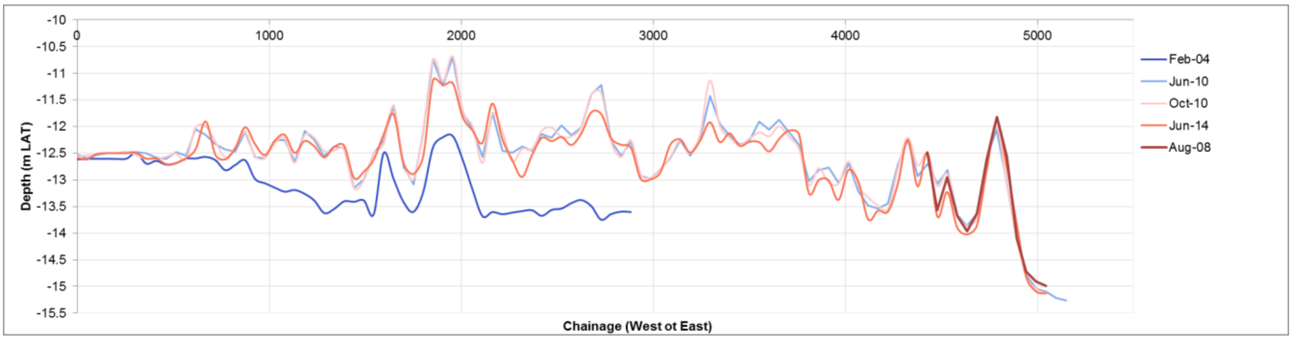

Figure 15. Long-sections showing change in bed elevation - Section 2 in Figure 13

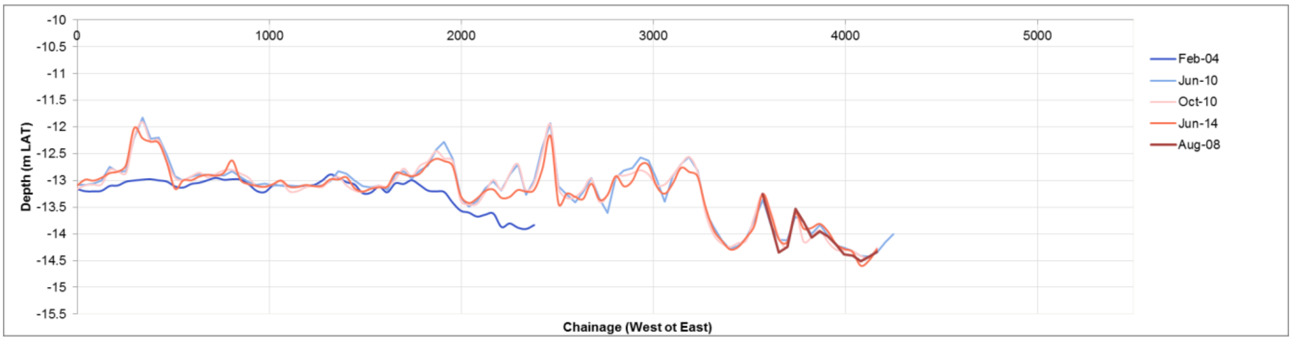

Figure 16. Long-sections showing change in bed elevation - Section 3 in Figure 13

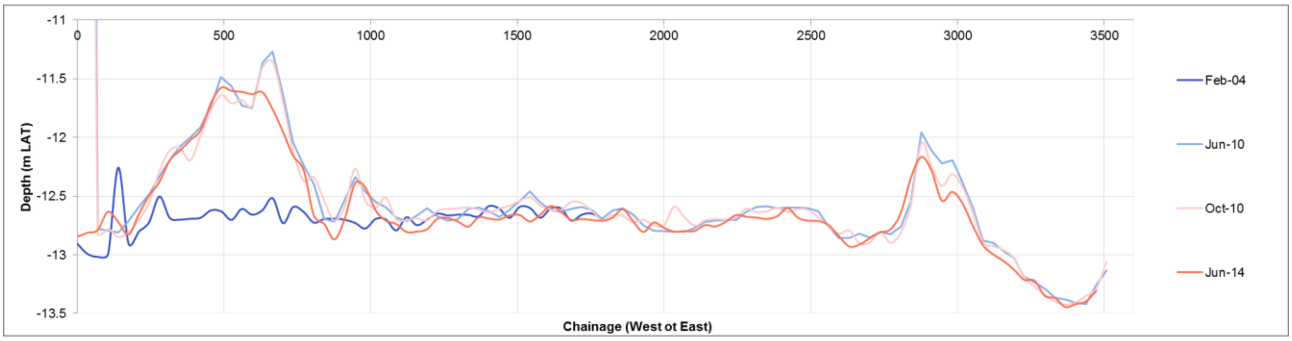

Figure 17. Cross-sections showing change in bed elevation - Section 4 in Figure 13

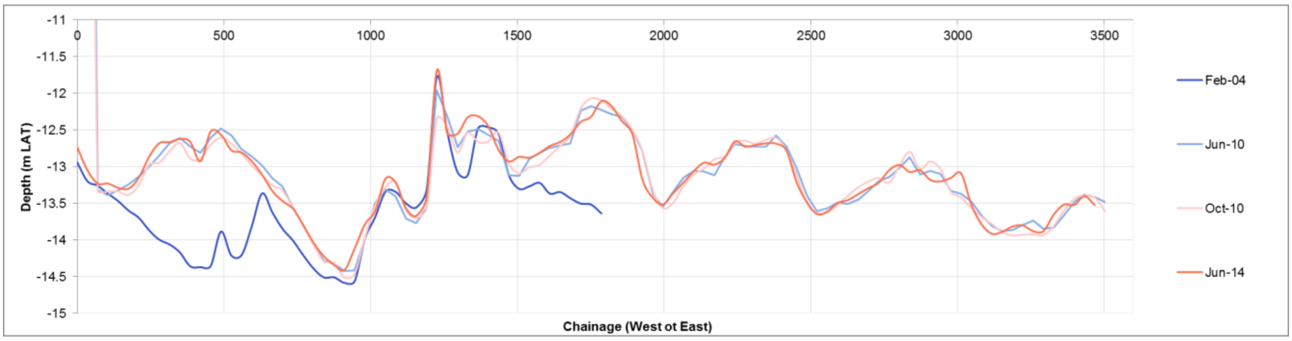

Figure 18. Cross-sections showing change in bed elevation - Section 5 in Figure 13

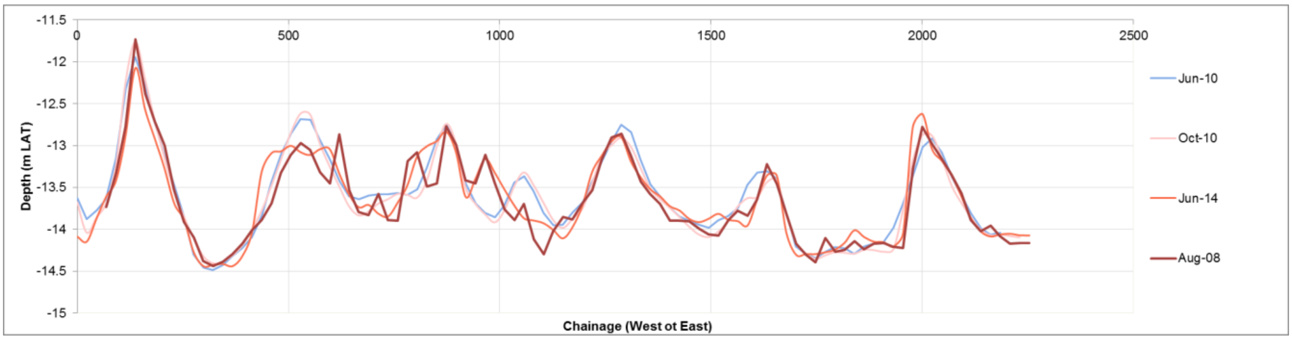

Figure 19. Cross-sections showing change in bed elevation - Section 6 in Figure 13

3.4 Discussion

The bathymetric data indicates that during the capital dredging campaign in 2006 placement of sediment occurred in 5 rows (southwest to northeast orientation), creating shallower ridges on the previously relatively flat and uniform seabed in the **existing material placement site**. In the eight year period between 2006 and 2014, these shallow ridges have remained in place with some localised erosion of the higher points and deposition in the deeper areas.

The bathymetric data collected four years after the 2006 capital dredging and two years after a maintenance dredging campaign showed that approximately 75% of the sediment which was placed in the existing material placement site was retained within the site. However, some sediment would be expected to be lost during the dredging and placement process, especially in an environment like Hay Point which is subject to relatively strong tidal currents.

The amount of sediment lost during the dredging and placement process would be dependent on the dredging approach and the metocean conditions at the time of dredging, but typically between 5 and 10% of the fine grained sediment proportion dredged is lost at the drag/cutter head and as overflow when filling the hopper. In addition, up to 20% of the fine grained sediment proportion can also be lost during the placement of the material as it is suspended in the primary plume as the entire placement material volume drops to the seabed.

Up to 40% of the sediment dredged during the capital dredging was fine grained silts and clays; therefore up to 12% of the total volume of sediment dredged could have been lost prior to it reaching the seabed in the existing placement site. As such, over the four years following the placement of the sediment from the capital dredging, when TC Ului impacted the area, the bathymetric surveys show a loss of material due to ongoing erosion of approximately 13%. This correlates with the erosion the bathymetric surveys show occurred in the following four years, when TC Dylan impacted the area, when an additional 11% of the material was lost due to erosion.

Extreme events which can result in strong winds and large waves, such as tropical cyclones, have the potential to result in relatively large changes to the bathymetry in the material placement sites over a short period of time. RHDHV recently completed a bathymetric analysis and modelling exercise at the Port of Hay Point for NQBP (RHDHV, 2016). In this study more frequent surveys of the channel were undertaken as well as some pre and post cyclone surveys. The assessment found that TC Dylan (January 2014) resulted in erosion of between 300,000 and 725,000m^3 (the large range is due to possible bias with a survey) of the apron and departure channel, with average erosion depths of between 0.1 and 0.2m. Applying the lower end of the range (0.1m) across the area of the existing material placement site would result in a potential volume loss of 1,844,000m^3. However, this is more than six times the measured volume change which occurred over the period when TC Dylan impacted the area. This competitive assessment indicates that the existing material placement site is relatively resistant to erosion even during extreme events.

The **previous material placement site** appears to be highly retentive, with almost all of the sediment dredged appearing to be retained at the site. However, the capital dredging for the DBCT Berth 4 (400,000m^3) was completed in December 2005 and the bathymetric survey was also carried out in December 2005. It is therefore likely that some fine grained sediment was lost during the dredging and placement activity. The reason the volume indicates very little loss is because of the relatively high percentage silt and clay in the sediment (>50%). The dredging and placement activity can break up some of the highly consolidated fine grained sediment, resulting in a reduction in its density and an increase in its volume, this is referred to as bulking and it can result in increases in volume of up to four times. As there are no further surveys it is not possible to test this assumption and determine how much the volume has reduced due to the subsequent compaction of the fine grained sediment over time and therefore how much material was potentially lost in the dredging and placement activity of the original 2005 campaign.

4 Summary

Based on the bathymetric data available the volume of sediment on the seabed has increased at both material placement sites due to the placement of sediment from dredging. Both placement sites are considered to be retentive.

The **existing material placement site** has retained 64% of the sediment from capital and maintenance dredging over the eight years after the main capital dredging campaign. This period has included two tropical cyclones, one of which resulted in significant erosion in the Port of Hay Point apron and departure channel.

The bathymetric surveys indicate that the **previous material placement site** was almost completely retentive. However, this is thought to be a result of the timing of the surveys (immediately after cessation of dredging) along with bulking of the fine grained sediment dredged. As such, based on the bathymetric data available it is not possible to accurately calculate the percentage of sediment which has been retained within the placement site but the site is considered to be retentive.

5 References

GHD 2005. Port of Hay Point – Capital Dredging Departure Path and Apron Areas, Sediment Sampling and Analysis Report. Prepared for Ports Corporation Queensland, March 2005.

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