Supplementary Information – Public Information Package Report

Proposed Maintenance Dredging at the Port of Hay Point

NORTH QUEENSLAND BULK PORTS

P 1300 129 255 E info@nqbp.com.au

nqbp.com.au

HAY POINT • MACKAY • ABBOT POINT • WEIPA

SMART PORTS · BRIGHT FUTURE

Preamble

On 8 December 2017, North Queensland Bulk Ports (NQBP) applied to the Great Barrier Reef Marine Park Authority (GBRMPA) for permission to undertake maintenance dredging, bed levelling and placement of dredged material at the Port of Hay Point in the Great Barrier Reef Marine Park (GBRMP).

The proposed work is maintenance dredging at the Port of Hay Point. An initial dredge program is proposed to remove approximately 356,553 m³ of naturally accumulated sediment from the departure channel located within the GBRMP and from the apron, berth pockets and Half Tide Tug Harbour located outside the GBRMP, but within the Port of Hay Point.

Future dredge programs with volumes of approximately 200,000 m³ in each five-year period during the period of the permit have been applied for.

An additional volume of 200,000 m³ over a ten-year period has been applied for as a contingency. The total volume of dredge material proposed to be placed in the Marine Park over a ten-year period will be 956,553 m³.

Between 22 June 2018 and 21 August 2018, NQBP released a Public Information Package (PIP) for a 60-day period and sought public comment on this Marine Park Permit application via public submissions to GBRMPA.

GBRMPA considered the public submissions made and to address the relevant concerns, requested NQBP (25 September 2018) to provide additional information on the Marine Park permit application (G40185.1).

This ***'Supplementary Information – Public Information Package Report'*** provides NQBP's responses to this additional information request.

Section 1 – Introduction

This ***'Supplementary Information – Public Information Package Report'*** provides responses to each question/topic included in Attachments A and B of GBRMPA additional information request (refer **Appendix C**).

The structure of this report is as follows:

- Section 2 – Response to questions arising from assessment process to date (refer questions 2a – 2d, page 1 of Appendix C)
- Section 3 – Response to 22 public comment questions (refer Attachment A of Appendix C)
- Section 4 – Response to GBRMPA's peer review of the dredge plume modelling (refer Attachment B of Appendix C)
- Appendix A – 'Unburnt coal in the marine environment – Port of Hay Point' weight-of-evidence report
- Appendix B – 'Hay Point Disposal Site Analysis' report
- Appendix C – GBRMPA 'request for additional information on Marine Park permit application G40185.1'

Section 2 and 3 Supplementary Report

Response to additional information on Marine Park permit application G40185.1

Contents

2. Response to questions arising from assessment process to date. 4
3. Response to information request 7
   3.1. Cabbage Tree Creek 9
   3.2. Acid sulphate soils 11
   3.3. Mobilisation and resuspension of fine silts 12
   3.4. Water clarity in the Whitsundays 15
   3.5. Land-based disposal 17
   3.6. Presence of Coal and Potential Effects. 19
   3.7. Coral 23
   3.8. Coastal land-based businesses 23

This section addresses questions 2a – 2d on page 1 of the "Request for additional information on Marine Park permit application G40185.1" dated 25 September 2018 (refer **Appendix C**).

Section 2 - Response to questions arising from assessment process to date

What is the anticipated volume of material to be dredged from that part of the departure channel within the Marine Park?

- **Over the 10-year proposed permit period a total of 33,509 m^3 is anticipated to be dredged from the departure channel within the marine park.**

All the material within the 'departure path' represents the anticipated volume of material to be dredged within the marine park. The current amount of material in the departure channel is shown in table below, estimated at 10,463m3.

Port Area	Maintenance Requirement (m^3)
Half Tide Tug Harbour	28,461
DBCT Berth 1	57,076
DBCT Berth 2	62,323
DBCT Berth 3	47,226
DBCT Berth 4	53,852
HPCT Berth 1	372
HPCT Berth 2	282
HPCT Berth 3	7,197
Apron Area	56,887
Departure Channel	10,463
Total	**324,139**
Allowance for over-dredge (10%)	**32,414**
Total Maintenance requirement	**356,553**

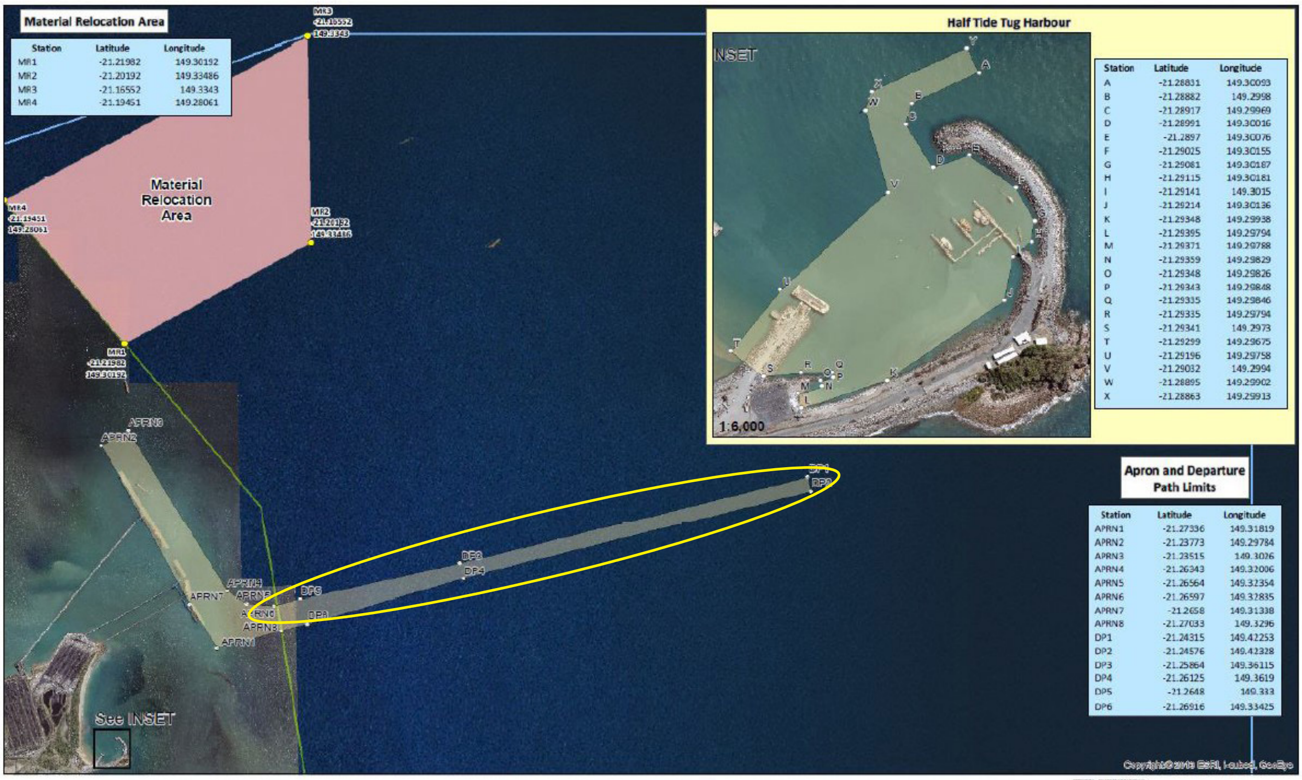
Siltation rates in the departure channel are typically low. A predictive model (Appendix E of the Port of Hay Point Sustainable Sediment Management Assessment) developed as part of the Port of Hay Point Sustainable Sediment Management Assessment estimated around 10,000 m^3 accumulation in each 10-year period.

An additional 10,000 m^3 would be allowed for within the 200,000 m^3 cyclone contingency.

Period	Maintenance within Marine Park (m^3)
2019 – year 1	10,463
1-10 years	10,000
Cyclone contingency	10,000
Total	*30,463*
Allowance for over-dredge (10%)	*3,046*
Total 10-year permit requirement in Marine Park	**33,509**

Can you confirm where bed levelling activities are likely to occur in the Marine Park?

Bed levelling activities will only occur in the Marine Park within the defined departure channel of the Port of Hay Point. The departure channel is circled below.



In relation to the Environmental Risk Assessment (ERA) Introduction and Synopsis document, the following items:

Page 14 - a copy of the industry guidelines for avoiding, assessing and mitigating impacts on EPBC Act listed migratory shorebird species, mentioned on page 14?

The reference on Page 14 refers to EPBC Act Policy Statement 3.21 '*Industry guidelines for avoiding, assessing and mitigating impacts on EPBC Act listed migratory shorebird species*, Commonwealth of Australia 2017 which can be found at http://www.environment.gov.au/epbc/publications/shorebirds-guidelines

Page 24 – a summary of the environmental management mechanisms

Page 24 makes reference to the design features of the Trailing Suction Hopper Dredge (TSHD) Brisbane which assist in minimisation of environmental impacts. The TSHD Brisbane was designed with mechanisms to mitigate the environmental impacts caused by the dredging operations. These mechanisms are equivalent to the features installed in the latest TSHD models used around the world and ensure environmental harm is minimised during the dredging works. Since the commissioning of the TSHD Brisbane it has been updated regularly to incorporate environmental advances in dredging technology, ensuring the TSHD Brisbane operates at the same level as the most recent built TSHDs. The environmental impact mitigation features are described below:

Central weir discharge system (green valve): the overflow turbidity is minimised by controlling the discharge of the water. The water overflows at the central weir then exits via the hull valve. The overflow operation starts when the water level inside the hopper is lowered by opening 1 of 3 weir rings in stages starting from the top down. The opening of the conical bottom valve is regulated by a programmable logic controller (PLC) which ensures an equal amount of water flows out through the centre weir as comes in through the dredge inflow pipes. The balance in the inflow/outflow prevents the formation of a cascade effect inside the central weir, minimising the entrapment of air during the vertical flow as it leaves the vessel. No air in the water means that no air bubbles, which could otherwise

carry material to the water surface and generate an excessive plume, are generated.

Below keel discharge point: the discharge of sediment from the hopper occurs at keel level in order to prevent unnecessary turbidity and dispersal of fine sediments.

Turtle deflection devices: a flexible chain deflector is attached to the dragheads to prevent the entrainment of sea turtles during dredging operations. The device design has been evolving for the last twenty years and its efficiency confirmed by several research projects.

Low wash hull design: by minimizing the size of wash waves created by the vessel movement, the low wash hull design reduces agitation on the water surface, minimizing the interference with the sediments suspended in the water column during discharge. This design can also reduce fuel consumption and damage to riverbank environments.

Electronic positioning system: the TSHD Brisbane is equipped with a global positioning system which is used during the operations. The positioning data is used during the discharge operations to identify the beginning and end of the material placement locations and provide evidence to the regulators to ensure compliance with the material placement boundaries. The GPS data also assists the contractor and clients to identify the areas of origin of the sediment for each cycle and overflow operations location. Environmental Management Plan (EMP): an Environmental Management Plan is developed by the ports and implemented by the dredging contractor for each maintenance dredging campaign. The dredging and disposal associated monitoring arrangements and corrective actions are incorporated. Implementation of the EMP is audited by the ports environmental staff and relevant government agencies.

Page 41 – was there any visitation data for Brampton and Keswick Island or any tourism trends in the Mackay region more broadly?

Specific data and trends on visitation were not researched further as part of the ERA as Keswick Island and Brampton Islands are approximately 20 km and 33 km northeast of Hay Point, respectively and considered well outside the area of influence from maintenance dredging and placement at Hay Point.

NQBP does however have a permanent water quality logger at Keswick Island as part of its well established and ongoing ambient marine water quality monitoring program, and permanent coral transect monitoring sites as part of the well-established and ongoing coral monitoring program. Keswick Island coral monitoring has also been included in our impact monitoring program for maintenance dredging.

Both islands are listed on the Mackay Regional Tourism site. For further information visit https://www.mackayregion.com/explore/islands.

ERA – Appendix F – since that report was run, the scalloped hammerhead has been listed as conservation dependent under the EPBC Act and hence is a protected species within the Marine Park. Are you aware of that species being found in the vicinity of the proposed conducts?

The EPBC Act listing advice (TSSC 2018) states that within Australian waters the scalloped hammerhead extends from New South Wales (approximately from Wollongong, where it is less abundant), around the north of the continent and then south into Western Australia to approximately Geographe Bay, though it is rarely recorded south of the Houtman Abrolhos Islands. Scalloped hammerhead are mobile animals that range widely over shallow coastal shelf waters, but rarely venture into or across deep ocean waters.

There are no records of the species within the Port of Hay Point or the port area, although this does not necessarily indicate the species is absent. Open water fast moving species such as sharks, fin fish and dolphins are rarely impacted directly by dredging activities or dredge vessels due to the slow speeds at which vessels move. Any indirect impacts leading to habitat alienation from vessel presence, noise or turbidity will be temporary and short term in nature. Significant impacts are not expected.

Section 3 - Response to information request

A number of questions have been posed through the 60-day public information package period from [22 June to 21 August 2018] and provided in an Information request from GBRMPA (refer **Appendix C**). The questions have been grouped and addressed in the following sections and responses to 22 questions can be further referenced in sections stated in table below.

3.1. *Comment on potential effects at Cabbage Tree Creek (near Campwin Beach)*
3.2. *Comment on the potential for effects from acid sulphate soils*
3.3. *Comment further the mobilization and resuspension of fine silt*
3.4. *Comment further changes in water clarity expected, giving emphasis on the Whitsundays*
3.5. *Comment further on the assessment of land-based disposal*
3.6. *Comment on the presence of coal and the potential effect this may have*
3.7. *Comment on potential for coral loss*
3.8. *Comment on potential for impacts to coastal businesses*

Topic	Issues and comments raised in the submission	NQBP Response
Coal	Is there a potential for leaching from coal proposed to be dumped at the disposal site? What are the implications of this?	Refer section 3.6
Coal	Is there a potential for coal dumped at the disposal site to float ashore and contaminate turtle nesting beaches? What are the implications of this?	Refer section 3.6
Coal	Is there a potential for coal dumped at the disposal site to cause human health issues in relation to people swimming at beaches adjacent to the disposal site?	Refer section 3.6
Coal	Is there a potential for coal dumped at the disposal site to contaminate fish or invertebrates caught by recreational or commercial fishers?	Refer section 3.6
Coal	Is there a potential for coal dumped at the disposal site to be toxic to any marine wildlife including crocodiles?	Refer section 3.6
Coal	What distance might coal disperse after being dumped at the inshore and mid-shelf sites?	Refer section 3.6
Coal	How much coal is in the material to be dredged and dumped?	Refer section 3.6
Coal	How much of the coal in the material to be dredged and dumped is less than 400μm?	Refer section 3.6
Coal	Is there any data on the toxicity or bioavailability of leachate from coal dredged and dumped from the proposed activities?	Refer section 3.6
Coral	Do you expect a similar level of coral loss from the proposed dredging as experienced in 2006 (2-5 percent loss at islands up to 6km away as described in Smith et al. 2007?	Refer section 3.7
Economic impacts	What is the potential for effects from increased sedimentation/turbidity on the ongoing viability of coastal land based businesses?	Refer section 3.8
Water quality	What is the potential for increased sedimentation to affect, restrict and potential block the entry of tidal waters at Cabbage Tree Creek? How would you mitigate this risk?	Refer section 3.1
Water quality	What is the potential for changed patterns of current flows of seawater, possibly redirecting sediment and contaminants into Cabbage Tree Creek? How would you mitigate this risk?	Refer section 3.1
Water quality	What is the potential for water quality to have increased sedimentation/turbidity in Cabbage Tree Creek? How would you mitigate this risk?	Refer section 3.1
Water quality	What is the potential or acid sulphate soils to be released as a result of dredging? Where would those dredge plumes flow to?	Refer section 3.2
Water quality	How much fine silt is mobilised as a result of dumping? Where is it predicted to go? Will it flow north to the Whitsundays?	Refer section 3.3
Water quality	Does NQBP have any evidence that a reduction in water clarity in the Whitsundays was caused by the capital dredging and dumping in 2006/7?	Refer section 3.4
Water quality	How quickly is sediment likely to reach the Whitsundays? The public submissions estimated that this would take between 4.2 and 6.7 days.	Refer section 3.3

Topic	Issues and comments raised in the submission	NQBP Response
Water quality	How much sediment will be resuspended in each proposed placement area from tidal currents and surface wave action?	Refer section 3.3
Water quality	What is the effect of dumping fine silts in a placement area which is usually coarse sand?	Refer section 3.3
Water quality	Is there still an expected 36 percent loss of material from the inshore dump site as happened in the 2006 capital dredging campaign?	Refer section 3.3
Water quality	Why can't an onshore solution to disposal be prioritised above the at sea proposals?	Refer section 3.5

3.1 Cabbage Tree Creek

What is the potential for increased sedimentation to affect, restrict and potential block the entry of tidal waters at Cabbage Tree Creek? How would you mitigate this risk?

What is the potential for changed patterns of current flows of seawater, possibly redirecting sediment and contaminants into Cabbage Tree Creek? How would you mitigate this risk?

What is the potential for water quality to have increased sedimentation/turbidity in Cabbage Tree Creek? How would you mitigate this risk?

- Water quality and sedimentation is expected to remain within the natural ranges experienced in the Hay Point area. Dominant sediment transport processes are to the north, whereas Cabbage Tree Creek is approximately 10-15km to the south. No changes to Cabbage Tree Creek water are expected.

The above three questions related to water quality issues at Cabbage Tree Creek have been addressed below:

Maintenance dredging is proposed at the Port of Hay Point berth pockets, apron, departure channel and half-tide tug harbour located approximately 10-15 kilometres north of Cabbage Tree Creek, which is adjacent to Campwin Beach.

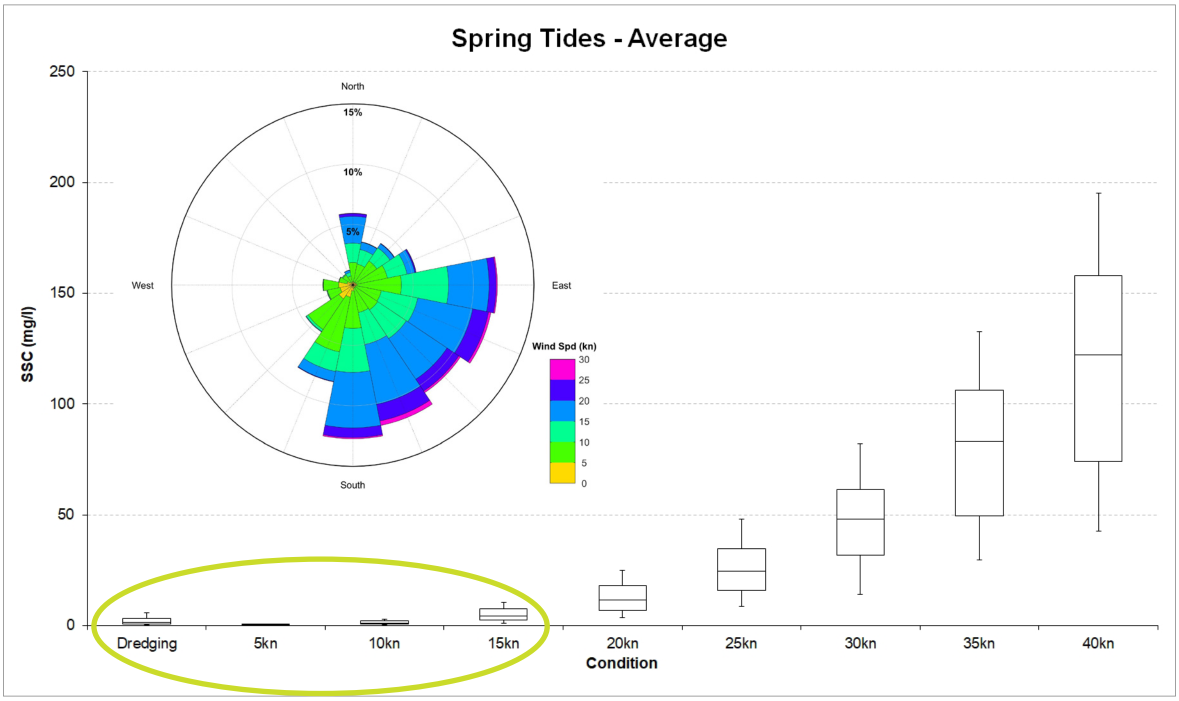
Maintenance dredged material will be relocated approximately 4-6 kilometres north of the proposed maintenance dredging areas at the Port of Hay Point. The Dredged Material Placement Area (DMPA) is expected to retain two-thirds of material and remain close to the DMPA even during extreme wet weather events (i.e. cyclone).

Modelling (Appendix A of Port of Hay Point Environmental Risk Assessment) has showed that that sedimentation/ turbidity (water clarity) would remain within the natural range of the Hay Point area, up until 800,000 m^3 or more was dredged and placed in a single maintenance dredging program (which is not proposed).

The maintenance dredging program proposed is of a much lower volume, being 356,553 m^3 initially and staged programs of 200,000 m^3 each thereafter.

The numerical modelling, based on 3-years of water quality data, demonstrated that maintenance dredging and placement of up to 400,000 m^3 resulted in water clarity comparable to that experienced during calm conditions (wind speeds of 15 knots and under, see figure below).

No changed patterns of current flows are predicted and navigational infrastructure (berth pockets, apron, departure channel) are only being restored to original design depths.



NQBP has overseen a comprehensive ongoing ambient marine (water quality, seagrass, coral) monitoring program since 2014. The program has previously and is currently being undertaken by James Cook University marine scientists as part of a new three-year partnership. This program helps NQBP understand the natural marine environment and collects data to drive continual improvement.

Furthermore, NQBP will mitigate risks by implementing an adaptive monitoring program which will provide real-time water quality information. This will commence 4 weeks prior to maintenance dredging commencement and end 4 weeks after completion of dredging. The four sites that will be monitored are Round Top island, Victor Island, Slade Island and Freshwater Point. NQBP notes that Cabbage Tree Creek is located between Victor Island and Freshwater Point monitoring sites. This monitoring information will be available to the public and regulators in real-time on our website.

Therefore, we expect:

1. No increased sedimentation that affects, restricts or blocks the entry of tidal waters at Cabbage Tree Creek.
2. No change in patterns to current flows of seawater at Cabbage Tree Creek.
3. No increased sedimentation / turbidity in Cabbage Tree Creek.

3.2 Acid sulphate soils

What is the potential of acid sulphate soils to be released as a result of dredging? Where would those dredge plumes flow to?

- We expect the potential for acid sulphate soils to be released as a result of dredging to be negligible and dredge plume flows with acid sulphate soils to be also negligible and with very low risk of oxidation and acidification.

Dredging and disposal of Potential Acid-Sulphate Soils (PASS) containing sediments in the marine environment are unlikely to result in either significant oxidation of this material, acid production, or release of significant quantities of heavy metals to the water column (SEWPAC, 2013).

Treatment of Acid-Sulphate Soils (ASS) is normally more of an issue with land disposal, particularly with dredged development or capital material. Specific management techniques need to be adopted where acid sulphate soils exist and have little or no self-neutralising capacity. Exposure of these soils to air can lead to the production of sulphuric acid and the release of toxic quantities of iron, aluminium and heavy metals. Lined treatment area and the application of lime are common management controls that assist in mitigating water quality impacts, should such material be placed on land. Land placement of such material is liable to require costly long-term management and monitoring to avoid issues associated with acidic water discharges unless all such material is placed below the water table. (Dredging and Australian Ports - Subtropical and Tropical Ports (Ports Australia, 2014)).

Actual acid sulphate generating soils do not typically occur in dredged maintenance material as this material results from the natural sediment transport process of unconsolidated sediments that accumulate in the Port area. No Actual Acid Sulphate Soil (AASS) was found through the extensive testing undertaken for our Sediment Characterisation Report.

Potential Acid Sulphate Soil (PASS) was found in 9 of the 16 sampling locations generally in the apron and berth pocket areas. This is consistent with most marine sediments involved in dredging projects in inshore subtropical and tropical Australia Waters (Dredging and Australian Ports - Subtropical and Tropical Ports (Ports Australia, 2014)).

Analysis of the acid neutralizing capacity (ANC) indicated a high natural neutralizing capacity. Placement of dredged material will be below the keel of dredge (i.e. underwater) which further limits oxidation potential.

Therefore, we expect the potential for acid sulphate soils to be released as a result of dredging to negligible and dredge plume flows containing acid sulphate soils to be also negligible and with very low risk of oxidation and acidification.

3.3 Mobilisation and resuspension of fine silts

How much fine silt is mobilised as a result of dumping? Where is it predicted to go? Will it flow north to the Whitsundays?

How quickly is sediment likely to reach the Whitsundays? The public submissions estimated that this would take between 4.2 and 6.7 days.

How much sediment will be resuspended in each proposed placement area from tidal currents and surface wave action?

What is the effect of dumping fine silts in a placement area which is usually coarse sand?

- Approximately 60% will be finer material, of which two-thirds is expected to remain directly within the placement area. Most of the remainder will settle out adjacent to the placement area and quickly consolidate into seafloor sediment matrix.
- Dominant sediment transport processes are to the north, but 'direct' passage of fine silts to the Whitsundays is unlikely as sediment particles do not remain in suspension.
- Finer material will start to consolidate into the seafloor matrix shortly after disposal.
- Minor resuspension regularly occurs as a result of typical wave and tidal conditions, but resuspension will occur mostly during high energy events as would widespread resuspension of the surrounding seabed.

The percentage of clays and silt (<0.075 mm diameter) represents approximately 60% of the proposed material to be relocated.

Most of the material is expected to remain in or adjacent to the Dredged Material Placement Area (DMPA). Bathymetric analysis of the DMPA (refer **Appendix B** - Hay Point Disposal Site Analysis) and the modelling (refer Appendix A of Port of Hay Point Environmental Risk Assessment) undertaken as part of this assessment has predicted that approximately two thirds of the material placed would be retained.

Natural sediment transport in the area is to the north and south, with a dominance to the north. Normal wave and wind energy is enough to mobilise the finer disposed material, but insufficient to mobilise larger material. Finer material will start to consolidate a short time after disposal (1-week to 1-month) after which normal wave and wind energy will be insufficient to mobilise this material.

Resuspension at the DMPA is due to relatively short duration large wind events, the most severe of which occur in the wet season (e.g. a tropical cyclone) as opposed to regular resuspension due to tidal currents and typical wave conditions. It is important to note that during these types of high energy events widespread resuspension of the surrounding seabed would be expected, which would result in very high natural suspended solids concentrations. The modelling results (refer Appendix A of Port of Hay Point Environmental Risk Assessment) have also shown that during these specific metocean conditions there is the potential for short duration, low SSC increases at Keswick Island due to the maintenance dredging when the outer mid-shelf DMPA is used. For dredge volumes of 200,000 m^3 and 400,000 m^3 the SSC increases are limited to discrete small areas adjacent to the island, but for volumes of 800,000 m^3 and above the whole area surrounding the island is subject to these increases. When the existing, proposed DMPA is used the maintenance dredging is not predicted to increase the natural SSC at Keswick Island.

The modelling (refer Appendix A of Port of Hay Point Environmental Risk Assessment) undertaken also shows deposition of the sediment resuspended from the DMPAs during events occurs primarily in the areas directly adjacent to the DMPAs.

The Port of Hay Point Sediment Dynamics report (AECOM, 2016), reports that it is predominantly sediment ranging from clay to very fine sand that can be regularly resuspended by tidal currents and waves and transported in suspension in the Hay Point region. During larger wave events and/or periods of strong tidal currents it is possible that coarser particles (medium to coarse sand, gravel and gravel sized coal particles (>10 mm)) can be mobilised, but these particles will be transported as bedload rather than suspended load. When a particle is transported as bedload it will remain very close to the seabed which limits the distance that the sediment can be transported (e.g. 10s to

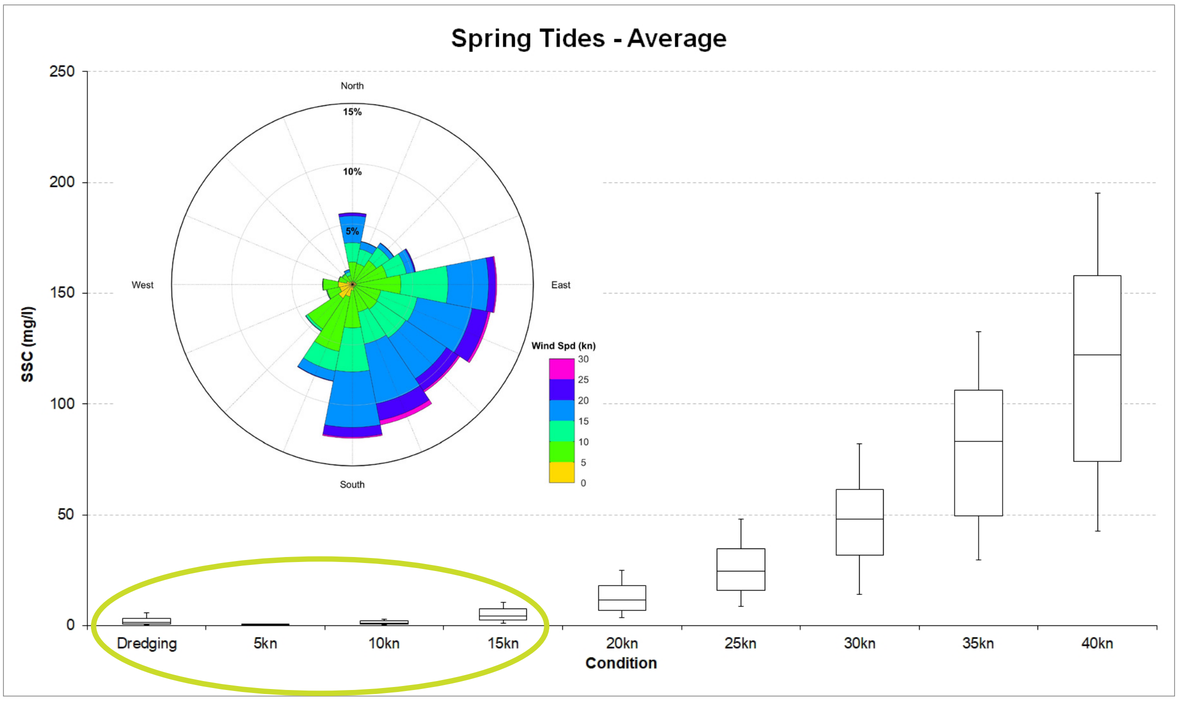
100s of metres per transport event) compared to suspended load (100s to 1,000s of metres per transport event). As these coarser particles are only transported occasionally during larger wave events or periods with very strong tidal currents and as they are not transported as far as finer grained sediment, which is transported in suspension, means that the particles would typically not be transported quickly, potentially with rates ranging from 10s of metres to a few kilometres per year depending on the sediment properties, local conditions and metocean conditions over the year. The only exception to this would be when these particles are in the nearshore wave breaking zone close to the shoreline, when the regular wave breaking could result in higher rates of longshore transport.

Based on the known velocities of local currents near the DMPA anything that remains in suspension (of which sediments would not), may travel a residual distance of 30-50km northward over a 30-day period (depending on season). With the southernmost Whitsunday Island approximately 80km north of the Port of Hay Point DMPA, it could take 1.5 months for fine-grained particle (assuming it never settles out, which is not the case) to reach the Whitsunday islands. Importantly sediment particles do not remain in suspension and readily consolidate into the natural seafloor matrix.

Sediment within the berth pockets, apron and departure channel at the Port of Hay Point requiring maintenance dredging has already been resuspended and transported naturally to be deposited.

The numerical modelling demonstrated that maintenance dredging and placement of up to 400,000m^3 resulted in suspended solids concentrations comparable to that resuspended naturally during calm conditions (wind speeds of 15 knots and under), as shown in the figure below.

Refer also Figures 19 and 20 of "Natural Sediment Resuspension Assessment" (refer Appendix B of Port of Hay Point Environmental Risk Assessment) for the relationships between wind speeds and dredging on suspended sediment concentrations (SSC).



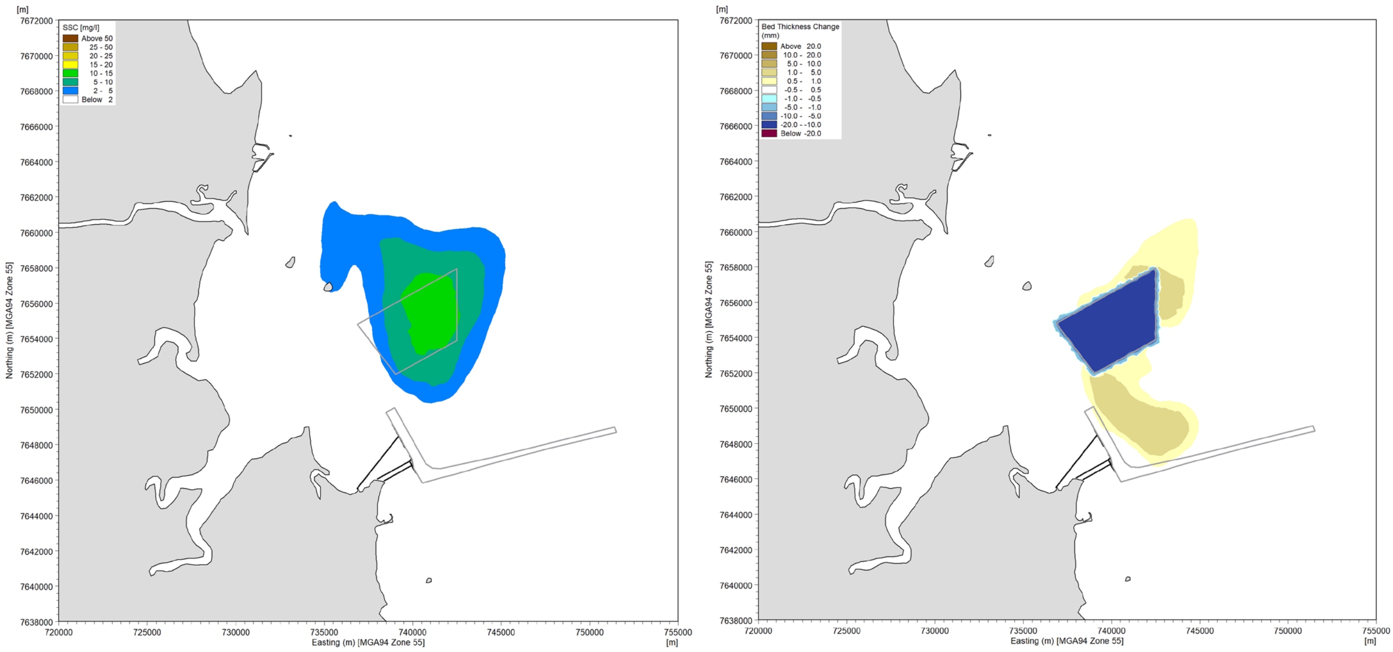
Is there still an expected 36 percent loss of material from the inshore dump site as happened in the 2006 capital dredging campaign?

- The modelling undertaken as part of this assessment has also predicted that approximately two thirds of the material placed at either the existing or outer DMPAs would be retained.

The existing material placement site has retained 64% of the sediment from capital and maintenance dredging over the ten years after the main capital dredging campaign (in 2006). This period has included two tropical cyclones (refer **Appendix B** - Hay Point Disposal Site Analysis).

The deposition of sediment modelled to be resuspended from either of the DMPAs occurs primarily in the **areas directly adjacent to the DMPAs** with both the existing and mid-shelf DMPA's retaining approximately two-thirds of the material placed at either. Refer to Figures 193 - 196 of Section 7.6 of Plume Modelling assessment (refer Appendix A of Port of Hay Point Environmental Risk Assessment).

NQBP intend to use the existing DMPA, of which the relevant figures from the plume modelling assessment are shown below.



a) 99th percentile SSC

b) Change in bed thickness

Figure 194: Long-term resuspension results showing (a) the 99th percentile SSC and (b) the change in bed thickness for 400,000m³ of sediment using the existing DMPA.

3.4 Water clarity in the Whitsundays

Does NQBP have any evidence that a reduction in water clarity in the Whitsundays was caused by the capital dredging and dumping in 2006/7?

- NQBP has no data of reduced water clarity in the Whitsundays and is not aware of any declines in water clarity that may be attributed to capital dredging in 2006/7. NQBP does note that the current application is also for 'maintenance' dredging and disposal.

Long-term water quality data for the Mackay-Whitsunday region can be found in the '*Annual Report for inshore water quality monitoring 2015-2016*' (GBRMPA, 2017). An extract of the key water quality trends is provided in the figure below.

The report provides some commentary regarding water clarity in the Whitsundays:

- Turbidity showed peaks in 2011 and 2014, with values above the guideline
- The trend-lines for both TSS and Secchi depth only showed minor changes, with slight decreases in TSS and corresponding increases in Secchi depth
- The trend line for TSS has remained at values around the guideline, while Secchi depth has been consistently non-compliant with the guideline
- Combined, the turbidity, TSS and Secchi depth data indicate that the water "clarity" in the Mackay Whitsunday region has decreased
- Concentrations of PN and PP have increased over the sampling period, with both being above guideline values in 2015–16

None of the post capital dredging (8.6 Mm^3) reporting from 2006/7 presents any known ongoing changes in water quality resulting from the program. Importantly, for the current maintenance dredging proposed, impacts to sensitive environmental values is not expected if the dredging volume remains under 800,000 m^3 in any single maintenance dredging program. Water quality is expected to remain within natural conditions common to the area and management triggers have been be established to reflect local ecological thresholds.

The maintenance dredging program proposed is of a much lower volume, being 356,553 m^3 initially with future staged programs of approximately 200,000 m^3 each over a ten-year period.

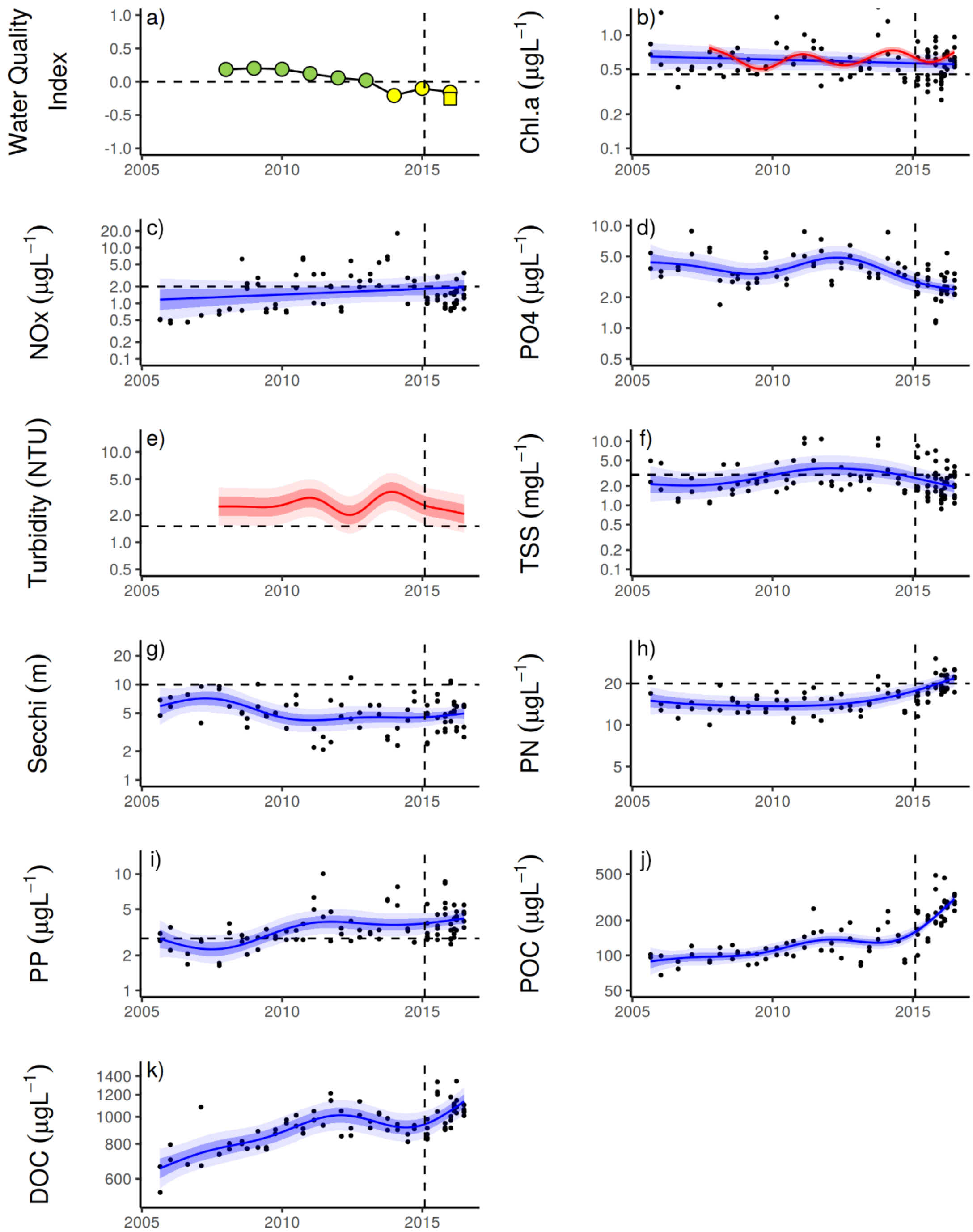


Figure 3-51: Temporal trends in water quality for the Mackay Whitsunday focus-region. a) water quality index, b) Chl-a, c) nitrate/nitrite, d) phosphate, e) turbidity, f) TSS, g) Secchi depth, h) PN, i) PP, j) POC and k) DOC. Water quality index colour coding: dark green – 'very good'; light green – 'good'; yellow – 'moderate; orange – 'poor'; red – 'very poor'. Note that in 2015–16 a separate score for the data collected by both AIMS and JCU are shown as a single point in Figure 3-42a, Trends in manually sampled water quality variables are represented by blue lines with blue shaded areas defining 95% confidence intervals of those trends accounting for the effects of wind, waves and tides after applying x-z detrending, black dots represent observed data. Trends of records from ECO FLNTUSB instruments are represented in red, individual records are not displayed. Dashed horizontal reference lines indicate yearly guideline values and the vertical dashed lines represent when the sampling design was changed (Feb-2015), both lines are only shown for reference.

3.5 Land-based disposal

Why can't an onshore solution to disposal be prioritised above the at sea proposals?

- Land-based disposal facilities would need to be 30-50 ha in size. No feasible beneficial reuse for dredged material has been identified, and as such additional onshore facilities (30-50 ha) would need to be considered to accommodate the long-term operation of the Port.
- Land-based options were highly constrained by terrestrial environmental values, are among the highest cost options, and would effectively result in sterilising future uses of large land parcels.
- No feasible solutions were found to completely avoid ongoing sediment accumulation at the Port of Hay Point, with traditional maintenance dredging and at-sea disposal being, on balance of environmental, social and economic considerations, the preferred option.

The Port of Hay Point Sustainable Sediment Management Project (SSM) identified a number of possible sites for the placement of maintenance dredged material. This included two land-based disposal facility sites, two land-based reclamation sites, potential mangrove rehabilitation, as well as a number of at-sea locations.

In summary, at sea options performed better against most factors including impacts to the environment, social and cultural values. Land-based options were highly constrained by terrestrial environmental values, are among the highest cost options, and would effectively result in sterilising future uses of large land parcels, as no feasible beneficial reuses were identified. The SSM also identified that significant land would be required and each pond which would only accommodate one dredging program's volume without removal of dried sediment or significant augmentation. Additional onshore facilities (30-50 ha) would need to be considered to accommodate the long-term operation of the Port and continued maintenance dredging needs.

There are several important environmental values that occur in the vicinity of the land-based sites. The following features are of note.

- Representations of World Heritage Outstanding Universal Value (OUV) in the form of migratory shorebird habitat at Dudgeon Point and a diversity of mangrove species in estuarine areas at both locations
- Indigenous cultural heritage values at both locations, but particularly at Dudgeon Pont where there are artefacts, sites and a connection to Country
- Habitat for the endangered water mouse at both locations
- Listed regional ecosystems and wetlands of state and local significance
- Social values in terms of residents, transport infrastructure, economic land uses, amenity and access

Each of these key values is likely to be impacted by the construction and/or operation of land-based dredge material disposal facility to some extent. Particular consideration to the management of the following matters would be necessary to mitigate environmental or social impacts.

- Potential acid sulphate soils and groundwater management
- Tail water discharge and suspended sediment management of nearby waterways
- Air quality
- Traffic and road upgrades
- Amenity, reduced access and aesthetics

Many of these potential impacts and constraints are likely to be present at any coastal Queensland site selected for land-based disposal facility development.

Although land-based disposal is unlikely to impact the World Heritage OUV attributes at the property scale, significant impacts to MNES would need to be managed and a referral under the EPBC Act required.

Habitat restoration (particularly mangrove restoration) has been identified as a potential future reuse option, although significant additional supporting studies will need to be undertaken to assess if feasible opportunities exist in or near the Port of Hay Point area. NQBP has committed to investigate the habitat restoration or creation beneficial reuse options further and has established a scientific advisory group to help scope a feasibility assessment. These studies are expected to be completed prior to the second dredging program under this permit.

The comprehensive Sustainable Sediment Management Assessment for the Port of Hay Point developed eleven long term strategies, combining the various disposal alternatives, over a 25-year timeframe.

A structured decision-making process showed how each of the eleven strategies compared when equally considering each of the key themes (Environmental, Cultural Heritage, Port Economics and Operations, Health and Safety, Social, Innovation, World Heritage).

The structured decision-making process was also able to show how the comparison would change if the outcomes were significantly weighted (75%) to any one particular theme.

Long Term Strategy	At Sea Existing x 1 Reclamation Hay Point x 4	At Sea Existing x 1 Habitat Rehabilitation x 1 At Sea Existing x 3	At Sea Existing x 1 Habitat Rehabilitation x 1 Reclamation Hay Point x 3	At Sea Existing x 1 Habitat Rehabilitation x 1 Onshore Dudgeon Point x 3	At Sea Existing x 1 Onshore Dudgeon Point x 4	At Sea Existing x 1 Habitat Rehabilitation x 1 Onshore Mackay x 3	At Sea Existing x 1 Onshore Mackay x 4	At Sea Existing x 5	At Sea Mid-shelf x 5	At Sea Existing x 1 At Sea Coral Sea x 4	At Sea Mid-shelf x 1 Habitat Rehabilitation x 1 At Sea Mid-shelf x 3
Equal weights	41	70	45	54	52	47	44	71	68	56	68
Environment (75%)	39	69	44	63	60	61	57	65	72	46	75
Social (75%)	36	57	41	54	53	37	31	57	56	52	56
Economic (75%)	44	80	44	48	49	39	40	89	74	59	69
Cultural (75%)	74	92	78	73	68	71	65	92	91	88	91
WHA (75%)	42	68	50	64	60	62	57	65	55	68	60

■ Best score for an option under a particular weighting scenario

■ Second best score for an option under a particular weighting scenario

■ Worst score for an option under a particular weighting scenario

A sensitivity analysis was undertaken to ensure that no one measure was substantially biasing the results.

The results identified **three higher performing options:**

- continued and ongoing at-sea disposal at the existing Dredged Material Placement Area (DMPA).
- a combination of continued at-sea disposal at the existing DMPA and habitat restoration at some time in the future (pending a range of additional studies and feasibility assessment), reverting to continue at-sea disposal thereafter.
- a combination of at-sea disposal at a new mid-shelf DMPA and habitat restoration at some time in the future (pending a range of additional studies and feasibility assessment), reverting to continue at-sea disposal thereafter.

3.6 Presence of Coal and Potential Effects

How much coal is in the material to be dredged and dumped?

How much of the coal in the material to be dredged and dumped is less than 400μm?

What distance might coal disperse after being dumped at the inshore and mid-shelf sites?

Is there any data on the toxicity or bioavailability of leachate from coal dredged and dumped from the proposed activities?

Is there a potential for leaching from coal proposed to be dumped at the disposal site? What are the implications of this?

Is there a potential for coal dumped at the disposal site to float ashore and contaminate turtle nesting beaches? What are the implications of this?

Is there a potential for coal dumped at the disposal site to cause human health issues in relation to people swimming at beaches adjacent to the disposal site?

Is there a potential for coal dumped at the disposal site to contaminate fish or invertebrates caught by recreational or commercial fishers?

Is there a potential for coal dumped at the disposal site to be toxic to any marine wildlife including crocodiles?

It is noted that there have been anecdotal concerns regarding coal as a contaminant in the marine environment. NQBP has undertaken a multiple lines-of-evidence review of the concerns regarding unburnt coal in the marine environment, with key findings summarised below.

- Dredging and material placement at either the existing or mid-shelf Dredged Material Placement Areas (DMPA) is unlikely to be a source of historical, existing or future significant concentrations of coal.

Both coal terminals at the Port of Hay Point operate within the guidance of an Environmental Authority (EA) that is administered by the Department of Environment and Science. Significant effort goes into ensuring the risk of coal spillage from coal terminal activities is minimised and managed in accordance with the numerous conditions of their respective EAs.

It is expected that any coal spillage that might arise is most likely to occur in berth pockets where vessels are tied along the wharf infrastructure for loading coal. In consideration of this, there are several important facts to consider when assessing whether significant quantities of coal are likely to be present in the maintenance material and have been or will be transported to the DMPA.

- Maintenance dredging of the berth pockets last occurred in 2004,
- Material from 2004 maintenance dredging was placed at the ‘old’ material placement area some distance to the west of the existing placement area,
- Maintenance dredging in 2008 and 2010 was of the apron area and departure path only, and did not include berth pockets,
- As such:
    - no maintenance material from berth pockets (where likelihood of coal spillage is higher than other areas within the port) has ever been relocated to the existing or mid-shelf DMPA’s.
    - the DMPA’s are not a historic or existing source of coal.

- During the analysis of maintenance sediments in accordance with the National Assessment Guidelines for Dredging (NAGD) 2009, NQBP recognized the potential for coal to be present in the sediment samples, particularly within berth pockets.
- NQBP, following advice from GBRMPA, sieved samples that contained visible coal particles through a 400µm screen to ensure sediment testing is not compromised.
- In the recent 2018 sediment assessment (*Maintenance Dredging Sediment Characterisation Report – Port of Hay Point, Advisian, May 2018*), coal fragments were only observed at 4 of 43 sampling locations.
- Other studies undertaken in 2014 (Receiving Environment Monitoring Programs for DBCT and BMA, Koskela Group, 2014), measured and quantified amounts of coal in the sediments, concluding:
    - There were trace amounts of coal in sediments at Half Tide Tug Harbour (<0.6%).
    - The percentage of coal within sediment at an offshore control site (approximately 1km from shore) ranged from 0.1% to 0.2%.

  Coal is not currently a significant part of the sediment matrix in the maintenance material, as it would be expected to occur in many more of the samples taken.

The presence of coal on some beaches north of the Port of Hay Point has been of recent interest to select individuals. A recent investigation by the State Department of Environment and Science of coal samples found on a beach near Mackay concluded that "*while is it not entirely possible to pinpoint the exact region this coal (came) from, it is possible to rule out that this coal originated from the Bowen Basin and Galilee Basin. If it is from Australia, it is most likely to come from the Southern Queensland coalfields or the NSW coalfields*."

- The capacity for coal from the Port of Hay Point to be a significant contaminant is unlikely.

The potential for dredged maintenance material to be a source of contamination is addressed and managed through the *National Assessment Guidelines for Dredging (NAGD) 2009*. Appendix A of the NAGD sets out the extensive sampling and laboratory requirements for characterising dredge material, including:

- basic sediment characteristics
- organic compounds of concern
- inorganic compounds of concern
- as well as the acceptable screen level

Screen levels in the NAGD are provided for:

- *Metal and Metalloids* - Antimony, Arsenic, Cadmium, Chromium, Copper, Lead, Mercury, Nickel, Silver and Zinc.
- *Organics* – Total PCBs, Pesticides (5 discrete pesticides), polycyclic aromatic hydrocarbons (PAHs) petroleum hydrocarbons and Tributyltin (TBT).
- *Radionuclides* – sum or gross alpha and beta

An assessment (*Maintenance Dredging Sediment Characterisation Report – Port of Hay Point, Advisian, May 2018*), in accordance with the NAGD undertaken at the Port of Hay Point in 2018, concluded:

> *"it is recommended that the sediments to be dredged from the Port of Hay Point navigational areas outlined in this report are suitable for unconfined placement at sea at the DMPA (Dredged Material Placement Area) on the basis that all 95% UCLs of the mean for chemical substances analysed are below respective NAGD (National Assessment Guidelines for Dredging) or agreed local screening levels."*

This gives a high level of comfort that if finer coal particles are present in the maintenance material, they are not providing a source of contamination.

Considering the main contaminants of concern in the marine environment (as listed in Appendix A of the NAGD), there is some further useful known information about the coal products at the Port of Hay Point. This information has been consolidated in the weight-of-evidence report titled *"Unburnt Coal in the Marine Environment at the Port of Hay Point"* (Koskela Group, 2018) which is attached at **Appendix A.**

Sulphur Content

- Coals with low sulphur content (<2%) produce more pH neutral runoff and are more likely to demonstrate low contaminant bioavailability (Ahrens and Morrisey 2005).
- Coals shipped through the Port of Hay Point display very low sulphur content.
- Previous testing of coals shipped through DBCT indicated a range of sulphur content from 0.3% to 0.74% inclusive of thermal, PCI (Pulverised Coal Injection) and coking coals.
- Similar sulphur content of ~0.5% has been reported for coals shipped through HPCT (Barlow Jonkers 2007).

Given the review of low sulphur coals by Ahrens and Morrisey (2005) - *it is expected that coals shipped through the Port of Hay Point will pose a low risk of producing either acidic water runoff or enhanced contaminant bioavailability.*

Metals

The release of metals from representative coal samples has been directly investigated for product shipped through HPCT (Koskela Group 2011a). This testing determined that:

- Bioavailable metal concentrations in representative coal samples, as determined by dilute acid extraction, did not exceed the National Assessment Guidelines for Dredging screening level (NAGD; DEWHA 2009) for any metal contaminant when the dilution attenuation factor was applied; and
- Metal concentrations dissolved into water via coal elutriation (95% UCL) did not exceed the ANZECC Water Quality Guidelines for marine water (95% species protection) for any metal contaminant.

This indicates that - *there is very little to negligible risk that coals shipped through the Port of Hay Point will release metal contaminants into the water column.*

PAHs

With respect to PAHs, it is likely that the overwhelming origin of PAHs in coastal sediments of the central GBR is pyrogenic emissions from sources such as petrol and diesel vehicles, heavy machinery and vessel engines, rather than unburnt coal.

This does not suggest that the presence of such contaminants may not impact turtle nesting, human health, fish or other marine wildlife, but rather, unburnt coal is unlikely to be a significant source of such impact. It is noted that beach sand and sediments have not been specifically examined with respect to this issue.

Human Health

A study has been undertaken to examine the human health risks associated with potential bioaccumulation of contaminants in selected biota including mud crabs, fish and whelks at the Port of Hay Point (Koskela Group 2014a and 2014b). This study did not identify the accumulation of any metal above the accepted background concentration for these food types as listed in FSANZ guidelines and FSANZ (2003).

Elutriate and pore water have been considered in previous sediment quality assessments at the Port of hay Point, and there has been no forthcoming concerns regarding toxicity or bioavailability. It is acknowledged that the interactions of coal with sediment quality, pore water and surface waters has not been directly investigated to date.

MARPOL Annex V assessment

In 2012 composite coal samples from Hay Point Coal Terminal were tested in accordance with criteria under MARPOL Annex V. MARPOL is the International Convention for the Prevention of Pollution from Ships which was adopted by the International Maritime Organization in 1973.

Based on the results of a freshwater and marine transformation/dissolution test, the composite coal sample did not meet the criteria for classification as an Environmentally Hazardous Substance considered harmful to the marine environment under MARPOL Annex V, or the criteria of a Class 9 dangerous good for the purpose of land (ADG, 2011) or marine (IMO, 2010) transport.

Weight-of-Evidence Review

Lines of evidence (LOE's) within a weight of evidence (WOE) (as per Simpson et al. 2013) has been conducted to determine the likelihood of environmental impact associated with unburnt coal (refer **Appendix A**).

Simpson et al. (2013) proposed the following ranking system and a methodology to determine as such:

1) (no concern);
2) (possible concern); and
3) (significant concern).

The key findings of the report are that, strong evidence exists that the unburnt coal product shipped through the Port of Hay Point has a low capacity to release contaminants. Furthermore, all available lines of evidence indicate that the impact of unburnt coal in the marine environment at the Port of Hay Point is very low and results in a WOE score of 1.

Based on this weight of evidence report (refer **Appendix A**), we expect very low potential for unburnt coal to impact on the marine environment in any of the following ways:

- bioavailability of leachate from coal
- leaching from coal
- floating ashore or contaminating turtle nesting beaches
- causing human health issues in relation to people swimming at beaches adjacent to the disposal site
- contaminating fish or invertebrates caught by recreational or commercial fishers, or
- being toxic to any marine wildlife including crocodiles

3.7 Coral

Do you expect a similar level of coral loss from the proposed dredging as experienced in 2006 (2-5 percent loss at islands up to 6km away) as described in Smith et al. 2007?

No coral loss is expected as a result of maintenance dredging and disposal.

Risks to sensitive habitats such as coral communities (at Round and Flat Top islands, and Slade Islet) are predicted to be low to negligible as they lie outside of the area expected to have altered turbidity and sedimentation.

No change to natural water conditions is expected if the dredging volume remains under 800,000 m^3, in any single maintenance dredging program.

The Environmental Impact Statement for 2006 capital dredging predicted a potential loss of up to 16 per cent coral cover at the impact sites. Although being a large and extended capital dredging program, post-dredging coral surveys found only slight reductions in hard coral cover at Round Top and Victor Island of 1% and 3% respectively. The reduction in cover was not statistically significant and similar to changes observed at the reference site at Slade Islet (Trimarchi and Keane, 2007).

Smith et al. 2007 also stated 'In contrast at Hay Point the coral community was significantly separated from the works (over 10 Km) however the scale of dredging works was orders of magnitude greater (9 million m^3) and there was limited opportunity for management intervention. Monitoring results to date indicate that coral cover was impacted up to 6 km from the works, though limited to levels below adopted maximum allowable change (GHD, 2005). Estimated monitoring costs were $1.2 million, approximately 2% of the capital works.

The maintenance dredging program proposed is of a much lower volume, being 356,553 m^3 initially and future staged programs of 200,000 m^3 each.

NQBP also has a comprehensive marine monitoring program in place, which will be further scaled up during maintenance dredging. Additional impact coral monitoring will include pre and post-dredging surveys at the existing 24 transects at four island locations (Victor Island, Round Top Island, Slade Islet and Keswick Island).

3.8 Coastal land-based businesses

What is the potential for effects from increased sedimentation/turbidity on the ongoing viability of coastal land-based businesses?

The potential for effects from increased sedimentation/turbidity to impact ongoing viability of coastal land-based businesses is very low.

Modelling has showed that sedimentation/turbidity would remain within the natural range up until 800,000 m^3 or more was dredged and placed in a single maintenance dredging program.

The maintenance dredging program proposed is of a much lower volume, being 356,553 m^3 and staged programs of 200,000 m^3 each.

The extensive bathymetric modelling undertaken by NQBP shows that ongoing maintenance dredging and placement volumes at the Port of Hay Point are relatively low and are expected to be undertaken infrequently (approximately every 3-5 years).

Section 4

Response to GBRMPA's peer review of the dredge plume modelling

December 2018

PORT OF
HAY POINT

Attachment B - REQUEST FOR ADDITIONAL INFORMATION – Maintenance dredging at Port of Hay Point

BRIEF OVERVIEW OF FINDINGS

The overall report is well written and the approach to the dredging conceptualisation and sediment resuspension scenarios are well considered and sound. The models applied have the necessary physics and ability to model the behaviour of suspended sediment concentrations associated with dredging operations and resuspension weather and tide events.

An issue however is that there is no description of the 3D grid that was employed in the hydrodynamic modelling. There is a description of the horizontal 2D grid but there is a lack of detail about the vertical grid. The only reference is from the general model description.

"In the horizontal plane an unstructured grid is used, while in the vertical domain a structured mesh is applied (DHI, 2017a)." S3.2 P26

The report does not provide a clear indication of vertical shear and the existence of any bottom boundary layer at the timescales presented so that the significance or not of these phenomena is accounted for. Tidal currents can have significant phase lags in the current profile and can at times have reversals from top to bottom. These are important considerations that will impact SSC behaviour.

Regardless of the adequacy of the 3D hydrodynamic modelling the sedimentary module applied only uses the depth averaged hydrodynamics not the full water column profile.

"As all of the natural SSC simulations were undertaken in two dimensional depth averaged mode, all of the dredging runs are presented as depth averaged to ensure they are directly comparable to the natural conditions." P96 S7.1

Assumptions of other aspects of the model setup are appropriate and reasonable however the boundary forcing for waves is less than optimal. The Mackay wave rider buoy to the north is used to force the deeper southern boundary.

The model in general does perform well in the validation exercises however there are some areas that should be improved in any future effort. The short period spiking in SSC at key resuspension events are not well replicated by the model.

The availability of data for validation and calibration of currents and SSC is limited and spread across a number of years rather than simultaneously made. It is recommended that a more comprehensive spatial and concurrent set of observations be made over periods long enough to capture all weather conditions that impact Hay Point are made to improve any future modelling and inform any dredging campaigns in the future.

As presented this report needs to provide further clarification and justification as there remains uncertainty over the adequacy of the 3D hydrodynamic model implementation and that:

"*The sediment transport model of natural conditions was setup in two dimensional depth averaged model as the underlying equations were all derived in two dimensions.*" S4.5 P66

The comment P96 S7.1: "As all of the natural SSC simulations were undertaken in two dimensional depth averaged mode, all of the dredging runs are presented as depth averaged to ensure they are directly comparable to the natural conditions." Assumes that SSC is uniform through the water column. This assumption needs rigorous validation.

Review Criteria Assessment

1. Baseline information on site/environmental conditions a. Is the baseline site/environmental data used within the model, and the period of time that it was collected, sufficiently representative of all possible weather/metocean events to reasonably predict sediment plumes, deposition and long term resuspension of sediment caused by dredging/disposal to be undertaken periodically over a ten year period?

The availability of data for validation and calibration of currents and SSC is limited at the Hay point location requiring access to data further north as far as Mackay and is spread across a number of years rather than a more preferable situation where multiple site, long term observations were made over a common period.

In spite of these limitations the available data is considered adequate and the model cal/val undertaken takes a sensible approach to deal with the staggered observations. The report covers the most important weather and metocean events required for planning the dredging/disposal over the 10 year period.

The existence of an offshore branch of the EAC in the outer lagoon has not been included in the modelling and is justified in this case as its impact on this exercise would be negligible.

Peer review recommendation	NQBP response
It is recommended that a more comprehensive spatial and concurrent set of observations be made over periods long enough to capture the most significant weather conditions that impact the Hay Point locale rather than further afield and are made to improve any future modelling and inform any dredging campaigns in the future.	In August 2018, NQBP installed two Acoustic Doppler Current Profilers (ADCPs) at the Port of Hay Point. One ADCP was installed at the northern end of DBCT berths and one ADCP was installed at the southern end of HPCT berths. NQBP will use data from these ADCPs, along with its continued ambient water quality monitoring program, to inform any future dredging programs.

b. Have all seasonal and multi-year climatic variables been accounted for in the environmental data and represented in the model outputs?

The seasonal and multi-year climatic variables that are relevant to this study have been accounted for.

2. Modelling approach a. Is the numerical model used for the report adequate to predict sediment transport for the dredging/disposal activity and has it been sufficiently tested in similar applications?
Yes – subject to the implementation issues identified in 2b.

b. The majority of the hydrodynamic and sediment plume modelling conducted is 3D, however the long-term resuspension model is 2D depth averaged. Does this have a material effect on the prediction?

Peer review recommendation	NQBP response
Clarification is needed over the 3D grid specification and time stepping to resolve spatial and temporal resolutions. The technical requirement for 2 grid cells with the shipping channel does not seem to have been met in the outer channel. All SSC simulations (not just the long term re-suspension model) however use 2D depth averaged currents from the 3D model. The	The dredge plume model was setup with five sigma layers, with each representing 20% of the water column. The MIKE21/3 Flexible Mesh model has a dynamic timestep, meaning that the model will calculate the timestep required throughout the simulation (with the upper limit to this being specified by the user, in this case 60 seconds was set as the maximum timestep).

significance of this simplification needs to be ascertained. It may be acceptable in shallow regions however it may have ramifications in the deeper offshore areas such as the outer DMPA in 25-20m of water. A 2D depth averaged model run for the longer term 12 month run is deemed to be acceptable.	The outer part of the Hay Point departure channel does not adhere to the GBRMPA recommendation that a minimum of two grid cells are included in the width of a dredged channel to ensure changes to the hydrodynamics are represented. This is because there is minimal difference between the dredged channel and the natural bathymetry in this area (less than 1 m, dredged channel is -14.7m LAT and surrounding bathymetry is less than -14m LAT) and so the channel would not be expected to result in a noticeable change to the hydrodynamics. In addition, no dredging was included in the modelling in this area and so a lower resolution was considered justified. All natural SSC modelling was undertaken using a 2D approach. This was considered appropriate given our understanding of the physical processes within the study area and uniformity of current speeds through the water column, as shown by the measured data. To ensure the modelling activities associated with excess SSC met the GBRMPA guidelines, all dredge plume sediment transport model simulations were undertaken using the 3D model. The 3D model consisted of 5 sigma layers to include any vertical variability in the tidal currents through the water column. The 12 month long simulations of resuspension from the DMPA were undertaken using the 2D depth averaged model as noted.

c. Have all relevant impact pathways (e.g. SSC, sediment deposition etc.) been accounted for within the model?

Yes.

d. Are the assumptions reasonably conservative?

Yes.

3. Dredging description a. Is the predicted sediment composition reasonably supported?

Yes. Detail on the assumptions, approach was adequately provided and informed by analysis of sediment samples.

b. Is the dredging approach realistic in the context of the proposed dredging activity described in the Introduction?

Yes.

4. Model Calibration and Validation a. Is the level of accuracy demonstrated through calibration and validation reasonably adequate to reliably predict sediment transport from the dredging activity to be undertaken periodically over a ten year period?

Yes it is reasonably adequate.

Recommendation	**NQBP Response**
However some further investigation is warranted to improve model performance for short timescale spiking events and to improve wave boundary forcing.	Further SSC data are being collected by NQBP to better understand whether the short duration spikes in SSC are due to the SSC measurements having been collected close to the seabed, or if they are present throughout the water column. This will help to inform future modelling studies. With regard to the wave boundary forcing conditions; the northern and southern boundaries of the spectral wave model were not applied over the full length of the tidal boundaries, but ended at the -15m LAT contour. This was shown to provide a good calibration and validation at Hay Point. See section 2 of the accompanying technical note for further details and discussion regarding the wave model boundary.

5. Results and Conclusions a. Are the conclusions supported by the results?

Yes.

b. Have any results or conclusions not been reported that may be relevant to impacts on the environment?

No

Consistency with GBRMPA Hydrodynamic Modelling Guidelines

Table 24. P94 of the report summarises the approaches the authors have taken to ensure the relevant requirements of the GBRMPA Hydrodynamic Modelling Guidelines have been met. It is the considered opinion of the reviewers that the self-assessment is accurate and adequate except in the following areas:

Comment	**NQBP Response**
The sediment transport models have used depth averaged current from the 3D hydrodynamic model rather than the required 3D current profiles.	The dredge plume sediment transport models were all in 3D and applied 3D current profiles from the 3D hydrodynamic model. Only the natural SSC simulations (which are not required by the GBRMPA modelling guidelines) and the long-term resuspension simulations were undertaken using a 2D depth averaged current.
Vertical shear and the existence of any bottom boundary layer are likely to be of significance in the controlling the behaviour of SSC. Tidal currents can have significant phase lags through	The available measured current data which was used for the study was analysed to assess the currents and their variability through the water column. No significant

Comment	NQBP Response
the current profile and can at times have reversals at different water depths. These are potentially important considerations that will impact SSC behaviour, particularly for near bed processes at deeper disposal areas.	differences in current behaviour was noted through the water column (i.e. flow reversal through a section of the water column). The calibration of the natural SSC model involved fine-tuning the model erosion and deposition parameters and given the level of calibration achieved, it is considered that the model is able to represent the vertical shear and bed stresses (and associated bottom boundary layer) resulting from both waves and tidal currents relatively well.
The comment P96 S7.1: "As all of the natural SSC simulations were undertaken in two dimensional depth averaged mode, all of the dredging runs are presented as depth averaged to ensure they are directly comparable to the natural conditions." Assumes that SSC is uniform through the water column. This assumption needs more rigorous validation.	The presentation of the simulations as depth averaged plots of SSC does not assume that the SSC is uniform through the water column, it assumes that the variation in SSC through the water column can be adequately represented by averaging the SSC (i.e. the spatial and temporal patterns in SSC are similar through the water column, it is just the concentration which differs (higher near the bed, lower near the surface)). The dredge plume modelling results confirm this (see Section 4 of accompanying Technical Note). Additional water quality logging is being undertaken to further assess this (concurrent logging near bed and near surface).
The model does not perform well in simulating the observed short time-scale spiking during some weather events as acknowledged by the authors and some underestimation of waves is apparent.	The short duration spikes are being further investigated as part of ongoing data collection works, as it is possible that they could be due to short duration localised near-bed resuspension and therefore not representative of the SSC throughout the water column. Based on the findings of the further work, future modelling will be refined to better represent the natural SSC. It is important to note that the underestimation of the wave conditions noted is only during the peak of the largest wave events over a 12 month period (Tc Ului), which is not important for the dredge plume modelling as the periods selected do not include any wave events of this size. The wave model validation shows that the 99th percentile significant wave height (H_s) is within 0.02 m of the measured data at the Hay Pt WRB (measured = 1.72m, modelled = 1.74m) which shows that the model provides a very good representation

Comment	NQBP Response
	of the more typical larger wave events which occur at Hay Point.
Need clarification that the wave-current interaction that improved the model performance was included in the SSC model runs not just for the validation run. See S4.41 P59.	The influence of tidal currents on the wave conditions was not included in all SSC model runs, as it was only observed to result in a noticeable improvement in H_s at MK1, which was located directly to the east of Mackay Harbour in an area where very high tidal currents occur. Comparison between the measured and modelled wave conditions at the Hay Point WRB suggest that the influence of tidal currents on the waves are not required to accurately represent the wave conditions in this area. The hydrodynamic model does take into account the tides, wind and waves as specified in the GBRMPA guidelines.
The baseline observational current data is borderline in adequacy due to its patchiness and being spread out over a number of years. The authors have however done well to bring it all together for the cal/val.	In August 2018, NQBP installed two Acoustic Doppler Current Profilers (ADCPs) at the Port of Hay Point. One ADCP was installed at the northern end of DBCT berths and one ADCP was installed at the southern end of HPCT berths. NQBP will use data from these ADCPs to improve baseline observational current data as part of our continuous improvement processes.

Detailed Expert Assessment	NQBP Response
The overall report is well written and the approach to the dredging conceptualisation and sediment resuspension scenarios are well considered and sound. The models applied have the necessary physics and ability to model the behaviour of suspended sediment concentrations associated with dredging operations and resuspension weather and tide events.	Comment noted.
An issue however is that there is no description of the 3D grid that was employed in the hydrodynamic modelling. There is a description of the horizontal 2D grid but there is a lack of detail about the vertical grid. The only reference is from the general model description. “In the horizontal plane an unstructured grid is used, while in the vertical domain a structured mesh is applied (DHI, 2017a).” S3.2 P26	Additional detail on the 3D grid configuration could have been included in the report. Section 1 of the accompanying technical note provides further clarification on this.
S4.3.2 Figures 32-40 shows near bed, mid and near surface observations vs model however all others throughout the report are mid column or depth averaged. Figures 32-40 do not provide a clear indication of vertical shear and the existence of any bottom boundary layer at the timescales	Based on the measured data the currents in the Hay Point region appear to be relatively uniform (with speeds higher near the surface and lower near the bed), with currents throughout the water column rotating together as the tide changes. This

Detailed Expert Assessment	**NQBP Response**
presented. More highly resolved temporal plotting of the vertical profiles of observed and model current would be informative to indicate the significance or not of these phenomena. Tidal currents can have significant phase lags in the current profile and can have reversals from top to bottom. These are important considerations that will impact SSC behaviour however any appraisal of that remains lacking.	is further detailed in the Section 3 of the accompanying technical note.
Regardless of the adequacy of the 3D hydrodynamic modelling the sedimentary module applied only uses the depth averaged hydrodynamics not the full water column profile.	The dredge plume sediment transport model was undertaken in 3D, with 5 equally spaced sigma layers, and used the 3D hydrodynamic model. The natural sediment transport model was undertaken in 2D and adopted a depth averaged current (although a pseudo 3D approach is adopted by the model to estimate the near bed current speed). This is further clarified in Section 1 of the accompanying technical note.
"As all of the natural SSC simulations were undertaken in two dimensional depth averaged mode, all of the dredging runs are presented as depth averaged to ensure they are directly comparable to the natural conditions." S7.1 P96	N/A
It is possible a pseudo 3D model effect is achieved by applying some form of profile that includes a bottom boundary layer, however the 3D hydrodynamic model should be providing the full dynamic water column structure. There is no information supplied on the details of the physical assumptions behind this component of the modelling just a reference to the commercial software. See Section S3.3 P27 & P32	There has been some confusion regarding the dredge plume sediment transport modelling undertaken as the report did not clearly explain what was adopted for the different components of the modelling. We can confirm that all of the dredge plume sediment transport models were in 3D and applied 3D current profiles from the 3D hydrodynamic model (as recommended by the GBRMPA guidelines) and so no pseudo 3D model was required for these simulations. The modelling of the natural sediment transport, which is not required as part of the GBRMPA guidelines (and so the approach can be considered to be exceeding the guidelines), was undertaken in 2D and adopted a pseudo 3D approach with respect to the near bed currents.
Assumptions of other aspects of the model setup are appropriate and reasonable however the boundary forcing for waves is less than optimal. The Mackay wave rider buoy to the north is used to force the deeper southern boundary. The buoy data would have been affected by shoaling and have limited swell propagation through Capricorn	The eastern boundary of the wave model was designed to have as consistent a depth as possible, with depths typically between 35 and 40 m (below LAT). The deepest section is the northern corner where depths of up to 48 m (below LAT) occur. As the wave model boundary was located approximately 10 km offshore of

Detailed Expert Assessment	**NQBP Response**
Channel than what would be incident at the southern boundary when that was significant.	the Mackay WRB the wave heights were scaled (increased by between 5 and 10% depending on the wave conditions) to achieve calibration at the Mackay WRB. Based on a spatial plot showing the model domain and Mackay WRB relative to the Capricorn Channel, it appears that the Mackay WRB would receive similar swell propagation through the Capricorn Channel compared to the south-eastern corner of the model domain. In addition, as the calibration and validation of the model shows that the model can consistently represent the measured wave conditions at the Hay Point WRB, regardless of wave direction, the wave model boundary forcing is considered to be suitable.
The model in general does perform well in the validation exercises however there are some areas that should be improved in any future effort. The short period spiking in SSC at key resuspension events are not well replicated by the model.	The short duration spikes are being further investigated as part of ongoing data collection works, as it is possible that they could be due to short duration localised near-bed resuspension and therefore not representative of the SSC throughout the water column. Based on the findings of the further work, future modelling will be refined to better represent the natural SSC.
The availability of data for validation and calibration of currents and SSC is limited and spread across a number of years rather than simultaneously made. It is recommended that a more comprehensive spatial and concurrent set of observations be made over periods long enough to capture all weather conditions that impact Hay Point are made to improve any future modelling and inform any dredging campaigns in the future.	Three years of measured SSC data at seven sites were available for the modelling study, while in most other locations SSC data are only collected for project specific purposes and so continuous multi-year datasets are not usually available. The GBRMPA guidelines state that for dredging campaigns of less than 1 month (Hay Point maintenance dredging is likely to be around 1 month duration) a minimum of one month of baseline data collection is required, based on this the three years of SSC data greatly exceeds the requirements. It would be preferable for concurrent hydrodynamic data to be available along with the SSC data so that both the hydrodynamics and sediment transport models could be calibrated and validated over the same periods. The recent (August 2018) deployment of two ADCPs at the Port of Hay Point by NQBP ensures that concurrent hydrodynamic and SSC data are available for future dredging investigations and modelling.

Detailed Expert Assessment	**NQBP Response**
As presented this report needs to provide further clarification and justification as there remains uncertainty over the adequacy of the 3D hydrodynamic model implementation and that: "The sediment transport model of natural conditions was setup in two dimensional depth averaged model as the underlying equations were all derived in two dimensions." S4.5 P66	There has been some confusion regarding the dredge plume sediment transport modelling undertaken as the report did not clearly explain what was adopted for the different components of the modelling. We can confirm that all of the dredge plume sediment transport models were in 3D and applied 3D current profiles from the 3D hydrodynamic model (as recommended by the GBRMPA guidelines). The modelling of the natural sediment transport, which is not required as part of the GBRMPA guidelines (and so the approach can be considered to be exceeding the guidelines), was undertaken in 2D and adopted a pseudo 3D approach with respect to the near bed currents. See Section 1 of the accompanying technical note for further details.

Specific Comments	**NQBP Response**
S2 P9: Long met and wave records. Currents patchy Jan-Apr 2017 off Mackay & Sep –Nov 2011-2012,	In August 2018, NQBP installed two Acoustic Doppler Current Profilers (ADCPs) at the Port of Hay Point. One ADCP was installed at the northern end of DBCT berths and one ADCP was installed at the southern end of HPCT berths. NQBP will use data from these ADCPs to improve baseline observational current and wave data as part of our continuous improvement processes.
S2.3 P9: "only one tidal current direction for each tidal cycle" inference only one tide – but it was still there it was just dominated by the wind. Would have also had an effect on the wave height	Agree that this does not mean that the tides became diurnal. Agree that the tropical cyclone would also have had an effect on the wave height, the influence of tropical cyclones on wave heights is discussed in Section 2.5 where it is noted that cyclones are responsible for the largest waves which occur at the site.
P10 & Fig 8 P13: these do use coastal stations to influence the estimation of altimeter derived geostrophic currents. It is very much tide and wind dominated in the shallow coastal region. The Coral Sea circulation is more about the SEC forming the EAC along the outer GBR that can also drive a lagoonal branch along the lagoon inside of the outer reef matrix (Brinkman et al 2006)	Comment noted.
P14: Characterisation of east to west movement of cyclones is typical e.g. TC Hamish and many other tracks	Agree that this is typically the case.

Specific Comments	**NQBP Response**
S2.9 P20: WQ & deposition 2014-17 by JCU – frequency of sampling unknown.	The loggers measured turbidity and deposition every 10 minutes.
P21 Fig 16: A better explanation of the box & whisker plots are needed – definition (fig 17 does better). Would like to see the sampling locations and depth of water for each site.	The box and whisker plot shows the 10th percentile (bottom of whisker), lower quartile (bottom line of box), median (middle line of box), upper quartile (upper line of box), 90th percentile (top of whisker) and the mean (black dot). The sampling locations are shown in Figure 4 (this is referred to in the text in Section 2.9).
P24: Replace 'reliability' with reliably	Agree.
P27 S3.3: Only a 2D horizontal grid specified for MIKE3 hydrodynamics =>3d for MIKE21 wave & MIKE3 Mud. Only the horizontal grid is defined – no mention of the vertical resolution	To represent the water column 5 equally spaced sigma layers were applied in both the hydrodynamic and dredge plume sediment transport models.
P28 Fig 21: horizontal grid – 2 cells in the channel? 60m is the average size in the HTTH	The outer part of the Hay Point departure channel does not adhere to the GBRMPA recommendation that a minimum of two grid cells are included in the width of a dredged channel to ensure changes to the hydrodynamics are represented. This is because there is minimal difference between the dredged channel and the natural bathymetry in this area (less than 1 m, dredged channel is -14.7m LAT and surrounding bathymetry is less than -14m LAT) and so the channel would not be expected to result in a noticeable change to the hydrodynamics. In addition, no dredging was included in the modelling in this area and so a lower resolution was considered justified. For Half Tide Tug Harbour (HTTH) the 60m mesh resolution was selected to ensure that the berth region was 2 cells wide (width of 140m) as this is where the majority of the maintenance dredging occurs.
P29 S3.4: Nav charts and local surveys – why not Beaman 3DGBR 100m or now the 30m interpolated grid?	At the time the model was developed the navigation charts combined with local surveys in the areas of interest was considered the best available information. For future modelling the more recently available GBR bathymetry datasets will be incorporated.
P30 3.6: How were tides forced for the offshore/east boundary?	The offshore boundary was driven by a spatially varying water level along the boundary which was extracted from a regional Coral Sea model.

Specific Comments	**NQBP Response**
P30 3.7: the use of a non-spatially varying wind isn't well argued nor evidence provided. SE trades correlate well over the entire region but sea breeze and storm/cyclone events are key events with more complex structure in any resuspension	It is agreed that for some cases, such as tropical cyclones, adopting a non-spatially varying wind will not represent the processes as accurately as a spatially varying wind field. However, based on the model calibration achieved (both for the hydrodynamic and spectral model) it can be seen that given the scale of the model extent (100km by 60km) a non-spatially varying wind field is sufficient to represent the wind conditions.
P30 S3.7: Wind stress units are missing. Wind stress is the square of the wind – so not sure why a linear interpolation was used. Are we talking about the wind stress coefficient here? Needs clarification.	The values do not represent the wind stress, they represent the wind drag coefficient which does not have any units.
P30 S3.8: The justification for using the Mackay waverider buoy located at the northern end of the grid as a boundary condition has little evidence of adequacy for the southern and eastern model boundary.	The Mackay WRB is located approximately mid-way along the eastern boundary of the model domain (albeit 10 km inshore from the boundary) and not at the northern end. This is further explained in Section 2 of the accompanying technical note.
P32: 2D runs to keep the long term model runs manageable. There will still be boundary layers. Current variability within the profile – especially at the deeper off shore site in 25-30m is likely.	The 2D hydrodynamic model calculates the near bed conditions based on the depth averaged current (i.e. it a adopts a pseudo 3D approach).
P34: S4.3.1: water level validation 2 weeks over 2 periods Sep and Nov 2011 & 1 month in March 2017 TC Debbie – goes into April though (Mar 23-Apr 7 as an extratropical low)	The peak in TC Debbie at Mackay was on the 28th March 2017 and so is included in the validation period.
P36 Figs 24-29, 30-31: should also plot the residuals on the same plot scale to more easily identify the timing and amplitudes	The plots without any residuals are considered to clearly show that the hydrodynamic model can accurately predict water levels in the region. The residual difference between the measured and modelled water levels can be included in future NQBP modelling reports to provide additional clarity.
P40: high winds should include strong SE Trades not just TCs	Agree that strong SE trades influence the tidal currents as well. The text in the report discussing the wind conditions during the March 2017 calibration period, was aimed at showing that the model could represent the worst case of winds during a TC influencing the currents. The September 2011 calibration period does include strong SE trade winds, the wind speeds were consistently between 8 and 11 m/s between the 2nd and 6th September 2011. Figure 34 in the report shows how over this period both the measured and modelled current

Specific Comments	NQBP Response
	speeds were increased on the ebbing tide (to the north) and decreased on the flooding tide (to the south). This shows that the model is also able to represent the change in currents due to strong SE trade events.
P36 Figs 32-40: Should show winds to assist with determination if residuals are from them – and again the residual currents – preferably along the tidal principal component directions	Plots showing the wind conditions during the three calibration periods are included in Section 5 of the accompanying technical note. The plots without any residuals are considered to clearly show that the hydrodynamic model can accurately predict current speeds and directions for the majority of the time in the region. The residual difference between the measured and modelled currents can be included in future NQBP modelling reports to provide additional clarity.
Fig 41-46: Near bed & near surface - what height? Are the top line plots current residuals? Not documented. Would be good to see a few plots showing the vertical profile from both the model and observations on a shorter time frame – e.g. turn of tide	The near bed measured current is approximately 1.5-2m above the seabed, the model represents the bottom 20% of the water column (depths at Site 1 = -12m LAT and at Site 4 = -10m LAT. The measured near surface currents were approximately 11m above the seabed and 9m above the seabed at the two sites and the surface layer in the model was used.
P59 S4.4.1: Were wave-current interactions included in the final dredge model?	The influence of tidal currents on the wave conditions was not included in all SSC model runs, as it was only observed to result in a noticeable improvement in H_s at MK1, which was located directly to the east of Mackay Harbour in an area where very high tidal currents occur. Comparison between the measured and modelled wave conditions at the Hay Point WRB suggest that the influence of tidal currents on the waves are not required to accurately represent the wave conditions in this area. The hydrodynamic model does take into account the tides, wind and waves as specified in the GBRMPA guidelines.
Under-representing waves probably due to the use of Mackay waverider as forcing – waves would have shoaled at that location so when applied to the southern boundary forcing it is likely to be too weak.	Agree that this is possible, could also be due to the wave steepness setting in the model not having been refined sufficiently for extreme wave conditions such as tropical cyclones meaning that wave breaking occurred too soon. This will be further investigated by NQBP as part of

Specific Comments	NQBP Response
	more detailed cyclonic wave modelling for other studies.
P66 S4.5: Sediment model is 2D depth averaged	The sediment transport model for the natural sediment transport was 2D depth averaged, the dredge plume sediment transport model was a 3D model with five sigma layers, each representing 20% of the water column.
P69 table 19: Victor Island model is lower than obs. Obs higher at most locations except round Top Island – not all resuspension events replicated in the model. Concludes the short duration wind wave spikes are not replicated – just works on average	Given the complexities of the modelling and the typical lack of quantified sediment transport calibration statistics, existing approaches adopted for evaluating sediment transport calibration/validation, such as the normalised mean absolute error (see Los & Blaas, 2010), would likely show that the calibration and validation at all sites was very good and so the approach of comparing percentiles was considered more informative and robust in this case. At present it is impossible to know whether the issue is related to the sediment transport model not accurately representing the processes, or if it is associated with the measured data. Further field investigations are being undertaken to see if the spikes are due to short duration near-bed increases in SSC or occur through the water column. This improved understanding will allow future models to be improved.
P89 S5.3: PSD acronym needs defining – only apparent in Fig67	Agree.
P93: Results of water column effect of dispersion and advection suggested no different from a uniform release throughout the water column – but no evidence provided	It was not considered to be necessary to include two plots showing almost identical results. See section 4 of the accompanying technical note for the plots.
P96 S7.1: "As all of the natural SSC simulations were undertaken in two dimensional depth averaged mode, all of the dredging runs are presented as depth averaged to ensure they are directly comparable to the natural conditions	There has been some confusion regarding the dredge plume sediment transport modelling undertaken as the report did not clearly explain what was adopted for the different components of the modelling. We can confirm that all of the dredge plume sediment transport models were in 3D and applied 3D current profiles from the 3D hydrodynamic model (as recommended by the GBRMPA guidelines). The modelled results showed slightly higher SSC near the bed and slightly lower near the surface. For the report the SSC results were processed to calculate the depth averaged SSC and this was presented.

280 Flinders St. PO Box 1379
Townsville, Qld 4810 Australia

Phone +61 7 4750 0700

info@gbrmpa.gov.au
www.gbrmpa.gov.au

Specific Comments	NQBP Response
	The modelling of the natural sediment transport, which is not required as part of the GBRMPA guidelines (and so the approach can be considered to be exceeding the guidelines), was undertaken in 2D and adopted a pseudo 3D approach with respect to the near bed currents. The output from the natural sediment transport was the depth averaged SSC and so was directly comparable to the calculated depth averaged SSC from the 3D dredge plume modelling.

PORT & COASTAL SOLUTIONS

Technical Note

Date: 04/12/2018
To: Damian Snell
From: Andy Symonds
Subject: Request for additional information on Marine Park permit application G40185.1
Classification: Project Restricted

This technical note provides additional detail to some of the tabulated responses included in the letter FINFO-NQBP-G40185_PCS_Responses.docx. Specific sections of this note are referred to in the responses in the letter in case additional detail is required.

1. Model Configuration

The MIKE21/3 Flexible Mesh model has a dynamic timestep, meaning that the model will calculate the timestep required throughout the simulation. An upper limit for the timestep was specified as 60 seconds, meaning that this was the maximum timestep adopted in both the three-dimensional (3D) and two-dimensional (2D) hydrodynamic models.

The modelling approach adopted is considered to have exceeded the GBRMPA modelling guidelines. In addition to the dredge plume sediment transport and long-term resuspension modelling, as required by the guidelines, the modelling also included the modelling of natural sediment transport. This approach is only possible in areas where there is extensive measured turbidity/suspended sediment concentration (SSC) data available, such as the Hay Point and Mackay region, to ensure that the model can provide a realistic representation of the natural conditions. This approach allows the predicted excess SSC due to the maintenance dredging to be directly compared to the natural SSC at specific points in time to better understand potential impacts. Details of the modelling are provided below:

- Dredge plume sediment transport: the dredge plume sediment transport model was setup in 3D with five evenly spaced sigma layers, each representing 20% of the water column;
- Natural sediment transport: the natural sediment transport model was setup in 2D depth averaged mode. This was considered appropriate as (i) the water column is considered to be well mixed with limited variability in the tidal currents through the water column (see Section 3), and (ii) the GBRMPA guidelines do not specify that natural sediment transport modelling is required or needs to be undertaken in 3D; and
- Long-term resuspension: this model was setup in 2D. Due to the long timescales associated with the simulations it would not be possible to run them in 3D and the results between the two simulations would not be expected to differ significantly.

2. Wave Boundary

The model domain is shown in Figure 1 along with the locations of the measured wave data (including the Mackay wave rider buoy (WRB)) and the Capricorn Channel. The plot shows that the Mackay WRB is located approximately mid-way along the eastern boundary of the wave model. In addition, based on the wave exposure to the south-east (from Capricorn Channel), and given that the depth along the southern half of the eastern boundary of the wave model is similar (approximately 35 to 40m below LAT), it seems reasonable to assume that the wave conditions measured at the Mackay WRB would be approximately representative of the wave conditions along the eastern boundary down to the southern boundary.

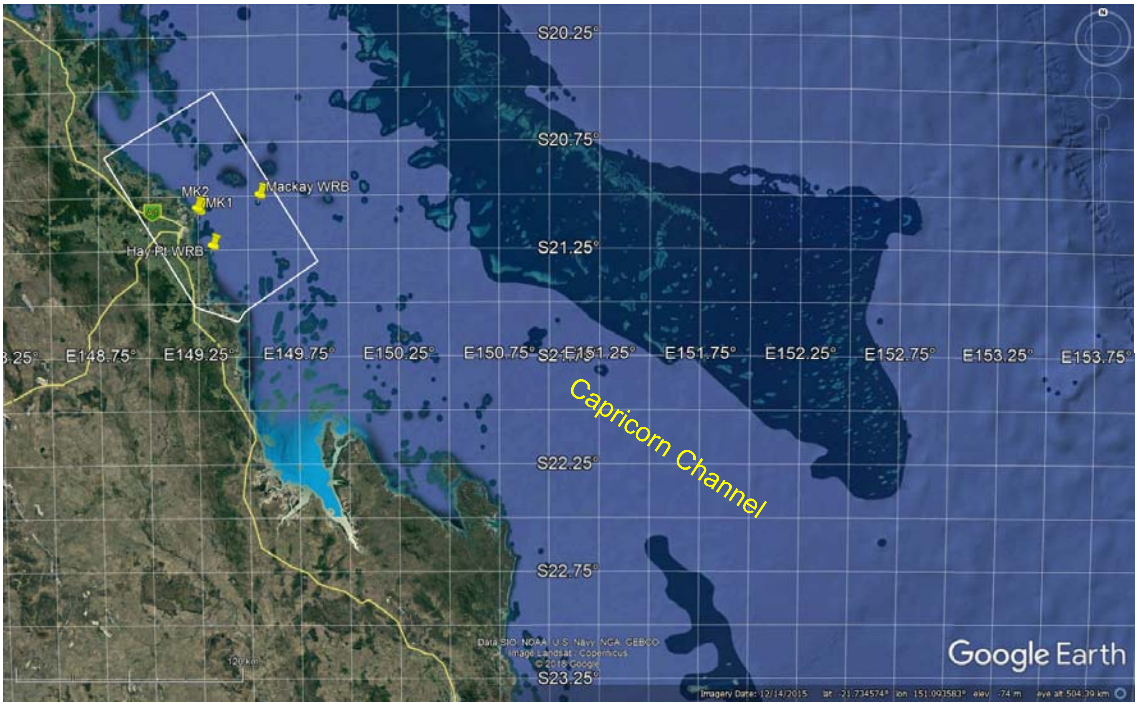


Figure 1: Model domain (white box) along with measured wave data sites (yellow pins).

3. Vertical Variability in Currents

The measured tidal currents at ADCP Site 4, (located adjacent to the previous dredge material placement site, at a depth of approximately 15m below LAT), are shown during a spring tide through the water column and over time at the turning of the tide at low water (Figure 2) and at high water Figure 3. The plots show that as the tide turns the current direction changes throughout the water column, with similar changes in direction occurring at all depths and no indication of flow reversals occurring. As a comparison, the modelled currents through the water column are shown in Figure 4 during the same spring tide around high water[1]. The plot shows that the modelled current directions are almost identical through the water column as the tide turns and they also correspond well to the directional changes shown by the measured data in Figure 3.

[1] the scaling for the length of the lines are not identical for the modelled and measured plots. The current speeds were up to 0.2 m/s over the slack water periods shown. For verification that the modelled and measured current speeds are comparable please refer to Figures 44 to 46 in the Hay Point Maintenance Dredging, Dredge Plume Modelling Assessment report (RHDHV, 2018).

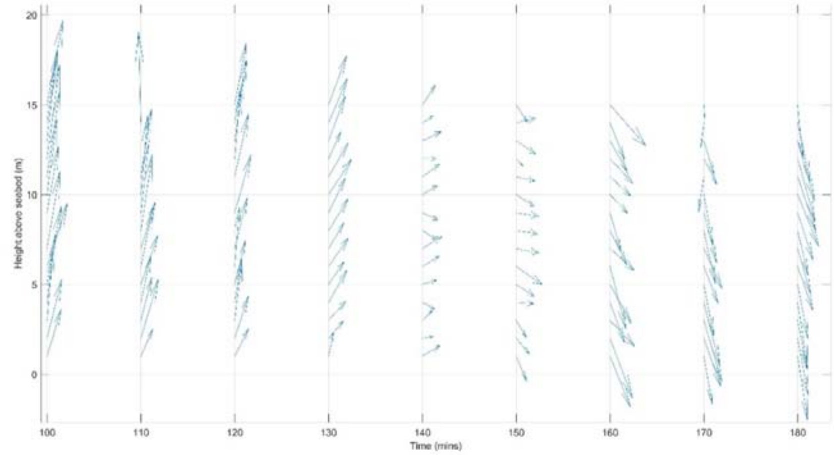


Figure 2: Measured currents around low tide slack water 03/05/2012 15:00 (Site 4).

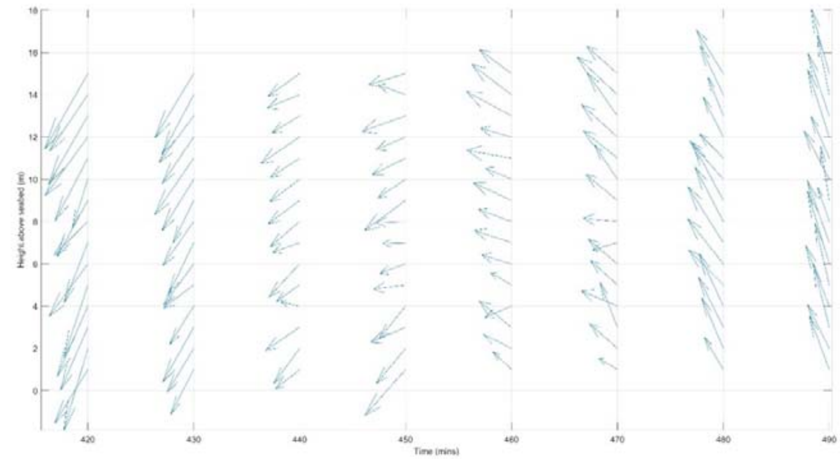


Figure 3: Measured currents around high tide slack water 03/05/2012 21:00 (Site 4).

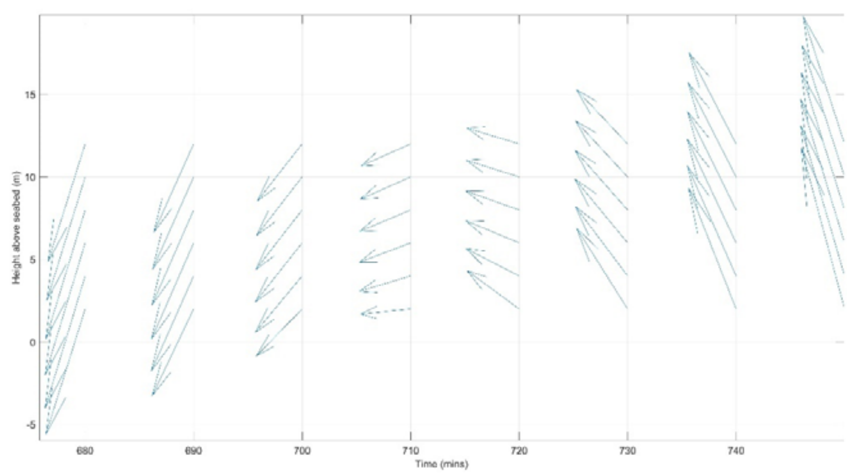


Figure 4: Modelled currents around high tide slack water on 03/05/2012 21:00 (Site 4)

Note: the current directions shown by the vectors are directions in the horizontal and not vertical (i.e. if the arrow is perfectly following the y axis grid lines and pointing to the top of the plot then the current direction is to the north).

4. Dredge Plume Modelling Sensitivity Testing

The 95th percentile SSC for a dredge scenario (400,000 m^3 in the wet season) is shown for the bed layer, middle layer, surface layer and depth averaged over the five layers as a summary in Figure 5, and individually in Figures 6 to 9. The plots show that there is a difference in SSC between the different layers of the water column, with higher SSC at the bed and lower SSC at the surface, but also that the same spatial pattern in SSC occurs in all the layers. Comparison between the 95th percentile based on the depth averaged SSC and based on the middle layer of the model show very similar results.

Figures 10a and 10b show how the 95th percentile SSC, (this was selected over the median as it provides more information to compare), varies when the sediment released from the dredging is assumed to be released uniformly through the water column (Figure 10a), when it is released near the bed (drag head and propeller wash) and mid water column (overflow and material placement) (Figure 10b). Although there are some small differences between the results, the plots give confidence that the assumption regarding the location of the release in the water column does not influence the final results. This is likely to be due to the uniformity of the currents through the water column and the relatively high tidal current speeds, meaning the plume would be advected and dispersed through the water column quickly.

5. Wind Conditions

Wind conditions during the three tidal current calibration periods are shown along with the current speed and direction calibration plots in Figure 11 to 13. The plots are for the near-surface current calibration, as opposed to the mid or near-bed, as currents in this layer will be more influenced by wind conditions.

PORT & COASTAL SOLUTIONS

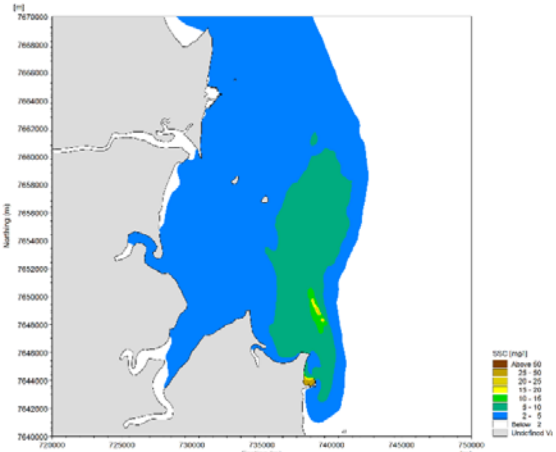


Figure 5a: 95[th] percentile SSC, Bed layer

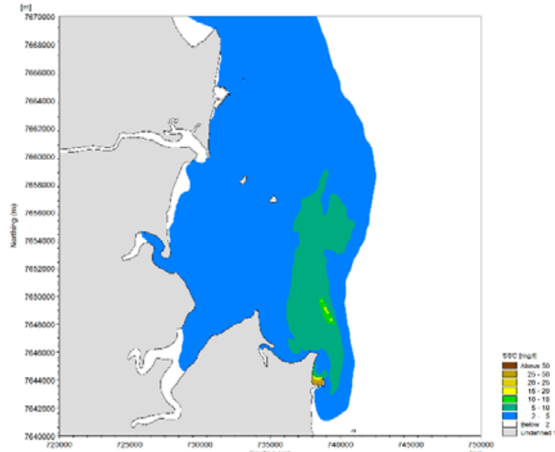


Figure 5b: 95[th] percentile SSC, Middle layer

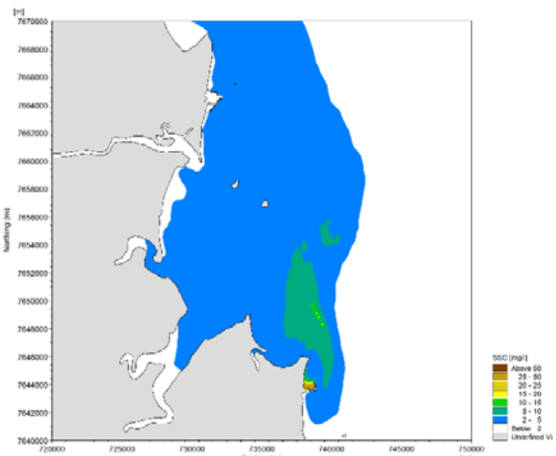


Figure 5c: 95[th] percentile SSC, Surface layer

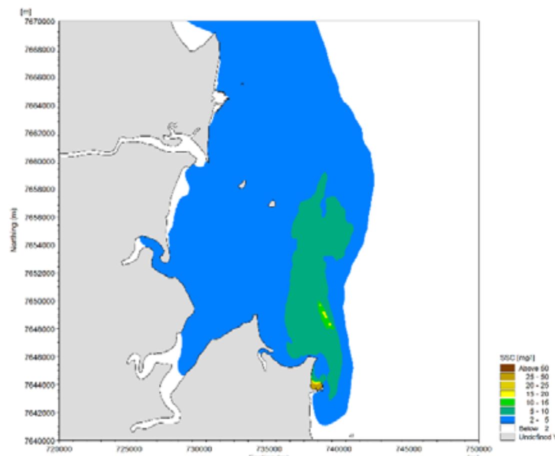


Figure 5d: 95[th] percentile SSC, Depth averaged layer

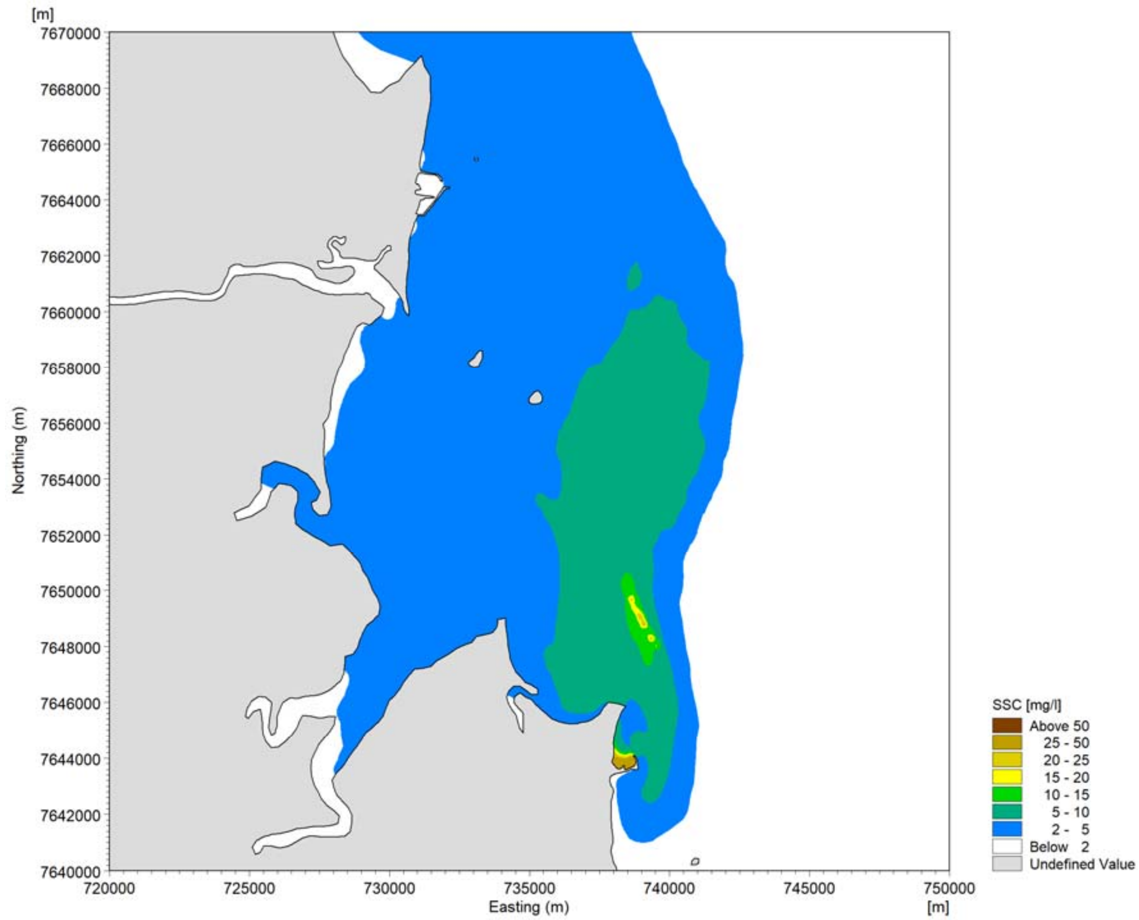


Figure 6: 95th percentile SSC calculated using the bed layer of the model.

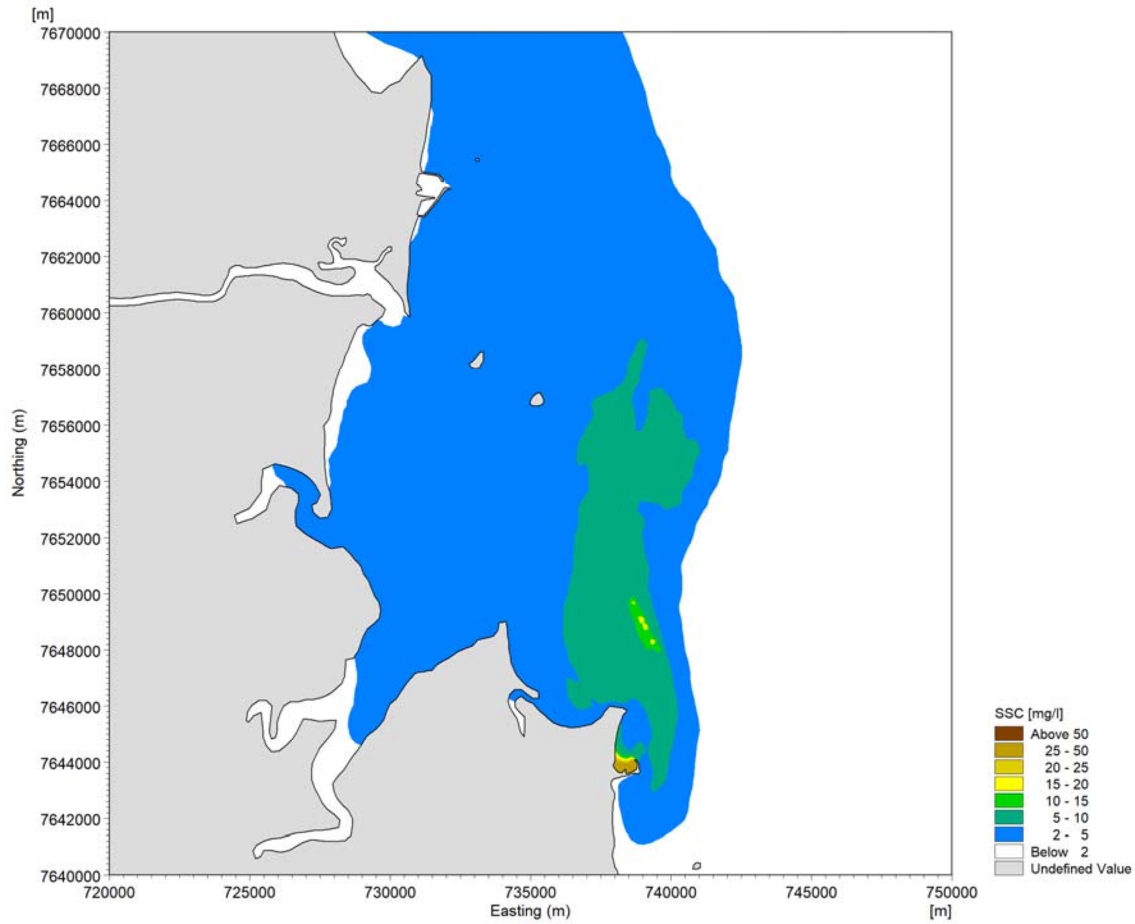


Figure 7: 95th percentile SSC calculated using the middle layer of the model.

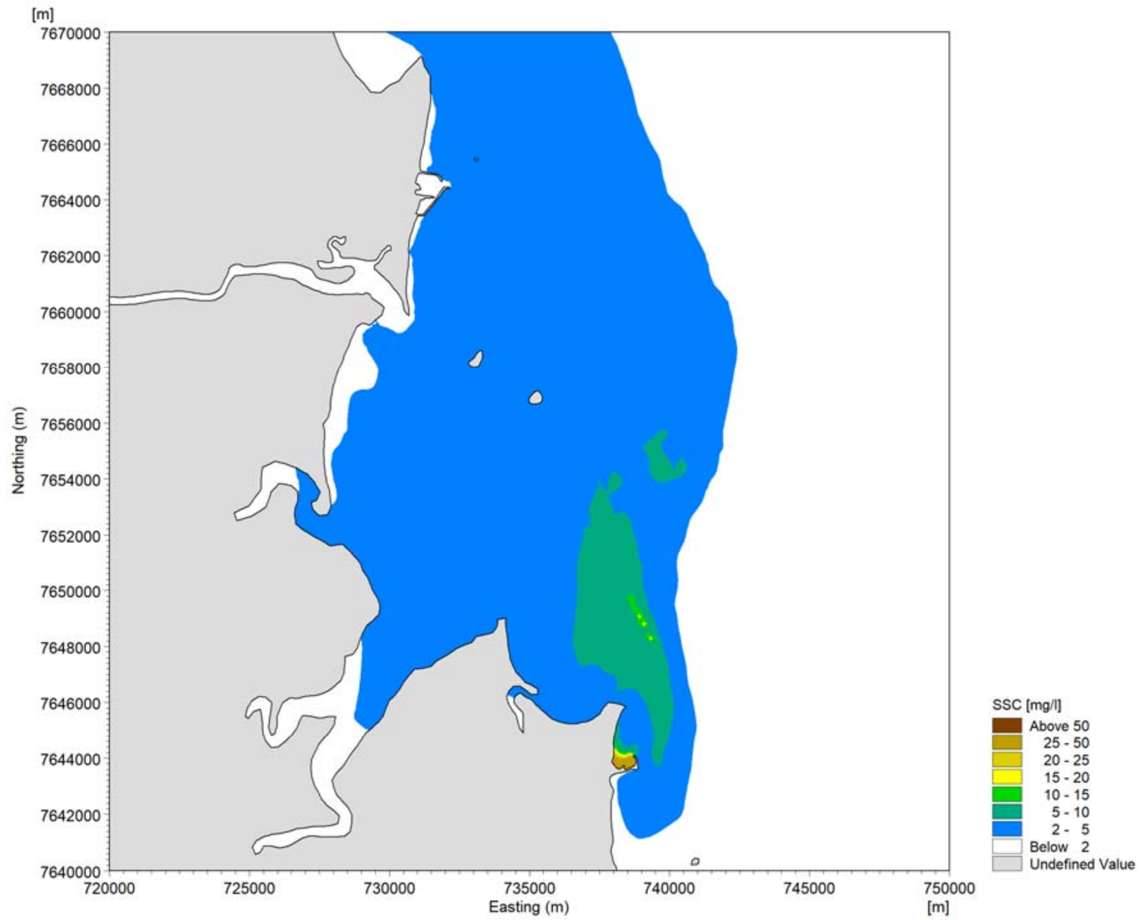


Figure 8: 95th percentile SSC calculated using the surface layer of the model.

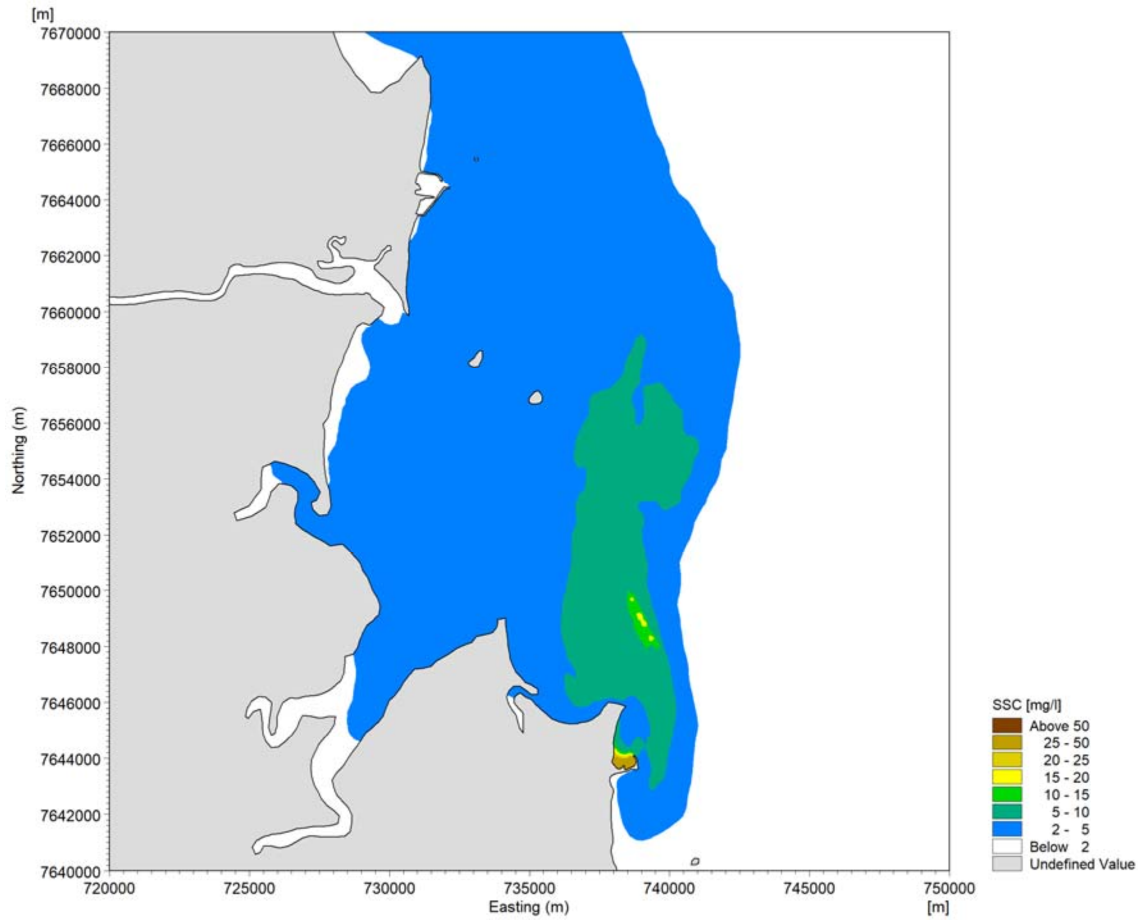


Figure 9: 95th percentile SSC calculated using all layers of the model (i.e. depth averaged SSC).

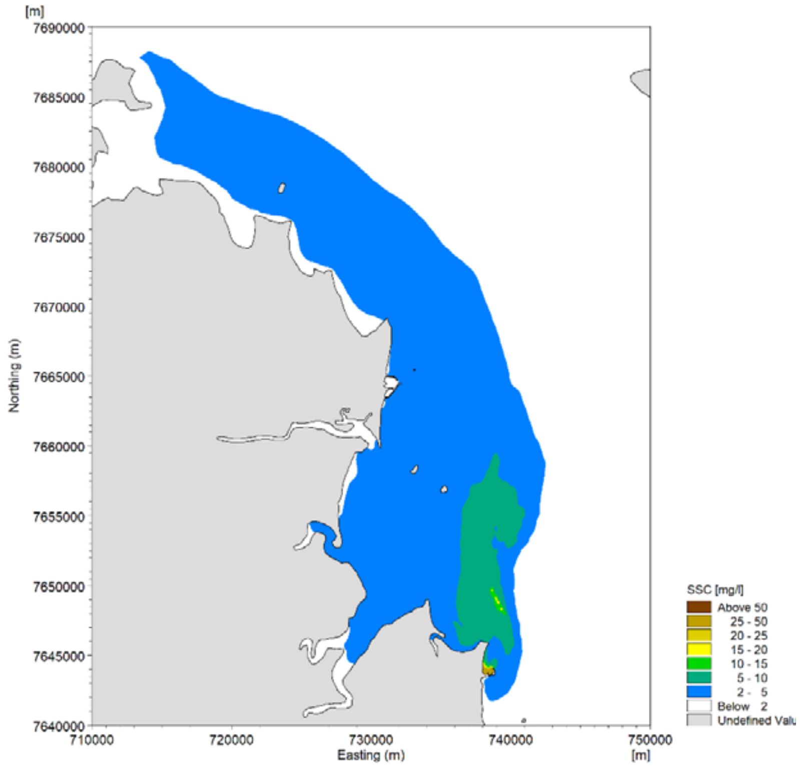


Figure 10a: 95th percentile SSC calculated assumed the dredged sediment is released uniformly through the water column

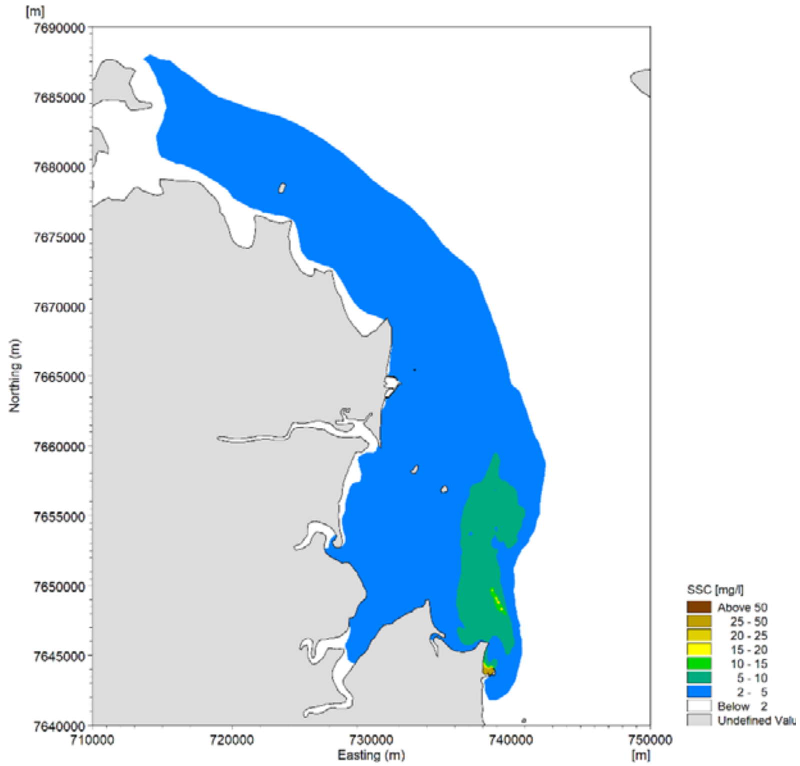


Figure 10b: 95th percentile SSC calculated assumed the dredged sediment is released near the bed (drag head and propeller wash) and mid water column (overflow and placement release)

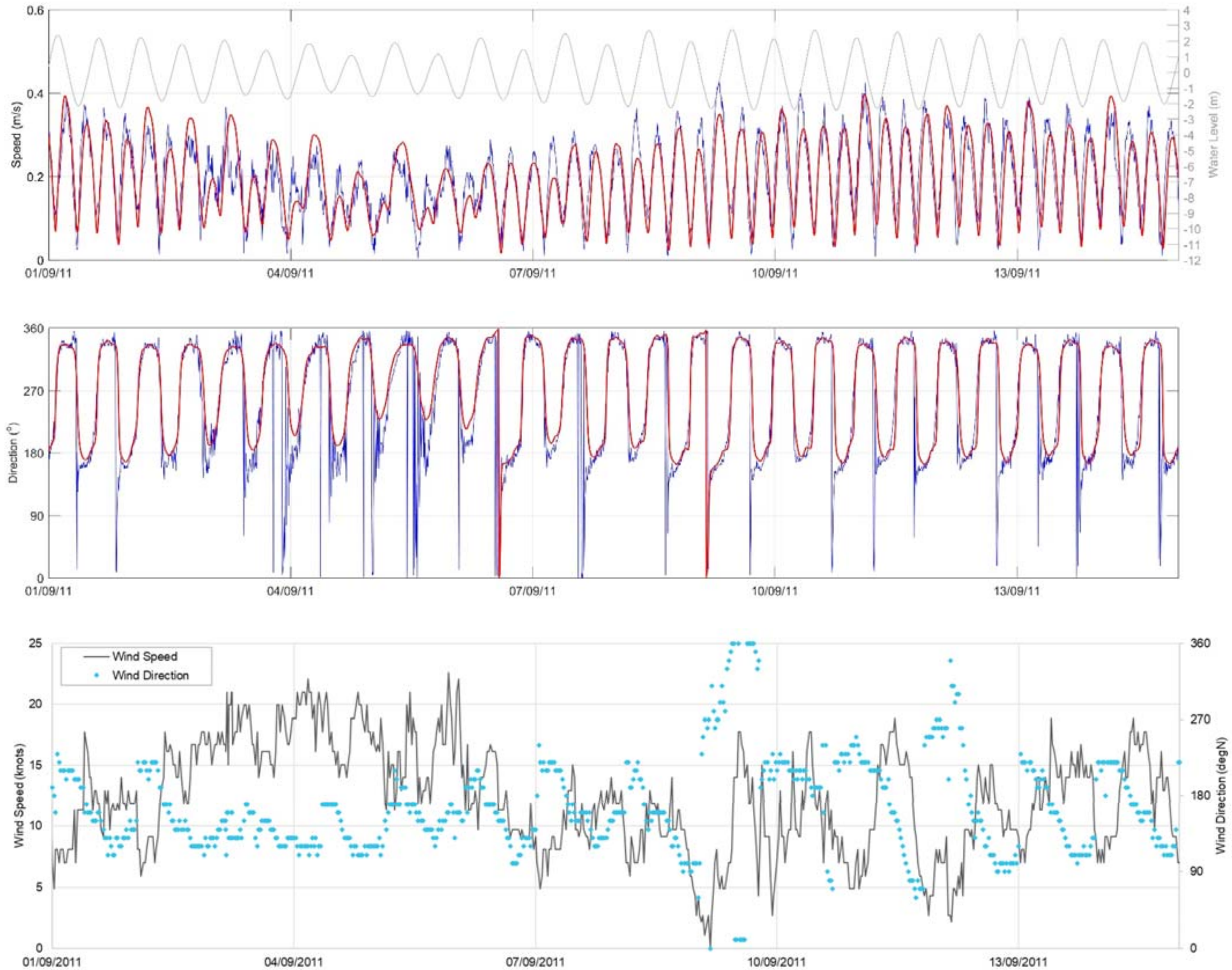


Figure 11: Measured (blue) and modelled (red) near surface currents at Site 1 and measured wind conditions during September 2011 model calibration period.

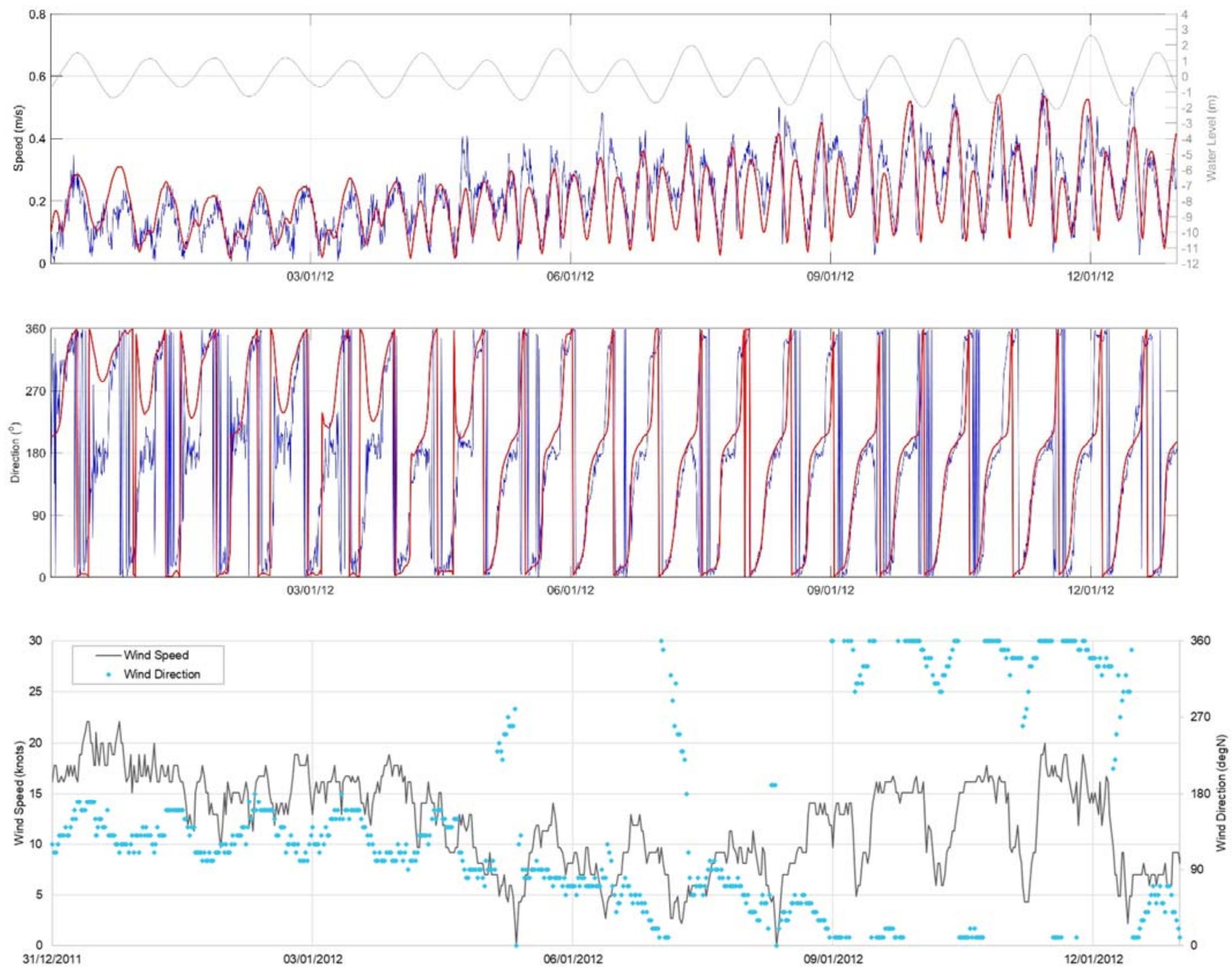


Figure 12: Measured (blue) and modelled (red) near surface currents at Site 2 and measured wind conditions during January 2012 model calibration period.

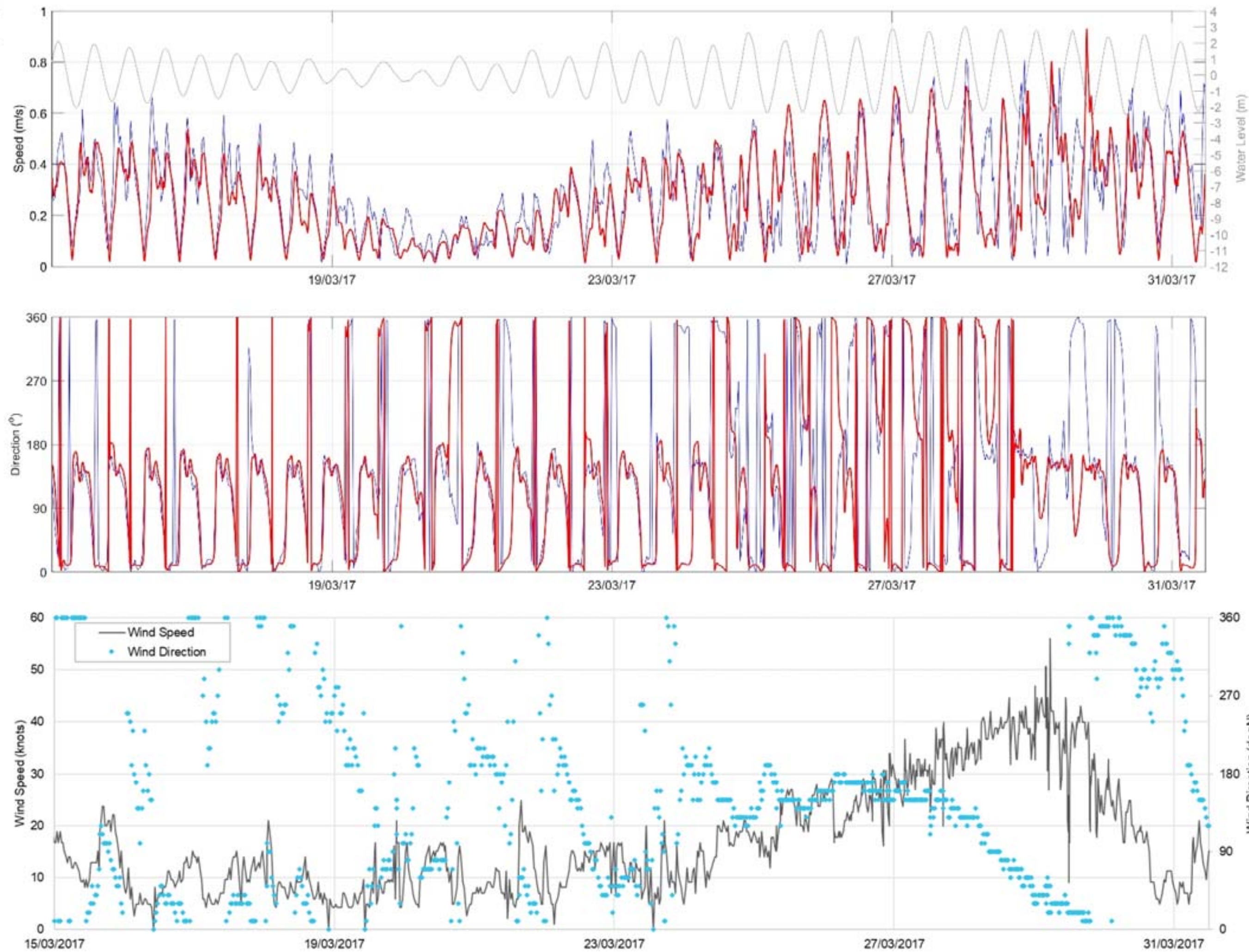


Figure 13: Measured (blue) and modelled (red) near surface currents at MK1 and measured wind conditions during March 2017 model calibration period.

APPENDIX A

Unburnt Coal in the Marine Environment

December 2018

PORT OF
HAY POINT

Marine and Catchment Science

Unburnt Coal in the Marine Environment at the Port of Hay Point

For

North Queensland Bulk Ports

December 2018

Koskela Group © **ABN 58 560 270 401**

71 Yangoora Crescent,
Ashmore, QLD 4214, Australia

mb:0419 731 694
e: rkoskela@koskelagroup.com.au

December 2018

Document Control

Revision Number	Document Type	Date	Author	Reviewers	Approved
0.1	Draft	07/10/2018	Dr Riku Koskela	Dr Ray Correll Dr Don Morrisey Professor Michael Ahrens	RWK
0.2	Final	03/12/2018	Dr Riku Koskela	Dr Ray Correll	RWK

Contents

Executive Summary **vi**

Unburnt Coal in the Marine Environment vi
Potential Impact of Unburnt Coal at the Port of Hay Point vii
Potential Human Contamination ix
Weight of Evidence ix
Conclusion x

1 Introduction **1**

1.1 Port Operations 1
1.2 Receiving Environments 1
1.3 Land Use Activities 1
1.4 Coal as a Potential Contaminant 2
1.5 Objective 2
1.6 Scope 2

2 Unburnt Coal as a Contaminant Source **6**

2.1 Introduction 6
2.2 Historical Reports 6
2.3 Coal as a Contaminant 7
2.4 Fugitive Coal Losses at the Port of Hay Point 9
2.5 Acid-Generating Potential 11
2.6 Metals 12
2.7 PAHs 23
2.8 Physical Impacts of Unburnt Coal 39

3 Weight of Evidence **43**

3.1 Acid Generating Potential 43
3.2 Metals 44
3.3 PAHs 45
3.4 WOE Score 46

4 Conclusions **48**

5 References **49**

Table Index

Table 1 Dilute Acid Extraction of metals from representative coal samples (HPCT) with particle size ≤ 1 mm. Data presented as arithmetic mean and 95% Upper Confidence Limit (UCL) of the mean. The 95% UCL is compared with the NAGD screening level (DEWHA 2009; Yellow shading = exceeds NAGD screening level). From Koskela Group (2010a). 15

Table 2 Seawater elutriation of representative coal samples with particle size ≤ 2 mm. Data were corrected for background seawater concentration and presented as arithmetic mean and 95% Upper Confidence Limit (UCL) of the mean. Compliance with ANZECC/ARMCANZ Water Quality Guidelines for Marine Waters was determined after correction with the Dilution and Attenuation Factor (DAF) according to standard NAGD procedure (DEWHA 2009). The DAF corrected 95% UCL is compared; Yellow shading = DAF corrected 95% UCL exceeds guideline for 95% species protection. From Koskela Group (2010a). 16

Table 3 Effect of stormwater discharge on the concentration of trace metals in water at site RE15 17

Table 4 Interim Local Guidelines (Trigger Values) for Contaminants in the Groundwater of Hay Point derived from 80th percentile data obtained from background groundwater bores and the intersection of two aquifers. 18

Table 5 Compliance of sediment contaminant concentrations (95% UCL of mean) with adopted sediment quality trigger values (mg/kg dry weight) from Koskela Group (2014a and 2014b). 19

Table 6 Comparison of acid volatile sulfides and simultaneously extracted metals (mmole/kg) from Koskela Group (2014a and 2014b). 20

Table 7 Mean concentrations of total metal and metalloids (mg/kg wet weight) in the muscle tissue of test species averaged over the three locations (from Koskela Group, 2014a and 2014b; Yellow shading, exceeds FSANZ guideline). 21

Table 8 Probabilities obtained from approximate F test for locations and test species (from Koskela Group, 2014a and 2014b). 22

Table 9 Some relevant diagnostic ratios for PAHs to determine source contributions (adapted from Moyo et al. 2013; Stogiannidis and Laane 2015). 26

Table 10 Passive sampling of PAHs using water column deployed semi-permeable membrane devices (from Koskela Group 2014a and 2014b). 29

Table 11 Diagnostic ratios of PAHs to determine likely source contributions for sediment data provided by REMP (Sandfly Creek, Half Tide Tug Harbour, Mick Ready Creek; Koskela Group 2014); sediment sampling for maintenance dredging (HPCT Berth 3, DBCT Berth 1, Half Tide Tug Harbour; Advisian 2018) and sediment sampling by grab and sediment trap Central GBR (IS9, IS10, PRC4-5 free-floating trap, IS9ST boat tethered trap; Burns and Brinkman 2011). Petrogenic source; mixed source; pyrogenic source; non biomass. 35

Table 12 Organic analytes of biota contaminant study (from Koskela Group 2014a and 2014b). 37

Table 13 No observed effect concentration (NOEC) and lowest observed effect concentration (LOEC) for various life history stages of the coral *A tenuis* exposed to suspended particulate coal (modified from Table 2 Berry *et al.* 2017). 42

Table 14 Weight of Evidence to assess the potential impact of unburnt coal on the receiving marine environment at the Port of Hay Point. P1=provisional score of 1. 47

Figure Index

Figure 1 General Location – Port of Hay Point 3

Figure 2 Location of Dalrymple Bay Coal Terminal and Hay Point Coal Terminal facilities at the Port of Hay Point 4

Figure 3 Port limits for Port of Hay Point inclusive of designated dredge material disposal ground (Chart Au249). 5

Figure 4 Summary PAH concentrations in sediment for Sandfly Creek, Tug Harbour, Inshore Control, Salonika Creek and Mick Ready Creek (from Koskela Group 2014a and 2014b). 31

Figure 5 PAH concentration in sediments for Sandfly Creek (Koskela Group 2014a and b), DBCT Berth 1 (Advisian 2018) and offshore site IS10 (Burns and Brinkman 2011). 32

Abbreviations

ANZECC/ARMCANZ guidelines	Australian and New Zealand water quality guidelines for fresh and marine waters
BPDE	benzo(a)pyrene diolepoxide – a mutagenic/carcinogenic breakdown product of benzo(a)pyrene that instigates damage to intercellular DNA
DBCT	Dalrymple Bay Coal Terminal
FSANZ	Food Standards Australia New Zealand
HPCT	Hay Point Coal Terminal
ISQG	Interim Sediment Quality Guideline
LOE	Line of Evidence
NAGD	National Assessment Guidelines for Dredging
Nitro-PAHs	Nitrated Polycyclic Aromatic Hydrocarbons
NQBP	North Queensland Bulk Ports
PAHs	Polycyclic Aromatic Hydrocarbons
PCI	Puverised Coal Injection
REMP	Receiving Environment Monitoring Program
SPDM	Semi-permeable membrane device (passive sampler for organic contaminants)
WOE	Weight of Evidence

Abbreviations for some Polycyclic Aromatic Hydrocarbons

PAH	Abbreviation	Ring number	Solubility (mg/L)	Carcinogen/Mutagen	Known source of Nitro-PAH
Naphthalene	Nn	2	32	No	Yes
Fluorene	F	3	1.9	No	Yes
Phenanthrene	Ph	3	1.1	No	Yes
Anthracene	An	3	0.05	Low	Yes
Pyrene	Py	4	0.13	No	Yes
Fluoranthene	Fl	4	0.26	No	Yes
Chrysene	Ch	4	0.002	Low	Yes
Benz(a)anthracene	BaA	4	0.014	Yes	
Benzo(b)fluoranthene	BbF	5	0.008	Yes	
Benzo(k)fluoranthene	BkF	5	0.0014	Yes	
Benzo(a)pyrene	BaP	5	0.003	Highly carcinogenic	Yes
Benzo(e)pyrene	BeP	5	0.005	No	
Perylene	Per	5	0.0004	Low	
Dibenz(ah)anthracene	DahA	5	0.0005	Highly carcinogenic	
Benzo(ghi)perylene	BghiP	6	0.00026	Low	
Indeno(123-cd)pyrene	IP	6	0.00019	Yes	

Executive Summary

North Queensland Bulk Ports manages the Port of Hay Point. This Port contains two international shipping terminals, these being Hay Point Coal Terminal (HPCT) and Dalrymple Bay Coal Terminal (DBCT), as well as associated rail lines, rail loops, stockyards for the storage of coal stockpiles, stormwater detention basins, roads, trestles, conveyors, wharfs, seven shipping berths for bulk carriers and tug and pilotage operations.

The Port of Hay Point employs an intensive program of dust mitigation, stormwater capture and transport control to minimise loss of coal and coal dust to the surrounding environment. This review has been commissioned to better understand the potential environmental impacts associated with unburnt coal in the marine environment, with specific attention to the operations and environment at the Port of Hay Point. To achieve this, the review provides:

- Detailed assessment of coal as a contaminant, with specific attention to the coals shipped through the Port of Hay Point;
- Review of all relevant recent studies undertaken within the immediate receiving environment of the Port;
- Appraisal of environmental performance of the Port through a Weight of Evidence Assessment, according to the approach outlined by Simpson *et al*. (2013); and
- Identification of information gaps.

Unburnt Coal in the Marine Environment

Mineral coal is a highly variable product. It has been determined that the capacity for coal to release contaminants and impact the quality of water, sediment and pore waters is determined by source-specific criteria, such as:

- Coal rank (broad classification system for coals);
- Formation history (coalification);
- Sulphide content and acid-generating potential; and
- Solubility of key contaminants including trace metals and polycyclic aromatic hydrocarbons (PAHs).

Given such specificity, it is important to determine potential impacts of unburnt coal on a source or product-specific basis.

The coals shipped through the Port of Hay Point can be characterised as being:

- High rank bituminous and predominantly metallurgical coals;
- Sourced from a single basin (Bowen), thus sharing similar formation history;
- Uniformly of very low sulphur content and of very low acid-generating potential;
- Low capacity to release metal contaminants; and
- Undefined properties with respect to PAHs.

Potential Impact of Unburnt Coal at the Port of Hay Point

Water Quality

While dust emissions have not been quantified as part of this report, assessments of coal leachate and stormwater runoff from the Port have been undertaken (Koskela Group 2011a, 2011b, 2013, 2014a and 2014b). These assessments determined that stormwater outflows from the Port of Hay Point were within water quality guidelines for pH (acidity), most metals and PAHs. Metals that exceeded guideline values were determined to be within the background concentration for the Port area. During stormwater overflow from the coal terminals, coal content in immediate receiving waters at the Port of Hay Point did not exceed 2.8 mg/L at the Half Tide Tug Harbour monitoring location and were less than 0.01mg/L immediately outside the Half Tide Tug Harbour. Suspended coal particles were also determined to be of very small size (95% <10 µm).

Sediment Quality

Sediment quality within the receiving environment at the Port of Hay Point has been examined in multiple reports (i.e. Advisian 2018). Sediments within the Port Area were compliant to ISQG low trigger levels for all metal and PAH contaminants (ANZECC/ARMCANZ 2000 revised 2018; NAGD 2009). Surveyed locations included:

- Sandfly Creek,
- Half Tide Tug Harbour;
- DBCT berth pockets;
- HPCT berth pockets;
- Apron area; and
- Departure path.

Analysis of Total Organic Carbon (TOC) determines the percentage of carbon present in sediment from all sources natural and anthropogenic sources, both biological and mineral. A recent survey within the Port of Hay Point (Advisian 2018) identified low TOC for terminal berth pockets (<2%); apron area (<1.2%) and departure path (<0.2%). The contribution of coal to this TOC is expected to be a smaller fraction. This is supported by a study of percentage coal in sediment at Sandfly Creek (1% coal), Half Tide Tug Harbour (<0.6%) and at an inshore site adjacent to the tug harbour (0.1% to 0.2%; Koskela Group 2014a and 2014b).

Carcinogenic/Mutagenic Potential

Preliminary examination of water and sediment PAHs indicates a higher carcinogenic/mutagenic potential in the immediate vicinity of port operational areas. This potential appears to diminish away from port operations. It is probable that this is primarily derived from combustion engine emissions.

Pore Water

Information was not available for the determination of pore water quality.

Biota

A study has been undertaken to examine the human health risks associated with potential bioaccumulation of contaminants in selected biota including mud crabs, fish

and whelks at the Port of Hay Point (Koskela Group 2014a and 2014b). This study did not identify the accumulation of any metal above the accepted background concentration for these food types as listed in FSANZ guidelines and FSANZ (2003). The examination of PAHs within this biota did not achieve a sufficiently low detection limit to make a determination of potential bioaccumulation.

Source Contributions of PAHs

Detailed and extensive research has determined that marine sediments globally contain a background concentration of PAHs derived predominantly from pyrogenic sources (primarily combusted fossil fuels). These background PAHs exist in characteristic ratios of components that are distinct for individual point source contributions and are not affected to a practical degree by natural degradation (Stogiannidis and Lanne 2015; Moyo *et al*. 2013). Point source contributions themselves can be further delineated using such ratios. A series of diagnostic ratios and characteristics were applied to available sediment PAH data for the Port of Hay Point and limited offshore locations. This assessment determined that:

- Sandfly Creek sediments contain PAHs that are compliant to sediment quality guidelines and are derived almost entirely from unburnt coal;
- Half Tide Tug Harbour sediments contain PAHs that are compliant to sediment quality guidelines and are derived from a mix of sources likely to include combusted fossil fuels associated with port operations, background pyrogenic sources and a small contribution from unburnt coal and;
- Shipping berths contain PAHs that are compliant to sediment quality guidelines and are derived from a mix of sources likely to include combusted fossil fuels associated with port operations, background pyrogenic sources and a small contribution from unburnt coal; and
- Background locations contain PAHs that are compliant to sediment quality guidelines and are predominantly derived from background pyrogenic sources.

This preliminary appraisal indicates that the influence of unburnt coal on PAH concentrations is likely to be spatially confined to Sandfly Creek. For most operational areas within the port, such as at the shipping berths, unburnt coal does not appear to be the primary mediator of PAHs. In these instances, the primary contributing sources appear to be pyrogenic in origin and include localised combustion engine activity and background contributions from such sources.

Physical Impacts

Sediment Modification

The historical dumping of colliery waste and use of coal in heavy industrial applications and as shipping fuels has substantially altered marine sediments at various locations across the world. Where coal shipping terminals operate with minimal dust and spillage controls, sediment coal content is also significant. However, the Port of Hay Point operates with a variety of dust mitigation and spill control measures that appear to have limited operational contributions of unburnt coal in sediment to comparatively low levels.

Biota

While many authors have raised the potential for unburnt coal to impact the environment, direct studies of impacts are limited. Despite this, recent studies have provided lowest observed effects concentrations (LOECs) for suspended coal particles (Berry *et al*. 2017). It is apparent that inadvertent fugitive coal losses from the Port of Hay Point create suspended coal concentrations that are orders of magnitude lower than these LOECs. Given the high current velocities of the receiving environment and the presence of coral communities immediately adjacent to the terminal, it is likely that unburnt coal exerts very low to negligible physical impacts on benthic communities at the Port of Hay Point. In addition, studies of mangrove pneumatophores from Sandfly Creek failed to find any coal particles in 100 microscopically examined samples, indicating that respiration in these plants was not affected. Suspended coal particles as a deleterious litter cannot be discounted, but its risk as an impact is probably many orders of magnitude lower than more abundant types of debris, such as fragmented plastic and anthropogenic foams.

Potential Human Contamination

There is some community interest in the interaction of beachgoers with unburnt coals and the potential for contamination by PAHs. This is of no small consideration, as PAHs have recently been identified by the International Agency for Research on Cancer (IARC) as a primary mediator of cancers in humans. The mechanism of exposure is primarily via lung respiration of fumes and particulate matter associated with tobacco (IARC 2012); bitumens (IARC 2013a); combustion engine exhausts (IARC 2013b); related air pollution (IARC 2015) and via the digestion of contaminated foods (IARC 2018).

The capacity of unburnt coals to release PAHs has not been formally determined for the Port of Hay Point. However, it is likely that a beachgoer’s continued exposure to PAHs via IARC declared mechanisms (i.e., combustion engine fumes) will far outweigh episodic interactions with unburnt coal.

Weight of Evidence

The various findings of the present review can be used as lines of evidence (LOE’s) within a weight of evidence (WOE) appraisal (Simpson *et al*. 2013) to determine the likelihood of environmental impact associated with unburnt coal according to the rankings:

- 1 (no concern);
- 2 (possible concern); and
- 3 (significant concern).

According to the various LOEs presented here, with respect to potential environmental impact associated with unburnt coal in the marine environment at the Port of Hay Point, a WOE score of 1 is rendered.

This score indicates that no reasonable evidence for non-compliance to the present environmental guidelines is apparent.

It is noted that knowledge gaps exist with respect to:

- Potential release of PAHs from coal, either as export product or as fugitive coal residing on the seabed or beaches;

- Quality of pore water and the relationship between sediment, pore water and surface water, as this relates to metals and PAHs;
- Source attribution of PAHs within the coastal environment; and
- Bioaccumulation and the appraisal of either mutagenic or carcinogenic potential within selected biota.

.

Conclusion

Unburnt coal has been demonstrated to be of some environmental concern to the marine environment in various locations worldwide. Despite this, strong evidence exists that the unburnt coal product shipped through the Port of Hay Point has a low capacity to release contaminants. Furthermore, all available lines of evidence indicate that the impact of unburnt coal in the marine environment at the Port of Hay Point is very low.

1 Introduction

The Australian state of Queensland is the largest contributor of seaborne metallurgical coal in the world, with approximately 151Mt shipped in 2015 (Queensland Government 2018). This coal is primarily sourced from the Bowen Basin of central Queensland. The primary point of export for this coal is the Port of Hay Point, which is situated 38 km south of Mackay on the central Queensland coast (Figure 1). The Port of Hay Point consists of Dalrymple Bay Coal Terminal (DBCT) and Hay Point Coal Terminal (HPCT) (Figure 2). In 2016/17 these terminals shipped a combined total of 106.5Mt, of which approximately 80% was metallurgical coal (NQBP, 2018).

1.1 Port Operations

Coal product mined from the Bowen Basin is shipped via rail to the Port where it is diverted to either DBCT or HPCT on respective rail loops. Within each terminal the coal is unloaded and stacked in multiple large stockpiles that correspond to specific coal grades. These stockpiles are periodically watered with automatic sprayers to reduce airborne dust. Stockpiles are progressively depleted and replenished using mechanical stacker reclaimers. Coal is transported from the stockyard to respective loading wharfs via terminal specific trestles and covered conveyors. Once at the wharf, coal is loaded directly from each conveyor to the holds of bulk carriers (four berths at DBCT and three berths at HPCT). The immediate receiving environment for stormwater discharge from Port of Hay Point is Sandfly Creek, which is a tropical intertidal estuary system. Sandfly Creek discharges to the partially protected waters of Half Tide Tug Harbour (Tug Harbour), which is flushed by the open ocean. Tug Harbour is also the location of tug operations that service shipping for the Port of Hay Point.

1.2 Receiving Environments

The Port of Hay Point is a tropical coastal system surrounded by a variety of habitats including estuaries containing mangrove forest, intertidal and sub-tidal rocky reef, and soft sand and muddy silt substrates. Fringing rocky reef communities occur at Round Top Island and Flat Top Island located 6km north of the port boundary and at Victor Islet located 2.1 km southeast of the port boundary (Figure 3). In addition, Hay Reef is located between the DBCT and HPCT trestles approximately 300m offshore from the point. The seabed of the area consists of bare substratum with a low percentage cover of benthos including macroalgae, ephemeral seagrasses (*Halophila decipiens* and *H. spinulosa*) and benthic invertebrates (Koskela Group 2009).

Sandfly Creek is a small intertidal wetland system at Hay Point. The creek is dominated by a tidal range in excess of 6.5m during a spring tide and less than 4.0m during a neap tide. As Sandfly Creek is situated in the upper intertidal zone, tidal waters do not enter the creek system during much of the neap tidal phase. Freshwater runoff enters the creek system following rainfall. This freshwater is primarily derived from the overflow of stormwater detention dams. Some inflow originates from the nearby community of Half Tide; from surrounding adjacent bushland; and from Hay Point Road, which crosses Sandfly Creek approximately 200m upstream from the creek entrance. During periods of low rainfall, Sandfly Creek wetland is dry, with the area only being fully inundated by seawater during spring tidal periods.

1.3 Land Use Activities

The catchment that discharges into Sandfly Creek is occupied by coal terminals with small areas of urban development to the south. Sandfly Creek has been designated as ‘environmental protection’ in the North Queensland Bulk Ports Corporation Land Use Plan for the Port of Hay Point (2010) in accordance with the Transport Infrastructure Act 1994. This designation allows it to be used as a buffer zone between the coal terminals and the receiving environment. Half Tide Tug Harbour has been designated as ‘access and port infrastructure’ and supports commercial tug operations which

may contribute some contaminants to the near shore environment. Land use in the region consists primarily of cattle grazing and sugar cane farms, rural residential and small townships, including Half Tide, Salonika Beach and Louisa Creek.

1.4 Coal as a Potential Contaminant

The continuous nature of the port operations and the logistics supply chain requires the stockpiling of large quantities of coal at stockyards located at DBCT and HPCT. Despite various controls, including dust suppression (water and veneer application), covered conveyors, and systems to minimise and retrieve coal spillage, a small amount of coal may still enter the receiving environment as whole product and dust. Coal can enter the environment via coal loading activities and through less obvious means such as the transport of fine particles within stormwater and the loss of coal within the rail system, which then makes its way to local catchments during times of flood. The presence of coal in the marine environment remains a matter of concern.

1.5 Objective

The objective of the present program is to delineate the potential impacts of unburnt coal on the marine environment associated with the storage of coal and shipping operations of the Port of Hay Point.

1.6 Scope

This will be achieved through:

- Detailed review of relevant available information targeting the impacts of unburnt coal in the marine environment, with specific attention to the coals and environment of Port of Hay Point;
- Weight of Evidence Assessment according to the approach outlined by Simpson *et al*. (2013); and
- Identification of Information Gaps.

Figure 1 General Location – Port of Hay Point

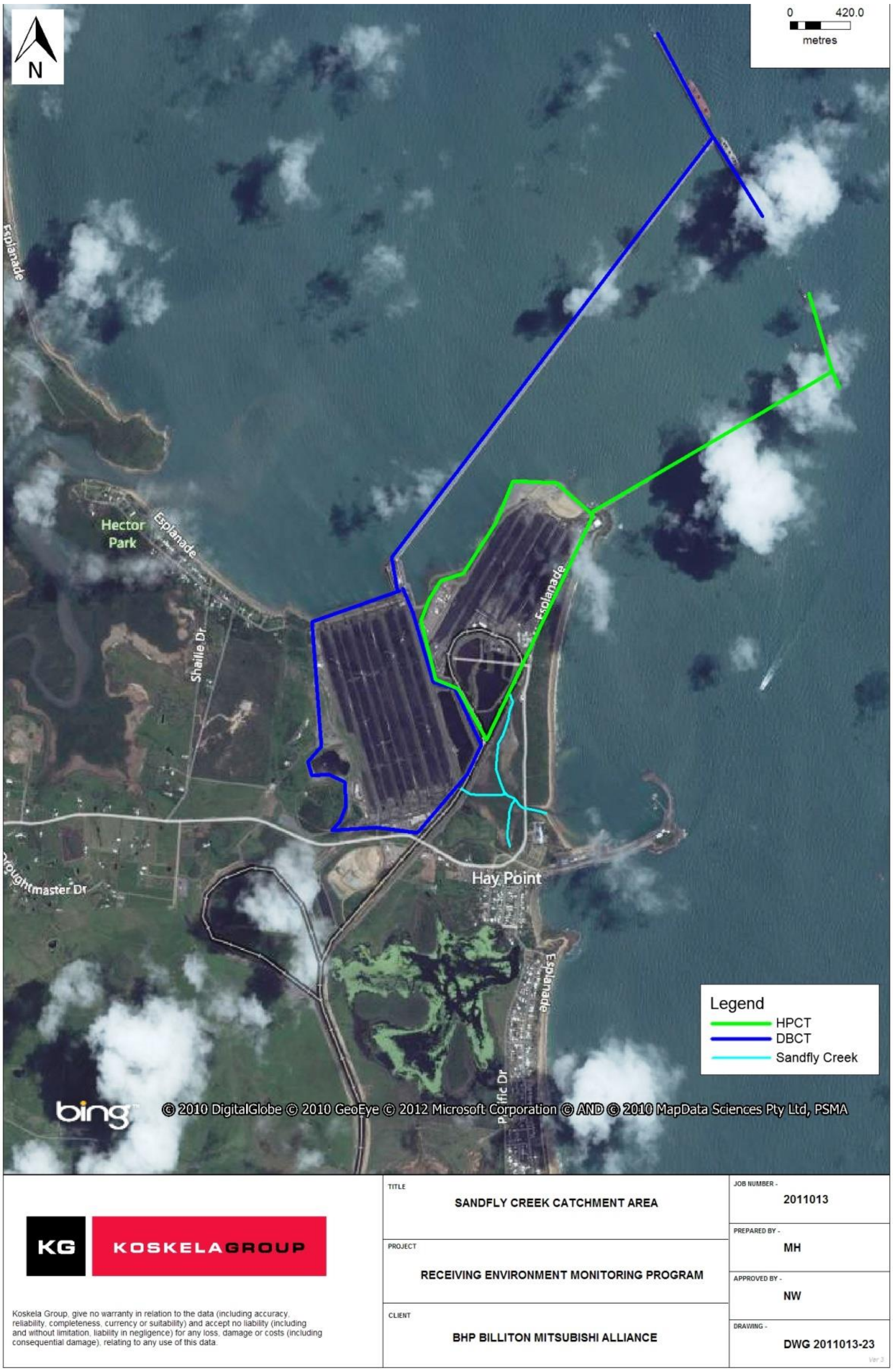


Figure 2 Location of Dalrymple Bay Coal Terminal and Hay Point Coal Terminal facilities at the Port of Hay Point

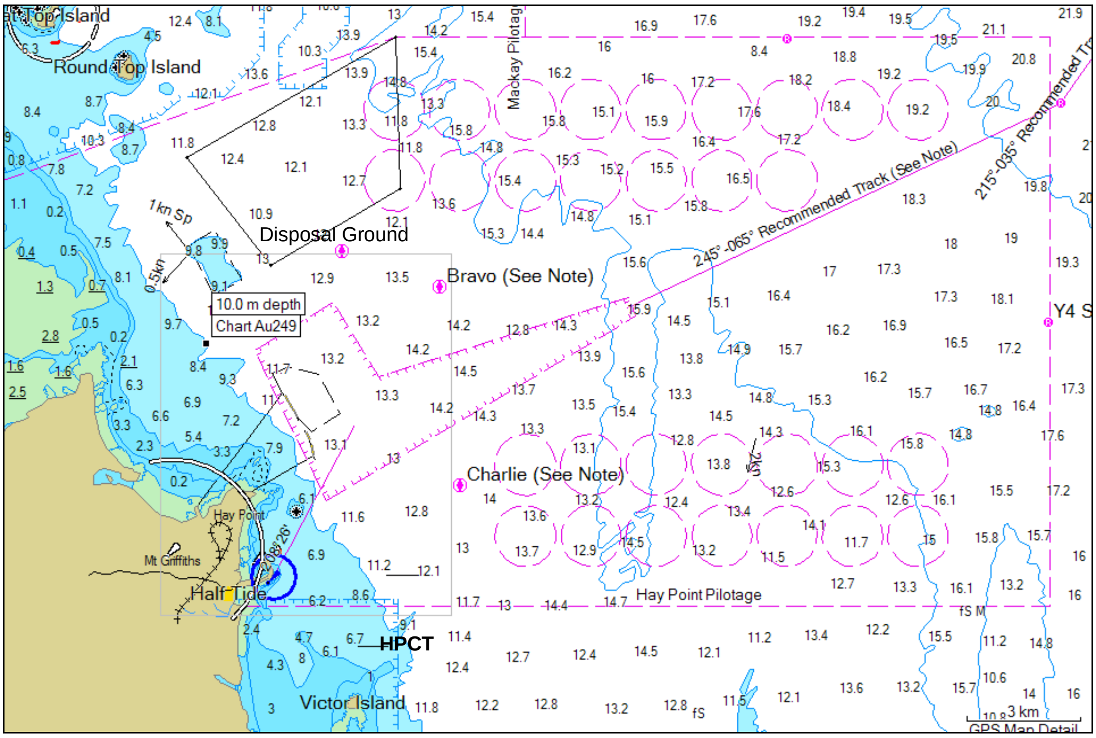


Figure 3 Port limits for Port of Hay Point inclusive of designated dredge material disposal ground (Chart Au249).

2 Unburnt Coal as a Contaminant Source

2.1 Introduction

Mineral coal is a very commonly mined and traded product, with worldwide production of more than 7.8 billion tonnes in 2014 (World Coal Association, 2018). Approximately 1.3 billion tonnes of this is hard coking coal (also referred to as metallurgical coal) used for the production of steel, with the remainder being thermal coal used for power generation. The seaborne trade in coal is more than 1 billion tonnes (2013) with approximately 300 million tonnes (Mt) being metallurgical coal. The Australian state of Queensland is the largest contributor of seaborne metallurgical coal, with approximately 151Mt shipped in 2015 (Queensland Government). The primary point of this export is the Port of Hay Point, which consists of Dalrymple Bay Coal Terminal (DBCT) and Hay Point Coal Terminal (HPCT). In 2016/2017 these terminals shipped a combined total of 106.5Mt, with approximately 80% being metallurgical coal (NQBP, 2018).

The potential environmental impact of unburnt coal in the marine environment has been a matter of limited scientific interest for some decades (Tripp *et al*. 1981; Ahrens and Morrisey 2005; Laumann *et al.*, 2011). While only a relatively small number of studies having been published in the peer reviewed scientific literature, a larger body of unpublished scientific reports exist. Where available, these reports provide an insight into the environmental impact of coal associated with specific industrial activities such as bulk handling, port operations and shipping. The review presented here utilises these various information sources to examine potential contamination of the marine environment and impacts associated with unburnt coal shipped through the Port of Hay Point.

2.2 Historical Reports

A significant review of coal as a potential environmental contaminant in marine systems was undertaken by Ahrens and Morrisey (2005). This review correlated key physical and chemical attributes of coals with potential marine environmental impacts. Principal contaminants associated with coals include heavy metals and polycyclic aromatic hydrocarbons (PAHs). A recent review of PAHs in aquatic systems has been undertaken by Stogiannidis and Laane (2015). This review examined the source contributions and factors influencing the distribution of PAHs. The present document does not seek to rework these two previous major reviews, but rather use them as a foundation upon which the present assessment is based.

Additionally, a number of unpublished reports have investigated specific interactions between coal and the environment at the Port of Hay Point. These reports examined:

- Capacity for coal shipped through Hay Point Coal Terminal to release metal contaminants to both marine and freshwater (Koskela Group, 2011a);
- Capacity for coal fines and sediment retained in detention basins at Hay Point Coal Terminal to release metal contaminants to the overlying water and porewaters (Koskela Group, 2011b);
- Testing of BMA composite coal sample for MARPOL annex V classification Toxikos (2012);

- Identification of coal particles within stormwater discharges at the Port of Hay Point, and pathways of migration and settlement within the receiving environment (Koskela Group, 2014a and 2014b);
- Impact of stormwater discharges from coal storage and terminal facilities on the water, sediment and biota of the receiving environment at the Port of Hay Point, including appraisal of contamination by metals and PAHs and their bioaccumulation in selected biota (Koskela Group, 2014a and 2014b);
- Evaluation of contaminant impacts at the Port of Hay Point using a Weight of Evidence approach (Koskela Group 2014a and 2014b); and
- Recent sampling and analysis of marine sediments at the Port of Hay Point for the determination of suitability for ocean disposal of dredged material (Advisian 2018).

While specific knowledge gaps may exist within this body of work, a broad understanding of the capacity for coal to leach contaminants, accumulation of such contaminants within the sediment and water column, and their bioaccumulation into the tissue of selected biota are available.

2.3 Coal as a Contaminant

Coal is a heterogeneous mineral with highly variable chemical properties (Ahrens and Morrisey 2005). This variability causes different coal types and coal sources to display a significant range in organic and inorganic composition, contaminant concentration and the capacity for contaminant release (i.e. Vassilev *et al*. 1996; Laumann *et al.* 2011; Ahrens and Morrisey 2005).

The two primary contaminants of unburnt coal are metals and PAHs. Thus sites involved with the storage and transportation of coal can potentially be exposed to contamination by metals and PAHs (Ahrens and Morrisey 2005; Laumann *et al.*, 2011). Fine particulate coal is easily transported to aquatic sediments where it can readily accumulate. Unburnt coal may also impact marine biota as a physical disturbance causing smothering, abrasion and interference of biological processes such as photosynthesis, respiration, feeding and reproduction (Ahrens and Morrisey 2005; Berry 2017).

2.3.1 Source

Unburnt coal enters the surface environment as an unintended consequence of mining, bulk transport, coal stockpiling, port operations and shipping (Ahrens and Morrisey 2005). This can result from the transmission of fine particulate coal as dust or as waterborne suspended particles; as leachate derived from wash down operations (including vessel wash down) and stormwater flows; and as fugitive losses during the transportation phase. Within port operations, receiving environments that may be at risk include catchments, drainage lines and immediate coastal waters adjacent to port storage areas, under-trestle areas and wharf quay lines.

Large coal stockpiles are located at the Port of Hay Point. These stockpiles are open to the elements. The interaction of stormwater on coal stockpiles and the subsequent transmission of leachates and fine particles to drainage lines, creeks and coastal habitats are of primary concern. Translocation of contaminants via the migration of dust, natural resuspension of seabed sediment, maintenance dredging operations and

tidal action is also a matter of interest (i.e. Burns 2014; Koskela Group 2014a and 2014b; Advisian 2018).

2.3.2 Coal Types

Coals sourced from the Bowen Basin, Queensland, Australia, are primarily derived from ancient plant communities and their associated deposits of peat that formed during the Carboniferous and Permian periods from 360 million to 250 million years before present. Once buried and subjected to heat and pressure, these ancient peat deposits underwent a process of coalification whereby carbon progressively concentrates via dihydroxylation, demethylation and condensation (Achten and Hofmann 2009). Coals are commonly ranked into four broad types according to this coalification (American Geosciences Institute 2018; Kumar and Kumar 2016; Flores 2014). Coals with the least amount of carbon fixing are classed as lignite coals (≈ 60-70 % carbon). Further coalification results in the formation of sub-bituminous coals (≈ 70 – 77 % carbon); bituminous coals (≈ 77 – 87 % carbon) and anthracite (>87% carbon). Continuation of this process leads to the formation of graphite (≈ 100% carbon).

2.3.3 Factors Determining Chemical Contamination

The factors that determine contaminant content and bioavailability in coals relate to the original source material (maceral); specific conditions and chemistry during formation; mineral makeup and interaction with overburden materials; and stage of coalification. Some principal considerations are presented here with specific consideration for metals and PAHs.

2.3.3.1 Acidity

While coalification progressively increases the carbon content of coals, it also leads to reductions in hydrogen, oxygen and sulphur (Laumann *et al*. 2011). As a result, lower ranked coals are generally more acidic than higher ranked coals, given the oxidation of metal sulphides in associated minerals such as pyrites (Blodau 2006). Thermal coals are generally derived from lignite, sub-bituminous and lower grade bituminous coals, while metallurgical coals are derived from higher grade bituminous and anthracitic coals. Thermal coals are thus likely to be more acidic. The broad range in sulphur content of various coal types is presented in Table 2 of Ahrens and Morrisey (2005). Examples include sub-bituminous and bituminous Spanish coals (2.2-9.5 %S), bituminous coals from Eastern USA (2.0-5.2 %S) and bituminous coals from Midwestern USA (1.1%S).

The capacity for coal to release contaminants is primarily determined by contaminant content and the potential to generate corrosive acids (Ahrens and Morrisey 2005). The primary driver of this is sulphur content. Ahrens and Morrisey (2005) summarised this by stating that coals with high sulphur content (%S >3%) generally produced leachate with low pH values. Examples of this are given in Table 4 of Ahrens and Morrisey (2005) and include bituminous coals from Eastern USA (4.6 %S and pH 2.1-3.8) and sub-bituminous coals from Western USA (1.1 %S and pH 4.6-8.3) Coals with higher sulphur content lend themselves to the release of metal contaminants. Some evidence indicates that sulphur-rich coals may also release greater concentrations of PAHs (Ahrens and Morrisey 2005; Achten and Hofmann 2009). This may be expected as the coal matrix breaks down during oxidation. Coals with low sulphur content (<2%) produce more pH neutral runoff and are more likely to demonstrate low contaminant bioavailability (Ahrens and Morrisey 2005).

2.3.3.2 Coal Origin

The origin of a coal includes its maceral precursor material, depositional environment, overburden, formation history and geological age (Vassilev *et al*. 1996; Achten and Hofmann 2009; Laumann *et al.* 2011). This plays an important role in determining contaminant concentration in coal. Trace metals and the precursors of PAHs are derived from the original plant material, in concert with co-deposited sediments, overburden material, groundwater inflows and their interaction with the unique location-specific chemistry that occurs during coalification (Schweinfurth 2005). As a result, the presence and availability of trace metals and PAHs varies widely in coal and somewhat independently of coal rank (Ahrens and Morrisey 2005).

2.3.3.3 Coalification

The bituminisation stage of coalification progressively generates and entraps aromatic hydrocarbons (Flores 2014). These comprise mainly 2-6 ring PAHs (Achten and Hofmann 2009.) As coalification continues, the coal is progressively debituminized with the expulsion of lower molecular weight hydrocarbons (Flores 2014). PAHs with higher ring numbers are formed at the expense of lower ring PAHs (Achten and Hofmann 2009). In this way, total PAH concentrations can at first increase and then progressively decrease with coalification, while the relative contribution of higher ring PAHs increases.

2.3.3.4 Soluble and Insoluble Hydrocarbons

The availability of PAHs also differs. While coal is primarily made up of hydrocarbons, it can be viewed as a two-component system made up of a macromolecular network of insoluble hydrocarbons and a smaller mobile phase, both of which contain PAHs (Laumann *et al*. 2011). While also relatively insoluble, this mobile phase, also known as the extractable fraction, can be released from the coal network more easily (Achten and Hofmann 2009). The concentration of extractable PAHs varies markedly among coal types. Laumann *et al*. (2011) found that extractable PAHs ranged from 14 mg kg^{-1} to greater than 2000 mg kg^{-1} (approximately 0.2% extractable PAHs) amongst coal samples obtained from various deposits worldwide. While these extractable PAH concentrations did not always correlate strongly with coal rank, they did appear to be influenced by the coals source and coalification history. These findings correlate with the organic chemical properties of coals as tabled by Ahrens and Morrisey (2005).

2.4 Fugitive Coal Losses at the Port of Hay Point

Coals shipped through the Port of Hay Point are sourced from mines located in the Bowen Basin of Central Queensland. Product is shipped via rail to the Port where it is diverted to either DBCT or HPCT on respective rail loops. Within each terminal the coal is unloaded and stacked in multiple large stockpiles that correspond to specific coal grades. These stockpiles are periodically watered with automatic sprayers to reduce airborne dust. Stockpiles are progressively depleted and replenished with mechanical stacker reclaimers. Coal reclaimed for shipment travels from the stockyard to respective loading wharfs via terminal specific trestles and covered conveyors. Once at the wharf, coal is loaded directly from each conveyor to the holds of bulk carriers that are tied to each of seven berths.

2.4.1 Dust, Conveyors and Loading

During this process, fugitive coal is most likely to enter the marine environment either as airborne dust or as inadvertent spills from either the trestle or during loading of the ships holds. Losses may also occur during post-loading ship cleaning activities.

2.4.2 Stormwater

The second mechanism of fugitive loss is via stockpile interaction with rainfall. The Port of Hay point receives heavy tropical summer rains that flow through the stockpiles and cause potential leaching and suspension of fine coal particles within the stormwater. The stockyards and operational areas of each terminal drain to sediment detention basins. In this way, stormwater that cannot be retained on either terminal site eventually flows directly into the upper reaches of Sandfly Creek and into Tug Harbour.

For DBCT, prior to 2015 there was a network of stockyard coal collection pits, final settling pits, an industrial dam (ID), and a quarry dam (QD) for harvesting water. DBCT have recently undertaken a Water Quality Improvement Project (WQIP) with the primary objective to reduce the frequency, volume and suspended solids concentration of uncontrolled discharges from the DBCT Industrial Dam (ID) to the receiving environment. This project included the installation of a flocculent plant, ID collection pits and containment cells and an increase in capacity of the ID. The project also included the installation of three high flow transfer pumps at the ID to increase the flow rate to a larger capacity Quarry Dam where the water can then be stored or can be transferred to a new Rail Loop Dam for final storage.

For HPCT there are a series of seven basins, each connected via a weir to enhance settlement of fine particulate coal. Once in the final basin (final polishing dam) water flows over a small weir and into a side arm of Sandfly Creek.

2.4.3 Quantifying Coal Losses

No information was available for this review to quantify fugitive coal losses from airborne dust or spillage from trestle conveyors or quay line loading operations. However, losses of fine particulate coal via stormwater overflow into Sandfly Creek have been determined for the 12-month period from June 2011 to June 2012 as part of the Receiving Environment Monitoring Program (REMP) conducted for HPCT and DBCT (Koskela Group 2014a and 2014b).

A combined stormwater overflow of 1,630ML occurred during this period. Total suspended solids (TSS) concentrations were highest during the first flush and decreased rapidly, with median TSS ranging from 15.5mg/L to 19 mg/L. The median contribution of coal within this suspended material ranged from 22% to 31% (<5mg/L) and a total estimated discharge for the period of less than 7.5 tonnes.

Estimated concentrations of coal in the immediate receiving waters did not exceed 2.8 mg/L coal in the Half Tide Tug Harbour and were less than 0.01mg/L coal immediately outside the tug harbour. Small concentrations of coal were detected in control creeks not directly impacted by stormwater flows from the terminals (0.3 mg/L).

2.4.4 Suspended Coal Particle Size

The design of the sediment detention basins at Hay Point ensures that only fine suspended coal particles will be transported off site during stormwater overflow. Very fine sediment particles (<2-5 μm) were the dominant size fraction in suspended solids

present in stormwater overflows during the REMP study, with approximately 95% of all particles being less than 10 μm (Koskela Group 2014a and 2014b).

2.4.5 Residence Time of Suspended Coals Particles

The residence time and spatial deposition of fine coal particles discharged from Sandfly Creek was examined using an integrated Spectral Wave/Hydrodynamic/Mud Transport numerical modelling approach (DHI Water; Koskela Group 2014a and 2014b). Average residence time of particles discharged during this event was approximately 21 hours. Deposition of sediment was found to occur predominantly in near-shore areas in times of neap tidal flow, before higher tidal regimes dispersed them. Residence time for coal particles in the sediment of the near-shore environment is predicted to be short, with coal particles almost entirely removed from the modelled system within 14 days.

2.4.6 Fine Coal Particles in Marine Sediment

Four surveys were conducted of marine and estuarine sediments at the Port of Hay Point during the REMP. The contribution of fine coal particles was examined. The percentage of coal was highest in the sediments of Sandfly Creek (approximately 1% coal). Lower amounts of coal (<0.6%) were measured in the sediments of Half Tide Tug Harbour, as well as in sediments of control creeks. The percentage of coal within sediment at an inshore control site (approximately 1km from shore) ranged from 0.1% to 0.2% (Koskela Group 2014a and 2014b).

It is evident that fugitive coal losses occur at the Port of Hay Point. The following sections will investigate the potential environmental impacts associated with these losses.

2.5 Acid-Generating Potential

Coals shipped through the Port of Hay Point display very low sulphur content. Previous testing of coals shipped through DBCT indicated in a range of sulphur content from 0.3% to 0.74% inclusive of thermal, PCI (Pulverised Coal Injection) and coking coals (DBCT, unpublished data). Similar sulphur content of ~0.5% has been reported for coals shipped through HPCT (Barlow Jonkers 2007). These values are not expected to fluctuate markedly as Port of Hay Point coal terminals maintain a relatively consistent supply from the same coal sources and seams. Given the review of low sulphur coals by Ahrens and Morrisey (2005) (refer to Section 2.3.3.1), it is expected that coals shipped through the Port of Hay Point will pose a low risk of producing either acidic water runoff or enhanced metal bioavailability.

2.5.1 pH of Stormwater

Stormwater overflow from the Port of Hay Point for the 12-month period from June 2011 to June 2012 exhibited a pH range (20th to 80th percentile; Koskela Group 2014a and 2014b) of:

- pH 7.3 to 7.6 for HPCT;
- pH 8.2 to 8.4 for DBCT; and
- pH 7.5 to 8.3 for Sandfly Creek.

These ranges were well within the adopted trigger range of pH 6 to 9 and none were acidic. These data supported the expectation that low sulphur content coal was unlikely to produce acidic stormwater runoff. Variations in pH between the terminals

are likely to reflect the differences amongst coal seams and source location in the Bowen Basin.

2.6 Metals

Metals are naturally occurring elements found throughout the environment. In low concentrations they are benign and many act as essential components in biological function at the cellular level. However, when concentrated, metals can become toxic. This toxicity can also be increased when physicochemical conditions are altered, such as in aquatic systems with highly acidic or alkaline pH. The capacity for unburnt coal to leach metals, alter pH or modify sediment chemical characteristics is thus a matter of concern.

2.6.1 Release from Coal

The release of metals from representative coal samples has been directly investigated for product shipped through HPCT (Koskela Group 2010a). This testing determined that:

- Bioavailable metal concentrations in representative coal samples, as determined by dilute acid extraction, did not exceed the National Assessment Guidelines for Dredging (NAGD; DEWHA 2009) screening level for any metal contaminant (Table 1); and
- Metal concentrations dissolved into water via coal elutriation (95% UCL) did not exceed the ANZECC Water Quality Guidelines for marine water (95% species protection) for any metal contaminant when the NAGD dilution and attenuation factor was applied (Table 2).

The results of elutriation presented in Table 2 correlate with the physicochemical properties of neutral coal leachates, as tabled by Ahrens and Morrisey (2005) and are similar to those concentrations reported by Lucas and Planner (2012). While the coals shipped through the Port of Hay Point have some capacity to release barium, manganese, cobalt and zinc more freely, they are clearly within a range of very low release when compared with other coal sources.

2.6.2 Stormwater

Metal concentrations were measured in Sandfly Creek for the 12-month period from June 2011 to June 2012 (Koskela Group 2014a and 2014b). During periods of stormwater overflow from the Port of Hay Point, metal concentrations within detention basins exceeded locally-derived receiving water guidelines for zinc (HPCT) and aluminium (HPCT and DBCT). However, this did not translate into increased concentrations of these metals in Sandfly Creek or in coastal waters monitored during the study. This is partly related to the very low concentrations selected as locally-derived guidelines.

It was noted that metal concentrations in receiving waters during stormwater overflow were similar to or less than ambient concentrations observed during non-discharge periods (Koskela Group 2014a and 2014b). This is illustrated by a typical appraisal of metal concentrations at site RE15 (a downstream site within Sandfly Creek), in which significant reduction in metal concentrations are observed for the majority of contaminants during overflow and post-overflow monitoring (**Error! Reference source not found.**). Naturally higher concentrations of metals do occur in the regional groundwater aquifers (Koskela Group 2013). These naturally high concentrations (80th

percentile, 270 µg/L aluminium and 370µg/L zinc, refer to **Error! Reference source not found.**) are likely to be expressed to creeks and coastal waters during dry periods (Koskela Group 2010b).

2.6.3 Sediment

The most recent assessment of sediment quality at the Port of Hay Point has been undertaken by Advisian (2018) as a sediment characterisation study for maintenance dredging. This report determined that for all study areas examined (berth pockets, apron area, departure path and Half Tide Tug Harbour) sediments did not exceed NAGD screening level guidelines for any metal.

Sediments have also been examined within Sandfly Creek, the Half Tide Tug Harbour, inshore locations and control creeks (Salonika Creek and Mick Ready Creek) as part of the REMP (Koskela Group 2014a and 2014b). In brief:

Sediments were surveyed on four occasions during the monitoring period. Metals and metalloid concentrations in sediments were compared to adopted sediment quality trigger values. These trigger values were derived from ISQG low trigger values (ANZECC/ARMCANZ, 2000) supplemented by locally derived trigger values calculated from control site data (Table 5).

All sediment metals in Sandfly Creek complied with ISQG low trigger levels. Sediments also complied with additional locally-derived guidelines, with the exception of:

- Cobalt, gallium, iron, manganese, and vanadium, in the drainage line that received stormwater from DBCT, the railway line and construction haul roads; and
- Iron, molybdenum and vanadium in the central creek line.

All sediments in Tug Harbour complied with the adopted sediment quality trigger values, while sediments of Mick Ready Creek (a reference creek 6 km south of Sandfly Creek) did not comply with the adopted sediment quality trigger value for bismuth.

The mean concentrations of Acid Volatile Sulfides and Simultaneously Extracted Metals (AVS-SEM) indicated low potential toxicity at all sites (Table 6). This was due to an excess of sulfide compared to available metals, allowing the binding of metals as they become available. As such, the risk of sediment derived metals being bioavailable is considered low.

This variety of studies indicates that while the coals shipped through the Port of Hay Point have some capacity to release metals into stormwater, their low acid-generating potential is likely to limit such release and mitigate any subsequent impacts on receiving water or sediment quality.

2.6.4 Bioavailability

2.6.4.1 Pore Water

It is recognised that pore water measurements provide the most direct measure of bioavailability pathways for metals. Detailed measurement of pore water contamination has not been undertaken at the Port of Hay Point.

2.6.4.2 Bioaccumulation

A human health risk assessment (Koskela Group 2014a and 2014b) was undertaken to determine concentrations of metals and metalloids in the muscle tissue of key estuarine species:

- yellowfin bream, *Acanthopagrus australia*;
- fantail mullet, *Paramugili georgi*;
- mud crab*, Scylla serrata*; and
- mud whelk, *Telescopium telescopium* (whole animal).

Samples were collected at Sandfly Creek, Salonika Creek and Mick Ready Creek.

Mean concentrations of metals and metalloids in the tissue of bream, mullet, mud crab and whelks are provided in Table 7. Spatial differences in metal concentrations were negligible for most contaminants with only three significant spatial interactions, these being higher arsenic concentrations in Sandfly Creek (F test p=0.015) and higher chromium and vanadium concentrations in Mick Ready Creek (F test p=0.008 and p=0.035 respectively; refer to Table 8).

Metal concentrations exceeded Food Standards Australia New Zealand (FSANZ) guidelines for the following elements:

- Arsenic in bream, mud crabs and whelks in both Sandfly Creek and the control creeks; and
- Copper in mud crabs and whelks in both Sandfly Creek and the control creeks.

Crustaceans and molluscs employ hemocyanin, a copper based protein, for the transport of oxygen. The 20th Australian Total Diet Survey (20th ATDS, FSANZ, 2003) reported that seafood may contain high concentrations of arsenic and copper. The 20th ATDS reports arsenic in the range of 0.31 to 0.68 mg/kg for raw fish fillet, 0.54 to 29 mg/kg for fish portions and 0.28 to 13 mg/kg for prawn. These ranges cover the range for fish, mud crabs and whelks reported here. The 20th ATDS also reports copper in the range of 1.1 to 16 mg/kg for prawn, which is similar to that of the mud crab reported here (95% UCL of 16mg/kg).

A similar study of metal concentrations in estuarine biota was undertaken by Anderson *et al*. (2005). This study listed contaminant concentrations in muscle tissue of mullet and whelks for a reference location in the Gladstone region. The range in arsenic and copper reported by Anderson *et al*. (2005) was similar to the ranges reported by Koskela Group (2014a and 2014b).

Given that neither arsenic or copper were identified as contaminants in the stormwater overflow from the Port of Hay Point and that arsenic and copper concentrations in these biota appear to be comparable to other background studies, it is determined that operations of the Port of Hay Point have not significantly impacted metal concentrations in selected biota. It is probable that the metal concentrations detected here are natural background for the region.

Table 1 Dilute Acid Extraction of metals from representative coal samples (HPCT) with particle size ≤ 1 mm. Data presented as arithmetic mean and 95% Upper Confidence Limit (UCL) of the mean. The 95% UCL is compared with the NAGD screening level (DEWHA 2009; Yellow shading = exceeds NAGD screening level). From Koskela Group (2010a).

Location/parameter	NAGD Screening level (mg/kg)	Mean (mg/kg)	95% UCL (mg/kg)
Aluminium		54.2	55.7
Antimony	2	0.25	0.25
Arsenic	20	0.25	0.25
Barium		5.5	6.1
Beryllium		0.25	0.25
Boron		0.25	0.25
Cadmium	1.5	0.25	0.25
Chromium	80	0.25	0.25
Copper	65	0.95	1.01
Iron		555	584
Lead	50	0.80	0.83
Manganese		10.7	11.4
Mercury	0.15	0.05	0.05
Molybdenum		0.25	0.25
Nickel	21	0.34	0.41
Selenium		0.45	0.53
Silver	1.0	0.25	0.25
Sodium		150	153
Tin		0.25	0.25
Zinc	200	1.24	1.34

Table 2 Seawater elutriation of representative coal samples with particle size ≤ 2 mm. Data were corrected for background seawater concentration and presented as arithmetic mean and 95% Upper Confidence Limit (UCL) of the mean. Compliance with ANZECC/ARMCANZ Water Quality Guidelines for Marine Waters was determined after correction with the Dilution and Attenuation Factor (DAF) according to standard NAGD procedure (DEWHA 2009). The DAF corrected 95% UCL is compared; Yellow shading = DAF corrected 95% UCL exceeds guideline for 95% species protection. From Koskela Group (2010a).

Location/parameter	ANZECC/ARMCANZ 95% Protection (µg/L)	Mean (µg/L)	95% UCL (µg/L)	DAF corrected 95% UCL (µg/L)
Aluminium		0	10*	0.1*
Antimony		1	3*	0.03*
Arsenic		1.1	3.6	0.036
Barium		116	127	1.27
Boron		0	0	0
Cadmium	5.5 (0.7†)	0.5	2*	0.02*
Chromium	27 (CrIII) 4.4 (CrVI)	1.5	4*	0.04*
Cobalt	1	3.9	4.5	0.045
Copper	1.3	0.83	1.1	0.011
Iron		0	10*	0.10*
Lead	4.4	1.5	4*	0.04*
Manganese	80	112	119	1.19
Mercury	0.4	0	0.1*	0.001*
Molybdenum		5.9	6.2	0.062
Nickel	70 (7†)	4.5	5.4	0.054
Selenium		2	5*	0.05*
Silver	1.4	0	1*	0.01*
Uranium		2.5	2.6	0.026
Vanadium	100	0.8	5*	0.05*
Zinc	15	70	76	0.76

Legend	
*	Laboratory Limit of Reporting
†	99% species protection level for Cd and Ni

Table 3 Effect of stormwater discharge on the concentration of trace metals in water at site RE15

	Non discharge	Discharge	Post discharge	F p value	K-W p value	D v Pre	D v Post
Aluminium	19	16	10	0.301	0.093	0.077	0.530
Antimony	0.55	0.50	0.50	0.215	0.131	0.133	NaN
Arsenic	6.4	2.0	1.6	0.000	0.000	0.000	0.064
Beryllium	1.0	0.9	1.0	0.000	0.000	0.001	0.011
Bismuth	10	10	10	NA	NaN	NaN	NaN
Boron	3602	1177	2731	0.000	0.000	0.000	0.000
Cadmium	0.37	0.29	0.35	0.001	0.000	0.001	0.011
Cobalt	5.01	0.54	0.89	0.000	0.000	0.000	0.217
Chromium	1.75	0.89	1.02	0.004	0.000	0.000	0.023
Copper	1.27	0.87	0.94	0.407	0.019	0.006	0.083
Gallium	0.55	1.01	0.50	0.000	0.000	0.002	0.001
Iron	18.5	34.3	4.9	0.029	0.007	0.530	0.001
Lanthanum	1	1	1	NA	NaN	NaN	NaN
Lead	0.50	0.51	0.50	NA	0.679	0.804	0.367
Manganese	20.5	15.1	52.5	0.001	0.003	0.918	0.004
Mercury	0.05	0.05	0.05	NA	NaN	NaN	NaN
Molybdenum	12.1	9.3	9.3	0.038	0.003	0.010	0.755
Nickel	2.47	1.35	2.02	0.127	0.006	0.005	0.156
Selenium	10.2	1.5	1.8	0.000	0.000	0.000	0.024
Silver	0.50	0.50	0.51	NA	0.234	NaN	0.268
Thallium	0.48	0.50	0.50	NA	0.454	0.351	NaN
Tin	0.81	1.38	0.51	0.340	0.016	0.067	0.398
Uranium	3.7	1.2	2.6	0.000	0.000	0.000	0.000
Vanadium	10.8	1.8	1.2	0.000	0.000	0.000	0.304
Zinc	17.0	14.1	8.8	0.021	0.057	0.300	0.228

F, probability derived from Student's t test; K-W, Kruskal-Wallis test; D v Non, discharge versus non-discharge; D v Post, discharge versus post-discharge. Orange shading indicates a significant difference; Red shading indicates highly significant difference.

Table 4 Interim Local Guidelines (Trigger Values) for Contaminants in the Groundwater of Hay Point derived from 80th percentile data obtained from background groundwater bores and the intersection of two aquifers.

Contaminant	Default (µg/L)	Locally derived (µg/L)	Adopted Draft Interim Trigger Value (µg/L)
pH	6 to 9	6.9 to 7.8	6 to 9
Petroleum Hydrocarbons C6-C9	20	NA	20
Petroleum Hydrocarbons C10-C36	100	NA	50
Aluminium	27	270	270
Arsenic	0.8	14	14
Cadmium	0.7	0.27	0.7
Chromium	0.14	1.1	1.1
Copper	0.3	11.5	11.5
Iron	300	3400	3400
Lead	2.2	0.39	2.2
Mercury	0.1	NA	0.1
Nickel	7	35	35
Zinc	7	370	370

All concentrations are expressed as µg/L with the exception of pH

Table 5 Compliance of sediment contaminant concentrations (95% UCL of mean) with adopted sediment quality trigger values (mg/kg dry weight) from Koskela Group (2014a and 2014b).

Analyte	Adopted TV mg/kg DW	95% Upper Confidence Limit (UCL) of mean concentration (mg/kg DW) SFC Northern	SFC Western	SFC Southern	SFC Central	Tug Harbour	Salonika Control	Mick Ready Control
Aluminium	13200	6033	12439	5910	9999	10786	4018	8863
Antimony	2	0.25*	0.38	0.25*	0.41	0.34	0.25*	0.35
Arsenic	52	4.8	25.1	8.3	23	47	30	16.7
Boron	41	19.4	34.5	21	22.5	33.7	17.8	18.9
Beryllium	0.60	0.2	0.54	0.23	0.4	0.48	0.2	0.37
Bismuth	20	4.4	2.5*	18.8	2.5*	2.5*	2.5*	40.6
Cadmium	1.5	0.05*	0.21	0.06	0.19	0.33	0.23	0.09
Chromium	80	11.3	48.5	11.2	40.9	19.0	9.9	22
Cobalt	36	4.9	46.5	4.7	20	9.2	4.6	11.8
Copper	99	10.4	54.4	10.8	31.5	13.5	7.8	32.6
Gallium	14	9	19.2	2.1	10.8	9.7	11.5	12.9
Iron	58000	10901	68378	15554	74160	33452	19101	35087
Lanthanum	12	2.7	8.1	3.2	6.8	9.8	4.3	7.3
Lead	50	4.1	12.1	5.6	18.2	6.9	3.4	13.8
Mercury	0.15	0.0125	0.014	0.01	0.008	0.012	0.008	0.009
Manganese	987	150	1324	208	921	614	274	591
Molybdenum	2.95	0.97	2.25	1.67	3.84	0.76	0.87	1.85
Nickel	22	5.7	13.5	4.5	8.2	9.2	3.4	7.8
Selenium	1.5	0.2	0.5	0.3	0.4	0.7	0.6	0.6
Silver	1	0.05*	0.08	0.05*	0.07	0.05*	0.05*	0.05*
Tin	1	0.5*	0.5*	0.5*	0.5*	0.5*	0.5*	0.5*
Thallium	1	0.5*	0.5*	0.5*	0.5*	0.5*	0.5*	0.5*
Uranium	1.3	0.7	1	0.7	0.8	0.9	0.5	0.6
Vanadium	145	24	216	39	230	91	50	85
Zinc	200	23	66	54	27	30	15	43
Total PAH	10	0.202	0.781	0.114	0.0583	0.0548	0.0175*	0.0448

DW, dry weight; * below laboratory PQL; Green shading, trigger value adopted from ISQG low (ANZECC/ARMCANZ, 2000); Orange shading, trigger value adopted from locally derived value (value exceeds ISQG low); Grey, no ISQG guideline so locally derived trigger value accepted. Cell highlighted in yellow indicates a UCL higher than the adopted sediment quality trigger value.

Table 6 Comparison of acid volatile sulfides and simultaneously extracted metals (mmole/kg) from Koskela Group (2014a and 2014b).

	Sandfly Creek						
Analyte	Northern	Western	Southern	Central	Tug Harbour	**Off shore**	**Control**
AVS (mmole/kg)	**1.70**	**0.83**	**1.88**	**0.74**	**1.9**	**0.27**	**1.2**
SEM.Arsenic	0.028	0.028	0.025	0.025	0.053	0.082	0.035
SEM.Cadmium	0.005	0.005	0.005	0.005	0.005	0.005	0.005
SEM.Chromium	0.033	0.026	0.031	0.083	0.037	0.037	0.018
SEM.Copper	0.044	0.136	0.040	0.043	0.038	0.018	0.039
SEM.Lead	0.046	0.030	0.017	0.028	0.027	0.014	0.019
SEM.Mercury	0.00025	0.00026	0.00025	0.00025	0.00025	0.00025	0.00025
SEM.Nickel	0.019	0.054	0.144	0.018	0.027	0.03	0.016
SEM.Zinc	0.139	0.489	0.336	0.095	0.13	0.053	0.059
Total SEM	**0.25**	**0.67**	**0.55**	**0.26**	**0.29**	**0.23**	**0.13**

Table 7 Mean concentrations of total metal and metalloids (mg/kg wet weight) in the muscle tissue of test species averaged over the three locations (from Koskela Group, 2014a and 2014b; Yellow shading, exceeds FSANZ guideline).

Analyte	FSANZ	Bream	Mullet	Crab	Whelk
Aluminium		28	130	2.0	240
Antimony	1.5	0.05	0.06	0.05	0.05
Arsenic	2.0[a] fish	2.3	1.4		2.4
	1.0[a] mollusc		(*1-1.6)	5.9	(*1.7-2.3)
Boron		2.4	3.1	2.0	4.6
Beryllium		0.05	0.05	0.05	0.05
Bismuth		0.50	0.50	0.50	0.50
Cadmium	0.2	0.01	0.02	0.02	0.03
Chromium		0.25	0.62	0.05	0.46
Cobalt		0.05	0.13	0.05	0.42
Copper	10 (fish & crab)	0.90	0.93 (0.3-0..5)	16	10 (*15-25)
Gallium		0.05	0.15	0.08	0.05
Lanthanum		0.49	0.12	0.05	1.1
Iron		51	300	4.1	440
Mercury	0.5	0.08	0.01	0.04	0.05
Manganese		6.3	19	0.55	46
Molybdenum		0.05	0.36	0.05	0.14
Nickel		0.05	0.19	0.05	0.44
Lead	2.5	0.16	0.38	0.05	0.19
Selenium	1.0	0.65	0.26 (*0.18-0.26)	1.0	0.44 (*0.44-0.52)
Silver		0.03	0.03	0.98	0.05
Tin	50	0.07	0.33	5.1	0.06
Thallium		0.05	0.05	0.06	0.05
Uranium		0.05	0.05	0.05	0.11
Vanadium		0.25	1.06	0.25	0.76
Zinc	150	21	12	42	24

FSANZ, Food Standards Australia New Zealand; [a] concentration of inorganic arsenic as set by FSANZ; * range identified by Anderson *et al*. (2005)

Table 8 Probabilities obtained from approximate F test for locations and test species (from Koskela Group, 2014a and 2014b).

Element	Location	Species
Aluminium	0.110	0.0000
Arsenic	0.015	0.0000
Boron	0.186	0.0000
Cadmium	0.846	0.0123
Chromium	0.008	0.0000
Cobalt	0.161	0.0000
Copper	0.344	0.0000
Lanthanum	0.111	0.0000
Iron	0.082	0.0000
Mercury	0.425	0.0031
Manganese	0.667	0.0000
Molybdenum	0.068	0.0098
Nickel	0.285	0.0000
Lead	0.425	0.0000
Selenium	0.387	0.2480
Silver	0.376	0.2650
Tin	0.343	0.2930
Uranium	0.119	0.0000
Vanadium	0.035	0.0000
Zinc	0.512	0.0000

Cells highlighted in yellow indicate significance at the $p < 0.05$ level, cells highlighted in red indicate significance at the $p < 0.001$ level. F test was based on effect of eliminating location or animal type from a full model

2.7 PAHs

2.7.1 About PAHs

Polycyclic aromatic hydrocarbons are a group of persistent organic pollutants consisting of conjoined aromatic rings, with benzene being a monocyclic molecule followed by the two ringed PAH naphthalene, then three ringed PAHs such as fluorene, phenanthrene and anthracene etc. (Stogiannidis and Laane 2015). Parent PAHs consist solely of fused rings. PAHs with one or more alkyl groups are referred to as alkylated PAHs. These are the homologues of the parent PAH and are generally listed where they are of toxicological concern. Hundreds of PAHs have been chemically identified. Only a small number of these are routinely monitored in the environment.

2.7.2 Mutagenic/Carcinogenic Potential

PAHs with lower ring numbers are more soluble (lower partition coefficient) and more volatile than higher ring number PAHs. Low ring number PAHs exhibit toxic effects but are not viewed as either mutagenic or carcinogenic. Higher ring number PAHs are not acutely toxic but are strongly mutagenic and carcinogenic (Stogiannidis and Laane 2015). Being less soluble, higher ring number PAHs tend to adsorb more readily to organic matter because of their low affinity for water. As such, they have a tendency to accumulate in sediments containing organic material. These PAHs also have the potential to bio-concentrate in biota.

The mutagenicity/carcinogenicity of PAHs is mediated by PAH breakdown products known as diolepoxide metabolites. These metabolites, such as benzo(a)pyrene diolepoxide (BPDE) binds directly to DNA and causes cell mutation (PubMed 2018). Piberger *et al.* (2018) have demonstrated that BPDE will cause damage to DNA in a linear dose-response-relationship at nanomolar and non-cytotoxic concentrations (10 nM BPDE).

2.7.3 Source Contributions

A detailed review of the primary sources of PAHs is provided in Burgess *et al*. (2003a). In brief:

Almost all PAHs originate from three possible sources: pyrogenic, petrogenic and diagenetic. Pyrogenic PAHs are formed from incomplete combustion of organic matter and will include combusted fossil fuels as well as combusted biomass from forests and agriculture. These PAHs exhibit a very strong bond with the soot carbon created during the combustion process and are in this way transported and co-deposited in aquatic sediment. Petrogenic PAHs are created by diagenetic processes over geologic time scales, leading to the formation of petroleum, coal and other fossil fuels. These PAHs will generally favour alkylated molecules and will reflect their formation history. Diagenetic PAHs are derived from biogenic precursors such as plants and will favour the formation of retene, derivatives of phenanthrene and chrysene, as well as perylene.

Stogiannidis and Laane (2015) summarise sources of PAHs in waterways as being primarily pyrogenic (combusted fossil fuels primarily from engine combustion) and a mix of petrogenic and diagenetic sources associated with human activity such as roads and transport, municipal wastewater and runoff from farmlands. Burns *et al*. (1997) identified 18 possible PAH sources in a large set of field data collected in

Prince William Sound, Alaska, USA, after the 1989 Exxon Valdez oil spill, including diesel oil, diesel soot, spilled crude oil in various weathering states, natural background, creosote, and combustion products from human activities and forest fires. Spill oil was generally found to be a small increment of the natural background in subtidal sediments, whereas combustion products were often the dominant source for subtidal PAHs. The contribution of lubricating oils to hydrocarbon pollution in Australian estuaries and coastal waters has also been highlighted (Volkman *et al*. 1992). This comes about primarily through the engine emissions of motor vehicles (Stogiannidis and Laane 2015). Pyrogenic PAHs often dominate in the aquatic environment in terms of concentration and geographical distribution (Burgess *et al.* 2003a; Mohd Tahir *et al*. 2014; Stogiannidis and Laane 2015). It is expected that where no other point sources exist, pyrogenic PAHs should be the dominant source of PAHs in the receiving environment.

2.7.4 Nitro-PAHs

Recent research also implicates lower ring number PAHs as the source materials for nitro-PAHs, a relatively un-researched group of organic pollutants (Bandowe and Meusel 2017). Nitro-PAHs are primarily produced in the emissions of combustion engines and in the post-emission transformation of parent PAHs. They are also commonly found in high concentrations in sewage sludge. While there is a general lack of research concerning nitro-PAHs, they are considered to be potentially more carcinogenic/mutagenic than their related PAHs (Bandowe and Meusel 2017). Nitro-PAHs have been implicated as an active carcinogen of vehicle emissions (IARC 2013).

2.7.5 Distinguishing PAH Sources

Hydrocarbon fingerprints are used to distinguish between petrogenic and pyrogenic PAH sources. However, it is difficult to distinguish between PAHs derived from coal versus those derived from oil (Achten and Hofmann 2009). The authors point out that particulate coal cannot be represented by a single set of diagnostic parameters for PAHs. Stogiannidis and Laane (2015) observe that crude oils are dominated by alkylnaphalenes, while higher ring number PAHs may be very low or non-detectable. Higher ranked coals, on the other hand, demonstrate a skewness towards parent PAHs for phenanthrenes, fluoranthenes and chrysenes, while low ranked coals display bell shaped curves in the homologue series for phenanthrenes, fluoranthenes and chrysenes.

The occurrence of higher ring number PAHs in these coals is similar to pyrogenic sources, in which, fluoranthene, pyrene, anthracene and to a lesser extent phenanthrene are abundant. Combusted diesels inherit this pyrogenic distribution (Stogiannidis and Laane, 2015) and while they share some similar PAH components with coals, the ratio of these components are likely to differ. A principal feature of this in coals is a generally much reduced contribution of anthracene and a greater abundance of chrysene.

Diagnostic ratios for source contributions of PAHs are presented in detail in Moyo *et al*. (2013) and Stogiannidis and Laane (2015). A condensed version of these ratios is presented here (Table 9), adapted from Table 3 within Moyo *et al.* (2013). These ratios can be used in conjunction with source characteristics to identify likely source contributions. As an example:

- Where the ratio of anthracene / (phenanthrene + anthracene) is < 0.1 the source is usually considered to be petrogenic; and
- Where the ratio of anthracene / (phenanthrene + anthracene) is > 0.1 the source is usually considered to be pyrogenic.

Thus, PAHs primarily contributed by unburnt coals should have at least a 10-fold higher concentration of phenanthrene (Ph) when compared with anthracene (An). As the influence of unburnt coal as a source contribution diminishes, this ratio should also diminish. Where An dominates over Ph then the source is predominantly pyrogenic (the expected background condition). When the dominance of An is in concert with fluoranthene (Fl) and pyrene (Py) then combusted fuels (diesel) are implicated (Stogiannidis and Laane, 2015). Combustion is also implicated when Fl concentrations exceed Py (Table 9).

Benzo(a)anthracene (BaA) is also produced during combustion and preferentially over chrysene (Ch). Given that Ch is likely to be a dominant PAH in the coals shipped through Port of Hay Point, this becomes a useful tool in separating the overlap between coal and combustion product signatures. When Ch markedly dominates over BaA, then coal is implicated as the primary source.

The presence of benzo(a)pyrene (BaP, a combustion product in engines) can be used in conjunction with benzo(ghi)perylene (BghiP), a product of biomass combustion, to determine the relative importance of biomass as a source. BaP is also useful to determine the age of combustion products as it very rapidly degrades in light (photo-degradation). In this way the various diagnostic ratios presented by Moyo *et al*. (2013) and Stogiannidis and Laane (2015) can be used to delineate the extent of various source contributions of PAHs at the Port of Hay Point.

Thus, a strong indication of unburnt coals as a source of PAHs is likely when:

- PAHs demonstrate a skewness towards parent PAHs for Ph, Fl and Ch and a reduced contribution of naphthalenes;
- Ch concentrations are greater than BaA;
- Py concentrations are greater than Fl;
- Ph is at least 10-fold greater than An; and
- Ratio between BaP and BghiP discounts biomass contribution.

As these relationships weaken, the influence of unburnt coal as a contributor of PAHs concomitantly diminishes. In such cases it is expected that the PAH signature will revert back to one of aged pyrogenic.

The examination of coal as a source of PAHs in the marine environment at the Port of Hay Point must therefore take into consideration:

- The presence of pyrogenic sources as an overriding contributor of PAHs in coastal waters and sediments; and
- The tendency for other petrogenic sources such as crude oil and lubricants to significantly contribute.

This examination is assisted by the understanding that coal product supplied to the Port of Hay Point is of high rank and generally uniform in quality and sulphur content, and is likely to contain PAHs skewed towards parent PAHs for phenanthrenes,

fluoranthenes and chrysenes (Stogiannidis and Laane 2015). In conjunction with the application of diagnostic ratios, a preliminary appraisal of coal's contribution to PAHs can be made.

Table 9 Some relevant diagnostic ratios for PAHs to determine source contributions (adapted from Moyo et al. 2013; Stogiannidis and Laane 2015).

Diagnostic ratio of PAHs	Petrogenic	Pyrogenic
An/(An + Ph)	<0.1	>0.1
Ph/An	>10 (>30 no pyrogenics)	<10
Fl/(Fl + Py)	<0.4	>0.4
Fl/Py	<1	>1
IP/(IP + BghiP)	<0.2	>0.2 but overlaps with coal
IP/BghiP	<0.25 petrogenic >0.25 % <1 mixed excl coal	>1 but overlaps with coal
F/F + Py	<0.5	>0.5
F / Py	<1	>1
BaA/BaA + Ch	<0.2 (likely to distinguish coal)	>0.35
BaA/Ch	<0.25 petrogenic >0.25 & <0.5 mixed	>0.5 pyro; >1 biomass
MP/Ph	Can be used to distinguish fuel sources	<1 petrol combustion >1diesel combustion
BaP/BghiP	Distinguishes biomass combustion from the combustion of fossil fuels	<0.6 non-traffic emissions >0.6 traffic emissions
BeP/BaP	<2 (overlap in range 1-2)	>2 (overlap in range 1-2)

2.7.6 Coal

High volatile bituminous coals generally contain the highest concentrations of extractable PAHs, with naphthalene, phenanthrene, chrysene and their alkylated derivatives being prominent (Achten and Hofmann 2009). It is accepted, however, that the presence of higher ring number PAHs and their ratios with low ring number PAHs is dependent on coalification history (Laumann *et al*. 2011). It is thus important to assess specific coal products to make accurate determinations of extractable PAH content. There is no available information on extractable PAH concentrations in coals shipped through the Port of Hay Point.

While coals may contain extractable PAHs, they are generally not bioavailable (Stogiannidis and Laane 2015). This notwithstanding, elutriation of coal samples, similar to the methods presented in Koskela Group (2010a), is likely to provide a direct appraisal of a coals capacity to release PAHs. This has not been undertaken for PAHs in coals shipped through the Port of Hay Point.

2.7.7 Stormwater

The capacity to measure PAHs in stormwater runoff from coal stockpiles is somewhat hampered by the fact that unburnt coals do not freely release PAHs into water, and when released, these PAHs will be at very low concentrations. Despite this, coal leachates commonly contain PAHs and their alkylated derivatives for naphthalene, phenanthrene, fluoranthene, pyrene and chrysene (Ahrens and Morrisey 2005). In addition, increased concentrations of fluoranthene, phenanthrene, pyrene and chrysene have been reported from coal pile runoff (Curran *et al*. 2000 in Stogiannidis and Laane 2015).

PAHs were measured at the Port of Hay Point in Sandfly Creek, Half Tide Tug Harbour and control creeks for the 12-month period from June 2011 to June 2012 (Koskela Group 2014a and 2014b). During dry periods PAHs were not detectable in water samples, with the rare exception of naphthalene at sites in Sandfly Creek, Tug Harbour and control creeks.

During stormwater overflows, phenanthrene was reported in the HPCT Final Polishing Dam at the laboratory practical quantitation limit (laboratory PQL) of 0.1 µg/L. Within the DBCT Industrial Dam, measurable quantities of PAHs were recorded for phenanthrene (0.3 µg/L); chrysene (0.4 µg/L) and benzo(b)&(k)fluoranthene (0.1µg/L). All organic contaminants complied with the adopted water quality guidelines.

PAHs were also detected in Sandfly Creek at or close to the relevant laboratory PQLs for naphthalene (0.1 µg/L); 2-methylnaphthalene (0.2 µg/L); fluorene (0.1 µg/L); phenanthrene (0.1 - 0.5 µg/L); chrysene (0.1- 0.2 µg/L); benzo(a)anthracene (0.1 µg/L); benzo(b)&(k)fluoranthene (0.2 µg/L) and pyrene (0.2 µg/L). These concentrations complied with the adopted water quality guidelines.

No detections of organic contaminants were identified during the overflow periods in either Half Tide Tug Harbour sites or Control creeks and no samples exceeded locally-derived water quality guidelines. While laboratory PQLs hamper diagnostic appraisal of this data, it is fair to say that the higher concentrations of chrysene and phenanthrene observed in stormwater overflows confirm the expectation of high grade coals as a contributing source.

2.7.8 Passive Samplers

While it is apparent that the coal stockpiles at the Port of Hay Point release PAHs at very low concentrations that are difficult to detect using standard laboratory and field procedures, they may still be important in an environmental sense. During the course of the Koskela Group (2014a and 2014b) study, four SPDM passive samplers (semi-permeable membrane devices) were deployed to the water column of the HPCT Final Polishing Dam, Sandfly Creek, the Tug Harbour and Mick Ready Creek (control) over a one-month period during post-stormwater flow (Table 10). These SPDMs act to concentrate organic contaminants over a period of time so that ultra-low detection limits can be achieved.

Concentrations of PAHs derived from SPDMs did not exceed locally derived water quality objectives, but were present in dissolved phase within the receiving environment. While naphthalene was at relatively similar concentrations at all sites, concentrations of phenanthrene, chrysene, benzo(b)fluoranthene and benzo(e)pyrene were highest within the HPCT Final Polishing Dam and diminished within Sandfly Creek. This provides evidence that coal is at least a locally important contributor of dissolved PAHs, all be it at a limited spatial scale and at very low concentrations. This is given some support by comparing the BeP/BaP ratio for discriminating source (Table 10). This ratio indicates that PAHs of both the Final Polishing Dam and Sandfly Creek have petrogenic sources (unburnt fossil fuel inclusive of coal) while PAHs in the Half Tide Tug Harbour and Mick Ready Creek are likely to be driven by predominantly pyrogenic sources (combustion of fuels).

As previously mentioned, while low ring number PAHs are toxic, those with higher ring numbers are classed as both carcinogenic and mutagenic. Principle among these are BaP and dibenz(ah)anthracene (DahA). To compare the relative carcinogenic and

mutagenic potential of PAH mixtures, equivalence factors have been developed to express comparative likelihood of cellular impacts, standardised to BaP units. These include:

BaP-Toxic Equivalence Factors for carcinogenic potential (BaP-TEQ; Nisbet and LaGoy 1992); and

BaP-Mutagenic Equivalence Factors for mutagenic potential (BaP- MEQ; Durant *et al*. 1999).

Application of these factors to the SPMD data indicates higher relative carcinogenic potential in Mick Ready Creek, and to a lesser extent, in Sandfly Creek; and higher relative mutagenic potential in Mick Ready Creek (approximately 60-fold greater than for the Final Polishing Dam).

Table 10 Passive sampling of PAHs using water column deployed semi-permeable membrane devices (from Koskela Group 2014a and 2014b).

PAH	Adopted TV (REMP) (pg/L)	FPD (pg/L)	SFC (pg/L)	Tug (pg/L)	MRC (pg/L)
Naphthalene	50,000,000	9,892	12,272	10,393	10,125
Acenaphthylene		62	199	0	40
Acenaphthene		0	122	0	0
Fluorene		69	124	0	42
Phenanthrene	600,000	147	101	104	86
Anthracene	17,000	17	19	0	9
Fluoranthene	1,000,000	1,227	1,151	1,356	771
Benz(a)anthracene		0	0	0	0
Chrysene		181	61	0	0
Benzo(b) fluoranthene		74	24	15	0
Benzo(k) fluoranthene		8	0	3	0
Benzo(e)pyrene		74	3	11	0
Benzo(a)pyrene	100,000	17	10	19	0
Perylene		0	0	18	0
Dibenz(a,h)anthracene		6	112	15	714
Indeno(1,2,3-cd)pyrene		0	107	15	622
Benzo(g,h,i)perylene		0	12	0	0
BeP/BaP <2 pyro		4.4	3.1	0.6	1
BaP-TEQ Carcinogenic		57	584	97	3,634
BaP-MEQ Mutagenic		24	80	29	401

FPD, Final Polishing Dam; SFC, Sandfly Creek; Tug, Half Tide Tug Harbour; MRC, Mick Ready Creek.

2.7.9 Sediment

Recent sediment surveys of PAHs have been undertaken at the Port of Hay Point as part of the REMP (Koskela Group 2014a and 2014b). These surveys were undertaken on four occasions over a 12-month period at multiple locations within Sandfly Creek, the Tug Harbour and control locations (Inshore Control, Salonika Creek and Mick Ready Creek). Summary results of this testing is provided in Figure 4. The adopted sediment quality trigger value for total PAHs is 10 mg/kg (dry weight) (Simpson *et al.*, 2013). All drainage lines in Sandfly Creek, Half Tide Tug Harbour and control locations complied with the adopted sediment quality guideline. It is apparent that PAHs within Sandfly Creek were skewed toward phenanthrene and chrysene. This is expected, given that these PAHs are likely to be abundant in higher ranked unburnt coal's (Stogiannidis and Laane 2015) and thus act as a strong indicator of source.

Sediment surveys have most recently been undertaken for the Port of Hay Point berth pockets, apron area, departure path and tug harbour (Half Tide Tug Harbour, HTTH) as part of determinations for the approval of maintenance dredging (Advisian 2018). These surveys concluded that all defined dredge areas were compliant to NAGD low level sediment quality guidelines for PAHs.

For the purpose of comparison, sediment PAHs for Sandfly Creek (Koskela Group 2014a and b) and DBCT Berth 1 are presented in Figure 5. While chrysene and phenanthrene are components of the PAHs at DBCT Berth 1, it is evident that they are not dominant constituents, as is the case in Sandfly Creek. The PAHs of DBCT Berth1 are characterised by the pyrogenic PAHs anthracene, fluoranthene, benzo(b)&(k) fluoranthene, benzo(a)pyrene and indeno(1,2,3cd)pyrene. It is probable that the PAHs of the seabed in the immediate vicinity of the wharf operations reflect joint pyrogenic contributions of port operations in concert with backgroud pyrogenic sources and with a lessened relative contribution of unburnt coal as indicated by the presence of chrysene.

A survey of PAH concentrations in sediment was also undertaken for offshore waters in the central Great Barrier Reef, eastward from the Port of Hay Point (Burns and Brinkman 2011). This survey included inshore sediment locations IS9 and IS10 (≈15 nm north and 12 nm south of Port of Hay Point respectively) along with floating sediment trap collections at IS9 (IS9ST) and PRC4-5 (≈ 40 nm northeast of Port of Hay Point) among various other locations. A comparison of sediment PAHs for IS10 (Burns and Brinkman 2011) with port sediments for Sandfly Creek (Koskela Group 2014a and b) and DBCT Berth1 (Advisian 2018) is provided in Figure 5. It is evident that for IS10 the relative contribution of chrysene and phenanthrene is low to negligible, while fluoranthene, pyrene and anthracene, the three most abundant background pyrogenic PAHs (Stogiannidis and Laane 2015), are important constituents. This pyrogenic signature is likely to reflect anthropogenic-derived background conditions for regional coastal sediments and is within the well accepted expectation that PAHs in coastal sediments are primarily derived from pyrogenic sources (Burgess *et al.* 2003a; Burns *et al.* 1997; Stogiannidis and Laane 2015; Mohd Tahir *et al*. 2014).

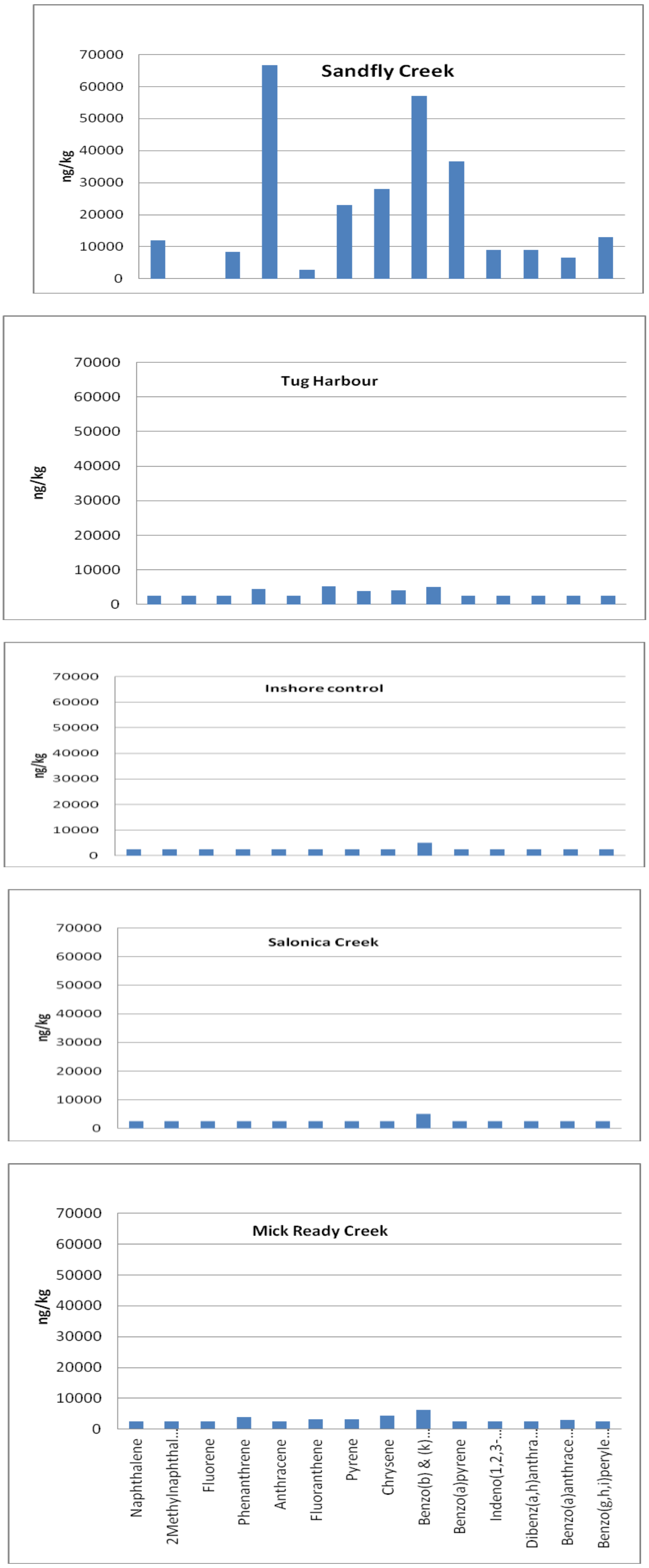


Figure 4 Summary PAH concentrations in sediment for Sandfly Creek, Tug Harbour, Inshore Control, Salonika Creek and Mick Ready Creek (from Koskela Group 2014a and 2014b).

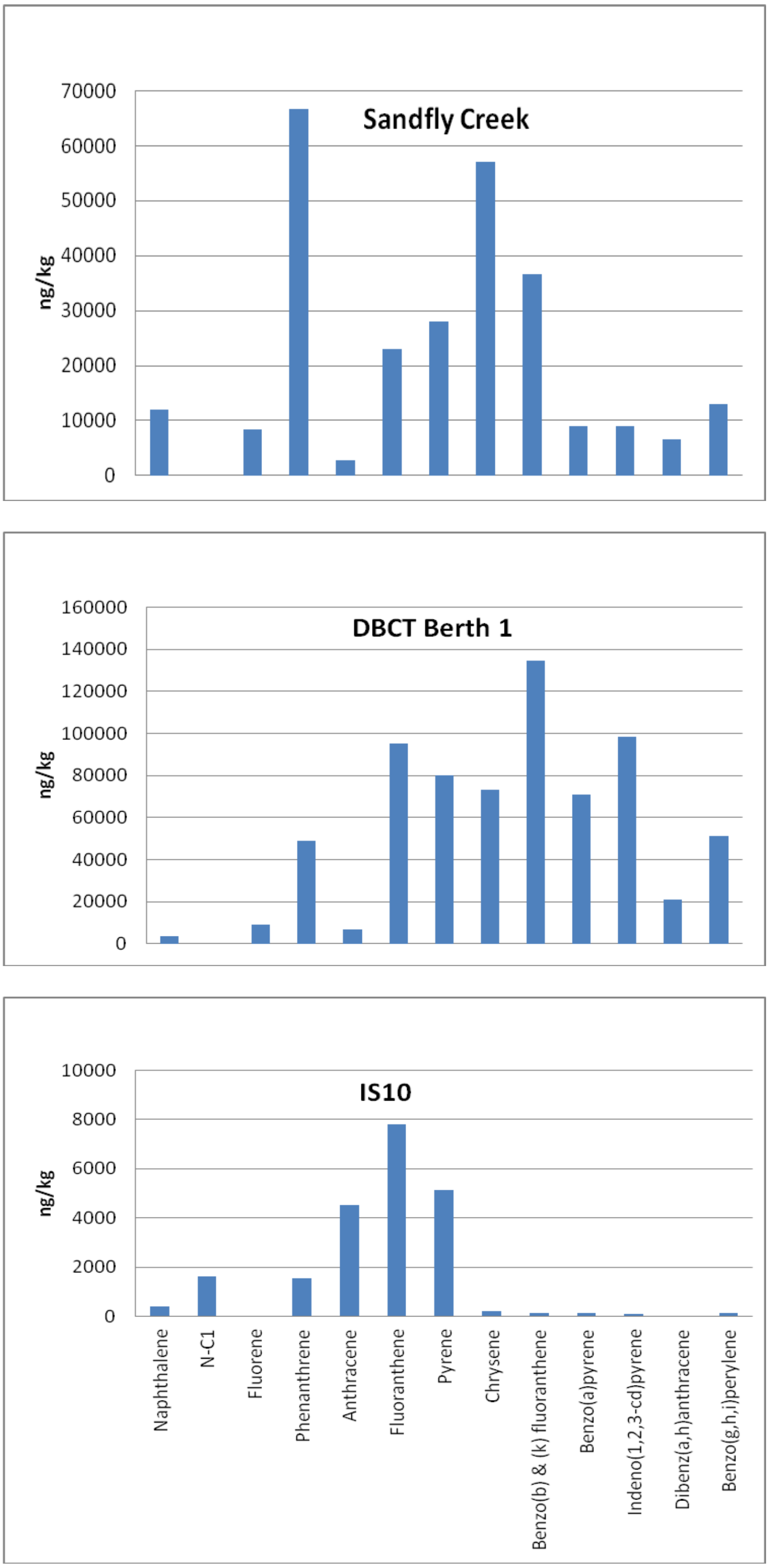


Figure 5 PAH concentration in sediments for Sandfly Creek (Koskela Group 2014a and b), DBCT Berth 1 (Advisian 2018) and offshore site IS10 (Burns and Brinkman 2011).

2.7.10 Carcinogenic/Mutagenic Potential

Sediment PAHs within the immediate vicinity of port operations differ from background locations in both concentration and makeup. Primary differences include a relative dominance of higher ring number PAHs associated with port operations and the conspicuous presence of the highly carcinogenic/mutagenic BaP and DahA. Draft calculations for BaP-TEQ and BaP-MEQ are provided in Table 11. It is evident that the wharf front areas of the port are likely to contain sediments with the highest carcinogenic and mutagenic potential. This is followed by diminished potential within Half Tide Tug Harbour sediments and further diminished potential within the sediments of Sandfly Creek. It is probable, but by no means certain, that this relates to the intense activities requiring diesel and heavy oil combustion, that are focussed on wharf front operations. The carcinogenic/mutagenic potential of combustion engine products, including nitro-PAHs, has been extensively demonstrated in recent years through the monograph series of the International Agency for Research on Cancer (IARC 2013b and IARC 2015) and through the recent review paper of Bandowe and Meusel (2017). It is evident that source determination of these PAHs requires further investigation.

The very preliminary results of BaP-TEQ and BaP-MEQ presented in Table 11 indicate that inshore coastal sediments located short distances away from port operations are likely to display reduced carcinogenic and mutagenic potential. This carcinogenic/mutagenic potential may further diminish in offshore sediments. A spatial assessment of source contribution, BaP-TEQ and BaP-MEQ, and interactions with pore water and biota would appear warranted, in addition to an assessment of emissions quality in key port locations.

2.7.11 Source Contributions of PAHs at the Port of Hay Point

It is recognised that no single characteristic is available to identify coal-derived PAHs in the environment (Achten and Hofmann 2009). However, a series of key diagnostic ratios for certain PAHs have been developed over time to assist in source attribution. These ratios have been separately summarised in the works of Moyo *et al.* (2013) and Stogiannidis and Laane (2015) as previously discussed. A set of these ratios have been applied to available sediment quality data presented in Koskela Group (2014a and b); Advisian (2018) and Burns and Brinkman (2011). The results of these appraisals are presented in Table 11.

The BaA/Ch ratio is particularly useful in the present instance, as benzo(a)anthracene is preferentially produced over chrysene during the combustion of fossil fuels and biomass, while chrysene is preferentially produced during coalification (Stogiannidis and Laane 2015). Chrysene is a principal component of PAHs in Sandfly Creek. This provides strong evidence of high ranked coals as the primary source. The BaA/Ch ratio provided a strong determination of petrogenic source in Sandfly Creek (unburnt coal), while identifying other port areas as being of mixed origin (primarily combusted fossil fuels).

The most abundant pyrogenic PAHs are fluoranthene, anthracene and pyrene. Fluoranthene is less favoured than pyrene in fossil fuel formation so the relative ratio of fluoranthene to pyrene is a strong indicator of origin. The Fl/Py ratio provided a strong determination of petrogenic source in Sandfly Creek while all other port areas, control creeks and offshore areas (i.e. Burns and Brinkman 2011) were identified to be of pyrogenic origin.

Phenanthrene is more stable than anthracene. Unburnt fossil fuels thus have much more phenanthrene when compared with anthracene. Anthracene is primarily produced with combustion. Changes in the ratio between these two PAHs provide a very effective diagnostic tool that is widely used in source determination (Stogiannidis and Laane 2015). The Ph/An ratio identified PAHs in Sandfly Creek as being almost entirely derived from petrogenic source (unburnt coal). PAHs at all other locations were identified as being of pyrogenic origin. As would be expected, offshore locations reported by Burns and Brinkman (2011) provided the strongest pyrogenic signal. This meets the expectation that background sediment contamination is primarily of pyrogenic origin. These PAHs are spread throughout coastal sediments through the deposition of fine, airborne soot from vehicle exhausts, which can travel large distances, and through the deposition of sediments from rivers that are impacted by pyrogenic combustion, and from the subsequent remobilisation of seabed sediments. Interestingly, all samples within Burns and Brinkman (2011) demonstrated anthracene concentrations far exceeding phenanthrene. Given that anthracene is generally less stable, this may indicate a recent pyrogenic contribution or other unspecified process.

Of the ten diagnostic ratios used to determine source contribution as either petrogenic, pyrogenic or mixed contribution:

- Seven ratios provided a clear determination that PAHs within the sediment of Sandfly Creek were derived from a petrogenic source; and
- The three other ratios, which are recognised to be less sensitive predictors of coal sources (Stogiannidis and Laane 2015) identified Sandfly creek as either of mixed origin or only weakly pyrogenic.

PAHs in the vicinity of Hay Point, including Half Tide Tug Harbour, DBCT Berth1, HPCT Berth3 and Mick Ready Creek (control creek), were determined to be of either pyrogenic origin (6-9 ratios) or mixed origin (1-2 ratios). Additionally, the PAHs from inshore sediment samples and inshore/offshore sediment trap samples (Burns and Brinkman 2011) were almost exclusively determined to be of either pyrogenic or mixed origin, with the exception of ratios for Py/BaP and BeP/BaP. In this instance it is believed that use of benzo(a)pyrene ratios at these locations is less effective, given the likely distances from sources and the rapid photo-degradation that this PAH exhibits. It is also noted that the biomass indicator (BaP/BghiP) did not detect biomass combustion as a primary source at any location.

While no program has been specifically conducted to delineate the spatial extent of PAH contributions from unburnt coal at the Port of Hay Point, the present review provides preliminary information in this regard. This review also provides a preliminary set of diagnostic tools to support a refined spatial sampling program for PAHs at the Port of Hay Point. Key diagnostic ratios such as BaA/Ch, Fl/Py and Ph/An appear to be effective in this regard. Further refinement in diagnostic approaches is required.

Table 11 Diagnostic ratios of PAHs to determine likely source contributions for sediment data provided by REMP (Sandfly Creek, Half Tide Tug Harbour, Mick Ready Creek; Koskela Group 2014); sediment sampling for maintenance dredging (HPCT Berth 3, DBCT Berth 1, Half Tide Tug Harbour; Advisian 2018) and sediment sampling by grab and sediment trap Central GBR (IS9, IS10, PRC4-5 free-floating trap, IS9ST boat tethered trap; Burns and Brinkman 2011). Petrogenic source; mixed source; pyrogenic source; non biomass.

Diagnostic Ratio	Source	Criteria	Comment	SFC	Tug	MRC	HPCT3	DBCT1	HTTH	IS9	IS10	PRC4-5	IS9ST
BaA/Chr	S&L	<0.25 petro 0.25 - 0.5 mixed >0.5 pyro	BaA preferential product of pyro	0.24	0.41	0.45	0.35	0.93	0.46				
BaA/(BaA+Ch)	Moyo	<0.2 petro >0.2 pyro	Key indicator	0.19	0.29	0.31	0.26	0.48	0.32				
BaA/BaP	This review	Potential indicator	BaP photolyzes quickly	2.65	0.71	0.44	0.28	0.49	0.65				
IP/(IP+BghiP)	Moyo	<0.2 petro	Coal overlaps	0.31	0.43		0.76	0.66	0.68	0.49	0.48	0.99	0.44
IP/BghiP	S&L	<0.25 petro 0.25 - 1 mixed >1 pyro	Coal overlaps	0.62	0.77		3.20	1.92	2.08	0.98	0.91	102*	0.79
BaP/BghiP	Moyo	<0.6 (Biomass) >0.6 combustion engine	Biomass indictor	1.03	0.77		2.59	1.38	0.83	1.44	0.98	75*	1.08
An/(An+Ph)	Moyo	<0.1 petro >0.1 pyro	Key indicator	0.07	0.25	0.23	0.24	0.12	0.23	0.75	0.74	0.75	0.73
Ph/An	Moyo/S&L	>10 petro >30 exclusively petro	Key indicator	23.92	3.60	4.47	3.10	7.31	3.44	0.34	0.34	0.33	0.37
Py/BaP	S&L	>10 petro	BaP photo-sensitive	5.41	1.60	2.67	0.91	1.13	4.96	2.6	42. 5	74.3	12.8
Fl/(Fl+Py)	Moyo	<0.4 petro	Key indicator	0.40	0.54	0.51	0.53	0.54	0.54	0.65	0.60	0.60	0.73
Fl/Py	S&L	<1 petro	Key indicator	0.73	1.25	1.10	1.13	1.19	1.18	1.87	1.52	1.50	2.69
BeP/BaP	S&L	>2 petro <2 pyro	Range can overlap	3.6[a]	0.6[a]					0.9	1.1	2.3	1.4
BaP-TEQ	N&L	Draft Effect Indicator	Carcinogenic	18,747	35,700	6,712	20,615	207,085	16,840	6,068	2,411	733	4,964
BaP-MEQ	Durant	Draft Effects Indicator	Mutagenic	7,356	10,829	2,047	10,600	127,248	6,436	4,622	1,922	256	3,710

S&L - Stogiannidis and Laane (2015); Moyo - Moyo *et al*. (2013); N&L Nisbet and LaGoy (1992); Durant *et al*. (1999) * negligible BghiP detected; [a] data derived from water column SPMD. BaP –TEQ Carcinogenic equivalents normalised to 1% total organic carbon; BaP-MEQ Mutagenic equivalents normalised to 1% total organic carbon.

2.7.12 Bioavailability

2.7.12.1 Pore Water

Burgess *et al*. (2003a) observes that understanding and predicting any adverse environmental effects of PAHs depends on generating a reliable estimate of how much PAH is available for uptake. Simply knowing the total amount of PAH in sediment is insufficient for determining whether or not these contaminants are bioavailable. In sediments it has been observed that bioaccumulation and toxicity to organisms correlate much more strongly with contaminant concentrations in interstitial water (pore water). It is recognised that pore water measurements provide a more direct measure of PAHs bioavailability pathways. Detailed measurement of PAH concentrations in pore water has not been undertaken at the Port of Hay Point.

2.7.12.2 Bioaccumulation

A human health risk assessment (Koskela Group 2014a and 2014b) was undertaken to determine concentrations of organic contaminants in the muscle tissue of key estuarine species:

- yellowfin bream, *Acanthopagrus australia*;
- fantail mullet, *Paramugili georgi*;
- mud crab*, Scylla serrata*; and
- mud whelk, *Telescopium telescopium* (whole animal).

Samples were collected at Sandfly Creek, Salonika Creek and Mick Ready Creek.

There was no detection of any organic contaminant in the tissue of any tested organism at any location. A list of the organic analytes and their laboratory practical quantitation limits (PQLs) are given in Table 12. While it is expected that the low concentrations of bioavailable organic contaminants in the receiving environment at the Port of Hay Point would result in low potential for bioaccumulation, it is recognised that laboratory PQLs used in this study were too high to be of practical use and thus hampered diagnostic appraisal of this data.

Various examples demonstrate the need for future sampling to discriminate at µg/kg concentrations or lower (i.e. Sinaei and Mashinchian 2014). Present European food guidelines limit BaP to 5 µg/kg in molluscs; and the sum of the PAH4 (BaP, BaA, BbF and Ch) to 30 µg/kg (Zelinkova and Wenzl 2015). Furthermore, the recent review paper of Bandowe and Meusel (2017) calls for the measurement of nitro-PAHs across environmental compartments (sediment, pore water, water and biota) and highlights the use of mutagenicity tests using cell lines.

As previously outlined, a preliminary examination of carcinogenic/mutagenic potential in marine sediments indicates a higher potential for biological impact in the areas immediately associated with port operations. It is probable, but by no means certain, that this increased carcinogenic/mutagenic potential relates to the activities of diesel and heavy oil combustion engines.

Table 12 Organic analytes of biota contaminant study (from Koskela Group 2014a and 2014b).

Analyte	PQL (mg/kg)
Aniline	0.1
2-Nitroaniline	0.1
3-Nitroaniline	0.1
4-Nitroaniline	0.5
4-Chloroaniline	0.05
Benzidine	0.01
Dibenzofuran	0.02
3,3-Dichlorobenzidine	0.5
n-Nitrosodi-n-propylamine	0.5
n-Nitrosodiphenylamine	0.02
Acenaphthene	0.01
Acenaphthylene	0.01
Anthracene	0.02
Dibenz(a,h)anthracene	0.1
Benzo(a)anthracene	0.01
Benzo(a)pyrene	0.05
Benzo(b) & (k) fluoranthene	0.1
Benzo(g,h,i)perylene	0.1
Chrysene	0.01
Fluoranthene	0.02
Fluorene	0.02
Indeno(1,2,3-cd)pyrene	0.1
Naphthalene	0.02
Phenanthrene	0.05
Pyrene	0.02
2-Chloronaphthalene	0.01
2-Methylnaphthalene	0.01
Bis(2-ethylhexyl) phthalate	1.0
Butyl benzyl phthalate	0.1
Di-n-butyl phthalate	1
Diethyl phthalate	0.05
Dimethyl phthalate	0.05
Di-n-octyl phthalate	0.1
Nitrobenzene	0.05
2,4-Dinitrotoluene	0.1
2,6-Dinitrotoluene	0.1
2,4,6-trinitrotoluene	0.01
Isophorone	0.05
1,2,4-Trichlorobenzene	0.02
1,2-Dichlorobenzene	0.1
1,3-Dichlorobenzene	0.1
1,4-Dichlorobenzene	0.1

Analyte	PQL (mg/kg)
Hexachlorobenzene	0.02
Hexachloroethane	0.1
Hexachlorobutadiene	0.05
Hexachlorocyclopentadiene	2.0
Bis(2-chloroethoxy) methane	0.02
Bis(2-chloroethyl) ether	0.1
Bis(2-chloroisopropyl) ether	0.1
4-Bromophenyl phenyl ether	0.02
4-Chlorophenyl phenyl ether	0.02
Benzyl Alcohol	2.0

2.8 Physical Impacts of Unburnt Coal

2.8.1 Marine Habitats of Hay Point

The inshore habitat of Hay Point is a turbid environment with high tidal currents. Benthic biota is most abundant in near-shore waters (Koskela Group 2009). The focus of these aggregations is inshore rocky reefs, rocky shoreline and coarse gravelly substrate. Hay Rock is located between the HPCT and DBCT trestles. This rock has a high percentage cover of hard corals, soft corals, macro- and turfing algae. A rocky reef also runs seaward from Hay Point, predominantly south of the existing HPCT trestle. This rocky reef, referred to here as Hay Point Reef, is dominated by soft corals and macroalga. Strong currents exist at both Hay Rock and Hay Point Reef. Other inshore rocky reefs can be found both north and south of Hay Point. Coral cover on these reefs is relatively low.

Away from the rocky headland and Hay Point Reef, the predominant seabed type is bare silty sand substrate with some patches of bare gravely substrate. This predominantly bare seabed contains a low cover of seagrasses, benthic macroalgae and macroinvertebrates; with total biota cover not exceeding 5% at most locations (Koskela Group 2009). Fringing rocky reef communities of high coral cover occur at Round Top Island and Flat Top Island.

2.8.2 Sediment Modification

Ahrens and Morrisey (2005) provide a detailed historical review of the potential physical impacts of coals. Much of this work has centred on the dumping of colliery waste and the historical use of coal in heavy industrial applications and as shipping fuels. In these instances, coal particles and wastes make up a significant part of surface sediments in areas of large human populations and historically intense industrial activity. Examples of coal content in surface sediments are provided for Narragansett Bay (USA) of up to 1.9% coal, Chesapeake Bay (USA) of up to 8% coal and sub-tidal areas of northeast England subjected to colliery waste dumping (up to 14% coal by extrapolation).

Where coal shipping terminals operate with minimal dust and spillage controls, sediment coal content is also significant. In the immediate vicinity of the Roberts Bank Coal Terminal, British Columbia (Canada), surface coal content was up to 11% (Johnson and Busting 2006). In this instance coal content had increased significantly over time within the immediate port area but the overall spatial extent had not appreciably increased. The explanation for this probably lies in the settling characteristics of coal. Jaffrennou *et al.* (2007) simulated a coal spillage into a test tank. While fine coal particles became suspended and dispersed with the current, the vast majority of coal, being of large particle size, remained at the point of spillage. Environmental impacts other than direct smothering and temporary light attenuation were regarded to be unlikely. Modelling of coal particle movement at the Port of Hay Point indicated that the very fine coal particles suspended in stormwater (<10 µm) had an average residence time within the study area of only 21 hours (Koskela Group 2014a and 2014b). Accounting for deposition and resuspension, this coal was expected to be almost entirely removed from the area within 14 days. These variety of studies indicate that, where coal particles are large enough to settle quickly to the seabed, their further movement is constrained. Fine coal particles, on the other hand,

will remain suspended or resuspend easily and are far less likely to accumulate in high current environments.

The Port of Hay Point operates with a variety of dust mitigation and spill control measures including dust suppression and the covering of conveyors and ship loaders. As a result, coal content in sediment at the Port of Hay Point is comparatively very low (0.1% to 0.2% coal in inshore sediments of Hay Point; Koskela Group 2014a and 2014b) when compared with the sediments of the Robert Banks Coal Terminal ; Johnson and Busting 2006). It is evident that management controls can be effective in limiting both the concentration and spatial extent of any measurable impact.

2.8.3 Biota

While many authors have raised the potential for unburnt coal to impact the environment (see review by Ahrens and Morrisey 2005), direct studies of impacts are limited (Sanchez 2014). Berry *et al.* (2016) examined the effect of chronic exposure to coal particles on the coral *Acropora tenuis*, fish *Acanthochromis polyacanthus* and seagrass *Halodule uninervis*. Test organisms were exposed for 28 d to coal concentrations ranging from 38 mg/L to 275 mg/L. It was determined that chronic exposure to coal concentrations ≥ 38 mg/L can cause considerable lethal effects on corals and reduce the growth rates of seagrass and fish. This is likely to be at least partly due to light attenuation with respect to seagrass and coral, and to the energetic cost associated with physiological processes to remove coal from coral surfaces and the gills of fish (Berry 2017).

Berry *et al.* (2017) examined the effect of suspended coal particles on the early life history processes of *A. tenuis* by exposing early life stages to coal concentrations ranging from 12.5 mg/L to 800 mg/L. The no observed effect concentration (NOEC) and lowest observed effect concentration (LOEC) for various treatments is provided in Table 13 (modified from Table 2, Berry *et al.* 2017). This comprehensive study determined lowest observed effects at coal concentrations ranging from 40 mg/L to 800 mg/L. It is apparent that inadvertent fugitive coal losses from the Port of Hay Point (refer to Section 3.4.3) create suspended coal concentrations that are orders of magnitude lower than the LOECs reported by Berry *et al*. (2017).

Coal particles may also exact an energetic impact when inadvertently consumed by marine organisms. Berry (2017) identified particulate coal in the alimentary canal of fish exposed to suspended coal. Anastasopouloua *et al*. (2018) have recently examined macro and micro litter particles in the gut of various fishes caught in the Adriatic and Ionian seas. While the very large majority of litter particles were of plastic or foam (87% of fish caught in the northern Adriatic contained litter particles), a small number of coal particles were also identified in the gut of one species *Mullus barbatus* (red mullet). This provides direct evidence of particulate coal as a potentially deleterious litter.

Koskela Group *et al.* (2014a and b) studied the effect of coal particles in Sandfly Creek on mangrove pneumatophores. No coal particles were found in 100 sections of pneumatophores, indicating that there was negligible physical blocking of the aerenchyma tissue by coal particles.

Given the high current velocities of the receiving environment and the presence of coral communities immediately adjacent to the terminal, it is likely that unburnt coal exerts very low to negligible physical impacts on benthic communities at the Port of

Hay Point. The ability of these communities to tolerate this level of disturbance is unsurprising given that the Pioneer River, located north of the Port of Hay Point, contributes an estimated 3 Mt in suspended solids to coastal waters on a yearly basis (Neil *et al*. 2002). While the impact of suspended coal particles as a deleterious litter and disruptor of feeding processes is not discounted, it must rank very low in comparison to other and more abundant types of debris, such as fragmented plastic and foams.

2.8.4 Fugitive Beach Coal

It has been demonstrated through both modelling and monitoring that fine coal particles do not have long residence times within the Port of Hay Point (Koskela Group 2014a and 2014b). However, large coal particles, which may make up fugitive losses from conveyors and loading operations, are expected to be constrained to the seabed where they are deposited (i.e. Jaffrennou *et al.* 2007). These large particles are capable of being moved during large storm events and are thus sensitive to the wind and wave action that causes the prevailing northward movement of coastal sediments observed on the Eastern Coast of Australia (longshore drift). This prevailing action in combination with storm activity causes cycles of coastal sand build up and subsequent loss, termed alternate erosion and accretion. Over time, these processes may have resulted in the appearance of large coal particles on northern foreshores of the mainland. It is expected that continued wave action will break down these particles as they slowly migrate northwards. The environmental impact of this beach coal has not previously been evaluated.

Given that marine sediments of the Half Tide Tug Harbour, immediately seaward of Sandfly Creek, are compliant for both metals and PAH concentrations, it is likely that chemical contamination resulting from the presence of beach coal is negligible. However, this has not been specifically examined..

The potential risk of human contamination resulting from beach coal can be qualitatively examined in a preliminary fashion by looking at occupational hazards associated with exposure to fossil fuels, combustion products and lubricants. A very detailed and extensive examination of this was undertaken by IARC (IARC 2013b, Monograph 105). This work provided extensive studies related to exposure. Car mechanics work extensively with both combusted and uncombusted hydrocarbon fossil fuels and lubricating oils. The daily exposure of such an occupation can be regarded as many times that of inadvertent exposure to fugitive coal by a beach goer. As an occupation, car mechanics has been rated by IARC (2013b) as of relatively low exposure to volatile organic compounds and aromatic compounds when compared with other hydrocarbon and combustion exposed occupations such as professional drivers (e.g. taxi, truck, train).

It has been determined that while PAHs are now regarded as a primary mediator of cancers in humans, the mechanism of exposure is primarily via lung respiration of fumes and particulate matter associated with tobacco (IARC 2012), bitumens (IARC 2013a), exhausts (IARC 2013b) and related air pollution (IARC 2015); and additionally via the digestion of contaminated foods (IARC 2018). It can be expected that a beach goer's exposure to PAHs will be directly related to their relative exposure to vehicle exhausts, tobacco, road surfaces, general air pollution and contaminated food products. Any exposure to fugitive beach coal will produce a relative risk which is far less than that of a mechanic, which has been rated as relatively low.

Table 13 No observed effect concentration (NOEC) and lowest observed effect concentration (LOEC) for various life history stages of the coral *A tenuis* exposed to suspended particulate coal (modified from Table 2 Berry *et al.* 2017).

Development Stage	Response	Exposure Duration (h)	NOEC (mg/L coal)	LOEC (mg/L coal)
Gamete	Fertilisation	2.5	25	50
3h embryo	Survival	1	50	100
		12	400	800
		24	25	50
		72	25	50
	Settlement	24	800	-
		72	800	-
12h embryo	Survival	1	800	-
		12	50	100
		24	25	50
		72	25	50
	Settlement	24	800	-
		72	800	-
72h larvae	Survival	1	800	-
		12	800	-
		24	100	200
		72	800	-
	Settlement	24	400	800
		72	400	800
Adult	Survival	14 d	70	200
		28 d	0	40

3 Weight of Evidence

The principal objective of this study was to assess the potential impact of unburnt coal on the receiving marine environment at the Port of Hay Point. To do this, a range of indicators and diagnostic techniques were applied to available data including that of coal product derived from Port of Hay Point operations as well as water, sediment and biota samples obtained from Sandfly Creek, Half Tide Tug Harbour and port shipping areas, control creeks and offshore sites. This information is used as lines of evidence (LOE's) according to the general approach presented in Simpson *et al*. (2013). Scoring is used to determine the need for further testing according to a weight of evidence (WOE).

The WOE approach tabulates and ranks the results of all individual LOEs used. The LOE's have been given one of three rankings according to CSIRO (2010), these being 1 (no concern), 2 (possible concern) or 3 (significant concern). Compliance with a trigger value produces a LOE score of 1. Non-compliance to a trigger value produced an LOE score of 2. Direct evidence of environmental harm (or likelihood of harm derived from very high chemical contamination) scores an LOE of 3.

In the present instance, some LOE's cannot be assessed due to an absence of data. This lack of evidence warrants further investigation. However, as coals of Hay Point are likely to have a low capacity to release contaminants, an LOE score of 1 will be applied. The following WOE to assess the potential impact of unburnt coal on the receiving marine environment at the Port of Hay Point is presented here with a summary provided in Table 14.

3.1 Acid Generating Potential

3.1.1 Sulphur Content

The potential for coal to release contaminants is primarily reliant on acid generating potential as determined by sulphur content (Ahrens and Morrisey 2005). Coals are regarded as low risk when sulphur content is <2%. Coals shipped through the Port of Hay Point exhibit a range in sulphur content of 0.3% to 0.74%. Acid generating potential as determined by sulphur content is given an LOE score of 1.

3.1.2 pH of Stormwater

pH of coal stockpile runoff is a direct expression of acid generating potential. On this basis, range in pH during stormwater overflow at the Port of Hay Point (Koskela Group 2014a and 2014b) was:

pH 8.2 – 8.4 in DBCT Industrial Dam;

pH 7.3 – 7.6 in HPCT Final Polishing Dam; and

pH 7.5 – 8.3 in Sandfly Creek.

This ph is within the neutral range and is within the adopted water quality objective of pH 6 to 9. On this basis, pH of stormwater is given an LOE score of 1.

This score is not expected to alter in fugitive seabed and beach coal as it is assumed to be sourced from the coal stockpile.

3.2 Metals

3.2.1 Release from Coal

Representative coal samples obtained from Hay Point Coal Terminal were subjected to elutriation by seawater and dilute acid extraction (Koskela Group 2011a). In each case these samples met relevant water quality guidelines with respect to metals (NAGD screening level; ANZECC/ARMCANZ water quality objective with NAGD dilution and attenuation factor applied). On this basis, the capacity for coal shipped through the Port of Hay Point to release deleterious concentrations of metals is given an LOE score of 1.

This score is not expected to appreciably alter in fugitive seabed and beach coal as it is assumed to be sourced from the coal stockpile. However, any subsequent investigation of such coals should include the potential for release of metals as a matter of course.

3.2.2 Stormwater

Stormwater overflow from the Port of Hay Point did not significantly increase any dissolved metal concentrations above background within Sandfly Creek, Tug Harbour Salonika Creek or Mick Ready Creek (Koskela Group 2014a and 2014b). On this basis, metal concentrations in stormwater are given an LOE score of 1.

3.2.3 Sediment

The following recent sediment investigations have been undertaken at the Port of Hay Point:

- Advisian (2018) Berth pockets; apron area; departure path and Half Tide Tug Harbour;
- Koskela Group (2014a and 2014b) Sandfly Creek; Tug Harbour; Inshore Control; Salonika Creek and Mick Ready Creek.

In each of these surveys, all sediment sampling locations were compliant to the respective NAGD screening level and ISQG low levels for metals. Certain non-ISQG nominated metals exceeded locally adopted guidelines within the sediments of Sandfly Creek. However, AVS-SEM analysis determined that these metals were of low potential bioavailability. On this basis, metal concentrations in sediment are given an LOE score of 1.

3.2.4 Pore water

No data was available for determination. As the coals of Hay Point have a low potential risk for contaminant release (refer to 4.1.1), a provisional LOE score of 1 is provided.

3.2.5 Bioaccumulation

A Human Health Risk Assessment was undertaken at the Port of Hay Point (Sandfly Creek, Salonika Creek and Mick Ready Creek) to determine the concentration of metals in the muscle tissue of selected estuarine biota (Koskela Group 2014a and 2014b). Data were compared with Food Standard guidelines (FSANZ) and the 20th ATDS (FSANZ 2003). All metal concentrations complied with Food Standard guidelines with the exception of arsenic and copper. However, observed concentrations of these metals were within their expected ranges for fish and shellfish

as reported within the 20th ATDS. On this basis, metal concentrations in the muscle tissue of selected biota are given an LOE score of 1.

3.3 PAHs

3.3.1 Release from Coal

No data is available for determination of extractable PAHs in coal product shipped through the Port of Hay Point. As the coals of Hay Point have a low potential risk for contaminant release (refer to 4.1.1), a provisional LOE score of 1 is provided. A similar score is provided for fugitive coal located on the seabed and beach foreshore as it is assumed to be sourced from the coal stockpile.

The extractable PAHs that may be obtained from either coal product derived from the Port of Hay Point, or from fugitive coals residing on the seabed or beaches, are of undetermined mixture and concentration.

3.3.2 Stormwater

Stormwater overflow from the Port of Hay Point was compliant with locally adopted water quality guidelines for PAHs within DBCT Industrial Dam; HPCT Final Polishing Dam; Sandfly Creek; Tug Harbour; Salonika Creek and Mick Ready Creek (Koskela Group 2014a and 2014b). On this basis, PAH concentrations in stormwater are given an LOE score of 1.

3.3.3 Passive Sampler Surface Water

SPDM passive samplers for PAHs were deployed within HPCT Final Polishing Dam; Sandfly Creek; Tug Harbour and Mick Ready Creek (Koskela Group 2014a and 2014b). Concentrations of PAHs in the surface water of these locations were compliant with locally adopted water quality objectives for PAHs. On this basis, PAH concentrations in surface water are given an LOE score of 1.

It is noted that the very preliminary evaluation of this SPDM data in the context of BaP- MEQ (Durant *et al*. 1999) and BaP-TEQ (Nisbet and LaGoy 1992) ranks the surface waters of Mick Ready Creek as being of higher mutagenic and carcinogenic potential when compared with either Sandfly Creek or the Half Tide Tug Harbour. This indicates the importance of catchment derived PAHs as important source contributors.

3.3.4 Sediment

The following recent sediment investigations have been undertaken at the Port of Hay Point:

- Advisian (2018) Berth pockets; apron area; departure path and Half Tide Tug Harbour;
- Koskela Group (2014a and 2014b) Sandfly Creek; Tug Harbour; Inshore Control; Salonika Creek and Mick Ready Creek.

In each of these surveys, all sediment sampling locations were compliant to the respective NAGD screening level guidelines and ISQG low level/locally adopted sediment quality guidelines for PAHs. On this basis, PAH concentrations in sediment are given an LOE score of 1.

It is noted that the very preliminary evaluation of this sediment data, in the context of BaP- MEQ (Durant *et al*. 1999) and BaP-TEQ (Nisbet and LaGoy 1992), ranks the sediments of the wharf front as being of higher mutagenic and carcinogenic potential

than other locations, with descending relative potential ascribed to the Half Tide Tug Harbour; Sandfly Creek; inshore sediments (such as Mick Ready Creek and IS9); and finally offshore sediments.

It is also noted that very preliminary source attribution of PAHs, as determined by the presented diagnostic approach, ascribes an overriding contribution from the combustion of fossil fuels rather than from unburnt coal.

3.3.5 Pore water

No data is available for determination. As the coals of Hay Point have a presumed low potential risk for contaminant release (refer to 4.1.1), a provisional LOE score of 1 is provided.

3.3.6 Bioaccumulation

Bioaccumulation of PAHs within the muscle tissue of selected estuarine biota was examined (Koskela Group 2014a and 2014b). PAHs were not detected above the laboratory PQLs in any sample tested. However, it is recognised that:

(1) Laboratory PQLs were too high to allow meaningful diagnostic appraisal of this component; and

(2) International guidelines for permissible PAH concentrations in shellfish, where they are now available, are lower than the laboratory PQLs previously applied at Hay Point.

As the coals of Hay Point have a presumed low potential risk for contaminant release (refer to 4.1.1), a provisional LOE score of 1 is provided.

3.3.7 Source Contributions

Diagnostic ratios and other indicator characteristics of PAH concentrations in sediment provide a strong indication of unburnt coal as the primary source of PAHs within Sandfly Creek. These ratios also provide strong indication that:

- Mixed sources, being a combination of unburnt coal and pyrogenic sources (combusted fossil fuels and other organic materials), are the shared contributors of PAHs within the Half Tide Tug Harbour and coal terminal berths; while
- Pyrogenic sources provide the overriding contribution to coastal and offshore sediments elsewhere.

3.4 WOE Score

According to the various LOEs presented here, with respect to potential environmental impact associated with unburnt coal in the marine environment at the Port of Hay Point, a WOE score of 1 is rendered. This score indicates that no reasonable evidence for non-compliance to the present environmental guidelines is apparent.

Table 14 Weight of Evidence to assess the potential impact of unburnt coal on the receiving marine environment at the Port of Hay Point. P1=provisional score of 1.

Matrix	Acid Generating Potential				Contaminants of Coal				Weight of Evidence
	% Sulphur		pH of stormwater		Trace Metals		PAHs		
	Guideline range <2%	LOE	Guideline range ph 6-9	LOE	Analyte specific	LOE	Analyte specific	LOE	
Representative Coal	0.3 - 0.74%	1	DBCT pH 8.2-8.4 HPCT pH 7.3-7.6 SFC pH 7.5-8.3	1 1 1	DAE compliance to NAGD Elutriation compliant to ANZECC/ARMCANZ with NAGD DAFF	1 1	No data available	P1	
Fugitive Coal (seabed and beach)	As per coal	1	As per coal	1	As per coal	1	No data available	P1	
Stormwater					No increase to background concentration	1	Compliance to guideline	1	
Passive Sampling (surface water)					Compliance to guideline	1	Compliance to guideline	1	
Sediment					Compliance to guideline	1	Compliance to guideline	1	
Pore water					No data available	P1	No data available	P1	
Bioaccumulation					Compliant to (FSANZ and 20th ATDS (FSANZ 2003)	1	Data not sufficient	P1	
Source contributions					NA	NA	Coal with spatially limited extent	NA	
Comments	Within expectation for high ranked coal		Within expectation for high ranked coal		Compliant (no data available for pore water).		Compliant (no data available for coal or pore water).		WOE Score
Line of Evidence Score	1		1		1		1		1

4 Conclusions

While many authors have raised the potential for unburnt coal to impact the environment, direct studies of impacts are limited. Recent studies have provided LOECs for suspended coal particles for key tropical marine biota (Berry *et al*. 2017). It is apparent that inadvertent fugitive coal losses from the Port of Hay Point create suspended coal concentrations that are orders of magnitude lower than these LOECs.

Coal product shipped through the Port of Hay Point demonstrates a very low capacity to release contaminants. A Weight of Evidence assessment of potential environmental impact associated with unburnt coal at the Port of Hay Point resulted in a score of 1. This score indicates that no reasonable evidence for non-compliance to the present environmental guidelines is apparent.

Given the high current velocities of the receiving environment and the presence of coral communities immediately adjacent to the terminal, it is likely that unburnt coal exerts very low to negligible physical impacts on benthic communities at the Port of Hay Point. Suspended coal particles as a deleterious litter cannot be discounted, but its risk as an impact is probably many orders of magnitude lower than that of more common litter such as plastics and anthropogenic foams.

5 References

Achten C. and Hofmann T. 2009. Native polycyclic aromatic hydrocarbons (PAH) in coals - a hardly recognized source of environmental contamination. Sci Total Environ. 407(8):2461-73.

Advisian 2018. Maintenance Dredging Sediment Characterisation Report – Port of Hay Point *for* North Queensland Bulk Ports. 944pp.

Ahrens MJ and Morrisey DJ 2005. Biological effects of unburnt coal in the marine environment. *Oceanography and Marine Biology: Annual Reviews*. 43: 69-122.

Anastasopouloua A, Kovač M, Dubravka V, Varezićc B, Digkad N, Fortibuonief T, Korenb S, Mandićg M, Mytilineoua C, Pešićg A, Ronchie F, Šiljićc J, Torrea M, Tsangarisd K and Tutmanc P 2018. Assessment on marine litter ingested by fish in the Adriatic and NE Ionian Sea macro-region (Mediterranean). *Marine Pollution Bulletin* 133:841-851.

ANZECC/ARMCANZ 2000. Australian and New Zealand Guidelines for Fresh and Marine Water Quality. National Water Quality Management Strategy. Australian and New Zealand Environment and Conservation Council, Agriculture and Resource Management Council of Australia and New Zealand.

Bandowe BAM and Meusel H 2017. Nitrated polycyclic aromatic hydrocarbons (nitro-PAHs) in the environment – A review. *Science of the Total Environment* 581–582:237-257.

Barlow Jonker 2007. *Australian Coal Report*. Energy Publishing Pty Ltd.

Berry KLE, Hoogenboom MO, Brinkman DL, Burns KA and Negri AP 2017. Effects of coal contamination on early life history processes of a reef-building coral, *Acropora tenuis*. *Marine Pollution Bulletin* 114:505-514.

Berry KLE, Hoogenboom MO, Flores F and Negri AP 2016. Simulated coal spill causes mortality and growth inhibition in tropical marine organisms. *Sci. Rep.* **6**, 25894; www.nature.com/scientificreports 8pp.

Berry KLE 2017. Effects of Coal Contamination on Tropical Marine Organisms. PhD Thesis. James Cook Univerisity. 168pp.

Blodau C 2006.A review of acidity generation and consumption in acidic coal mine lakes and their watersheds. *Science of the Total Environment* 369:307-332.

Burgess RM, Ahrens MJ and Hickey CW 2003a. Geochemistry of PAHs in Aquatic Environments: Source, Persistence and Distribution *in* PAHs: An Ecotoxicological Perspective. Edited by Peter E.T. Douben. John Wiley & Sons Ltd: pages 35-45.

Burgess RM, Ahrens MJ, Hickey CW, Den Besten PJ, Ten Hulscher D, Van Hattum B, Meador JP and Douben PET 2003b. An Overview of the Partitioning and Bioavailability of PAHs in Sediments and Soils *in* PAHs: An Ecotoxicological

Perspective. Edited by Peter E.T. Douben. John Wiley & Sons Ltd: pages 99-126.

Burns K and Brinkman D 2011. Organic biomarkers to describe the major carbon inputs and cycling of organic matter in the central Great Barrier Reef region. Estuarine, Coastal and Shelf Science. 93:132-141.

Burns KA 2014. PAHs in the Great Barrier Reef Lagoon reach potentially toxic levels from coal port activities. Estuarine, Coastal and Shelf Science. 144:39-45.

Burns WA, Mankiewicz J, Bence AE, Page DS and Parker KR (1997). A principal-component and least-squares method for allocating polycyclic aromatic hydrocarbons in sediment to multiple sources. Environmental Toxicology and Chemistry, 16(6), 1119-1131.

Davis EC and Boegly WJ 1981. Review of water quality issues associated with coal storage. *Journal of Environmental Quality* 10:127-133.

DEWHA 2009. National Assessment Guidelines for Dredging. Commonwealth of Australia, Canberra. 90pp.

Durant J, Lafleur A, Busby W, Donhoffner L, Penman B, Crespi C. 1999. Mutagenicity of C24H14 PAH in human cells expressing CYP1A1. *Mutat. Res.-Genet. Toxicol*.446:1–14.

Flores RM 2014 Coal and Coal Bed Gases. *Elsevier*. pp167-233.

IARC 2012. Personal Habits and Indoor Combustions - IARC Monographs on the Evaluation of Carcinogenic Risks to Humans. *International Agency for Research on Cancer.* Monograph 100E:598pp.

IARC 2013a. Bitumens and Bitumen Emissions, and Some N- and S-Heterocyclic Polycyclic Aromatic Hydrocarbons - IARC Monographs on the Evaluation of Carcinogenic Risks to Humans. *International Agency for Research on Cancer.* Monograph 103:361pp.

IARC 2013b. Diesel and Gasoline Engine Exhausts and Some Nitroarenes - IARC Monographs on the Evaluation of Carcinogenic Risk to Humans. *International Agency for Research on Cancer.* Monograph 105:714pp.

IARC 2015. Outdoor Air Pollution. IARC Monographs on the Evaluation of Carcinogenic Risk to Humans. *International Agency for Research on Cancer.* Monograph 109:454pp.

IARC 2018. Red Meat and Processed Meat. IARC Monographs on the Evaluation of Carcinogenic Risk to Humans. *International Agency for Research on Cancer.* Monograph 114:511pp.

Jaffrennou C, Giamachi P, Cabon J, Stephan L, Burel-Deschamps L, Bautin F, Thomas A, Dumont J and Le Floch S 2007. Simulations of accidental coal immersion. *Marine Pollution Bulletin* 54:1932-1939.

Johnson R and Bustin RM 2006. Coal dust dispersal around a marine coal terminal (1977-1999), British Columbia. The fate of coal dust in the marine environment. *International Journal of Coal Geology* 68:57–69.

Koskela Group 2011a. Release of Metal Contaminants from Coal Shipped through Hay Point Coal Terminal for BM Alliance Coal Operations Pty Ltd Hay Point Coal Terminal. 42pp plus appendices.

Koskela Group 2011b. Potential Sources of Metals in Detention Basins located at Hay Point Coal Terminal for BM Alliance Coal Operations Pty Ltd Hay Point Coal Terminal. 54pp.

Koskela Group 2013. Interim Local Trigger Values for Contaminant Concentrations in Groundwater at Hay Point for BM Alliance Coal Operations Pty Ltd Hay Point Coal Terminal. 24pp plus appendices.

Koskela Group 2014a Receiving Environment Monitoring Program for BM Alliance Coal Operations Pty Ltd Hay Point Coal Terminal. 239pp plus appendices.

Koskela Group 2014b Receiving Environment Monitoring Program for Dalrymple Bay Coal Terminal. 242pp plus appendices.

Kumar D and Kumar D 2016. Evaluation of coking coal resources and reserves *in* 'Management of Coking Coal Resouces' *Elsevier* pp 61-112.

Laumann S, Micić V, Kruge MA, Achten C, Sachsenhofer RF, Schwarzbauer J, Hofmann T. 2011. Variations in concentrations and compositions of polycyclic aromatic hydrocarbons (PAHs) in coals related to the coal rank and origin. *Environ Pollut* 159(10):2690-7.

Lucas SA and Planner J 2012. Grounded or submerged bulk carrier: the potential for leaching of coal trace elements to seawater. *Marine Pollution Bulletin* 64(5):1012-1017.

Mohd Tahir N, Pang SY, Hill YS and Simoneit BRT 2014. Distribution and sources of perylene and other polycyclic aromatic hydrocarbons (PAHs) in South China Sea sediments off Southern Terengganu Coast, Malaysia *in From Sources to Solution*. Springer Singapore.

Moyo S, McCrindle R, Mokgalaka N, Myburgh J and Mujuru M 2013. Source apportionment of polycyclic aromatic hydrocarbons in sediments from polluted rivers. *Pure Appl. Chem*. 85(12):2175-2196.

Neil DT, Orpin AR, Ridd PV and Yu BD 2002 Sediment yield and impacts from river catchments to the Great Barrier Reef lagoon. *Mar. Freshwater Res*.53:733–752.

Nisbet I and LaGoy P. 1992. Toxic equivalency factors (TEFs) for polycyclic aromatic hydrocarbons (PAHs) *Regul. Toxicol. Pharmacol*. 16:290–300.

Piberger AL, Krüger CT, Strauch BM, Schneider B and Hartwig A 2018. BPDE-induced genotoxicity: relationship between DNA adducts, mutagenicity in the in vitro PIG-A assay, and the transcriptional response to DNA damage in TK6 cells. *Arch Toxicol.* 2018 92(1):541-551.

PubMed 2018. https://www.ncbi.nlm.nih.gov/BPDE-induced genotoxicity

Sanchez JO 2014. Coal as a marine pollutant. World Maritime University, Malmo, Sweden. Dissertation 479. 131pp.

Schweinfurth SP 2005. Coal-A Complex Natural Resource: An overview of factors affecting coal quality and use in the United States. US Geological Survey. URL: https:// pubs.usgs.gov /circ/c1143/html/text.html.

Simpson SL, Batley GE and Chariton AA 2013. Revision of the ANZECC/ARMCANZ Sediment Quality Guidelines. CSIRO Land and Water Science Report 08/07. CSIRO Land and Water. 128pp.

Sinaei M and Mashinchian A 2014 Polycyclic aromatic hydrocarbons in the coastal sea water, the surface sediment and Mudskipper Boleophthalmus dussumieri from coastal areas of the Persian Gulf: source investigation, composition pattern and spatial distribution. J Environ Health Sci Eng. 12: 59.

Smit R, Kingston P, Wainwright DH, Tooker R. 2017. A tunnel study to validate motor vehicle emission prediction software in Australia. *Atmospheric Environment* 151:188-199.

Tiwary RK. 2001. Environmental impact of coal mining on water regime and its management. *Journal Water, Air and Soil Pollution*. 132: 185-199.

Toxikos 2012. BMA Composite Coal Sample - MARPOL Annex V Classification. Toxikos Toxicology Consultants. 31pp.

Vassilev SV, Kitano K and Vassileva CG 1996. Some relationships between coal rank and chemical and mineral composition. Fuel 75 (13) 1537-1542.

Volkman JK, Holdsworth DG, Neill GP and Bavor HJ 1992. Identification of natural, anthropogenic and petroleum hydrocarbons in aquatic sediments. *Sci.Tot.Environ*. 112:203-219.

World Coal Association 2018. Coal Facts 2014. www.worldcoal.org. 3pp.

Zelinkova Z and Wenzl T 2015. The Occurrence of 16 EPA PAHs in Food – A Review. *Polycyclic Aromatic Compounds* 35(2-4):248-284.

Appendix A

Summary Statistic

Summary Site Diagnostic Ratios and Mutagenic/Carcinogenic Factors for PAHs

Ratios	SFC	Tug (RE19)	MRC	HPCT3	DBCT1	HTTH	IS9 (0-1)	IS10 (0-1)	PRC4-5	IS9ST	PFD Water	SFC Water	Tug Water	MRC Water
BaA)/Ch	0.247827	0.625	0.705128	0.354108	0.934516	0.46								
BaA/(BaA+Ch	0.198607	0.384615	0.413534	0.261506	0.483075	0.315068								
IP/(IP+BghiP)	0.406889	0.5	0.5	0.761905	0.657754	0.675676	0.494759	0.476793	0.990291	0.44021	0.5	0.89916	0.9375	0.998395
BeP/BaP							0.892342	1.099174	2.32	1.409462	4.352941	3.1	0.578947	1
IP/BghiP	0.686024	1	1	3.2	1.921875	2.083333	0.979253	0.91129	102	0.786385	1	8.916667	15	622
BaP/BghjP	0.698578	1	1	2.588	1.380859	0.833333	1.438912	0.975806	75	1.079225	17	0.833333	19	1
BbF/BkF							2.251356	2.780488	0.027778	3.026576	9.25	24	5	1
An/(an+Ph)	0.039008	0.357143	0.387931	0.243665	0.120287	0.225225	0.745296	0.744419	0.750951	0.730455	0.103659	0.158333	0.009524	0.094737
Ph/An	24.63586	1.8	1.577778	3.104	7.313433	3.44	0.341748	0.34333	0.331646	0.36901	8.647059	5.315789	104	9.555556
Py/BaP	3.083703	1.55	1.277778	0.90881	1.130127	4.96	2.630888	42.54545	74.26667	12.75911				
Fl/(Fl+Py)	0.452232	0.575342	0.502165	0.5296	0.54395	0.540741	0.651944	0.602502	0.599511	0.729023				
Fl/Py	0.825589	1.354839	1.008696	1.12585	1.192741	1.177419	1.873097	1.515734	1.496948	2.690355				
PER/5RPAH							98.8004	40.28103	0.294118	117.138	0.558659	0.561798	28.57143	0.139276
BaP-TEQ	18746.66	35700	6712.121	20615.6	207085	16840	6067.521	2411.3	732.66	4963.755	57.22	584.03	97.42	3633.52
BaP-MEQ	7355.823	10828.89	2047.142	10600.02	127247.6	6435.95	4621.761	1922.38	255.888	3709.542	24.449	79.674	28.739	401.219

Toxic Equivalence Factors (TEFs) for individual PAHs

Congener	TEF	Congener	TEF
Benzo(a)pyrene	1	Anthracene	0.01
Dibenz(a.h)anthracene	1	Naphthalene	0.001
Benz(a)anthracene	0.1	Acenaphthylene	0.001
Benzo(b)fluoranthene	0.1	Acenaphthene	0.001
Benzo(k)fluoranthene	0.1	Fluorene	0.001
Indeno(1.2.3.cd)pyrene	0.1	Phenanthrene	0.001
Chrysene 0.01	0.01	Fluoranthene	0.001
Benzo(g.h.i)perylene	0.01	Pyrene	0.001

APPENDIX B

Hay Point Disposal Site Analysis

31 March 2016

PORT OF
HAY POINT

REPORT

Hay Point Disposal Site Analysis

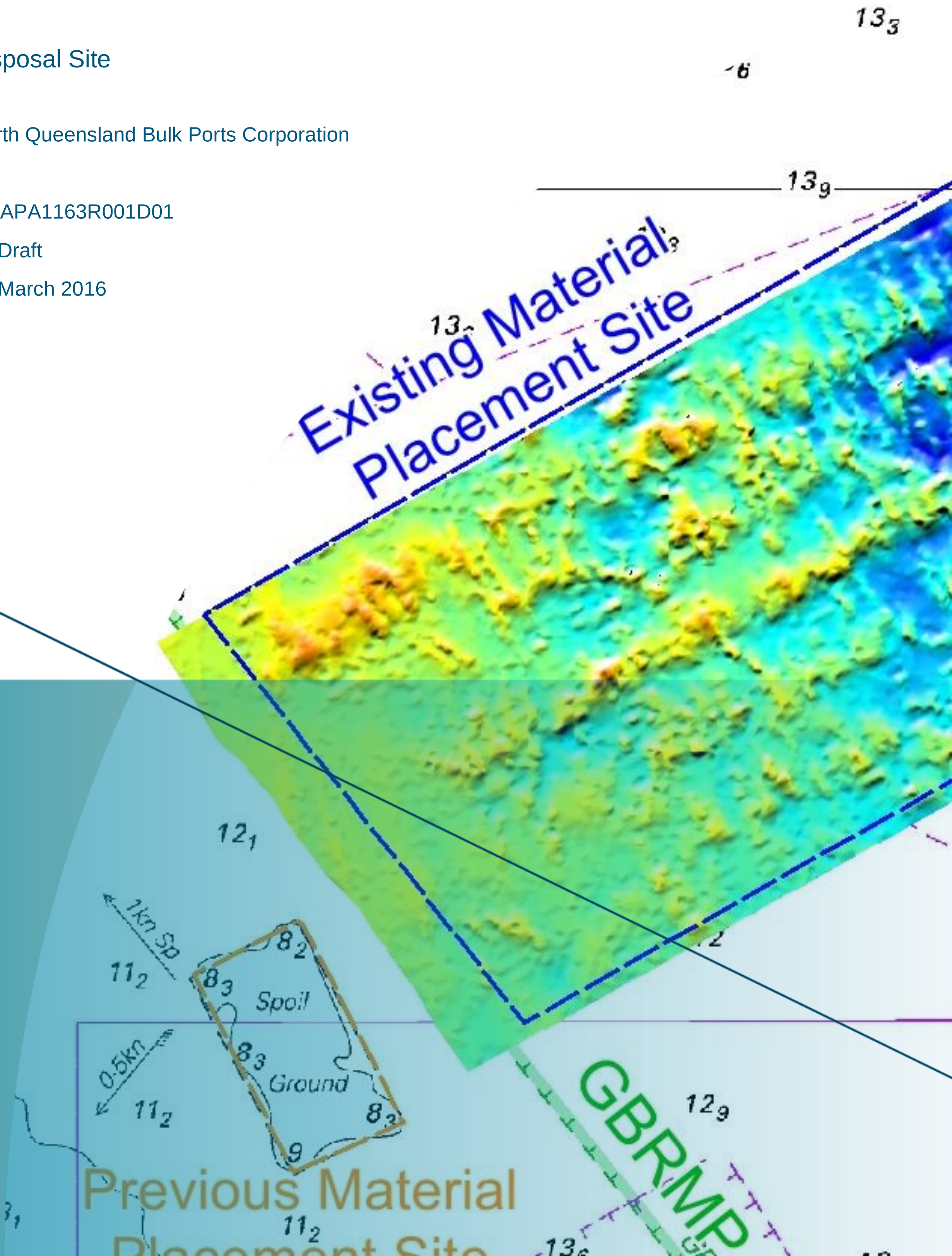
Hay Point Disposal Site

Client: North Queensland Bulk Ports Corporation

Reference: M&APA1163R001D01

Revision: 01/Draft

Date: 31 March 2016



HASKONING AUSTRALIA PTY LTD.

Unit 2
55-57 Township Drive
QLD 4220 Burleigh Heads
Australia
Maritime & Aviation
Trade register number: ACN153656252

Infosydney.mandw@rhdhv.com **E**
royalhaskoningdhv.com **W**

Document title:	Hay Point Disposal Site Analysis
Document short title:	
Reference:	M&APA1163R001D01
Revision:	01/Draft
Date:	31 March 2016
Project name:	Hay Point Bathymetric Analysis
Project number:	PA1163
Author(s):	Andy Symonds
Drafted by:	Andy Symonds
Checked by:	Dan Messiter
Date / initials:	30/03/2016 DM
Approved by:	Dan Messiter
Date / initials:	31/03/2016 DM

Classification
Click to enter "Classified"

MANAGEMENT SYSTEM CERTIFICATION
ISO 9001 = ISO 14001 = OHSAS 18001
DNV

Table of Contents

1	Introduction	1
1.1	Project Background	1
1.2	Port of Hay Point	2
1.3	Report Structure	3
2	Coastal Processes	5
2.1	Tides	5
2.2	Rainfall	6
2.3	Wind Climate	6
2.4	Wave Climate	7
2.5	Currents	10
2.6	Fluvial Discharge	13
2.7	Tropical Cyclones	13
2.8	Water Quality	14
2.9	Deposition	14
2.10	Sediment Properties	17
2.11	Summary	17
3	Bathymetric Analysis	19
3.1	Hydrographic Surveys	19
3.2	Analysis	20
3.3	Results	21
3.3.1	Spatial Changes	21
3.3.2	Volumetric	26
3.3.3	Sectional	29
3.4	Discussion	31
4	Summary	33
5	References	34

Table of Tables

Table 1. Historic in-situ dredging volumes at the Port of Hay Point since 2006. 2
Table 2. Overview of available data at the study site. 5
Table 3. Hay Point tidal planes 5
Table 4. Estimates of suspended sediment discharge load from river basins nearby to the Port of Hay Point 13
Table 5. Recent cyclone induced wind and wave recorded at Hay Point. 13
Table 6. Summary of background SSC measurements 14
Table 7. Physical characteristics of sediment from 2006 capital dredging 17
Table 8. Details of the material placement sites bathymetric surveys. 20
Table 9. Change in volume at Existing Placement Site 26
Table 10. Change in volume at Previous Placement Site 27

Table of Figures

Figure 1. Location of the existing and previous placement sites relative to the GBRMP. 4
Figure 2. Mackay average monthly rainfall. 6
Figure 3. Wind roses - Hay Point (2005 – 2015). 7
Figure 4. Wave roses - Hay Point waverider buoy (2008 – 2014). 9
Figure 5. Wave height and period scatter plot - Hay Point waverider buoy (2008 – 2014). 10
Figure 6. Current data approximately 1 km north-west of the DBCT berths 11
Figure 7. Current, wind and water level data 1 km north-west of the DBCT berths 12
Figure 8. Wave, SSC and deposition data recorded at Hay Point. 16
Figure 9. Bathymetric Survey Plan G290060 – 29/02/2004. 21
Figure 10. Bathymetric Survey Plan G290099 – 04/06/2010 22
Figure 11. Volumetric differences between successive surveys – Existing Placement Site 24
Figure 13. Volumetric differences between successive surveys – Previous Placement Site 25
Figure 14. Cross-section Locations 29
Figure 15. Long-sections showing change in bed elevation - Section 1 30
Figure 16. Long-sections showing change in bed elevation - Section 2 30
Figure 17. Long-sections showing change in bed elevation - Section 3 30
Figure 18. Cross-sections showing change in bed elevation - Section 4 30
Figure 19. Cross-sections showing change in bed elevation - Section 5 31
Figure 20. Cross-sections showing change in bed elevation - Section 6 31

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.

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.

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.

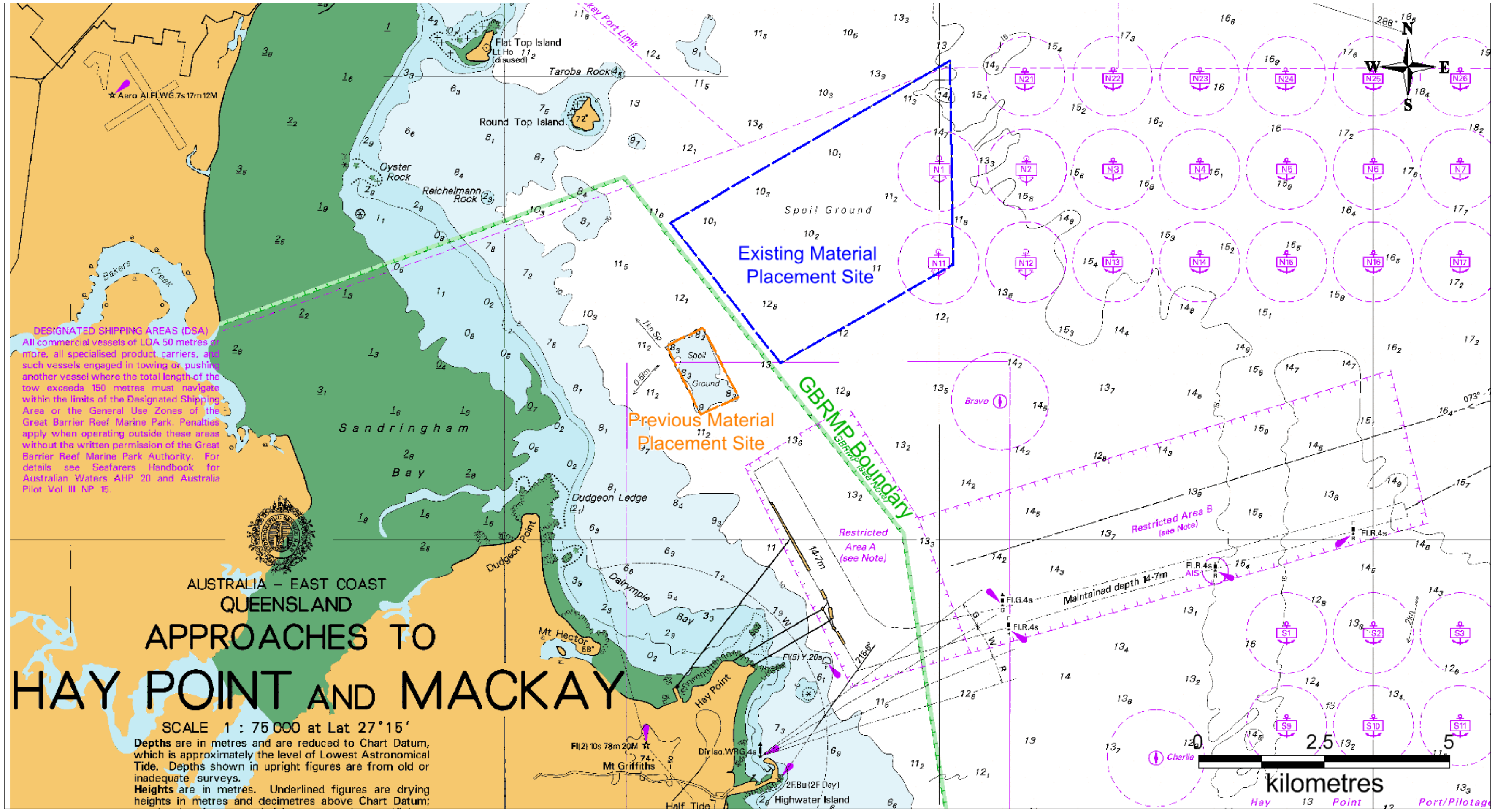


Figure 1. Location of the existing and previous placement sites relative to the GBRMP.

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.

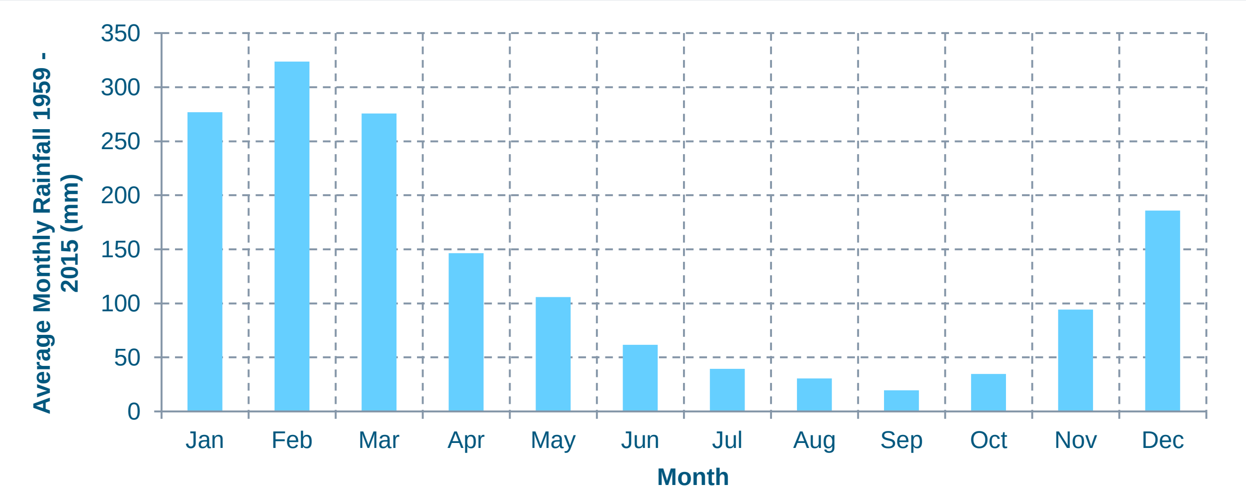


Figure 2. Mackay average monthly rainfall.

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**.

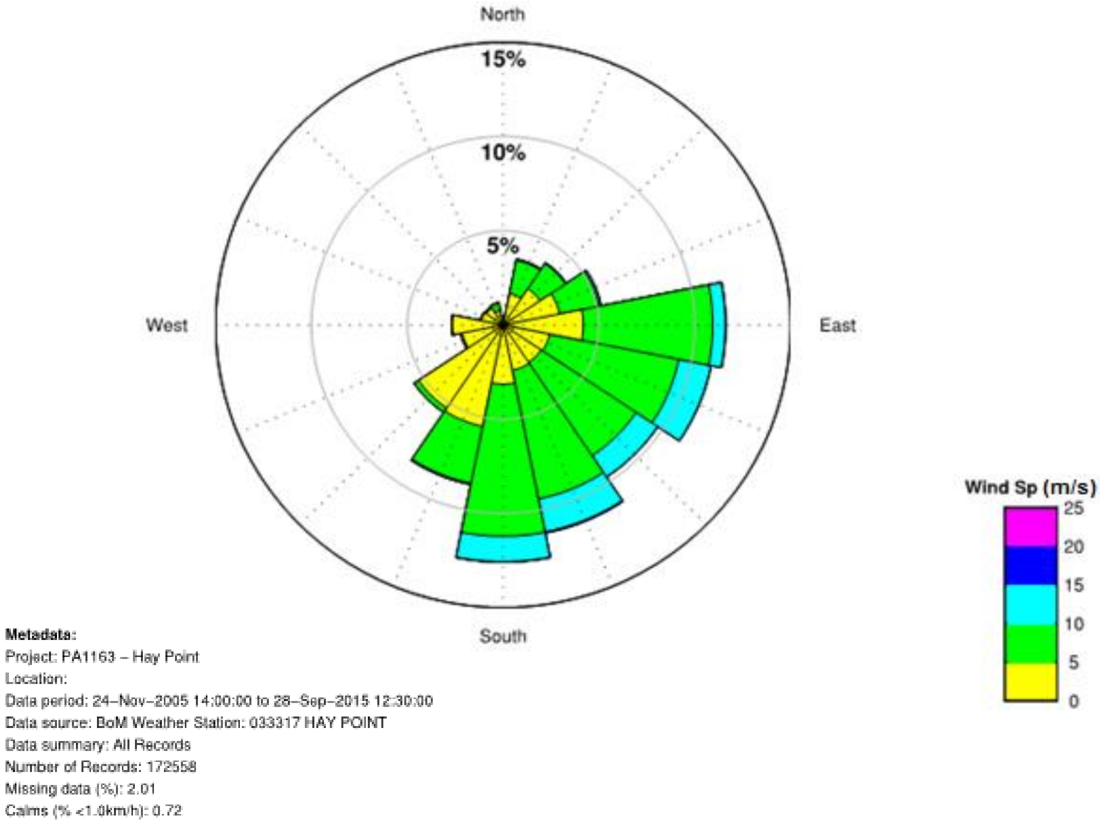
2.3 Wind Climate

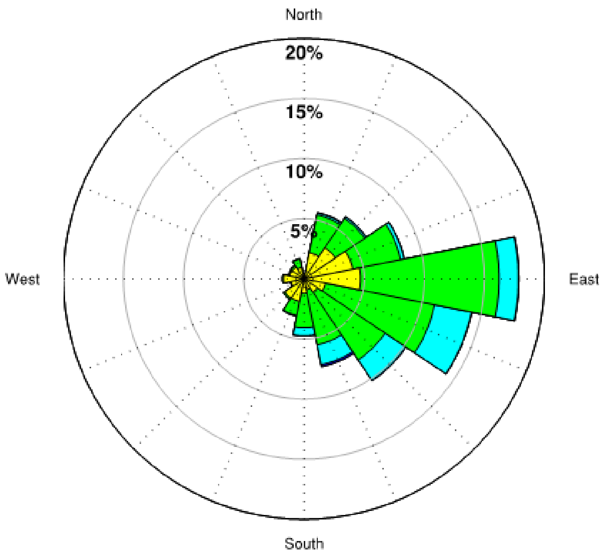
Hay Point lies in the trade wind belt for most of the year resulting in the local wind climate being governed by east to south-easterly winds. **Figure 3** presents wind data measured by the BoM at Hay Point and includes data recorded between 2005 and 2015. **Figure 3** highlights the prevalence of the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

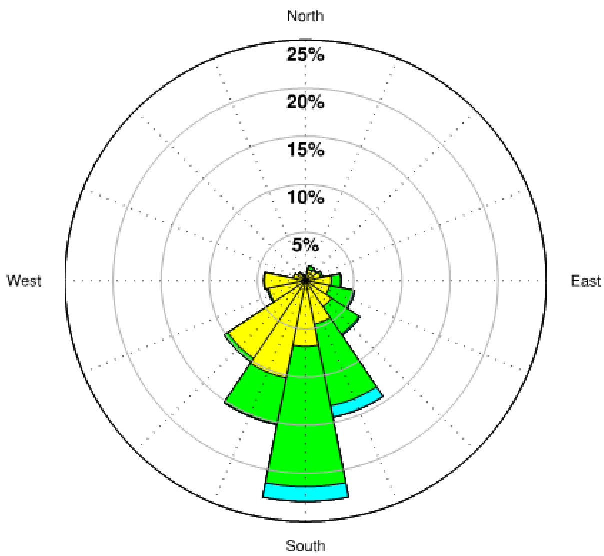
The higher wind speeds recoded at Hay Point are a result of tropical cyclones which can influence the area. The associated speed and direction of these winds are a result of the cyclones intensity and path.

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

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.

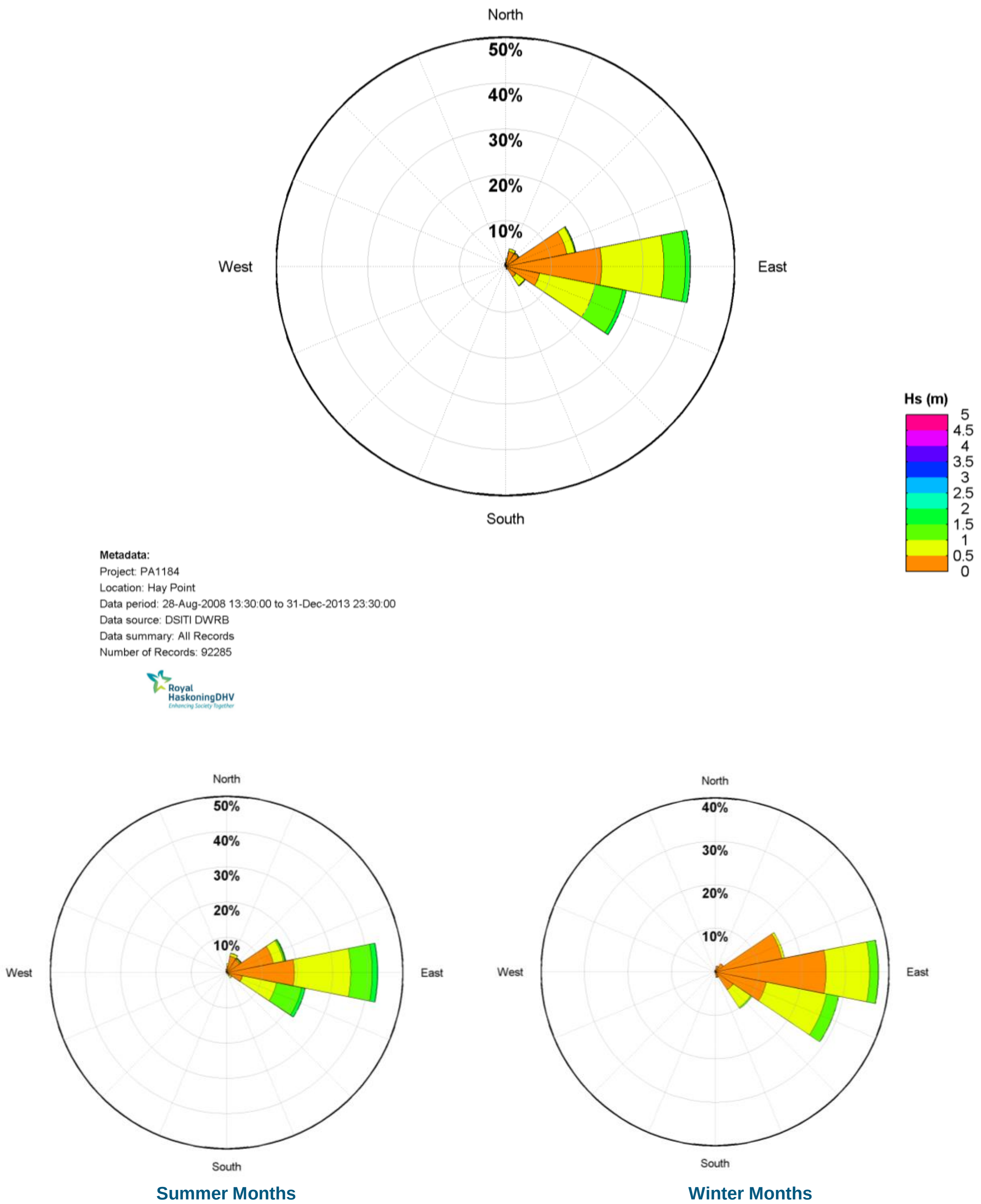


Figure 4. Wave roses - Hay Point waverider buoy (2008 – 2014).

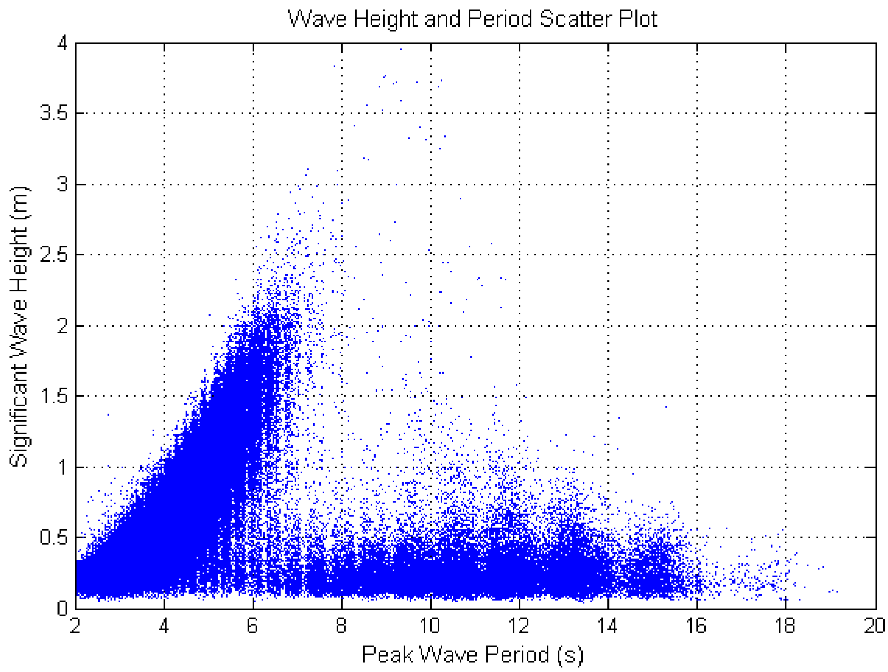


Figure 5. Wave height and period scatter plot - Hay Point waverider buoy (2008 – 2014).

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.

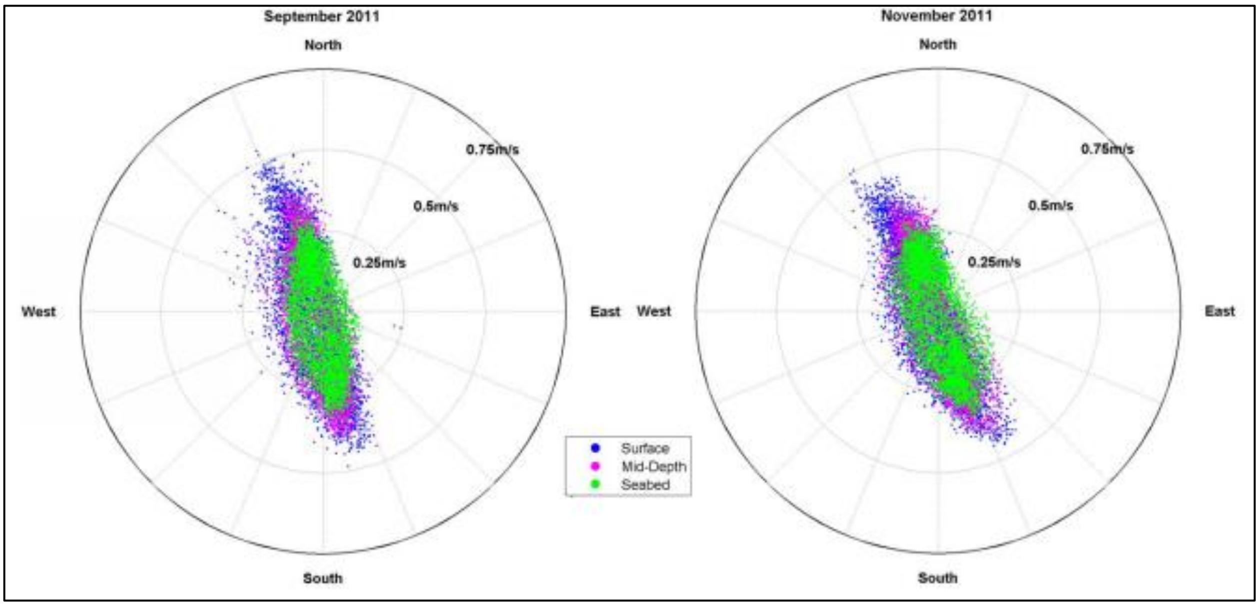


Figure 6. Current data approximately 1 km north-west of the DBCT berths (WorleyParsons, 2012).

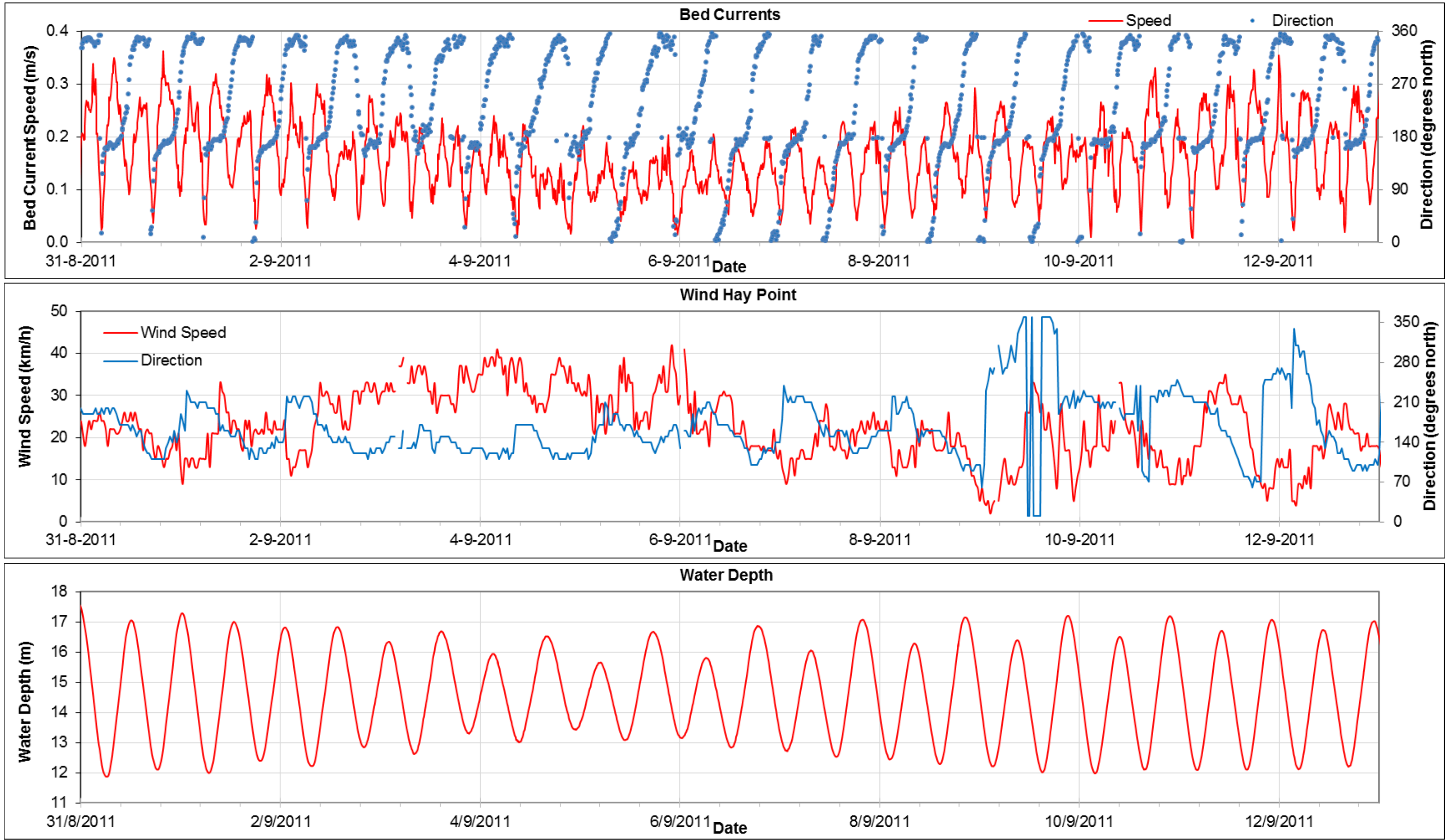


Figure 7. Current, wind and water level data approximately 1 km north-west of the DBCT berths (WorleyParsons, 2012).

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).

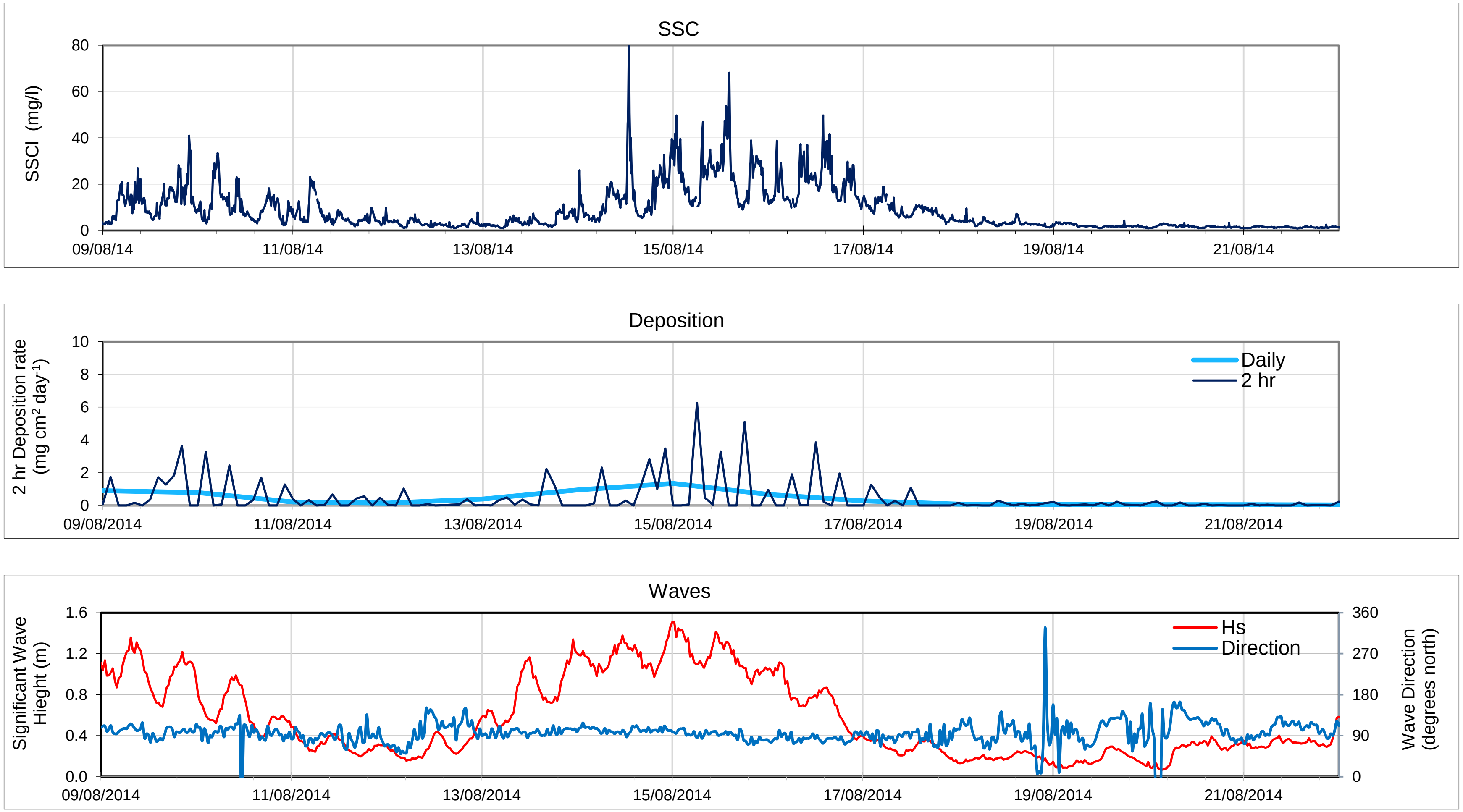


Figure 8. Wave, SSC and deposition data recorded at Hay Point.

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.

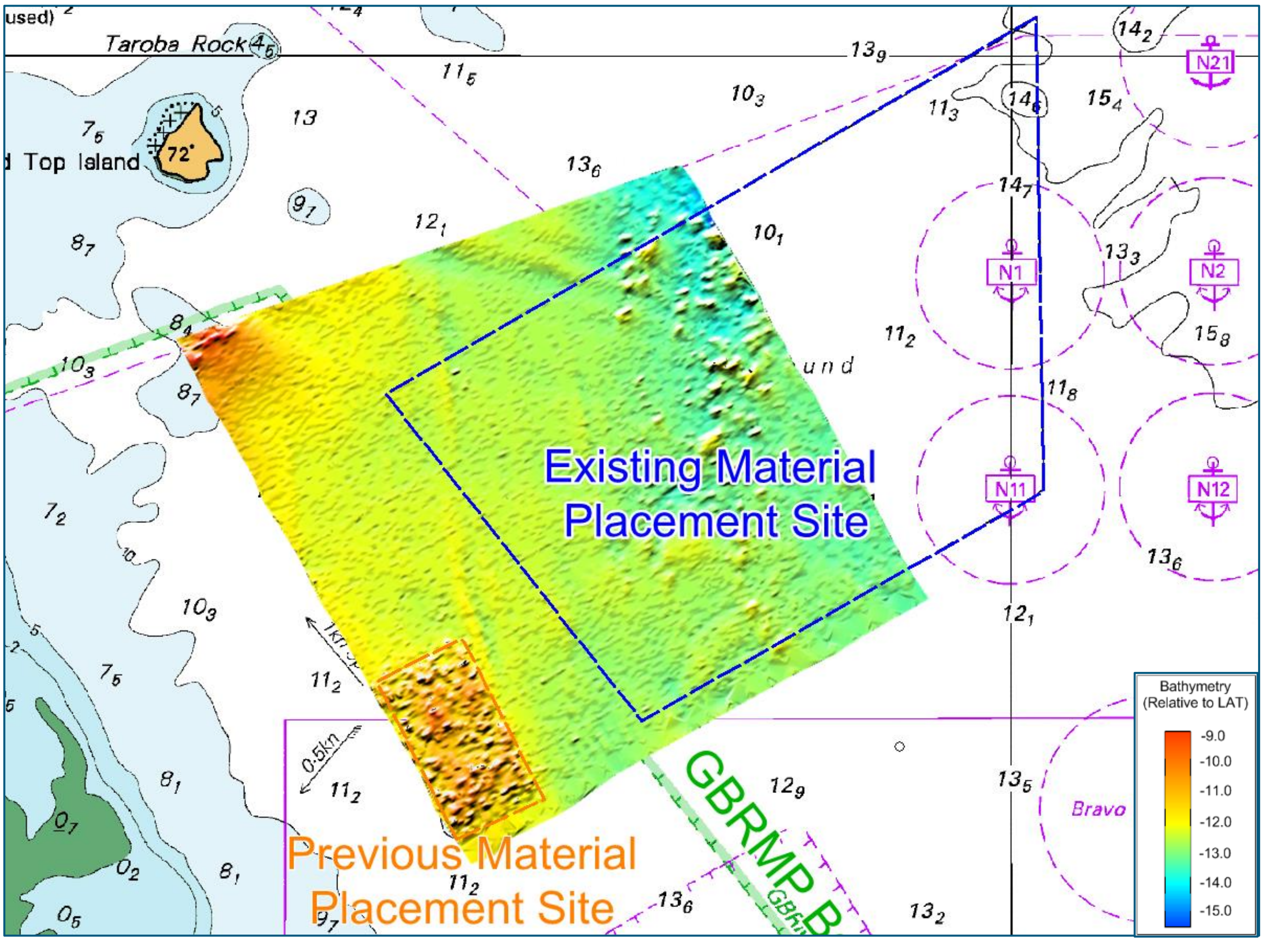


Figure 9. Bathymetric Survey Plan G290060 – 29/02/2004. Note: the survey did not extend to the eastern half of the existing placement site.

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.

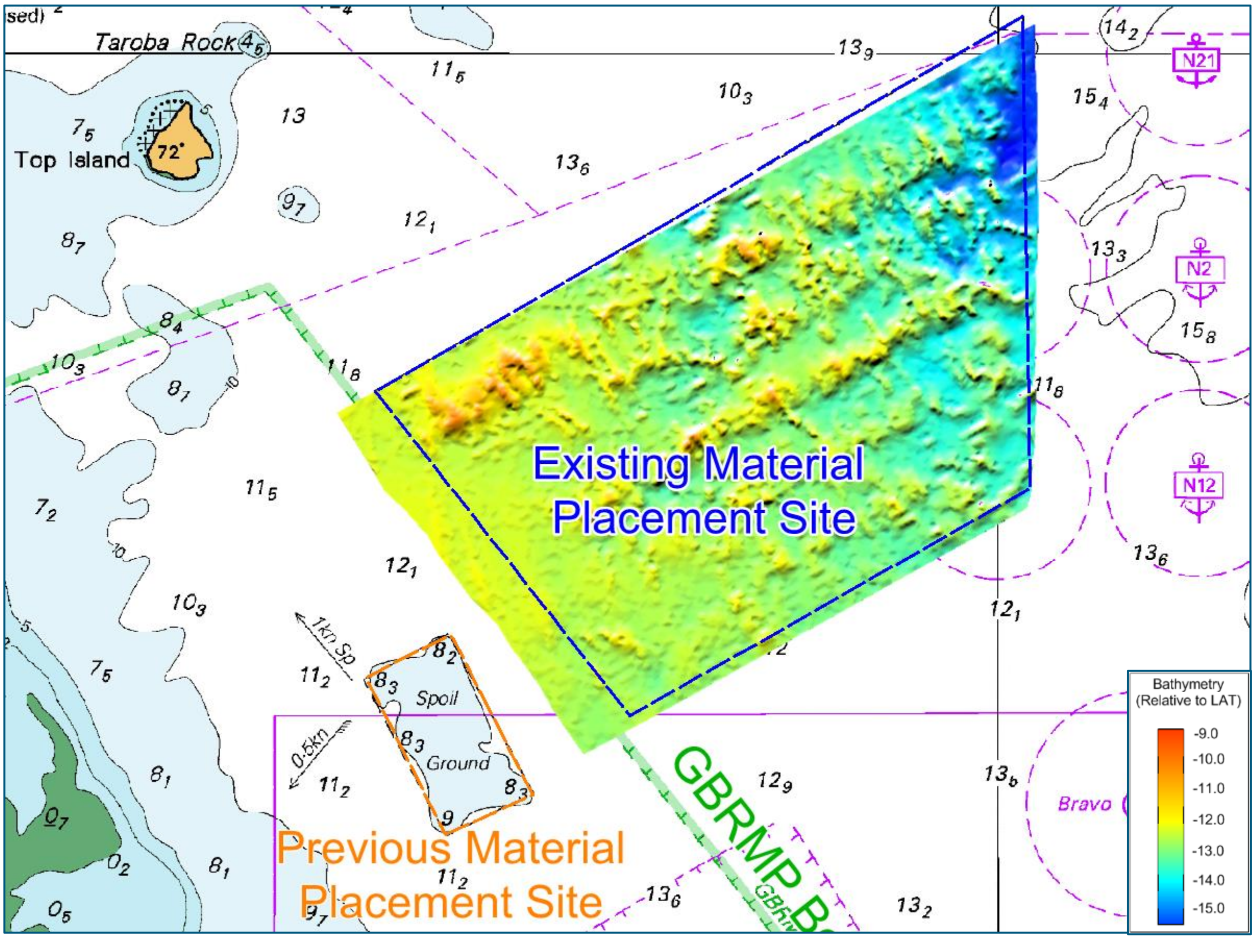


Figure 10. Bathymetric Survey Plan G290099 – 04/06/2010

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.

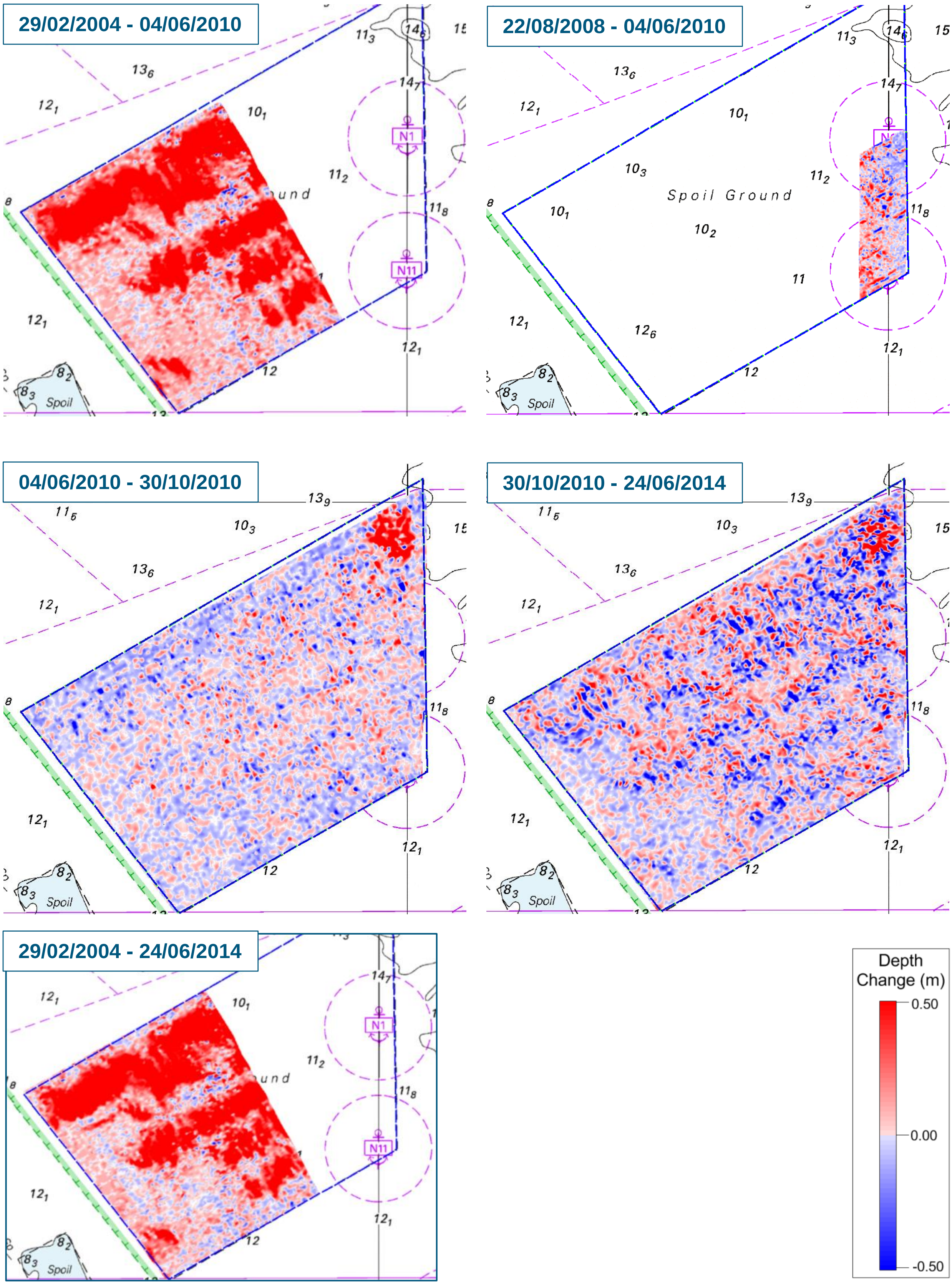


Figure 11. Volumetric differences between successive surveys – Existing Placement Site

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.

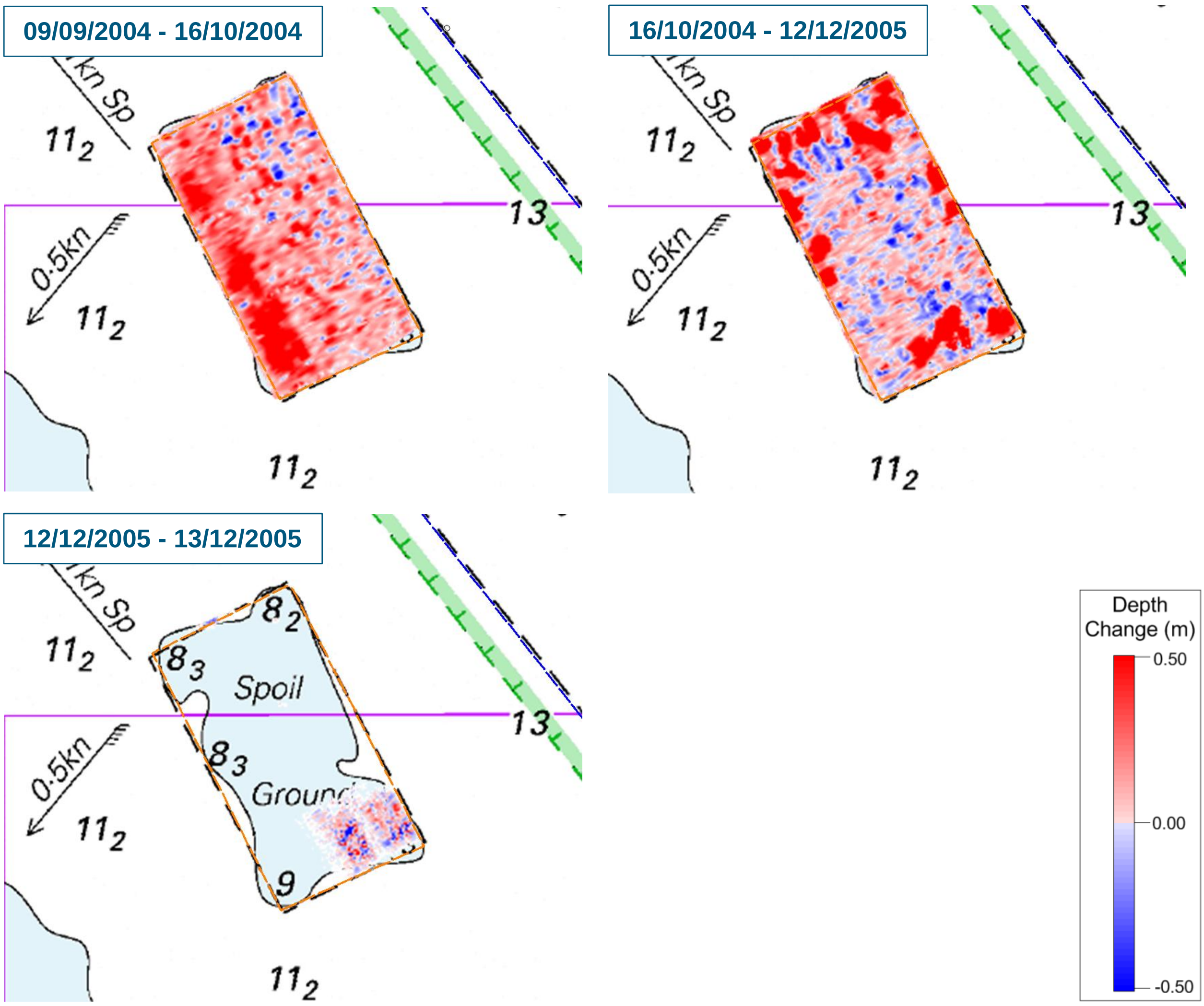


Figure 12. Volumetric differences between successive surveys – Previous Placement Site

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.

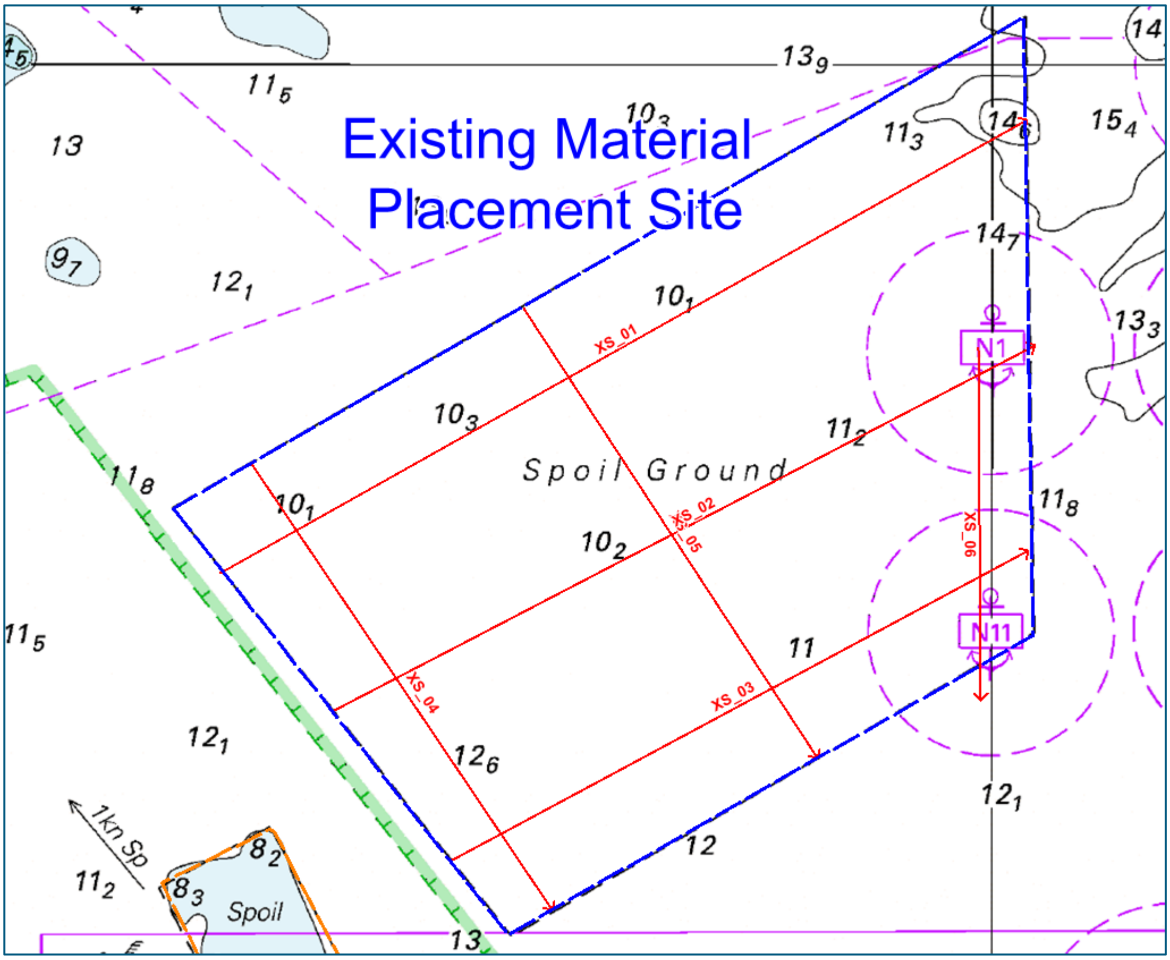


Figure 13. Cross-section Locations

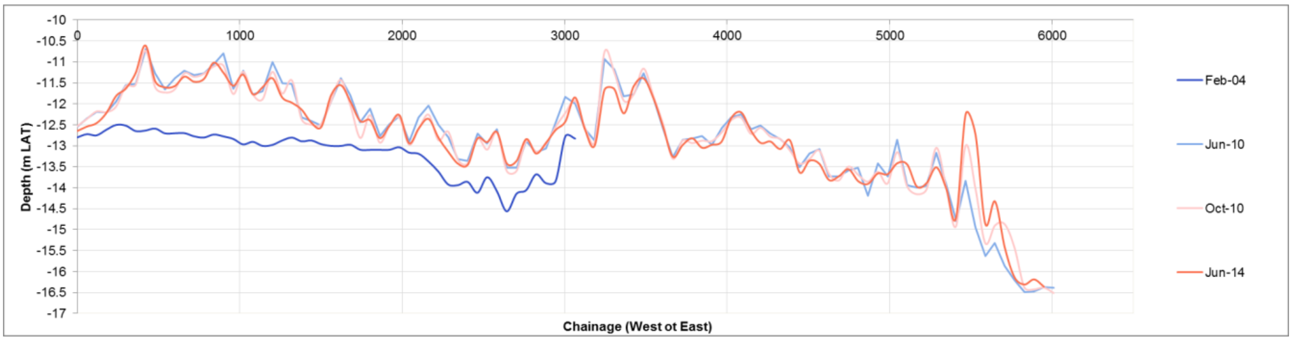


Figure 14. Long-sections showing change in bed elevation - Section 1 in Figure 13

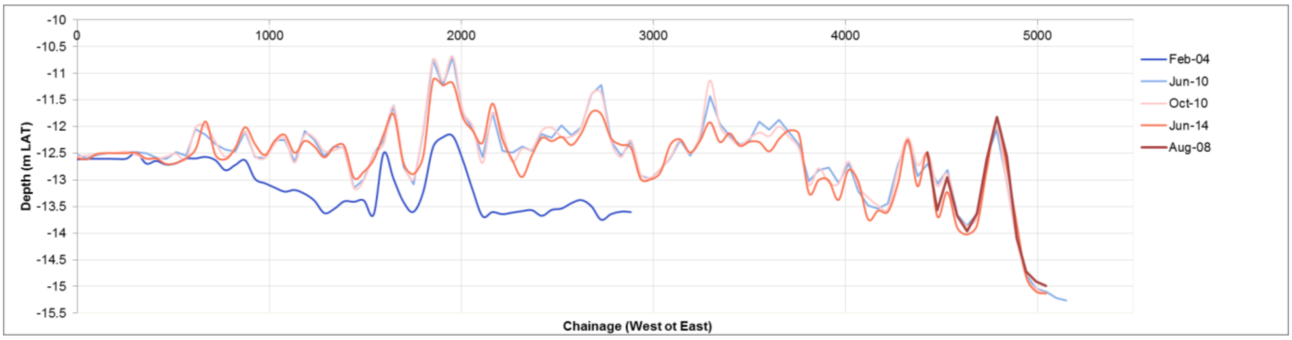


Figure 15. Long-sections showing change in bed elevation - Section 2 in Figure 13

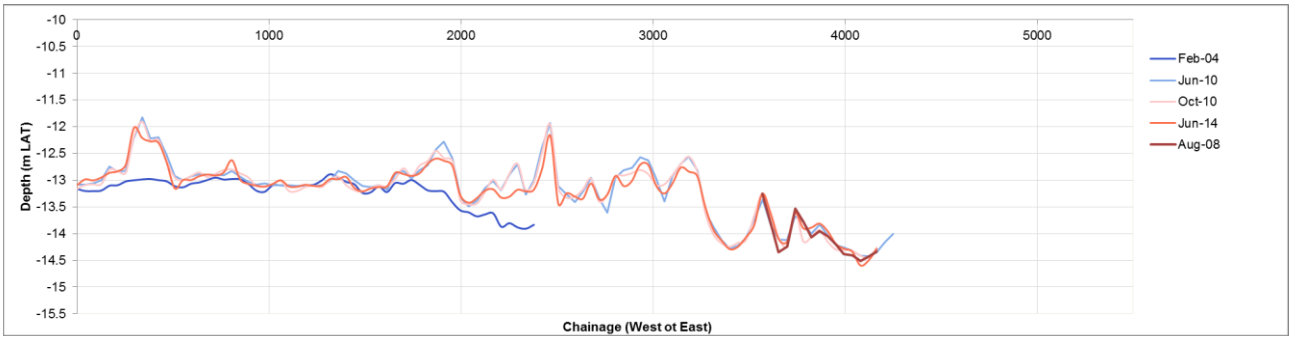


Figure 16. Long-sections showing change in bed elevation - Section 3 in Figure 13

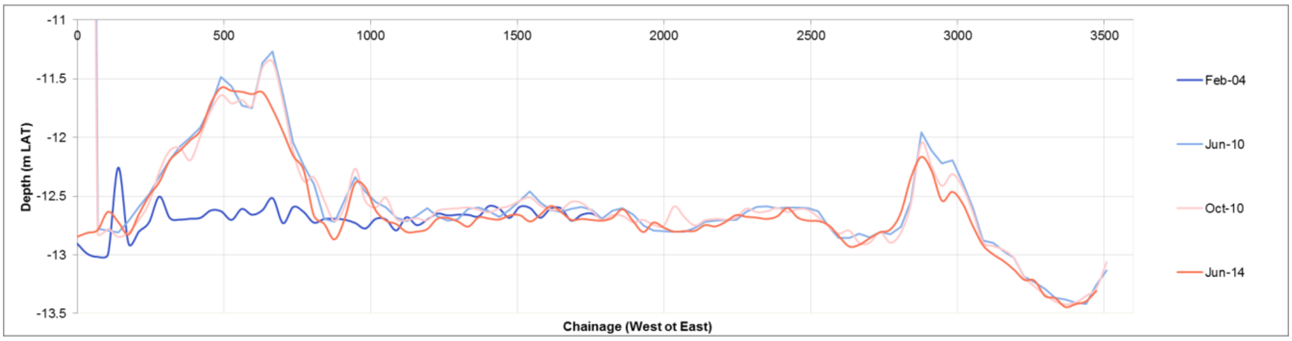


Figure 17. Cross-sections showing change in bed elevation - Section 4 in Figure 13

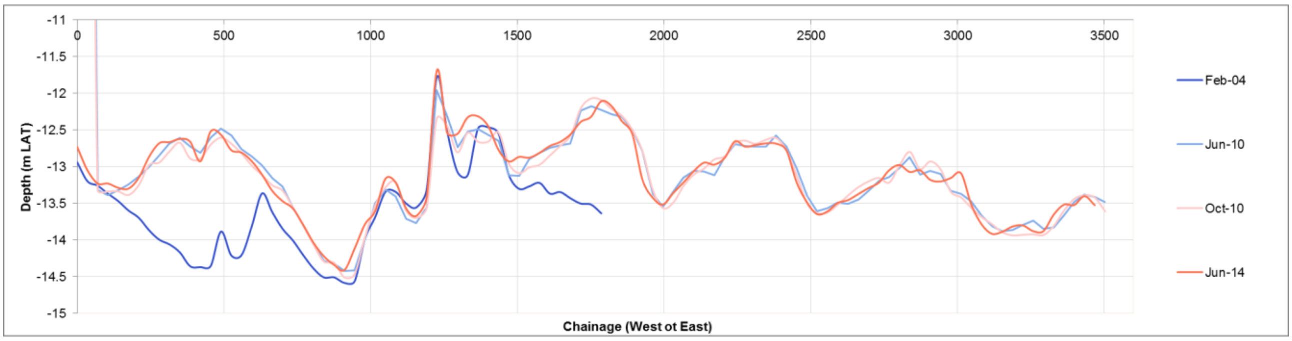


Figure 18. Cross-sections showing change in bed elevation - Section 5 in Figure 13

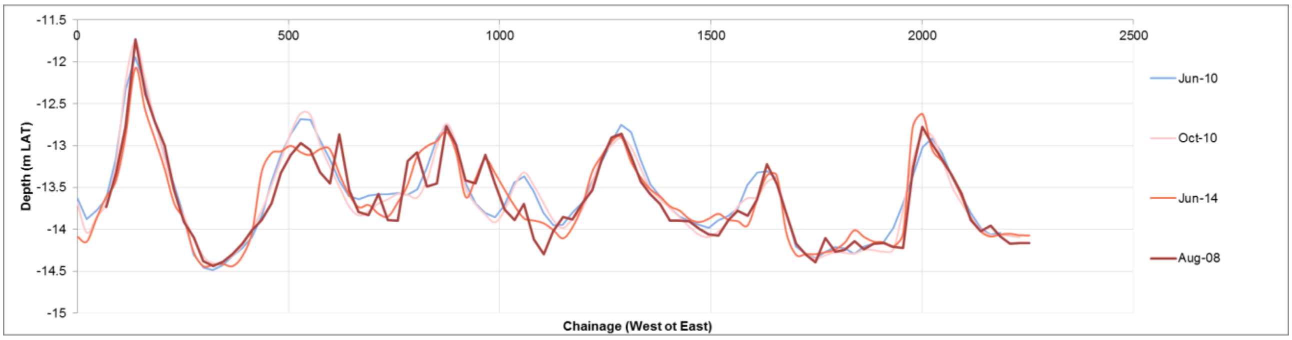


Figure 19. Cross-sections showing change in bed elevation - Section 6 in Figure 13

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.

APPENDIX C

Request for Additional Information on Marine Park permit application

25 September 2018

PORT OF
HAY POINT

File No.: P006822
Ref.: G40185.1

North Queensland Bulk Ports Corporation
PO Box 3340
NORTH MACKAY QLD
ATTN: Mr Kevin Kane (kkane@nqbp.com.au); Mr Damian Snell (dsnell@nqbp.com.au)

Dear Mr Kane and Mr Snell

Request for additional information on Marine Park permit application G40185.1

I am writing to you to request additional information pursuant to Regulation 88E of the *Great Barrier Reef Marine Park Regulations 1983* in relation to Marine Park permit application G40185.1.

Your application was publically advertised from 22 June 2018 through 21 August 2018. During this time the Great Barrier Reef Marine Park Authority (the Authority) received seven (7) submissions from individuals, businesses and the community. These submissions have been considered by the Authority and relevant concerns raised in these submissions have been detailed for further comment by you in **Attachment A**. The Authority also had the dredge plume modelling peer reviewed. Comments and suggestions by the reviewer are in **Attachment B**.

Please also note the Authority also commissioned a peer review of the following assessments: navigational maintenance; comprehensive beneficial reuse; comparative analysis of the technical report. It is anticipated this this review will be completed by 10 October 2018 and any issues requiring your follow up will be forwarded to you for a response.

As part of the assessment process, you are required to provide the following additional information to the Authority by 24 December 2018:

1) A report ('*Supplementary Information – Public Information Package Report*') providing a response that addresses each question/topic included in Attachments A and B. The report should include any necessary supplementary information such as modelling, engineering design drawings and any other data required to respond to the questions posed or commitments that you have made that may fall outside of the application yet are relevant to the issues raised in public submissions.
2) A response to the following further questions that have arisen from the assessment process to date:
    a. What is the anticipated volume of material to be dredged from that part of the departure channel within the Marine Park?
    b. Can you confirm where bed levelling activities are likely to occur in the Marine Park?
    c. In relation to the ERA Introduction and Synopsis document, the following items:
        i. Page 14 - a copy of the industry guidelines for avoiding, assessing and mitigating impacts on EPBC Act listed migratory shorebird species, mentioned on page 14?
        ii. Page 24 – a summary of the environmental management mechanisms
        iii. Page 41 – was there any visitation data for Brampton and Keswick Island or any tourism trends in the Mackay region more broadly?
    d. ERA – Appendix F – since that report was run, the scalloped hammerhead has been listed as conservation dependent under the EPBC Act and hence is a protected species within the Marine Park. Are you aware of that species being found in the vicinity of the proposed conducts?

Please note that if you do not provide the additional information by 24 December 2018 and do not request an extension of time, your application will be deemed to have lapsed. If you have any queries regarding the above please contact me on (07) 4750 0734 or email kirstin.dobbs@gbrmpa.gov.au

Yours sincerely,

Dr Kirstin Dobbs
Director
Environmental Assessment and Protection
25 September 2018

Attachment A - REQUEST FOR ADDITIONAL INFORMATION TABLE – Maintenance dredging at Port of Hay Point

Topic	Issues and comments raised in the submission	NQBP Response
Coal	Is there a potential for leaching from coal proposed to be dumped at the disposal site? What are the implications of this?	
Coal	Is there a potential for coal dumped at the disposal site to float ashore and contaminate turtle nesting beaches? What are the implications of this?	
Coal	Is there a potential for coal dumped at the disposal site to cause human health issues in relation to people swimming at beaches adjacent to the disposal site?	
Coal	Is there a potential for coal dumped at the disposal site to contaminate fish or invertebrates caught by recreational or commercial fishers?	
Coal	Is there a potential for coal dumped at the disposal site to be toxic to any marine wildlife including crocodiles?	
Coal	What distance might coal disperse after being dumped at the inshore and mid-shelf sites?	
Coal	How much coal is in the material to be dredged and dumped?	
Coal	How much of the coal in the material to be dredged and dumped is less than 400µm?	
Coal	Is there any data on the toxicity or bioavailability of leachate from coal dredged and dumped from the proposed activities?	
Coral	Do you expect a similar level of coral loss from the proposed dredging as experienced in 2006 (2-5 percent loss at islands up to 6km away_ as described in Smith et al. 2007?	
Economic impacts	What is the potential for effects from increased sedimentation/turbidity on the ongoing viability of coastal land based businesses?	
Water quality	What is the potential for increased sedimentation to affect, restrict and potential block the entry of tidal waters at Cabbage Tree Creek? How would you mitigate this risk?	
Water quality	What is the potential for changed patterns of current flows of seawater, possibly redirecting sediment and contaminants into Cabbage Tree Creek? How would you mitigate this risk?	
Water quality	What is the potential for water quality to have increased sedimentation/turbidity in Cabbage Tree Creek? How would you mitigate this risk?	
Water quality	What is the potential or acid sulphate soils to be released as a result of dredging? Where would those dredge plumes flow to?	
Water quality	How much fine silt is mobilised as a result of dumping? Where is it predicted to go? Will it flow north to the Whitsundays?	

Topic	Issues and comments raised in the submission	NQBP Response
Water quality	Does NQBP have any evidence that a reduction in water clarity in the Whitsundays was caused by the capital dredging and dumping in 2006/7?	
Water quality	How quickly is sediment likely to reach the Whitsundays? The public submissions estimated that this would take between 4.2 and 6.7 days.	
Water quality	How much sediment will be resuspended in each proposed placement area from tidal currents and surface wave action?	
Water quality	What is the effect of dumping fine silts in a placement area which is usually coarse sand?	
Water quality	Is there still an expected 36 per cent loss of material from the inshore dump site as happened in the 2006 capital dredging campaign?	
Water quality	Why can't an onshore solution to disposal be prioritised above the at sea proposals?	

Attachment B - REQUEST FOR ADDITIONAL INFORMATION – Maintenance dredging at Port of Hay Point

BRIEF OVERVIEW OF FINDINGS

The overall report is well written and the approach to the dredging conceptualisation and sediment resuspension scenarios are well considered and sound. The models applied have the necessary physics and ability to model the behaviour of suspended sediment concentrations associated with dredging operations and resuspension weather and tide events.

An issue however is that there is no description of the 3D grid that was employed in the hydrodynamic modelling. There is a description of the horizontal 2D grid but there is a lack of detail about the vertical grid. The only reference is from the general model description.

"In the horizontal plane an unstructured grid is used, while in the vertical domain a structured mesh is applied (DHI, 2017a)." S3.2 P26

The report does not provide a clear indication of vertical shear and the existence of any bottom boundary layer at the timescales presented so that the significance or not of these phenomena is accounted for. Tidal currents can have significant phase lags in the current profile and can at times have reversals from top to bottom. These are important considerations that will impact SSC behaviour.

Regardless of the adequacy of the 3D hydrodynamic modelling the sedimentary module applied only uses the depth averaged hydrodynamics not the full water column profile.

"As all of the natural SSC simulations were undertaken in two dimensional depth averaged mode, all of the dredging runs are presented as depth averaged to ensure they are directly comparable to the natural conditions." P96 S7.1

Assumptions of other aspects of the model setup are appropriate and reasonable however the boundary forcing for waves is less than optimal. The Mackay wave rider buoy to the north is used to force the deeper southern boundary.

The model in general does perform well in the validation exercises however there are some areas that should be improved in any future effort. The short period spiking in SSC at key resuspension events are not well replicated by the model.

The availability of data for validation and calibration of currents and SSC is limited and spread across a number of years rather than simultaneously made. It is recommended that a more comprehensive spatial and concurrent set of observations be made over periods long enough to capture all weather conditions that impact Hay Point are made to improve any future modelling and inform any dredging campaigns in the future.

As presented this report needs to provide further clarification and justification as there remains uncertainty over the adequacy of the 3D hydrodynamic model implementation and that:

"*The sediment transport model of natural conditions was setup in two dimensional depth averaged model as the underlying equations were all derived in two dimensions.*" S4.5 P66

The comment P96 S7.1: "As all of the natural SSC simulations were undertaken in two dimensional depth averaged mode, all of the dredging runs are presented as depth averaged to ensure they are directly comparable to the natural conditions." Assumes that SSC is uniform through the water column. This assumption needs rigorous validation.

Review Criteria Assessment

1. Baseline information on site/environmental conditions a. Is the baseline site/environmental data used within the model, and the period of time that it was collected, sufficiently representative of all possible weather/metocean events to reasonably predict sediment plumes, deposition and long term resuspension of sediment caused by dredging/disposal to be undertaken periodically over a ten year period?

The availability of data for validation and calibration of currents and SSC is limited at the Hay point location requiring access to data further north as far as Mackay and is spread across a number of years rather than a more preferable situation where multiple site, long term observations were made over a common period.

In spite of these limitations the available data is considered adequate and the model cal/val undertaken takes a sensible approach to deal with the staggered observations. The report covers the most important weather and metocean events required for planning the dredging/disposal over the 10 year period.

The existence of an offshore branch of the EAC in the outer lagoon has not been included in the modelling and is justified in this case as its impact on this exercise would be negligible.

Peer review recommendation	NQBP response
It is recommended that a more comprehensive spatial and concurrent set of observations be made over periods long enough to capture the most significant weather conditions that impact the Hay Point locale rather than further afield and are made to improve any future modelling and inform any dredging campaigns in the future.	

b. Have all seasonal and multi-year climatic variables been accounted for in the environmental data and represented in the model outputs?

The seasonal and multi-year climatic variables that are relevant to this study have been accounted for.

2. Modelling approach a. Is the numerical model used for the report adequate to predict sediment transport for the dredging/disposal activity and has it been sufficiently tested in similar applications?
Yes – subject to the implementation issues identified in 2b.

b. The majority of the hydrodynamic and sediment plume modelling conducted is 3D, however the long-term resuspension model is 2D depth averaged. Does this have a material effect on the prediction?

Peer review recommendation	NQBP response
Clarification is needed over the 3D grid specification and time stepping to resolve spatial and temporal resolutions. The technical requirement for 2 grid cells with the shipping channel does not seem to have been met in the outer channel. All SSC simulations (not just the long term re-suspension model) however use 2D depth averaged currents from the 3D model. The significance of this simplification needs to be	

ascertained. It may be acceptable in shallow regions however it may have ramifications in the deeper offshore areas such as the outer DMPA in 25-20m of water. A 2D depth averaged model run for the longer term 12 month run is deemed to be acceptable.	

c. Have all relevant impact pathways (e.g. SSC, sediment deposition etc.) been accounted for within the model?

Yes.

d. Are the assumptions reasonably conservative?

Yes.

3. Dredging description a. Is the predicted sediment composition reasonably supported?

Yes. Detail on the assumptions, approach was adequately provided and informed by analysis of sediment samples.

b. Is the dredging approach realistic in the context of the proposed dredging activity described in the Introduction?

Yes.

4. Model Calibration and Validation a. Is the level of accuracy demonstrated through calibration and validation reasonably adequate to reliably predict sediment transport from the dredging activity to be undertaken periodically over a ten year period?

Yes it is reasonably adequate.

Recommendation	NQBP Response
However some further investigation is warranted to improve model performance for short timescale spiking events and to improve wave boundary forcing.	

5. Results and Conclusions a. Are the conclusions supported by the results?

Yes.

b. Have any results or conclusions not been reported that may be relevant to impacts on the environment?

No

Consistency with GBRMPA Hydrodynamic Modelling Guidelines

Table 24. P94 of the report summarises the approaches the authors have taken to ensure the relevant requirements of the GBRMPA Hydrodynamic Modelling Guidelines have been met. It is the considered opinion of the reviewers that the self-assessment is accurate and adequate except in the following areas:

Comment	NQBP Response
The sediment transport models have used depth averaged current from the 3D hydrodynamic model rather than the required 3D current profiles.	

Comment	NQBP Response
Vertical shear and the existence of any bottom boundary layer are likely to be of significance in the controlling the behaviour of SSC. Tidal currents can have significant phase lags through the current profile and can at times have reversals at different water depths. These are potentially important considerations that will impact SSC behaviour, particularly for near bed processes at deeper disposal areas.	
The comment P96 S7.1: "As all of the natural SSC simulations were undertaken in two dimensional depth averaged mode, all of the dredging runs are presented as depth averaged to ensure they are directly comparable to the natural conditions." Assumes that SSC is uniform through the water column. This assumption needs more rigorous validation.	
The model does not perform well in simulating the observed short time-scale spiking during some weather events as acknowledged by the authors and some underestimation of waves is apparent.	
Need clarification that the wave-current interaction that improved the model performance was included in the SSC model runs not just for the validation run. See S4.41 P59.	
The baseline observational current data is borderline in adequacy due to its patchiness and being spread out over a number of years. The authors have however done well to bring it all together for the cal/val.	

Detailed Expert Assessment	NQBP Response
The overall report is well written and the approach to the dredging conceptualisation and sediment resuspension scenarios are well considered and sound. The models applied have the necessary physics and ability to model the behaviour of suspended sediment concentrations associated with dredging operations and resuspension weather and tide events.	
An issue however is that there is no description of the 3D grid that was employed in the hydrodynamic modelling. There is a description of the horizontal 2D grid but there is a lack of detail about the vertical grid. The only reference is from the general model description. "In the horizontal plane an unstructured grid is used, while in the vertical domain a structured mesh is applied (DHI, 2017a)." S3.2 P26	
S4.3.2 Figures 32-40 shows near bed, mid and near surface observations vs model however all	

Detailed Expert Assessment	**NQBP Response**
others throughout the report are mid column or depth averaged. Figures 32-40 do not provide a clear indication of vertical shear and the existence of any bottom boundary layer at the timescales presented. More highly resolved temporal plotting of the vertical profiles of observed and model current would be informative to indicate the significance or not of these phenomena. Tidal currents can have significant phase lags in the current profile and can have reversals from top to bottom. These are important considerations that will impact SSC behaviour however any appraisal of that remains lacking.	
Regardless of the adequacy of the 3D hydrodynamic modelling the sedimentary module applied only uses the depth averaged hydrodynamics not the full water column profile.	
"As all of the natural SSC simulations were undertaken in two dimensional depth averaged mode, all of the dredging runs are presented as depth averaged to ensure they are directly comparable to the natural conditions." S7.1 P96	
It is possible a pseudo 3D model effect is achieved by applying some form of profile that includes a bottom boundary layer, however the 3D hydrodynamic model should be providing the full dynamic water column structure. There is no information supplied on the details of the physical assumptions behind this component of the modelling just a reference to the commercial software. See Section S3.3 P27 & P32	
Assumptions of other aspects of the model setup are appropriate and reasonable however the boundary forcing for waves is less than optimal. The Mackay wave rider buoy to the north is used to force the deeper southern boundary. The buoy data would have been affected by shoaling and have limited swell propagation through Capricorn Channel than what would be incident at the southern boundary when that was significant.	
The model in general does perform well in the validation exercises however there are some areas that should be improved in any future effort. The short period spiking in SSC at key resuspension events are not well replicated by the model.	
The availability of data for validation and calibration of currents and SSC is limited and spread across a number of years rather than simultaneously made. It is recommended that a more comprehensive spatial and concurrent set of observations be made over periods long enough to capture all weather	

Detailed Expert Assessment	NQBP Response
conditions that impact Hay Point are made to improve any future modelling and inform any dredging campaigns in the future.	
As presented this report needs to provide further clarification and justification as there remains uncertainty over the adequacy of the 3D hydrodynamic model implementation and that:	
"The sediment transport model of natural conditions was setup in two dimensional depth averaged model as the underlying equations were all derived in two dimensions." S4.5 P66	

Specific Comments	NQBP Response
S2 P9: Long met and wave records. Currents patchy Jan-Apr 2017 off Mackay & Sep –Nov 2011-2012,	
S2.3 P9: "only one tidal current direction for each tidal cycle" inference only one tide – but it was still there it was just dominated by the wind. Would have also had an effect on the wave height	
P10 & Fig 8 P13: these do use coastal stations to influence the estimation of altimeter derived geostrophic currents. It is very much tide and wind dominated in the shallow coastal region. The Coral Sea circulation is more about the SEC forming the EAC along the outer GBR that can also drive a lagoonal branch along the lagoon inside of the outer reef matrix (Brinkman et al 2006)	
P14: Characterisation of east to west movement of cyclones is typical e.g. TC Hamish and many other tracks	
S2.9 P20: WQ & deposition 2014-17 by JCU – frequency of sampling unknown.	
P21 Fig 16: A better explanation of the box & whisker plots are needed – definition (fig 17 does better). Would like to see the sampling locations and depth of water for each site.	
P24: Replace 'reliability' with reliably	
P27 S3.3: Only a 2D horizontal grid specified for MIKE3 hydrodynamics =>3d for MIKE21 wave & MIKE3 Mud. Only the horizontal grid is defined – no mention of the vertical resolution	
P28 Fig 21: horizontal grid – 2 cells in the channel? 60m is the average size in the HTTH	
P29 S3.4: Nav charts and local surveys – why not Beaman 3DGBR 100m or now the 30m interpolated grid?	
P30 3.6: How were tides forced for the offshore/east boundary?	
P30 3.7: the use of a non-spatially varying wind isn't well argued nor evidence provided. SE trades	

Specific Comments	NQBP Response
correlate well over the entire region but sea breeze and storm/cyclone events are key events with more complex structure in any resuspension	
P30 S3.7: Wind stress units are missing. Wind stress is the square of the wind – so not sure why a linear interpolation was used. Are we talking about the wind stress coefficient here? Needs clarification.	
P30 S3.8: The justification for using the Mackay waverider buoy located at the northern end of the grid as a boundary condition has little evidence of adequacy for the southern and eastern model boundary.	
P32: 2D runs to keep the long term model runs manageable. There will still be boundary layers. Current variability within the profile – especially at the deeper off shore site in 25-30m is likely.	
P34: S4.3.1: water level validation 2 weeks over 2 periods Sep and Nov 2011 & 1 month in March 2017 TC Debbie – goes into April though (Mar 23-Apr 7 as an extratropical low)	
P36 Figs 24-29, 30-31: should also plot the residuals on the same plot scale to more easily identify the timing and amplitudes	
P40: high winds should include strong SE Trades not just TCs	
P36 Figs 32-40: Should show winds to assist with determination if residuals are from them – and again the residual currents – preferably along the tidal principal component directions	
Fig 41-46: Near bed & near surface - what height? Are the top line plots current residuals? Not documented. Would be good to see a few plots showing the vertical profile from both the model and observations on a shorter time frame – e.g. turn of tide	
P59 S4.4.1: Were wave-current interactions included in the final dredge model?	
Under-representing waves probably due to the use of Mackay waverider as forcing – waves would have shoaled at that location so when applied to the southern boundary forcing it is likely to be too weak.	
P66 S4.5: Sediment model is 2D depth averaged	
P69 table 19: Victor Island model is lower than obs. Obs higher at most locations except round Top Island – not all resuspension events replicated in the model. Concludes the short duration wind wave spikes are not replicated – just works on average	

Specific Comments	NQBP Response
P89 S5.3: PSD acronym needs defining – only apparent in Fig67	
P93: Results of water column effect of dispersion and advection suggested no different from a uniform release throughout the water column – but no evidence provided	
P96 S7.1: "As all of the natural SSC simulations were undertaken in two dimensional depth averaged mode, all of the dredging runs are presented as depth averaged to ensure they are directly comparable to the natural conditions	