REPORT

Maintenance Dredging Strategy for Great Barrier Reef World Heritage Area Ports: Technical Supporting Document

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Executive Summary

As the world's most extensive coral reef ecosystem, the Great Barrier Reef (GBR) is a globally outstanding and significant entity. Environmental values include the marine habitats, which need to be protected and maintained within the Great Barrier Reef World Heritage Area (GBRWHA), as well as the key marine flora and fauna communities, which inhabit these environments. Reef 2050 is a key component of the Australian and Queensland Government's response to the recommendations of the UNESCO World Heritage Committee for the continued World Heritage listing of the GBR. It addresses the findings of the Great Barrier Reef Marine Park Authority's (GBRMPA) Outlook Report 2014 and builds on the comprehensive strategic assessment of the World Heritage Area and adjacent coastal zone.

Reef 2050 contains several actions relating to the management of maintenance dredge material. The Department of Transport and Main Roads (TMR) has been tasked with completion of action WQA16, for which the main deliverable is the development of a State-wide coordinated maintenance dredging strategy which:

- Identifies each port's historical dredging volumes and likely future requirements and limits;
- Identifies appropriate environmental windows to avoid coral spawning, seagrass recruitment, turtle breeding and weather events;
- examines opportunities for the beneficial reuse of dredge material or on-land disposal from maintenance activities; and
- establishes requirements for risk-based monitoring programs.

This Technical Supporting Document provides technical support for the overall Strategy by dealing with each of the points noted above. This document focusses on the GBRWHA ports, but recognises the influence of maintenance dredging at other Queensland ports that are not adjacent to the GBRWHA but are also part of the annual maintenance dredging campaign by the TSHD Brisbane. The document, therefore, considers historical maintenance dredging volumes and likely future requirements at all recognised Queensland Ports. The development of this report has included: a comprehensive review of a significant body of relevant documentation; data analysis and interpretation; and a number of discussions, meetings and workshops with various government and non-government stakeholders.

The Strategy relates exclusively to maintenance dredging, as opposed to capital dredging. Maintenance dredging is a vital component of port operations as the depths of some channels, berths and swing basins may reduce over time due to natural sedimentation processes. Consequently, dredging is required to maintain designated depths to ensure ships can efficiently access port infrastructure and ports have an obligation under the QLD Transport Infrastructure Act to provide safe access to their facilities.

Maintenance dredging has been carried out at ports within the GBRWHA since the ports were established, with most dredge material being deposited in approved offshore placement areas. The vast majority of maintenance dredging involves the removal and disposal of uncontaminated silts.

Queensland ports located within the GBRWHA reside in a variety of different coastal environments and are subject to variability in local metocean conditions. As a result of these variabilities, each port encounters varying rates of sedimentation which is typically driven by a number of key coastal processes. For the majority of the GBR inner-shelf region (and, in turn, the GBR ports), sediment transport and sedimentation during typical conditions is primarily a result of wave and current induced sediment resuspension.

In this study, cyclone induced waves and currents have been found to play an important role in the supply of sediment to the inner shelf through the erosion and advection of sediments from the mid-shelf. Hence, and contrary to general perceptions, catchment runoff is not the sole source of sediment supply to the inner shelf of the GBR Lagoon. There is a significant body of evidence indicating that at the majority of

GBR ports, catchment runoff plays a low to negligible role in either feeding or driving sedimentation processes at these ports. GBR ports are either located too far from the major river systems or are located adjacent to rivers with relatively negligible sediment discharge (with the exception of Port Alma which has a relatively modest maintenance dredging requirement due to the scale of the port).

Any direct contributions from catchment runoff sediment loads will, in most coastal areas of the inner shelf, be overwhelmed by the magnitude of natural wind, wave and current-driven resuspension as the primary contributors towards elevating levels of turbidity. Consequently, whilst reducing catchment sediment runoff would have significant benefit generally, it will not significantly alleviate the volume, frequency and overall need for maintenance dredging at the vast majority of GBR ports over the duration of the Strategy.

The above statement does not apply to a number of non-GBR ports, such as Brisbane and Bundaberg where catchment runoff plays a much more significant role in driving sedimentation processes.

Applications for approval of ocean disposal of maintenance dredge material are subject to rigorous studies justifying why sea disposal is the most appropriate solution from an environmental, social and economic perspective. The relevant determining authority considers sea dumping applications and decides whether to grant the approval. If approval is granted, it is typically subject to conditions, which may include an approved environmental management plan, environmental site supervision and monitoring of water quality, and other factors throughout the dredging campaign.

The determining authority has the ability to grant long-term permits for the sea disposal of maintenance dredge material at each of the ports. Applications for long term maintenance dredging permits are favoured by port operators as they provide for an efficient approvals process and allow for certainty around future maintenance dredging requirements and, therefore, the efficient operation of the ports. It is noted that long-term maintenance dredging permits need to be site-specific and designed carefully in order to be functionally viable.

The maintenance dredging volumes over the last 10 years can be used as an indicator of the likely range and frequency of future maintenance dredging requirements at the ports. However, for a number of reasons, including the variability of processes that drive sedimentation, it is not possible to use the historic volumes alone to accurately predict the future requirements. As such, it is suggested that future volume estimates should take all reasonable factors into account and, even so, flexibility should be retained due to the risk of extreme situations, such as the occurrence of cyclones as well as long term climatic variations (e.g. La Niña effects).

There are a number of proposed capital dredging projects, which have the potential to increase future maintenance dredging at certain ports. However, due to limitations imposed on future capital dredging and a focus on mainly deepening of existing previously dredged areas, the overall increase in maintenance dredging is expected to be relatively minor and unlikely to change the typical frequency of maintenance dredging. The ports have proactively adopted a number of strategies to minimise maintenance dredging due to the high costs and approval requirements for dredging activities. There are limited options that GBR ports can adopt to try and reduce future maintenance dredging requirements given that the natural processes driving the need for maintenance dredging and sediment availability are not expected to alter significantly in the future.

A review of maintenance dredge material disposal opportunities to land has determined that significant constraints exist in comparison to the current practice of unconfined sea disposal. These constraints primarily relate to: the predominance of silts and clays within the maintenance dredging areas (which possess poor engineering qualities that limits the potential for reuse); the reoccurring large volumes of dredge material involved; direct and indirect impacts to the coastal environment; the general unavailability of large areas of nearby land for placement and dewatering of dredged sediment; the additional requirements necessary to obtain permits for land disposal (compared to sea disposal); and the economic and environmental impacts of additional processing and management requirements.

The arguments for preferential disposal of material from maintenance dredging on-land and for the selection of non-dispersive oceanic sites when material is placed at sea appear to be driven by the general view that disposal of maintenance dredge material at sea at dispersive sites is significantly increasing ambient levels of suspended material and the discontinuation of these practices will result in a reduced potential for environmental harm to the GBR ecosystem. Maintenance dredging volumes make up a negligible percentage of the overall sediment supply in the GBR Inner Lagoon. Materials from maintenance dredging are natural materials existing within the active sediment system and should not be considered as 'spoil', but rather be considered an integral part of the natural ecological system. Hence, the consequence of net removal of natural material from the active sediment system to be placed on land needs to be carefully considered, particularly where this material may otherwise provide net environmental benefit.

One beneficial reuse option that should be considered in the management of maintenance dredge material is to retain the material within the active natural system and, where possible, to mimic natural processes through strategic placement that benefits the natural environment (sustainable relocation). This option is consistent with worldwide dredging best practice (i.e. PIANC's Working with Nature approach). There are some legislative and regulatory challenges associated with such an approach. However, these obstacles have been overcome elsewhere with significant environmental and operational benefits.

Maintenance dredging activities have the potential to increase suspended sediment concentrations in the water column that in turn can reduce the productivity of pelagic and benthic primary producer communities. When prioritising the timing and management of maintenance dredging activities, port managers should assess the potential risks to these communities, the environmental windows (i.e. times where the communities are most susceptible) and any major storm or cyclone events that have preceded maintenance dredging.

From available measured data (not modelling) it can be confirmed that the plume intensities and extents during maintenance dredging and disposal are relatively low and localised, and often dissipate within hours of the dredging and/or disposal activities. Importantly, the environmental monitoring centred on detecting any potential environmental harm at sensitive receptor locations (e.g. seagrass meadows) has confirmed that key thresholds for maintaining health have not been breached by maintenance dredging activities.

The preliminary risk assessment has indicated that when the likelihood and consequences of various impacts were combined, maintenance dredging and disposal in Queensland's ports is unlikely to increase risk to key marine fauna or flora, or the habitats that support their life cycles. The risk level across the ports was Low. The only Medium risk identified during maintenance dredging for flora and key habitats (coral) was at the Port of Townsville. This Medium risk has been identified previously and management measures are in place to mitigate harm.

The risk assessment was supported by a range of targeted monitoring programs, centred on the same dredge plant (the TSHD Brisbane), which provided a firm foundation for informing the risk assessment across all GBR ports. Importantly, maintenance dredging and disposal plume intensity and extent at the ports that require frequent, and larger scale volumes, has been a key focus of scientific assessments. The outcomes of this work have demonstrated that maintenance dredging does not result in persistent environmental harm, and plumes travelled up to 1.5km and dissipated to background concentrations within two hours after cessation of the dredging or disposal activity. Based on the scientific observations, the actions of maintenance dredging and disposal are not considered a stressor of primary importance for conserving key flora and fauna species, and are not a threat to broader heritage and biodiversity.

However, it remains prudent for Queensland Ports to thoroughly assess the risks in relation to their maintenance dredging programs annually and take into consideration social and environmental processes of relevance.

With respect to addressing the Reef 2050 WQA16 actions, the following observations made in this report are particularly relevant:

Identifies each port's historical dredging volumes and likely future requirements and limits;

Historical maintenance dredging volumes provide a record of past maintenance dredging volumes and frequency at the ports but cannot be used to completely predict future requirements. A detailed understanding of coastal processes, the key drivers behind sedimentation, and the source of the sediment which deposits at the ports is important in understanding and explaining the historic and ongoing requirement for maintenance dredging. Based on historical volumes and expected future increases due to port expansion projects, an indication of average future maintenance dredging volumes per campaign and the typical frequency of dredging is provided in **Table i**.

Table i: Estimated average future maintenance dredging volumes per campaign and frequencies for Queensland ports.

Port	Average Campaign (m^3 / campaign)	Typical Maintenance Dredging Frequency (years)
Brisbane	530,000	1
Bundaberg	80,000	1
Gladstone	261,500	1
Port Alma	30,000	5
Hay Point	300,000	3
Mackay	90,000	3
Abbot Point	<25,000	20
Townsville	400,000	1
Lucinda	0	0
Mourilyan Harbour	0	0
Cairns	440,000	1
Cooktown	45,000	10
Cape Flattery	0	0
Quintell Beach	0	0
Weipa	635,000	1
Karumba	120,000	4

Identifies appropriate environmental windows to avoid coral spawning, seagrass recruitment, turtle breeding and weather events;

Best practice planning involves the timing of maintenance dredging to avoid periods of high risk or greater stress and critical or sensitive phases of the life cycle of marine species (i.e. the use of environmental windows). Therefore, consideration for the adoption of environmental windows is an important management consideration, they are appropriate when risk-based assessments identify the need. Examples of where environmental windows have been implemented include the Ports of Abbot Point and Hay Point, where as part of the long-term dredge management plans the Ports have committed to undertaking maintenance dredging activities outside of the turtle nesting season (NQBP, 2009; NQBP, 2010). If adopted, it is essential that those environmental windows be of an appropriate spatial and temporal scale to minimise the potential for ecological harm, but not unnecessarily constrain dredging activities.

Environmental windows should not be considered synonymous with periods of no dredging (albeit that there may be occasions when dredging may not be permitted within part of or all of the environmental window period as determined by the risk based approach) but rather a period during which environmental communities are most susceptible.

Environmental windows should be implemented when there is quantifiable and/ or perceived risk, recognising that in many instances stakeholder concerns and precautionary approaches are an important consideration, particularly in relation to species of high conservation value. If dredging is, however, required within an environmental window and a risk has been identified, then appropriate impact mitigation strategies should be adopted.

Examines opportunities for the beneficial reuse of dredge material or on-land disposal from maintenance activities; and

Opportunities for on-land disposal of dredge material are generally constrained and can lead to an increased risk of environmental harm. Development of port and regional sediment distribution maps, and sediment budgets, would assist with an understanding of sediment movement pathways and deposition areas for different sediment types and would facilitate options for beneficial reuse of maintenance dredge material within the natural marine environment. Opportunities for environmental rehabilitation within the GBRWHA are very limited due to the high conservation value of coastal fringe land and lack of degraded ecosystems providing opportunities for restoration.

Establishes requirements for risk-based monitoring programs

The National Assessment Guidelines for Dredging (DEWHA, 2009) sets out the framework for sediment quality assessment and permitting of unconfined ocean disposal of dredge material (NAGD, 2009). These guidelines are actively used by GBR ports, and form the basis of their approvals process. Each port in Queensland is committed to a tailored environmental risk management approach as an essential part of the planning and implementing of maintenance dredging. This process is guided by, and recorded within, the port management bodies Environmental Management Systems (EMS) that logs all environmental aspects, hazard and/or risk to the environment. A key component of this process is to define risk-based monitoring programs, management responses and opportunities for improvement (i.e. in accordance with ISO 14000). This management approach is considered world's best practice and ensures potential impacts on the environment are minimised and regulatory compliance is achieved.

The risk-based monitoring programs developed by Queensland Ports are reviewed annually, and provide a basis to assess risks associated with future maintenance dredging and the need for adaptive management during dredging. A series of management actions are then identified and incorporated into a maintenance dredging Environmental Management Plan (EMP).

This process is a fundamental component of the adaptive management approach for ensuring risk-based management of Queensland Ports is proactive and founded on the most current scientific understanding of each port marine ecosystem.

Queensland Ports will continue to lead and contribute to the development of environmental and coastal process based scientific investigations and monitoring programs. Queensland Ports have identified the need to understand the sediment dynamics within their region as a prerequisite to allow adaptive long-term environmental management, supporting sustainable development and minimising environmental harm to the ports and surrounding areas. The outcomes of such works help to inform how natural environmental variables behave, and how they interact/influence environmental values. Importantly, the outcomes of these programs will feed into the Queensland Ports annual risk assessments, helping to refine risk ratings and the risk-based monitoring that is required to ensure the environmental values are maintained into the future.

Cumulative impacts of the proposed maintenance dredging program are also taken into consideration by each of the ports in Queensland. This is particularly important if major natural perturbations occur (i.e. cyclones, flooding, etc). Cumulative impacts may also be of relevance when port development and channel upgrades are being executed, and each port needs to place these activities in context with the occurrence of the proposed maintenance dredging and the likelihood of interacting with sensitive environmental values.

1 Introduction

1.1 Context

In March 2015 the Australian and Queensland Governments jointly released the Reef 2050 Long-Term Sustainability Plan (Reef 2050) for the Great Barrier Reef World Heritage Area (GBRWHA). This document provides the overarching framework for protecting and managing the Great Barrier Reef (GBR) from 2015 to 2050.

Reef 2050 is a key component of the Australian Government's response to the recommendations of the UNESCO World Heritage Committee for the continued World Heritage listing of the GBR. It addresses the findings of the Great Barrier Reef Marine Park Authority's (GBRMPA) Outlook Report 2014 and builds on the comprehensive strategic assessment of the World Heritage Area and adjacent coastal zone. Reef 2050 focusses on actions intended to address key threats and directly boost the health and resilience of the GBR.

A list of key relevant terms, abbreviations and acronyms used in this report are shown in **Table 1**. A more comprehensive listing is provided in **Appendix A**.

Table 1: Key relevant terms, abbreviations and acronyms used in report

Term, abbreviation or acronym	Meaning
AMSA	Australian Maritime Safety Authority
Capital dredging	The removal of natural seabed to establish or increase depth and/or width of shipping channels, swing basins and berth pockets.
EHP	Department of Environment and Heritage Protection
GBR	Great Barrier Reef
GBRMPA	Great Barrier Reef Marine Park Authority
GBRWHA	Great Barrier Reef World Heritage Area
GPC	Gladstone Ports Corporation Limited
Maintenance dredging	Removal of sediments that accumulate in existing channels, swing basins and berths to enable ongoing use of the ports.
NQBP	North Queensland Bulk Ports Corporation Limited
Ports North	Far North Queensland Ports Corporation Limited
PoTL	Port of Townsville Limited
QPA	Queensland Ports Association
Reef 2050	Reef 2050 Long-Term Sustainability Plan
TMR	Department of Transport and Main Roads
TSHD	Trailing Suction Hopper Dredge
WHC	World Heritage Committee of UNESCO

1.2 Reef 2050

Reef 2050 contains a number of actions relating to 'reducing the impact of ports and dredging'. These actions have already had an impact on several proposed Queensland port dredging projects as Reef 2050 includes a directive to ban sea-based disposal of capital dredge material within the GBRWHA and to mandate the beneficial reuse or on-land disposal of port-related capital dredged material where it is environmentally safe to do so. This has since been enshrined in the Sustainable Ports Development Act 2015 (Qld) which further limits capital dredging to nominated priority ports.

In addition to restrictions placed on the disposal of capital dredge material, Reef 2050 also contains several actions relating to the management of maintenance dredge material. These are listed in **Table 2**.

Table 2: Reef 2050 actions relevant to maintenance dredging

Reef 2050 Action Reference	Description
WQA15	Develop and implement a dredging management strategy that includes: • an examination and, where appropriate, a potential pilot program to evaluate different treatment and re-use options for managing dredge material • measures to address dredging-related impacts on Reef water quality and ecosystem health • a 'code of practice' for port-related dredging activities
WQA16	Develop a State-wide coordinated maintenance dredging strategy which: • Identifies each port's historical dredging volumes and likely future requirements and limits • Identifies appropriate environmental windows to avoid coral spawning, seagrass recruitment, turtle breeding and weather events • examines opportunities for the beneficial reuse of dredge material or on-land disposal from maintenance activities • establishes requirements for risk-based monitoring programs
WQA17	Understand the port sediment characteristics and risks at the four major ports and how they interact and contribute to broader catchment contributions within the World Heritage Area.

1.3 Reef 2050 (WQA16)

The Department of Transport and Main Roads (TMR) has been tasked with completion of action WQA16, for which the main deliverable is the preparation of an overarching Maintenance Dredging Strategy to inform the management and maintenance dredging at Queensland Ports (TMR, 2015a). This document, therefore, focusses on the ports located within the GBRWHA, but also recognises the influence of maintenance dredging at other Queensland ports that are not adjacent to the GBRWHA but are part of the annual maintenance dredging campaign by the Trailer Suction Hopper Dredge (TSHD) Brisbane, which undertakes the vast majority of maintenance dredging operations at all Queensland ports. The document, therefore, considers historical maintenance dredging volumes and likely future requirements at all recognised Queensland Ports.

The Reef 2050 Action WQA15 will be addressed as part of supplementary works while WQA17 will be addressed by individual ports and relevant agencies, with TMR as the current nominated lead.

1.4 Purpose of this report

The purpose of this report is to provide a comprehensive review of all relevant technical issues and available scientific data associated with maintenance dredging activities within the GBRWHA, in order to address the Reef 2050 WQA16 actions relevant to maintenance dredging. The observations of the report will be used to inform the overarching Maintenance Dredging Strategy for GBRWHA Ports, which is being prepared by TMR.

1.5 Maintenance Dredging

1.5.1 Background

Maintenance dredging involves the removal of natural sediment (e.g. clay, silt and sand) that has settled within berthing pockets, swing basins and shipping channels as a result of natural sedimentary processes. Maintenance dredging is commonly undertaken using either hydraulic (e.g. suction) or mechanical (e.g. digging, grab) methods to remove the sediment, which is then either placed in a hopper/barge for sea disposal and/or pumped ashore. The nature of removal is generally determined through a consideration of: the nature of the materials to be dredged; availability of suitable plant; availability and location of suitable disposal areas; the environmental conditions at the location (e.g. swell); and potential environmental impacts.

Due to maintenance dredging materials being generally loose in nature (recently deposited sediments), hydraulic dredging using a Trailing Suction Hopper Dredge (TSHD) is generally used for the majority of maintenance dredging operations, apart from areas where access is limited, in which case a backhoe, grab or cutter suction type dredger may be utilised.

1.5.2 Navigational Requirement

The physical dimensions of the berth, basins and channels are determined by: the type, size, draft and frequency of design vessel(s) accessing the ports; meteorological/oceanographic (metocean) conditions at the ports; as well as a number of physical characteristics (such as nature of seabed, aids to navigation, channel side slopes, etc.). The minimum dimensions of the channel (both horizontal and vertical) are determined through a detailed assessment of empirical recommendations (e.g. PIANC, 2014) and detailed design and modelling (hydrodynamic, underkeel clearance (UKC) and vessel simulation). The primary objective is to provide the most efficient channel dimensions for the vessels which are expected to visit the port. The channel, basin and berth horizontal dimensions and vertical "declared depths" are determined through this process and signed off by the statutory authority (normally by the Regional Harbour Master). Ports undertake regular bathymetric surveys to ensure declared depths are current.

Natural sedimentary processes tend to reduce both the horizontal and vertical dimensions of the channels, basins and berths. Where there is evidence that the declared dimensions and depths of a dredged area have been reduced, the Harbour Master will apply vessel depth and/or operating restrictions to ensure that navigational and berthing safety is maintained at all times.

Natural sedimentation between maintenance campaigns is accommodated through allowing additional "insurance depths" below the declared depth with greater allowances where greater levels of sedimentation have been experienced, refer **Figure 1**. Interception methods may also be used to deflect and/or trap sediments prior to entering the shipping channels (groynes, insurance trenches, etc.). It is important to note that these insurance depths, interception methods and other similar methods do not generally reduce the quantity of maintenance dredging required but, rather, increase the duration between required maintenance dredging campaigns.

In order to achieve the dredge design depths, some degree of *overdredging* is expected/undertaken below the design depths, refer **Figure 1**. The amount of overdredging depends on the type and nature of equipment used for removal of material. However, modern dredgers are now equipped with very precise equipment and instrumentation and so the volume of overdredging is generally less with such dredgers.

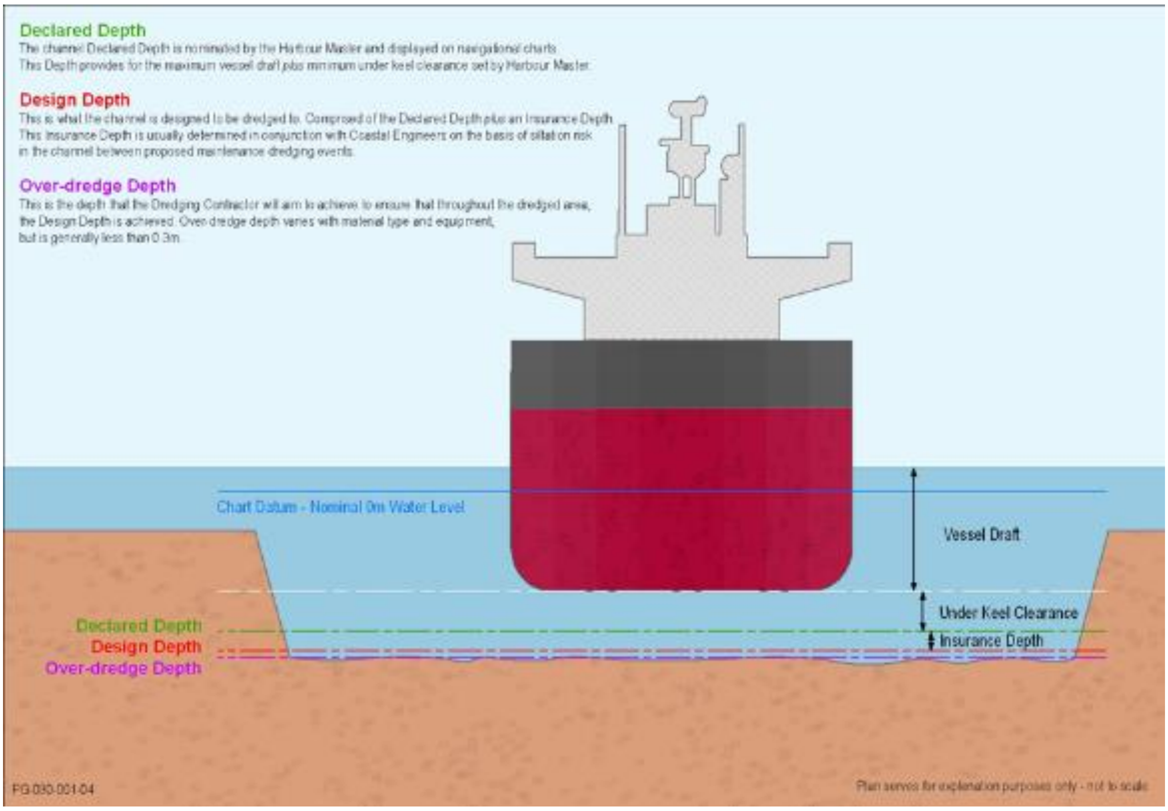


Figure 1: Typical shipping channel showing relative depths (Source: QPA 2015)

1.5.3 Economic, Social and Community Need

Shipping is the most efficient means to transport products from an economic, energy efficient and environmentally friendly perspective (PIANC, 2001). Ports play a key role in interfacing between landside (road/rail) and water (shipping) modes of transport and, from an economic perspective, there is always a desire to reduce the landside modes as much as possible in order to take advantage of the more efficient water modes of transport. The cost per tonne of material transported also reduces with the larger the shipment parcel.

Hence, a reduction in channel capacity (resulting in a reduction of the cargo volume) not only increases the cost of transport of those goods but also increases the supply chain uncertainty translating to both increased cost and supply uncertainty for the end user. Because it is a key link in the entire supply chain, if a port is not operating efficiently, neither will the remainder of the supply chain and additional costs will be incurred and suppliers may look for alternative, more efficient, means to transport their goods.

However, alternative means may not always be available or practical. Suppliers who have invested heavily in considerable infrastructure (e.g. factories, wharf facilities) will continue to operate inefficiently, if need be, in order to sustain their business. This may involve using less (economic, energy and environmental) efficient means of transport (e.g. trucks) to transport their product (e.g. to market or to alternative more distant port facilities). There is also considerable pressure on governments to assist and subsidise inefficient ports in order for them to compete with more efficient ports, especially if those inefficient ports are supporting vulnerable regional communities.

An efficient port, on the other hand, will sustain not only itself but also the community and surrounding regions (AECOM, 2013), with less dependence on additional financial support. Ports play a key role in the direct and indirect prosperity of their community and maintenance dredging plays a key role in maintaining that efficiency.

Ports also need to be very mindful of changes in the economic climate in which they operate and be able to respond to such changes. These changes are generally outside their control, such as changes in shipping types and global market demands. Often this may result in a need to deepen and/or reconfigure their navigation and infrastructure assets in response to such changes which may lead to both capital and additional associated maintenance dredging requirements. Failure to do so, once again, leads to port inefficiency, along with the associated economic and social (and environmental) impacts associated with such inefficiency, as well as a reliance on less efficient, older ships.

1.5.4 Environmental Sustainability

Ports need to develop and operate in an environmentally sustainable way and they also need to manage their maintenance dredging activities in a similar manner. This is not only reducing or avoiding any direct or indirect impacts on the environment associated with dredging and disposal operations but also: (1) ensuring that any required maintenance dredging operations are undertaken as efficiently as possible to avoid excessive vessel emissions; and (2) recognising that maintenance dredge material is not simply spoil but rather an integral part of the natural environment and care needs to be taken to avoid any long term impacts on the environment.

Where material has entered the berths, basins and channels through natural sedimentary processes and intercepted the natural transport of sediment, removing this material from the system has the potential to lead to longer term impacts, such as erosion of down-drift natural assets (beaches, wetlands, mangroves, etc.). Maintenance dredging, therefore, needs to be considered and undertaken in a manner to ensure long term environmental sustainability.

The action associated with maintenance dredging and material disposal can introduce environmental stressors that have the potential to impact upon environmental values. To ensure a sustainable approach is achieved, sufficiently robust risk assessments are required to identify priority risks and facilitate the development of appropriate management/mitigation strategies.

These aspects will be dealt with in greater detail in the body of this report.

1.6 Maintenance Dredging at Ports within the GBRWHA

Queensland has 20 recognised ports comprising of 15 trading ports, two community ports and three smaller non-trading ports, refer **Figure 2**.

These ports are distributed throughout the Queensland coastline and lie within a variety of coastal environments. The location of each of the ports is primarily based on unique geographic features such as: deep water access, natural harbours and proximity to sites such as communities, import markets, resource deposits and land side transport infrastructure.

Of the 20 recognised Queensland ports, 12 lie within or adjoin the GBRWHA, with only 8 ports within the GBRWHA historically requiring maintenance dredging. A brief description of each of the Queensland ports which lie within or adjoin the GBRWHA is provided in **Table 3**.

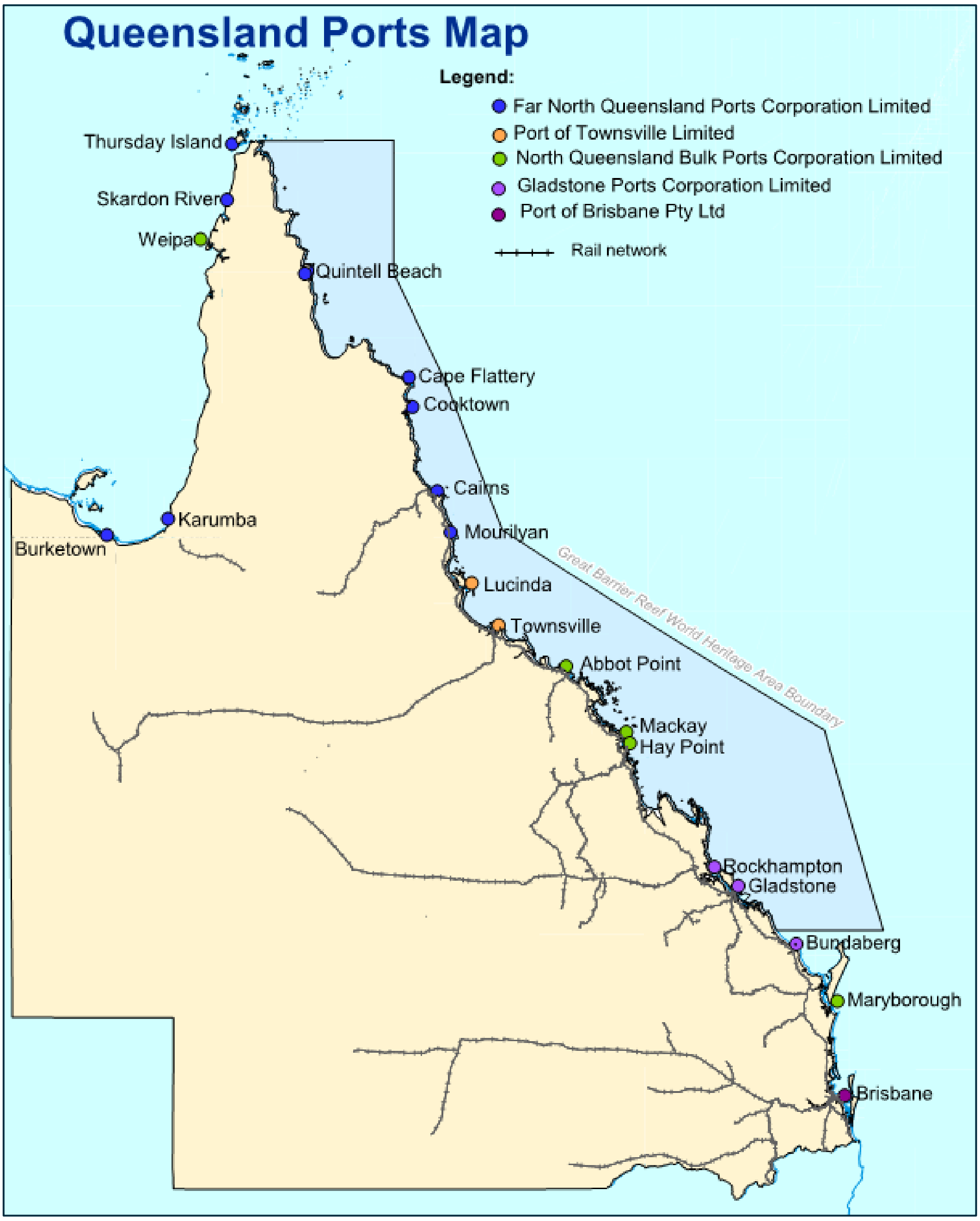


Figure 2: Queensland Ports Map

Table 3: Summary of Ports within the GBRWHA.

Port	Established	Primary Purpose	Approximate Channel Length	Maintained Channel Depth (below LAT)	Number of Berths	Maintained Depth of Berths (below LAT)	Average Depths Adjacent to Maintained Areas (below LAT)	Maintenance Dredging Requirement
Port of Gladstone	1863	Queensland's largest multi commodity Port with over 30 products handled.	40 km	12.5 m - 16.3 m	+20	6 m – 18.8 m	varies considerably, 0 m – 14 m	Annually
Port Alma	1884	Multi cargo port handling: ammonium nitrate, explosives, general cargo, salt and tallow.	-	-	3	9.2 m	6 m – 7 m	Episodic (5 years)
Hay Point (Hay Point and Dalrymple Bay Terminals)	1971	Coal export terminal.	11 km	14.7 m	7	16.6 m – 19.6 m	12 m – 15 m	Regular (2-4 years)
Port of Mackay	1939	Multi cargo port with the main exports being sugar and grain.	-	-	4	10.6 m – 12.5 m	8 – 9 m (Outside of Harbour)	Regular (3 years)
Abbot Point	1984	Coal export terminal.	4 km	17 m	2	19 m - 19.5 m	15 m – 17 m	Infrequent (20 years)
Port of Townsville	1864	Multi cargo port including the export of minerals and key import hub for North Queensland.	11 km	11.7 m	11	10.7 m – 12.2 m	4 m - 11 m	Annually
Lucinda	1958	Primarily a sugar export terminal, however does handle small amounts of general cargo.	-	-	1	13.6 m	13 m - 14 m	Not Required
Mourilyan	1883	Export of sugar, molasses and timber.	1 km	9.6	1	10.1 m	6 m – 10 m	Not Required
Port of Cairns	1887	Multi cargo port including: bulk and general cargo, defence, cruise shipping, fishing and tourism.	11 km	8.3	12	6 m – 10.5 m	0 m – 8 m	Annually
Cooktown	Not Available	Non-commercial trading Port.	800 m	3.1	1	4 m	0 m - 4 m	Infrequently
Cape Flattery	1967	Silica sand export terminal.	-	-	1	14.1 m	17 m – 12 m	Not Required
Quintell Beach	Not Available	Community port which handles general cargo.	-	-	1	Barge Landing	1 m - 3 m	Not Required

Historically, ports have developed around natural embayments, estuaries and harbours where safe refuge was provided to passing vessels. Modern container/cargo ports require not only suitable berth and navigation facilities but also large land backed areas to provide for efficient storage and handling of shipping products. Hence, many of these ports have been developed alongside river banks and embayments, such as Port Alma and Gladstone, both of which are within the GBRWHA. As a result, significant capital dredging operations may be required to deepen and widen the ports in response to global shipping trends and developing trades at the ports. Ports with long shipping channels through relatively shallow natural depths, such as Cairns and Townsville, are particularly subject to high levels of sedimentation due to natural sediment transport and coastal storm events.

Bulk ports (liquid/solid) have greater flexibility in that cargos can be stored ashore and piped/conveyed to/from the wharf to be loaded/unloaded onto/from the vessel. This means that the wharf facility can be located some distance offshore (should the prevailing metocean conditions permit loading/unloading operations) in deeper water which, in turn, reduces both initial capital and subsequent maintenance dredging requirements. A number of ports within the GBRWHA, such as Hay Point and Abbot Point, have been developed along these lines.

As noted in **Table 3**, a number of ports within the GBRWHA have either not historically required maintenance dredging or have required very infrequent maintenance dredging. This is because they are either: located in a non-depositional environment; in an area where resuspension of fines exceeds deposition rates; they have access to naturally deep waters; or they only service shallower draft vessels that can use natural channels for navigation to and from the port facilities.

Maintenance dredging in ports within the GBRWHA is undertaken on an annual basis at most of the larger, historically developed ports and less frequently at ports such as Hay Point and Abbot Point, for the reasons noted above. Since 2001, the majority of the maintenance dredging volume has been handled by the TSHD Brisbane (with grab dredgers also used by some ports to perform maintenance dredging to complement the TSHD Brisbane works), which is owned and operated by the Port of Brisbane Pty Ltd, with the vast majority of material relocated to approved offshore disposal sites.

The TSHD Brisbane travels up and down the Queensland coast to undertake the maintenance dredging each year. The schedule typically involves travelling up to Weipa (yearly) or Karumba (every second year) from Brisbane and then travelling back with maintenance dredging of the other ports being undertaken on route either on the way north or when returning south. The schedule for the TSHD Brisbane is confirmed each year following the wet season when any increased maintenance dredging requirements from extreme events such as tropical cyclones or floods are known. Further analysis of TSHD Brisbane schedule has been provided in **Section 4.2.1**.

2 Sediment Transport Processes

2.1 Introduction

Natural metocean processes can result in the transport and deposition of natural sediment (e.g. sand, silts and clays) within the coastal environment. These processes drive the need for maintenance dredging activities at ports as they result in sediment being deposited in the port's artificially deepened channels, aprons, basins and berths.

In the coastal waters of the GBR region, it is widely recognised that variations in turbidity is strongly related to resuspension by wind, currents and waves (Larcombe et al., 1995; Wolanski et al., 2005; and Fabricius et al., 2013). Orpin et al. (1999) noted that sediment advection driven through flood waters discharged from local estuaries and rivers and low frequency high energy storm and cyclone events can also be responsible for regional scale sediment transport within the GBR region.

Queensland ports within the GBRWHA are spread over a distance of approximately 1,500 km along the east coast of Queensland and, therefore, lie within a variety of coastal environments. The extensive distribution of the ports results in the ports being subject to variability in local metocean conditions. This can result in the relative influence of each of the above mentioned primary coastal processes varying significantly between each port.

Understanding the relative influence of each of the key processes on sedimentation is very important in both understanding the historical maintenance dredging activities and estimating future maintenance dredging requirements. This section provides a regional scale understanding on the processes driving sedimentation at the ports and outlines the relative importance and variability of the processes at each port. A detailed description of the key coastal processes influencing sedimentation at each of the GBR ports has been included in **Appendix B.**

2.2 Wave Climate

Local wave conditions can play an important role in the resuspension of bed sediments, as demonstrated by Fabricius et al. (2013) who found that wave height and period were strong predictors of turbidity levels within the GBR Lagoon. Waves can act to suspend/mobilise sediment from the seabed and the local currents then drive the advection of the suspended sediments. The amount of resuspension of the bed sediment resulting from waves is related to the critical bed shear stress, which is controlled by the characteristics of the bed sediment, and the bed shear stress exerted by the waves. The bed shear stress imposed by waves is caused by the oscillatory wave induced currents reaching the seabed and this is dependent on the wave conditions and local water depth. Bed shear stresses due to waves are typically capable of resuspending sediment in the relatively shallow coastal fringe areas. Wave induced bed shear stresses resulting from both locally generated wind waves and longer period swell waves are fundamental in the natural suspension of seabed sediments in the GBR, with wave driven sedimentation being more prevalent at some ports than others.

Waves can result in both the long-shore and cross-shore transport of sediment. This is dependent on: the morphology; alignment of the coastline; and prevailing direction of waves. In addition, under the simultaneous presence of even a weak current, sediment mobilised by wave action can also be subject to a net transport due to the current. Sediment mobilised by wave action can, therefore, be transported either by waves or by the dominant currents with some of this sediment ending up in the artificially deepened areas of the ports. Within these dredged (deepened) areas, the wave and current induced bed shear stresses are relatively low compared to the adjacent areas. This results in these deeper areas acting as sediment sinks with increased sedimentation and less potential for resuspension compared to the adjacent natural areas. The sedimentation rate is dependent on the metocean conditions, the sediment transport rates, settling velocity of the sediment and the 'trapping efficiency' of the dredged areas. Typically, the deeper and wider the dredged area, the more efficient they are as a sediment trap and, therefore, the higher the sedimentation rates. Sedimentation resulting from wave action is especially significant at the Port of Townsville and the Port of Cairns where navigational channels have been dredged through the relatively shallow bathymetry in Cleveland and Trinity Bays respectively.

In shallow coastal areas, typical wave conditions can contribute significantly to the resuspension and resultant transport of bed sediments as longshore drift. Higher wave generated bed shear stresses occur in shallower areas which results in the potential for increased sediment transport and therefore higher rates of sedimentation closer to the shoreline where longshore drift dominates. This occurs at the Port of Townsville where sedimentation rates have been found to be higher in the landward sections of the main navigational channel due to the higher wave resuspension rates in the shallower areas closer to the shoreline.

Similarly, areas of intertidal mudflats are particularly susceptible to wave induced sediment resuspension due to the shallow water depths in these areas. Even relatively small, locally generated wind waves have the potential to suspended fine grain sediments from these mudflats for further mobilisation by local currents. This process is particularly prevalent at intertidal mudflat areas surrounding the Ports of Cairns, Townsville and Gladstone.

The wave climate within the greater GBR lagoon can be broadly described as predominantly locally generated sea waves typically with short peak periods of less than 6 seconds and mean significant wave heights of less than 0.7 m (Orpin et al.,1999). The dominant wave direction is from the south east due to the prevailing south to south east trade winds which dominate in the region. Within the GBR Lagoon higher energy wave conditions generally occur during the summer months as a result of stronger wind speeds and possible cyclone occurrence during these months. Due to the presence of the extensive areas of outer reef throughout the majority of the GBRWHA (excluding Gladstone and Port Alma, but these ports are mainly located in sheltered locations), ports within the GBRWHA are typically sheltered from long period ocean swell waves from the Coral Sea. Some of the ports are subject to swell events but these events generally only occur during significant storm events or when particular ports are susceptible to longer fetch windows between sections of reef.

The discontinuous nature of the outer reef can allow for some longer period ocean swell waves to propagate through the reef system. For example, the outer navigational channel of Gladstone Port sees southerly swell conditions as a result of the gap in the reef between Sandy Cape and the Capricorn Bunker group of reefs (BMT WBM, 2014a). Similarly, the Ports of Mackay and Hay Point experience more frequent swell conditions than its northern neighbour Abbot Point Port, as Abbot Point is shielded from longer period swell waves from the south east as a result of sheltering effects from the Whitsundays Island group (Orpin et al.,1999). Although swell waves are not generally the dominant wave component in the region, swell waves can still play an important role in the mobilisation of bed sediments. For example, studies undertaken by Jing and Ridd (1996) found that swell waves are the dominant generator of bed shear stresses, and in turn sediment resuspension, in Cleveland Bay (PoTL, 2014).

Cyclone and storm induced wave events, often experienced during the summer months, can also have a significant impact on sedimentation at the majority of ports within the GBRWHA. The influence of these extreme events is further discussed in **Section 2.5**.

2.3 Currents

Currents and waves provide the mechanism by which sediments are resuspended and delivered to sedimentation zones. The characteristics of marine currents throughout the GBR are highly variable with astronomical tides and prevailing wind conditions primarily driving the local current conditions.

As shown in **Table 4**, the astronomical tides vary throughout the GBR region. Mackay and Hay Pont experience the largest tidal range of the ports (tidal range of approximately 7m) due to local tidal amplification at Broad Sound, while Cape Flattery experiences the smallest (tidal range of approximately 3m). Astronomical tides are a key indicator of the local tidal currents, and therefore the sedimentation resulting from tidal currents can be expected to vary depending on the local tidal range. Areas with larger tidal ranges often experience significantly higher tidal currents during spring tides which results in higher bed shear stresses, which in turn can potentially result in more regular resuspension, transport and deposition of bed sediment.

Table 4: Tidal planes at each Port within the GBRWHA.

Port	Highest Astronomical Tide above LAT (MSQ 2015)
Port of Gladstone	4.8 m
Port Alma	5.9 m
Port of Hay Point	7.1 m
Port of Mackay	6.6 m
Port of Abbot Point	3.6 m
Port of Lucinda	3.9 m
Port of Townsville	4.1 m
Mourilyan Harbour	3.5 m
Port of Cairns	3.5 m
Port of Cooktown	3.2 m
Cape Flattery	3.1 m

Additionally, regional and local wind conditions can also be an important driver to the local current conditions. Winds exert a frictional drag on the surface of the ocean which transfers momentum to the surface water and subsequently to the water column below. Due to the Earth's rotation there is a deflection in the water movement relative to the wind direction, this is known as the Coriolis Effect and in the Southern Hemisphere it results in a deflection to the left of the wind direction. The deflection results in an Ekman spiral forming, whereby each successive deeper layer of water moves to the left creating a spiral effect down to approximately 100m depth where the influence of winds cease. The net current direction is 90 degrees to the left of the wind direction; this is known as the Ekman transport direction (Knauss, 1997). However, typically in shallow water, such as where the ports in the GBRWHA are located, the angle between the horizontal wind direction and the surface water current direction is small (typically less than 15 degrees).

On a regional scale, the prevailing south easterly trade winds in the GBR lagoon are fundamentally responsible for the residual northward current direction and associated net northward flux of sediment in the GBR lagoon (Orpin et al.,1999). The trade winds tend to dominate in the dry season when the wind direction is typically from the south-east, while during the wet season the winds are more variable and potentially stronger with winds from the east dominating but with northerly and southerly winds also occurring. The seasonal variability in the wind can result in some seasonality in the currents, with a stronger northerly residual current typically occurring during the dry season, a higher chance of a reverse southerly residual in the wet season and the potential for stronger currents in the wet season due to cyclonic events. The relative importance of wind driven currents is dependent on the local wind conditions and the existing tidal conditions. Ports where local wind conditions are known to significantly influence local currents include: Abbot Point; Townsville; and Cairns.

Within Cleveland Bay (Port of Townsville) and offshore of Abbot Point, the prevailing south-east trade winds are seen to strengthen tidal driven flood currents towards the west while reducing, or at times reversing, the eastward ebb tide currents. This results in a residual net current flow to the west. In Cleveland Bay this residual westward current, when coupled with local sea and swell waves, results in the net longshore transport of sediment from the shallow coastal areas in the east of Cleveland Bay to the west. Some of the transported sediment is subsequently deposited into the dredged areas of the port. The spatial distribution of currents in Cleveland Bay also plays an important role in defining the sediment transport pathways influencing sedimentation in the main channel. While the inshore currents are generally orientated in an east-west direction (perpendicular to the channel), the influence of Magnetic Island means tidal currents in the outer reaches of the channel generally flow in a north-south direction (parallel to the channel). Currents running parallel to the shipping channel will result in less sediment being transported into the dredged channel compared to currents which are perpendicular to the channel. This is consistent with recent maintenance dredging operations at the Port of Townsville where sedimentation rates, and therefore maintenance dredging requirements, have been much higher in the inshore areas of the channel (PoTL, 2014).

Similarly, in Trinity Bay the prevailing hydrodynamic processes play a key role in defining sediment transport pathways around the Port of Cairns. Within Trinity Bay, the tidal currents tend to flow in an inshore/offshore direction, perpendicular to the bathymetry contours and parallel with the channel alignment. However, the wind induced currents resulting from the prevailing south-easterly trade winds result in a slight cross-channel directed current component. The wind induced current is more important in the outer areas of Trinity Bay, with wind driven currents becoming the dominant current component offshore of Trinity Bay during periods of strong prevailing winds. The dominant wind induced north-westerly directed current is a primary factor driving sedimentation in the outer areas of the channel.

The outer extent (adjacent to beacon 18) of the Cairns Entrance Channel impinges on the East Trinity mudflat. Recent maintenance dredging at the port has identified this particular section of the channel as an area with high sedimentation rates. This is primarily due to sediment from the mudflat being suspended and the net westerly currents transporting the suspended sediment into the main navigational channel. Once deposited, the sediment will tend to remain, since bed shear stresses in the artificially deepened channel rarely exceed the critical shear stress for resuspension. This process has also resulted in the natural westward progression of the mudflat, with the associated accretion having contributed significantly to maintenance dredging requirements at the port (Ports North, 2014).

In addition to tide and wind induced currents, regional scale circulation currents can also occur in the GBR Lagoon. These regional scale currents are dynamic and intermittent as they are primarily driven by a complex interaction between the oceanic inflows caused by the North Vanuatu Jet and the local wind driven circulation (Andutta et al., 2013). Although these regional scale ocean circulation processes can intermittently influence sediment transport processes in the GBR Lagoon and therefore at the ports, their impacts are considered minor relative to tidal and wind induced currents. For this reason, while regional scale ocean circulation currents do have the potential to influence where sediment is transported they are not expected to be critical drivers influencing sedimentation at the ports within the GBRWHA.

2.4 Rainfall and River Discharges

For the vast majority of the GBRWHA, the meteorological climate can be characterised as a tropical monsoonal climate with distinct wet and dry seasons. The wet season occurs between December and March when a significant proportion of the annual rainfall occurs. During the wet season, cyclones and periods of high rainfall can result in large volumes of sediment being input into the waters of the GBR via local river systems and their associated catchment areas. Such events result in rivers delivering the majority of their annual sediment load within days or weeks. Sediment output from rivers during these events is a key process responsible for the delivery of new terrigenous sediments to the GBR Lagoon.

The buoyant fresh water plumes discharged from the rivers during high rainfall events act to transport suspended sediments locally within the GBR inner-shelf. There is some debate over the distance that the turbid flood plumes discharged from rivers during high rainfall events can transport sediment within the GBR Lagoon, with distances ranging from tens to hundreds of kilometres (Brodie et al., 2010; Orpin & Ridd, 2012; Fabricius et al., 2014). An example plume from a 1 in 5 year flood event in the Burdekin River is shown in **Figure 4**, the sediment from this plume was reported to have been transported up to 50km along the coastline from the river mouth (Orpin & Ridd, 2012). Once sediment settles out from these flood plumes, currents and waves will then act as the primary driver responsible for the advection of these sediments regionally throughout the GBR inner-shelf.

The degree to which river discharges directly influence sedimentation rates at each port depends on the location of the ports relative to the river and creek mouths and the sediment load of the associated system. **Figure 3** depicts the location of each port with respect to the major rivers discharging into the GBR Lagoon. **Table 5** details the mean annual total suspended solids discharged from 10 major rivers into the GBR Lagoon, as estimated by Kroon et al. (2012). **Table 5** also indicates the closest nearby port and its distance from the river mouth. In addition to the major rivers, smaller local rivers and creeks which discharge directly into port areas can also influence sedimentation rates at the ports. An example includes the Boyne and Calliope Rivers which discharge directly into the Port of Gladstone.

At a number of ports within the GBRWHA, river sediment supply can directly influence sedimentation within the ports, but at most ports it is considered, on average, to result in less sedimentation than wave and current driven mechanisms.

Table 5: Pre and post European mean annual discharge for 10 major rivers discharging into the GBR Lagoon (Kroon et al., 2012).

River	Nearby Ports	Estimated Mean Annual TSS Discharge (t)	Estimated Mean Annual Pre- European Discharge (t)
Barron	Port of Cairns (6 km to the south)	100,000	25,000
N&S Johnstone	Mourilyan (10 km to the south)	320,000	41,000
Tully	Mourilyan (50 km to the north)	92,000	24,000
Herbert	Lucinda (6 km to the east)	380,000	110,000
Haughton	Port of Townsville (40 km to the north)	300,000	29,000
Burdekin	Abbot Point (55 km to the south) Port of Townsville (90 km to the north)	4,000,000	480,000
Pioneer	Port of Mackay (6 km to the north) Hay Point (16 km to the south)	52,000	50,000
Plane	Hay Point (14 km to the south)	550,000	54,000
Fitzroy	Port Alma (adjacent) Port of Gladstone (50 km to the south)	3,400,000	1,100,000
Burnett	Port of Gladstone (135 km to the north)	1,400,000	99,000
Total		10,594,000	2,012,000

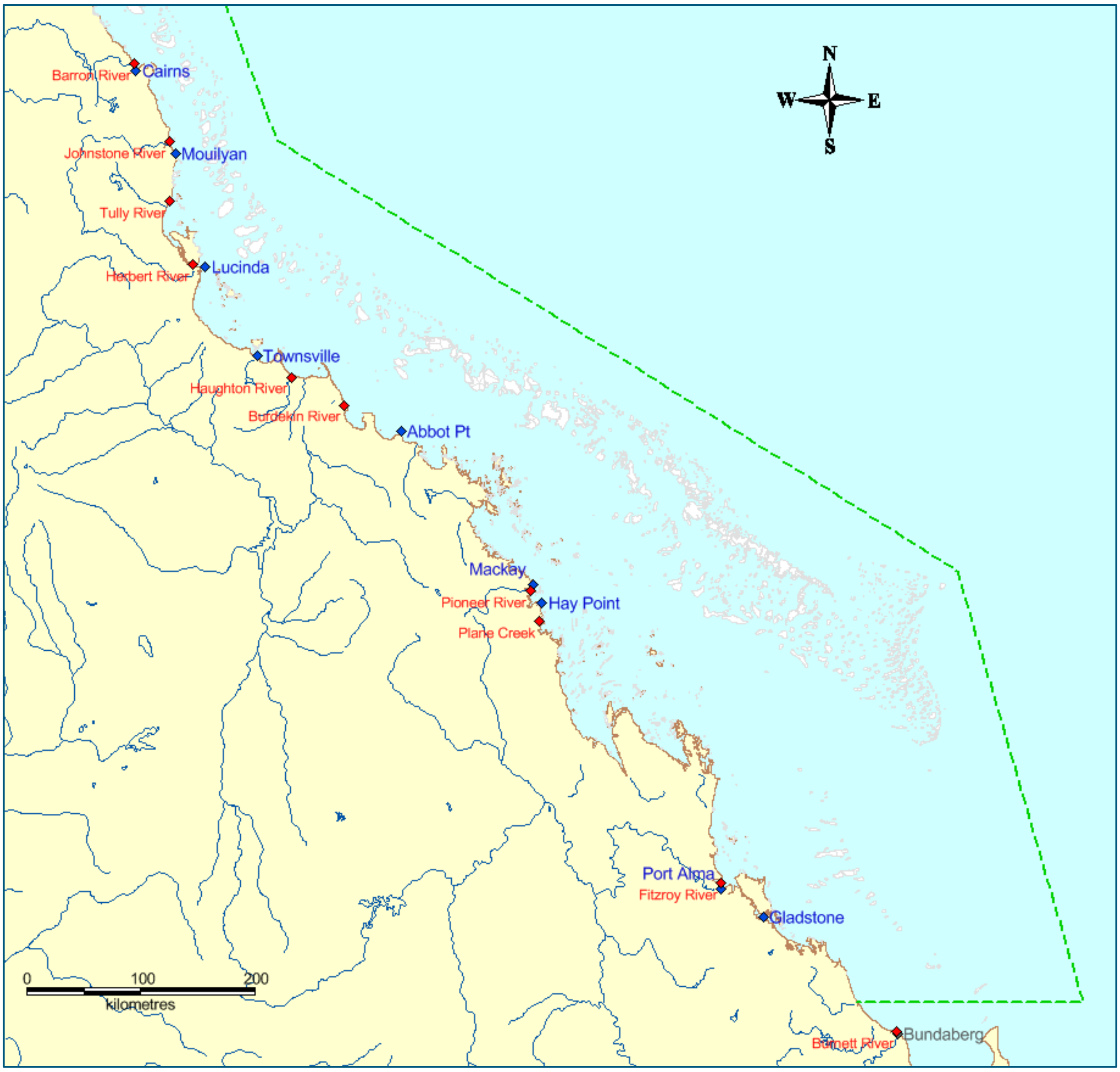


Figure 3: Queensland Ports nearby to the major rivers discharging into the GBR.

Also included in **Table 5** is an estimation of mean annual TSS loads discharged during pre-European settlement provided by Kroon et al. (2012). A comparison between these estimations suggests a 5 fold increase in TSS loads discharged from these 10 primary catchments since pre-European settlement. This is assumed to be a result of urban and agricultural development in these catchment areas increasing sediment loads entering the river systems.

Investigations by Lambrechts et al. (2010) suggested that the riverine sediment supply in Cleveland Bay (Port of Townsville) provides an important contribution to coastal turbidity. Their modelling suggested that a four-fold reduction in riverine sediment supply from the Ross and Burdekin rivers could halve the turbidity in Cleveland Bay within 170 days, indicating that the TSS in Cleveland Bay is sediment supply limited. Other investigations, such as Cooper et al. (2008), have also observed that high turbidity in Cleveland Bay can coincide with flooding of the Burdekin River.

However, reappraisal of the data by Orpin and Ridd (2012) showed that the timing of the high turbidity events in Cleveland Bay coincided with periods of strong winds and the plume from the Burdekin River did not result in high turbidity in Cleveland Bay (**Figure 4** *(overleaf, top)*). They concluded that TSS concentrations in this area are controlled primarily by wind and wave driven resuspension of the muddy seabed (as shown in **Figure 4** *(overleaf, bottom)*) rather than the input of fine grained sediment from the Burdekin River, as other research by Larcombe and Wolfe (1999) had also shown.

Within the GBR Lagoon, events with strong winds and large waves often coincide with high rainfall and increased river discharges. As highlighted by Orpin and Ridd (2012) this has resulted in some confusion as to the relative importance of river loads with regard to the water quality of the inner shelf of the GBR Lagoon. Although plumes resulting from the rivers which discharge into the GBR Lagoon can result in high turbidity plumes, they found that these tend to be relatively localised in nature (e.g. within 50km of the mouth) and do not result in increased turbidity across the entire inner shelf. Widespread resuspension of bed material within the inner shelf occurs primarily as a result of wind and wave conditions, as shown for the Cleveland Bay area in **Figure 4** *(overleaf, bottom)*.

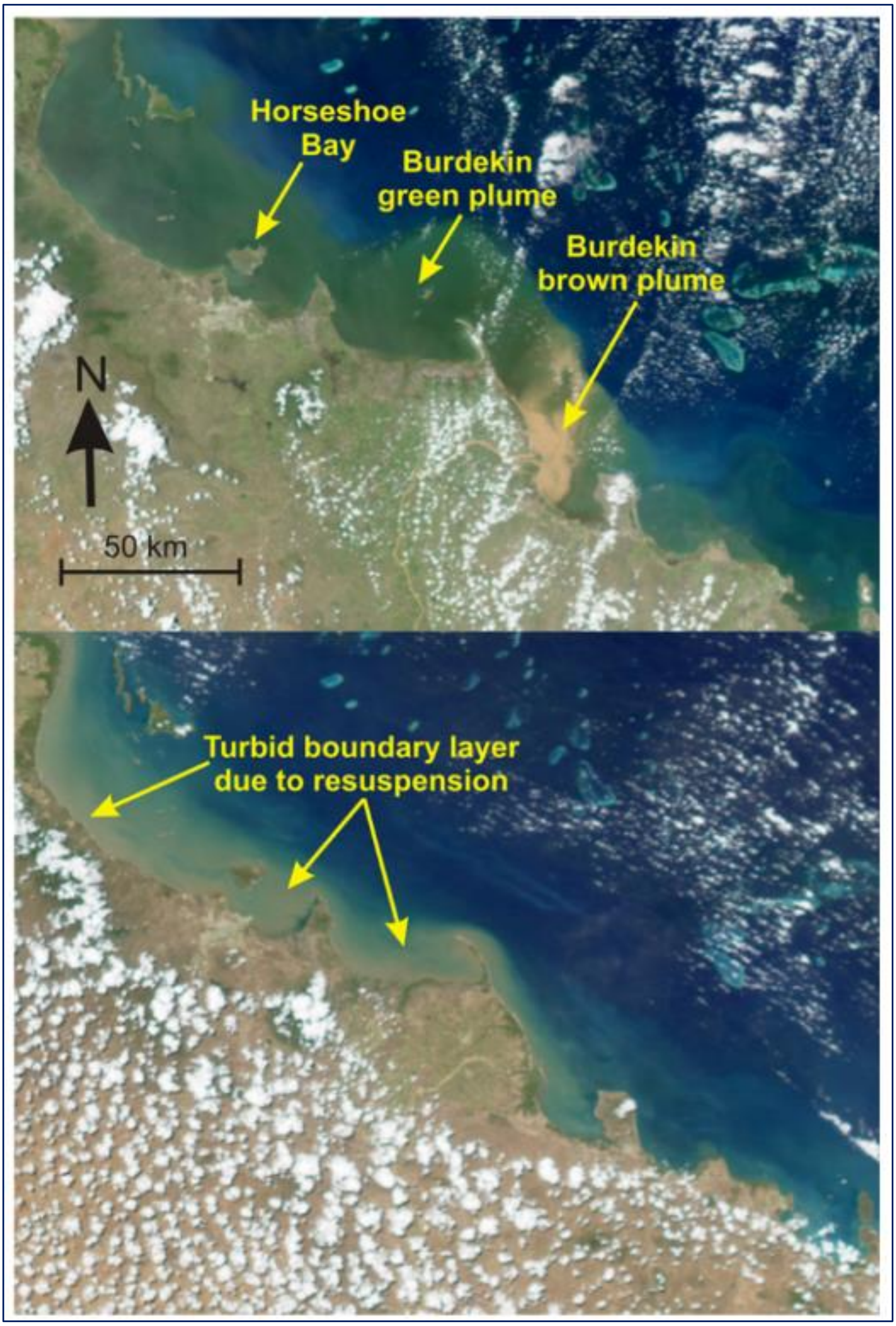


Figure 4: MODIS Aqua Images of: a flood plume from the Burdekin River, with the brown plume representing high TSS and the green plume low TSS (at Horseshoe Bay TSS was less than 5 NTU) (top): and resuspension from a high energy wind and wave during the dry season (at Horseshoe Bay TSS was 30 NTU) (bottom). Source: Orpin and Ridd (2012).

2.5 Tropical Cyclones and Storms

Cyclonic activity and severe storm events can occur along the GBR coastline during the summer months. The frequency and intensity of these events are highly variable, and therefore their influence on sedimentation rates at each of the ports is highly unpredictable. **Table 6** provides an overview of the average recurrence interval for cyclones passing within 100km of each of the GBR ports. The table highlights a general trend that the further north the port is located the greater the likelihood of cyclones occurring more frequently and therefore the higher the probability of the cyclones affecting sedimentation rates.

Table 6: Tropical cyclone average return interval (ARI) for each of the ports within the GBRWHA.

Port	ARI for cyclones passing within 100km of the Port.
Port of Gladstone	8.5 years
Port Alma	6.8 years
Port of Hay Point	4.1 years
Port of Mackay	4.4 years
Port of Abbot Point	3.6 years
Port of Townsville	3.3 years
Port of Lucinda	3.8 years
Mourilyan Harbour	3.4 years
Port of Cairns	2.8 years
Port of Cooktown	3.4 years
Cape Flattery	4.1 years
Quintell Beach	5.7 years

Tropical cyclones have the potential to discharge sediment into the GBR inner-shelf through high rainfall and increased river discharge, and also have the potential to drive sediment transport throughout the GBR inner shelf by generating large waves and strong currents. Compared to the wave and current transport mechanisms described in **Sections 2.2** and **2.3**, the difference during tropical cyclone events is that the processes typically occur at a higher intensity over a shorter period of time.

Throughout the GBR, tropical cyclones are responsible for the majority of the largest and longest period waves observed in the region. 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, as was the case with cyclone Yasi (2011). This suggests that even naturally deep water ports, such as Abbot Point, can be susceptible to cyclone induced sedimentation.

Similarly, cyclone induced currents are also greater than those under ambient conditions. 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 within the GBR Lagoon. Data collected offshore of Abbot Point in depths of 33 to 35 m LAT showed that the near bed current speeds during the passing of TC Dylan increased significantly (RHDHV, 2014). **Figure 5** shows that during this event, the peak near-bed current speeds increased from 0.2m/s up to 0.9m/s and during this time the currents were predominantly unidirectional to the west and north-west.

The peak significant wave height at this location during the event was 3.7m and the peak wave period was 6 seconds (RHDHV, 2014). The measurements showed significant resuspension of the existing bed material during the event. Based on the measured data this is considered to be primarily a result of the wind induced currents as opposed to the wave activity.

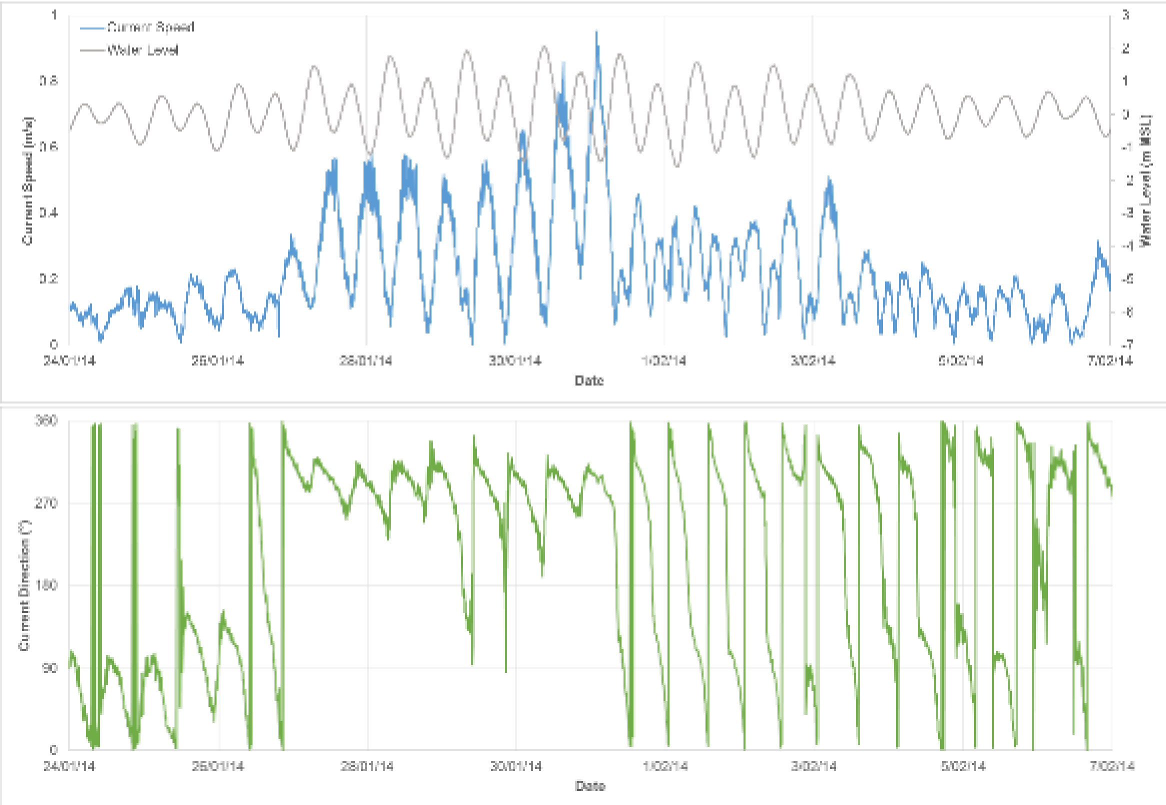


Figure 5: Measured water level and near-bed current speed and direction at 33 to 35 m LAT during TC Dylan (from RHDHV (2014)).

During cyclone events, storm-induced currents and waves can be capable of mobilising the upper few metres of bed sediment near to ports (Orpin et al., 1999). These high intensity sedimentation events can govern the need for maintenance dredging at ports. For example, the port maintenance dredging requirements at the Port of Cooktown have historically been purely driven by cyclone induced sedimentation of the channels and berths. The port has required infrequent maintenance dredging over the last 20 years as a direct result of sedimentation from tropical cyclones travelling within 50km of the port (TMR, 2015b).

Not only are cyclones responsible for mobilising and transporting large quantities of existing fine grained bed sediment, they are also primarily responsible for the transport of sand sized and coarser sediment throughout the inner shelf. The critical bed shear stresses required to mobilise these heavier materials are typically not realised under ambient wave and current conditions and so they can only be transported during high energy cyclonic conditions.

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. The inner-shelf of the GBR Lagoon, generally considered to extend from the shoreline to a depth of approximately 22m, is made up of riverine deposits of post-glacial muds and siliclastic sands (Orpin et al., 2004). While the mid-shelf of the GBR is considered to be between the 22 to 40 m depth contour and consists of a finer veneer of shelly muddy sand over beds of Pleistocene clay substrates (Orpin et al., 2004).

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 described above can result in erosion of Pleistocene clay substrates present in the deeper mid-shelf of the GBR. It is only during cyclone conditions when current speeds in the mid-shelf region are high enough to mobilise these bed sediments.

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. Sediment sampling undertaken following TC Winifred showed that 10 - 30% of the inner shelf storm layer (sedimentation layer resulting from a storm event) was comprised of mud originating from the mid-shelf of the GBR (Gagan et al., 1990). These findings highlight the important role that cyclones have in the supply of sediment to the nearshore areas of the GBR. The sediments eroded from the mid-shelf and transported shoreward may settle out directly in dredged areas of the ports or they may subsequently be resuspended and transported to these areas under ambient conditions.

2.6 Overview of Sedimentation Processes at GBR Ports

Based on the information presented in the previous sections and the local experience of the ports through historic activities, the relative importance of the key processes driving sedimentation at each port is summarised in **Table 7** overleaf. In addition, a more detailed description of each of the key coastal processes influencing sedimentation at each of the GBR ports has been included in **Appendix B**.

Through consideration of the key coastal processes detailed in **Table 7,** along with the port configuration, summarised in the previous **Table 3,** the ports can be grouped as follows:

- Resuspension from **waves and currents** as the dominant supply of sediment:
    - Ports with long (> 10km), **high trapping efficiency approach channels**: the Ports of Gladstone, Townsville and Cairns. These ports have the highest rates of sedimentation and therefore the highest maintenance dredging volumes and frequency. The high trapping efficiency in the approach channel is typically related to a large difference in depth between the adjacent natural areas and the dredged channels.
    - Ports with long (> 10km), **medium to low trapping efficiency approach channels**: Hay Point Port. This port is located in an environment with high natural sediment transport rates, but because the approach channel is only to 3m deeper than the adjacent areas it does not act as a very efficient sediment trap and therefore sedimentation rates are lower.
    - Ports with **no approach channel**: Mackay Port. This port does not have an approach channel and due to this and the harbour walls the maintenance dredging requirements are much lower despite the high sediment transport rates of the natural environment.
- Resuspension from **waves and currents**, especially during **cyclonic events** is the dominant supply of sediment: Abbot Point Port. The natural sediment transport rates are relatively low as the port is situated approximately 2.7 km offshore in relatively deep waters. The relatively deep water surrounding the port restricts sediment transport in the area and means that the trapping efficiency of the dredged areas is relatively low. Sediment transport around the dredged areas is primarily driven by waves and currents during extreme events (cyclones and storms), but due to the episodic nature of the events along with the low trapping efficiency, minimal maintenance dredging is required.

- **Cyclonic events** provide the dominant supply of sediment: Port of Cooktown. Sedimentation at the Port of Cooktown is typically instigated by cyclones travelling nearby to the port generating flooding and relatively large waves and high currents. It is generally only under these extreme processes that notable volumes of sediment are mobilised into the port's channels and berths.

The Ports of Cairns and Townsville both consist of long navigational channels which traverse relatively shallow coastal embayments. As a result, both tidal currents and locally generated wind waves can suspend natural bed sediment in the relatively shallow bays, while tidal and wind induced currents drive the advection of the suspended sediment. **Figure 6** shows two aerial photographs of Trinity Bay (Port of Cairns) under both calm conditions (Photograph 1) and during a south easterly wind event of 15 knots (Photograph 2). The aerial photographs highlight the natural variability in TSS resulting from the metocean conditions.

Table 7 also presents background measured TSS concentrations at each of the ports within the GBRWHA which require maintenance dredging. The TSS concentration is a result of the setting of the port, the dominant metocean processes, as well the composition of the bed sediment in the area adjacent to the ports. The table shows that background TSS concentrations vary considerably between the ports. In addition, the data shows that in some cases the TSS concentrations vary spatially and seasonally (e.g. the Port of Gladstone) while at others there is little variability (e.g. the Port of Abbot Point). As detailed in the previous sections, some seasonal variability exists in the river discharge, waves and currents. The ports which show a greater seasonal variability are those located in estuarine environments which would be more influenced by river discharges, while the more exposed open coastal ports exhibit less seasonal variability in TSS concentrations. It can be broadly inferred that the higher the background TSS concentration the higher the potential rate of sedimentation.

Table 7 also details the relative importance that storm and cyclonic events have on sedimentation at each port. These episodic events result in increased wave energy and currents and often significant flood discharges from adjacent rivers. Under these conditions, short lived, high intensity sedimentation can occur in any dredged areas. These events can influence all of the ports within the GBRWHA and the episodic and unpredictable nature of these events can lead to extreme variability in maintenance dredging requirements.

Table 7: Summary table showing relative importance of processes supplying sediment to the ports in the GBRWHA.

Port	Average Annual Siltation(2) (m^3 / yr)	Wave Climate	Tidal Currents	Wind Induced Currents	River Inputs	Cyclones and Storms	Mean Dry and Wet Season Background TSS (1)	Key Sediment Supply Mechanisms
Port of Gladstone (In Port)	190,000	2	3	1	1	2	Dry: 10 – 47 NTU Wet: 29 – 161 NTU(3)	Waves and currents
Port of Gladstone (Outer Channel)		3	2	2	1	2		
Port Alma	6,000	1	3	1	2	2	not available	Local currents
Port of Hay Point	100,000	3	3	2	1	2	Dry: 7mg/l; Wet: 16mg/l	Waves and currents
Port of Mackay	30,000	3	3	2	1	2	Annual: 19mg/l	Waves and currents
Port of Abbot Point	minimal (no data)	2	1	2	1	2	Dry: 12 – 16mg/l Wet: 11 – 20mg/l(3)	Waves, currents and cyclones
Port of Townsville	400,000	3	2	3	1	2	Dry: 9mg/l; Wet: 20mg/l	Waves and currents
Port of Cairns	400,000	3	2	3	1	2	Dry: 6 – 9mg/l Wet: 8 – 41mg/l(3)	Waves and currents
Port of Cooktown	5,000	1	1	1	1	3	not available	Cyclones

(1) Reference to background TSS values is detailed in **Appendix B**.
(2) These rates are based on historic maintenance dredging volumes detailed in Section 4.5.
(3) The ranges represent mean values from different monitoring locations.

High Importance	3
Medium Importance	2
Low Importance	1

Photograph 1: Taken during an ebbing spring tide on a day with light winds and little wave activity. The photograph illustrates natural turbidity in Trinity Bay (31 August 2015).

Photograph 2: Also taken during an ebbing tide, however on a day where there 15 knot south-easterly winds were present. The photograph illustrates the naturally high turbidity (40 NTU at beacon 10 at the time of the photograph) resulting from wave induced sediment resuspension. The photograph also illustrates the, by comparison, clean ebb tide waters flowing out of the main channel.

Figure 6: Aerial photographs illustrating natural TSS in Trinity Bay. (Vico, 2015, pers. comm., 6 November)

There has been some uncertainty as to what proportion of sediment resuspended by waves and currents is derived from recent sediment input from fluvial sources and how much is already naturally present in the system (McCook et al., 2015). In order to further investigate the river inputs and impacts on dredging operations, **Figure 7** (overleaf) has been prepared combining:

1. Estimated Mean Annual TSS Discharge (t) in **Table 5**;
2. Distance to port in **Table 5**; and
3. Average Annual Maintenance Dredging Requirement in **Table 7** (in tonnes/yr =0.7 times m^3/yr).

For example, the Port of Townsville is located some 90km north of the Burdekin River (x-axis) which is has been estimated (**Table 5**) to have an annual sediment discharge of 4Mtpa (y-axis). The Port of Townsville requires, on average, the dredging of around 280,000 tpa (=400,000 m^3/yr using a 0.7 conversion factor). In this way, each of the ports located near the major discharge rivers can be plotted.

Given the net northerly flux direction of sediment in the GBR, as previously noted in **Section 2.3**, should river inputs be a significant factor in channel sedimentation, it would be expected that ports with high sedimentation rates would lie adjacent to or immediately north of rivers with high discharges (and vice versa).

However, the plot shows quite different outcomes, namely:

- Most ports are located at or near rivers that have relatively low suspended sediment loads, including those ports with very high sedimentation rates;
- Most ports are not located between 50km south of and nearly 100km north of rivers that have relatively high suspended sediment loads
- The single port located within the above range (Port Alma) is located adjacent to a river that has a relatively high suspended sediment load (3.4Mtpa), but has a relatively low (7,000 tpa) maintenance dredging requirement partially due to its scale and configuration.

It has been shown by Fabricius et al. (2014) that river discharges influence water clarity in areas of the inner and mid-shelf of the central GBR. The authors also found that in the naturally more turbid coastal area of the inner-shelf, where the ports are located, the influence of river discharges on water clarity (and therefore TSS concentrations) was weaker. As such, any benefits gained through a reduction in suspended sediment contributions from the catchments will, in the coastal area of the inner-shelf, be minimal, or insignificant, in comparison to the contributions driven by natural wave and current-induced resuspension.

It can, therefore, be determined that efforts made to reduce sediment loads discharged into the GBR, although beneficial for a number of reasons (see below), may not help to significantly alleviate the volume, frequency and overall need for maintenance dredging at the vast majority of GBR ports.

It is noted that any decrease in catchment sediment runoff does have the potential to improve water quality, reduce sedimentation, and reduce the input of nutrients from runoff in the areas of the GBR Lagoon adjacent to the river mouths (important initiatives in their own right), however, this is not expected to significantly reduce the volume or frequency of maintenance dredging required.

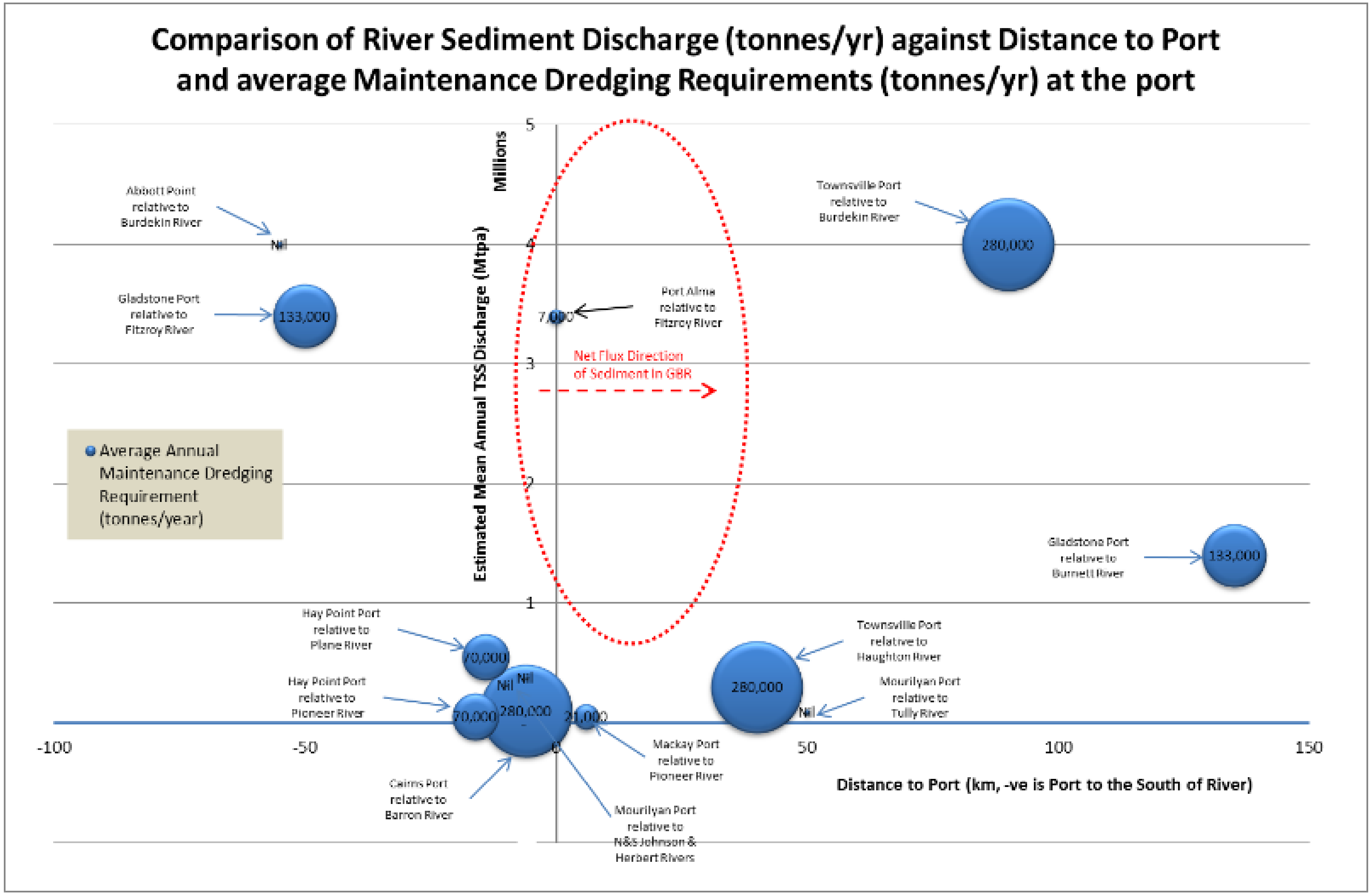


Figure 7: Comparison of River Discharge (Mtpa, y-axis) against Distance to Port (x-axis) and average Maintenance Dredging Requirements (tonnes/yr, marker size)

2.7 Summary

Queensland ports located within the GBRWHA reside in a variety of coastal environments and are subject to variability in local metocean conditions. As a result of these variabilities, each port sees varying rates of sedimentation which is typically driven by a number of key coastal processes. For the majority of the GBR inner-shelf region and in turn the GBR ports, sediment transport and sedimentation during typical conditions is primarily a result of wave and current induced resuspension.

The configuration and orientation of each port relative to the natural sediment transport pathways also plays a key role in the sedimentation which occurs in the artificially deepened areas. Wave and current induced bed shear stresses are fundamental in the natural resuspension of sediment on the bed in the shallow nearshore waters of the GBR inner-shelf. Lower bed shear stresses occur in the artificially deepened areas of the ports, which results in sedimentation occurring in these areas. Compared to the adjacent natural areas, the bed shear stresses from waves and currents in the artificially deepened areas are less likely to resuspend any deposited sediment. It is generally the case that the deeper and wider the dredged area, the higher its ‘trapping efficiency’. It is therefore a combination of the metocean conditions and port configuration which essentially controls the sedimentation rates at each port.

Cyclones also play an important role in the input of new sediment to the inner shelf of the GBR Lagoon through: river flooding, seabed erosion from the mid-shelf, and reef breakage (Larcombe & Carter, 2004). In particular, cyclone induced waves and currents play an important role in the supply of sediment to the inner shelf through the erosion and advection of sediments away from the mid-shelf.

A detailed understanding of coastal processes, the key drivers behind sedimentation, and the source of the sediment which deposits at the ports is important in explaining the need for both current and future maintenance dredging. Future long term maintenance dredge management plans would benefit from a detailed description of the local processes which drive sediment transport, which will help to relate the maintenance dredging to the natural processes and explain the natural processes which result in sedimentation within the ports.

3 Legislative Requirements

3.1 Introduction

Legislative requirements play an important function in the management of maintenance dredging operations at all ports. Dredging activities at ports within the GBRWHA are managed under both State and Commonwealth legislation. The application of the State and Commonwealth legislation varies depending on specific legislative requirements applicable at each port. The legislative context around existing maintenance dredging and disposal practices at ports within the GBRWHA is further detailed in **Sections 3.2** and **3.3**.

3.2 Commonwealth Legislation

There are three key Commonwealth Acts applicable to the loading and placement of dredge material in Australian waters, these are:

- *Environment Protection (Sea Dumping) Act 1981;*
- *Environment Protection and Biodiversity Conservation Act 1999 (the EPBC Act); and,*
- *Great Barrier Reef Marine Park Act 1975.*

A description of each of these acts and their applicability to maintenance dredging activities at ports within the GBRWHA is described in the following subsections.

3.2.1 Environment Protection (Sea Dumping) Act 1981

The Environmental Protection (Sea Dumping) Act 1981, commonly known as the Sea Dumping Act regulates the loading and placement of wastes and other matter at sea. The Act was implemented in order to fulfil Australia's international responsibilities under the London Convention of 1972 and has been amended to include the 1996 Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972 (the London Protocol).

The aims of the London Protocol are to protect and preserve the marine environment from all sources of pollution and to prevent, reduce and eliminate pollution by controlling the dumping of wastes and other materials at sea. Annex 1 of the London Protocol lists the types of materials that may be considered for ocean disposal (dredged material being one of these), with dumping of these materials requiring a permit which must be issued in accordance with the provisions of Annex 2. The International Maritime Organisation (IMO), as administrators of the London Protocol have developed guidelines which are intended for use by national authorities responsible for regulating sea dumping and evaluating applications for disposing of wastes in a manner consistent with the provisions of the London Convention 1972 or the 1996 Protocol. These processes are reflected in Australia's regulatory framework and guidelines implemented here in Australia. Australia, as a party to the Protocol, reports annually to the IMO on all permitted and emergency sea dumping activities in Australian waters.

The Sea Dumping Act applies to all Australian waters, from the low water mark out to the limits of the Exclusive Economic Zone (**Figure 8**) and as a result, permits are required for any sea disposal activities in these areas. The Act is currently administered by the Department of the Environment (DoE) or the GBRMPA if loading or disposal is to take place within the GBRMP. A review of the maintenance dredging sea dumping permits currently approved for ports within the GBRWHA is provided in **Table 8**.

Table 8: Current maintenance dredging sea dumping permits for ports within the GBRMP.

Port	Current Length of Sea Dumping Permit (years)
Port of Gladstone	2 years 8 months (2015-2018)
Port Alma	-
Port of Hay Point	-
Port of Mackay	10 (2012 – 2022)
Port of Abbot Point	-
Port of Townsville	1 (2015/16)
Port of Cairns	10 (2010 – 2020)
Port of Cooktown	-

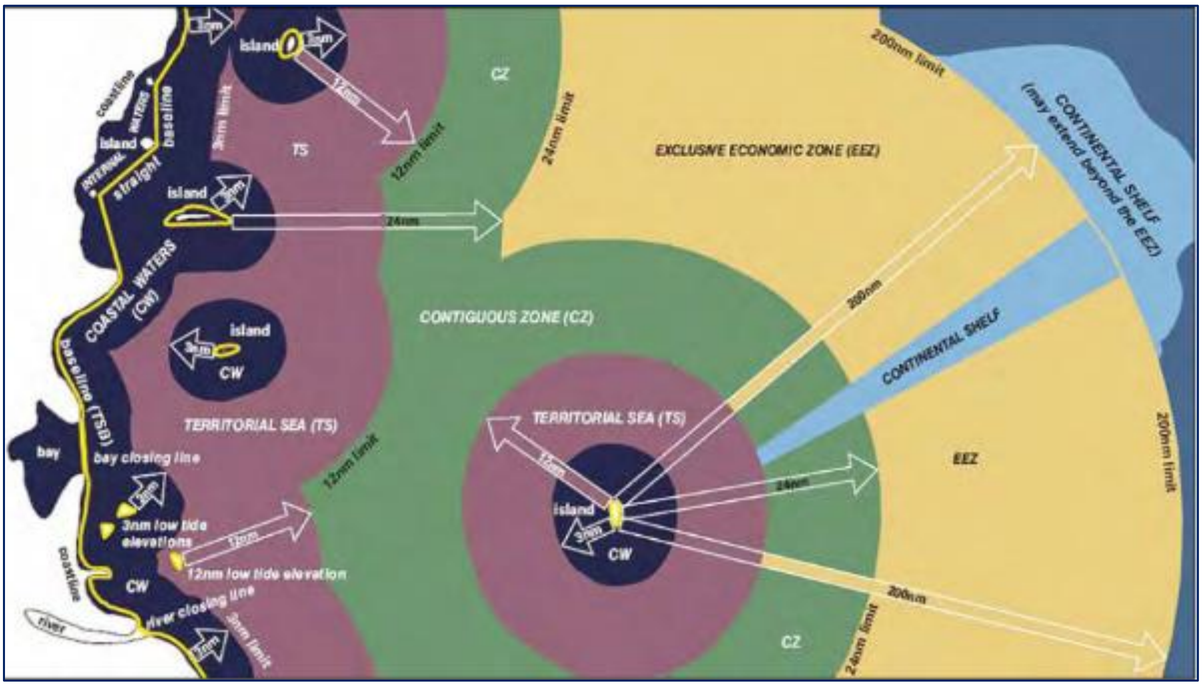


Figure 8. Maritime zones in Australian waters (NAGD, 2009)

The National Assessment Guidelines for Dredging (NAGD, 2009) sets out the framework for the environmental impact assessment and permitting of the ocean disposal of dredge material. The intention of the NAGD is to provide greater certainty about the assessment and permitting process behind dredging approval applications. Not a legislative act itself, the NAGD provides guidance for all dredging activities undertaken in Australian Waters. The framework set out in the NAGD includes guidance on all Australian legislation applicable to dredging applications. This framework has been presented in **Figure 9**.

While the NAGD provides for the continued case-by-case assessment of individual dredging proposals, it also considers the long term management of on-going maintenance dredging activities. The NAGD identifies that a determining authority will grant long-term permits for maintenance dredging on the following basis:

1. An assessment of the applicant's ability to meet their obligations under the Sea Dumping Act and any permit granted;
2. Establishment of a Technical Advisory and Consultative Committee (TACC) for long-term management; and
3. Development and implementation by the applicant of a satisfactory long term Environmental Management Plan (EMP) for loading and dumping activities, which provides for sampling and analysis to support future permit applications.

Applications for long term maintenance dredging approvals are favourable for port operators as they provide long term certainty regarding future maintenance dredging activities.

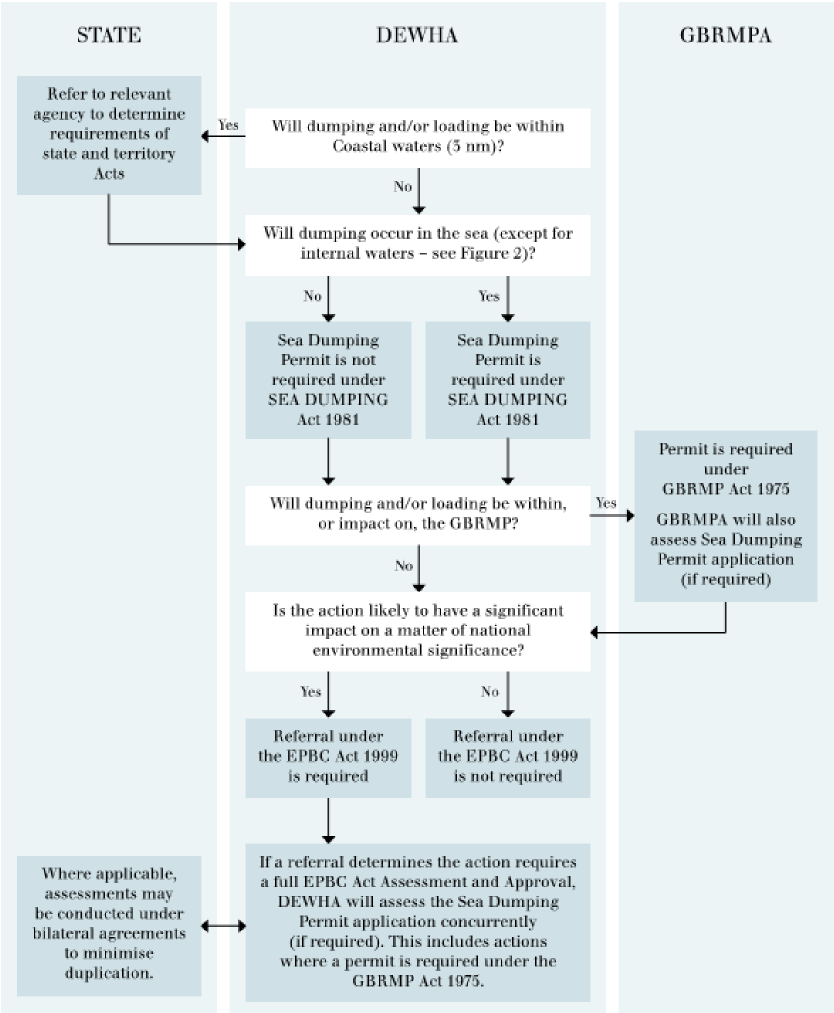


Figure 9. Commonwealth legislative framework and permitting requirements for dredging works (NAGD, 2009).

Great Barrier Reef Marine Park Act 1975

The primary objective of the *Great Barrier Reef Marine Park Act 1975 (GBRMP Act)* is to provide for the long term protection and conservation of the environment, biodiversity and heritage values of the Great Barrier Reef Region. As previously mentioned, where the loading and or placement of dredge material is to take place within the boundaries of the GBRMP, the Commonwealth delegates authority to GBRMPA to regulate the Sea Dumping Act.

The *Great Barrier Reef Marine Park Act 1975* establishes a framework for the establishment, control, management and development of the GBRMP and as such GBRMPA must assess any project that has the potential to impact on the marine park. State marine park legislation (Queensland Marine Parks Act 2004) is also combined into the Commonwealth permit where boundaries overlap. As many ports within the GBR either fall within, share borders with or have Dredge Material Placement Areas (DMPAs) within the GRBMP, maintenance dredging approvals (sea dumping) are often assessed by GBRMPA under this Act.

Environment Protection and Biodiversity Conservation Act 1999

The *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) regulates actions that have, will have or are likely to have, a significant impact on matters of national environmental significance. An activity, or action, requires assessment and approval under Part 9 of the EPBC Act, only if it is likely to have a significant impact on one or more of the following matters of national environmental significance:

- World Heritage Properties;
- Ramsar wetlands;
- Listed threatened species and ecological communities;
- Listed migratory species;
- The environment of the Commonwealth marine areas;
- National heritage places;
- Nuclear actions; and,
- Actions on Commonwealth land or involving a Commonwealth agency.

During the assessment for a dredging permit application under the Sea Dumping Act, the determining authority (DoE or GBRMPA) must also consider advice from the Commonwealth Environment Minister (or delegate), if the action is likely to have a significant impact on ‘the environment’. The EPBC Act is more applicable to capital dredging developments than maintenance dredging works as it is considered less likely that any matters of national environmental significance would be significantly impacted by ongoing maintenance dredging activities. This is confirmed by the DoE significant impact guidelines 1.1, which states:

> *“Dredging to maintain existing navigational channels would not normally be expected to have a significant impact on the environment where the activity is undertaken as part of normal operations and the disposal of spoil does not have a significant impact.” (Commonwealth of Australia 2013)*

However, the proponent of a dredging campaign should consider whether the dredging or disposal activities are likely to have a significant impact on the environment and prepare a separate EPBC referral if necessary.

3.3 Queensland State Legislation

Additionally to Commonwealth legislative requirements, the Queensland Government provides regulations under the State’s own legislation for maintenance dredging works that occur within State Waters. Waters that lie within the constitutional limits of the State varies depending on the coastal features at any one location, however it essentially covers coastal waters up to three nautical miles off the Queensland coastline (**Figure 8**). There are a number of Queensland legislative acts which relate to maintenance dredging activities in State Waters, these include:

- *Transport Infrastructure Act 1994*
- *Marine Parks Act 2004;*

- *Sustainable Planning Act 2009;*
- *Coastal Protection and Management Act 1995;*
- *Environmental Protection Act 1994; and*
- *Fisheries Act 1994.*

As all ports within the GBRWHA also reside within Queensland state waters, Queensland State legislative acts are applicable to all GBRWHA port maintenance dredging operations. These legislative requirements are further discussed in the following sections.

3.3.1 Transport Infrastructure Act 1994

The primary objective of the *Transport Infrastructure Act 1994* is to allow for and encourage effective integrated planning and efficient management of a system of transport infrastructure. Section 275 of the Act requires ports to establish, manage and operate efficient port facilities and services which include the provision of safe navigational channels. Therefore, all maintenance dredging activities are a legislative requirement in accordance with each port's obligation under the *Transport Infrastructure Act 1994*. The Act is administered by the Department of Transport and Main Roads.

3.3.2 Sustainable Planning Act 2009

The *Sustainable Planning Act 2009* (Planning Act) is the principle legislation guiding planning and development in Queensland. The purpose of the act is to ensure environmental sustainability is achieved by providing an overarching framework for Queensland development and planning approvals. Works undertaken within port limits may require development approval under the Planning Act and the associated Integrated Development Assessment System (IDAS). IDAS is the state process for assessing and deciding on development in the state.

Works to maintain structures developed under an approved development permit are excluded from assessable development and do not require further development approval. In the case of maintenance dredging, a development approval would have been required at an earlier stage to facilitate the creation of the first 'structure' being the dredged channel. This would have been required as part of a capital dredging campaign. Once the original channel is dredged, the proponent does not need an additional development approval under the SP Act to undertake maintenance dredging.

3.3.3 Marine Parks Act 2004

The primary purpose of the *Marine Parks Act 2004* is to provide for the conservation of Queensland's marine environment by regulating and controlling activities undertaken within the areas declared as Marine Parks, which includes the GBRMP. The state marine park legislation (*Marine Parks Act 2004*) is combined into the Commonwealth Act (*Great Barrier Reef Marine Park Act 1975*) where boundaries overlap.

3.3.4 Coastal Protection and Management Act 1995

The *Coastal Protection and Management Act 1995* is the principal legislation governing development in the Queensland coastal zone, with the regulatory mechanisms administered under the Planning Act. The Coastal Act specifies areas of the coastal zone as: coastal waters (s9 Coastal Act – Queensland waters to the limit of the Highest Astronomical Tide (HAT)), and all areas to the landward side of coastal waters in which there are physical features, ecological or natural processes that affect, or potentially affect, the coast or coastal resources (s11 Coastal Act). Under this Act, works within State Waters, including dredging, reclamation and the disposal of dredge material at sea, constitute 'tidal works' or 'operational works' in the coastal zone.

Additionally, for maintenance dredging activities where material is brought ashore for sale, used for reclamation above the high water mark, removed for dewatering or other environmental purposes involving a land-based disposal site, the works will also need to be assessed under the Coastal Act for the allocation of Quarry Material.

3.3.5 Environmental Protection Act 1994

The primary objective of the *Environmental Protection Act 1994* (EP Act) is to protect Queensland's environment while allowing for development that improves the total quality of life and maintains the ecological processes on which life depends. The Act requires Ports to obtain or hold all the relevant environmental approvals, permits or licences from the Department of Environment and Heritage Protection (DEHP), in accordance with this Act and other state regulations. The key approval or environmental authority (EA) granted by the DEHP for maintenance dredging works relates to the Environmentally Relevant Activity (ERA) of extractive and screening activities, otherwise known as ERA 16.

3.3.6 Fisheries Act 1994

The primary objective of the *Fisheries Act 1994* is to provide a framework for the management, conservation and enhancement of the State's fisheries resources and fish species. Under this Act, marine and tidal plants, including seagrasses, mangroves, marine algae and saltmarsh, may not be removed or damaged without a permit. The Act also prohibits work in a declared fish habitat area (FHA) without approval. Permits are assessed and approved under the IDAS framework. With respect to maintenance dredging activities, ports may need to gain approval for dredging works which will result in the damage or removal of marine plants or if dredging and or placement is to occur within a declared FHA.

3.4 Best Practice Guidelines

Additionally to legislative requirements, there also exists a number of standards and guidelines relevant to the management and monitoring of dredge activities in the GBRMP. Although not legislative requirements themselves, these standards and guidelines provide best practice guidance on associated maintenance dredging activities. These guidelines include:

- NAGD: As previously described in **Section 3.2.1,** the NAGD is the principle guideline which sets out the framework for the environmental impact assessment and permitting of the ocean disposal of dredge material;
- Queensland Acid Sulfate Soil (ASS) Technical Manual (DSITIA, 2014): These guidelines offer technical and procedural advice to avoid environmental harm and to assist in achieving best practice management of ASS. The guidelines include considerations and guidance on maintenance dredging activities which may disturb ASS;
- Environmental Protection (Water) Policy 2009 (EPP Water 2009): The EPP water is subordinate legislation under the EP Act and provides a framework for identifying environmental values (EVs) of waterways and establishing corresponding water quality objectives (WQOs) to protect the identified EVs. It is important to note that WQO derived from the EPP (water) are not intended to be applied as mandatory standards nor intended to be used for short term compliance issues associated with dredging projects.
- Queensland Water Quality Guidelines 2009 (QWQG): The QWQG provide guideline water quality values that are specifically tailored to Queensland regions and water types. The guidelines further provide processes/frameworks for deriving and applying these local guidelines. The QWQG provide a mechanism for recognising and protecting local Queensland waters and are not mandatory legislative standards;
- Water Quality Guidelines for the Great Barrier Reef Marine Park, 2010 (WQGGBRMP): The WQGGBRMP describe the concentrations and trigger values for sediment, nutrients and

pesticides that have been established as necessary for the protection and maintenance of marine species and ecosystem health of the Great Barrier Reef. It is important to note that the guidelines ultimately provide environmentally-based values for water quality contaminants, based upon a compilation of currently-available scientific information, which, if breached, will trigger management actions, and are not for use as single point compliance triggers as part of a dredging project;

- National Environment Protection (Assessment of Site Contamination) Measure 1999 (the 'NEPM') and amendment 16 May 2013. These guidelines establish a nationally consistent approach to the assessment of site contamination. They aim to provide adequate protection of human health and the environment. The guidelines can be applicable to maintenance dredging campaigns for the assessment of dredge material for beneficial reuse on land and,
- ANZECC/ARMCANZ (2000) Guidelines for Fresh and Marine Water Quality: The ANZECC/ARMCANZ water quality guidelines provide a guide for setting water quality objectives required to sustain current or likely future, environmental values for waters in Australia and New Zealand. The guidelines can be used where regional guidelines (QWQG/WQGGBRMP) are not adequate or available, for example, when assessing toxicants such as metals. Similar to the QWQG, the guidelines were not intended to be applied as mandatory standards nor intended to be used for short term compliance issues associated with dredging projects.

As the above mentioned guidelines do not constitute legislative requirements, adherence to these guidelines does not guarantee maintenance dredging approval.

3.5 Summary

In summary, all dredging activities in Queensland are managed under both State and Commonwealth legislation, giving rise to the multiple layers of approvals required for maintenance dredging works at GBR ports. Of all the legislative acts applicable to maintenance dredging works, approval for a sea disposal permit is generally considered as the central approval governing maintenance dredging authorisation. The primary reason for this is that the timeframes at which sea dumping permits are granted lapse, unlike EAs. Furthermore, there has been a recent trend for these permits to be granted for shorter intervals, resulting in the ports being continually required to gain sea dumping approval.

Submissions for ocean disposal approval are supported by studies justifying why ocean disposal is the most effective solution to dredge material disposal. Submissions are required to consider alternatives to ocean disposal which includes assessment of environmental, social and economic impacts. The determining authority (GRBMPA or DoE) considers the application and decides whether to grant the approval. Approval is generally subject to conditions which are appended to the permit and specify: approved activity; location and volume of the material to be dredged and location of the disposal site(s); loading and disposal methods and measures to mitigate impacts; environmental monitoring; and reporting (NAGD, 2009).

As detailed in the NAGD, the determining authority has the ability to grant long-term permits for maintenance dredging requirements at each of the ports. Applications for long term maintenance dredging approvals are favoured by port operators as they provide for an efficient approvals process and allow for certainty around future maintenance dredging requirements.

4 Maintenance Dredging

4.1 Introduction

The maintenance dredging requirements vary considerably between Queensland Ports. As detailed in **Section 2**, this is dependent on both the coastal setting and the port configuration. It is therefore important to understand the maintenance dredging which has been undertaken historically in order to assist in predicting future maintenance dredging requirements and identify any approaches to minimise or optimise future maintenance dredging.

This section addresses the historical and likely future maintenance dredging requirements at all recognised Queensland Ports, as these requirements influence the future availability of the TSHD Brisbane. This section provides details on:

- existing maintenance dredging practices at the ports, including the dredging equipment, operational approaches and any existing strategies adopted to minimise maintenance dredging;
- historical dredging volumes at the ports over the last 10 years and details of the variability in these and the associated causes;
- the likely future maintenance dredging requirement at each port in Queensland. This includes details of any projects which could influence the future requirements and the extent of the increase; and
- any potential management or engineering options which could be considered at the ports to reduce future sedimentation levels.

4.2 Dredging Equipment & Operational Approaches

The majority of maintenance dredging in Queensland has historically been undertaken using a trailing suction hopper dredger (TSHD), although small grab, backhoe and cutter suction dredgers (CSD) are also used. The larger volumes of material are removed by the TSHD, while smaller volumes are removed by the CSD and grab dredgers. Bed levelling is also undertaken at some ports as an operational approach to reduce maintenance dredging frequency.

4.2.1 Trailing Suction Hopper Dredger

TSHD dredgers have typically undertaken the majority of the maintenance dredging at Queensland Ports as they are the most suitable type of dredger. They have high production rates, can operate in offshore areas and heavily trafficked areas, have a hopper allowing offshore placement, and are well suited to dredging soft unconsolidated sediment typically associated with maintenance material.

The TSHD Brisbane was specifically designed for the maintenance dredging of Queensland Ports and has been the equipment of choice of the Queensland ports to undertake the maintenance dredging programs since it was commissioned in 2000. Whilst it is noted that future maintenance dredging could be undertaken by other TSHDs with similar equipment features, as the dredging has primarily been undertaken by the TSHD Brisbane since 2000, the following sections are primarily focused on this vessel.

Technical Aspects

The TSHD Brisbane is a trailing suction hopper dredger built in Cairns in 2000 by North Queensland Engineers & Agents (NQEA) and commissioned in 2000. The TSHD Brisbane is owned and operated by the Port of Brisbane Pty Ltd (POBPL). The technical specifications of the Brisbane are provided in **Table 9** and design drawings are shown in **Figure 10**.

Table 9: TSHD Brisbane Specifications

THSD Brisbane specifications	
Type of vessel	Twin screw trailing hopper suction dredger
Classification	Lloyd's Register +100 A1 +LMC UMS TM Hopper Dredger
Owner	Port of Brisbane Pty Ltd
Designer/builder	NQEA Australia
Length overall	84.10 metres
Length, waterline	81.70 metres
Beam	16.00 metres
Draft	(maximum) 6.25 metres (minimum) 3.0 metres
Displacement	5,890 tonnes at 5.50 metres draft
Main engines	2 x Caterpillar 3606 DITA @ 1850kw
Propulsion	2 x variable pitch propellers with nozzles
Bow thruster	1 x 310kw
Dredge pumps	2 x Warman 28/24 @ 750kw each
Jet water pumps	2 x Warman 10/8 @ 310kw each
Dredging depth	25 metres
Hopper capacity	2,900m^3
Maximum cargo	4,206 tonnes
Maximum speed	13 knots
Maximum speed, fully loaded	11 knots
Discharge	Pump ashore by bow coupling or bottom dump
Crewing	13

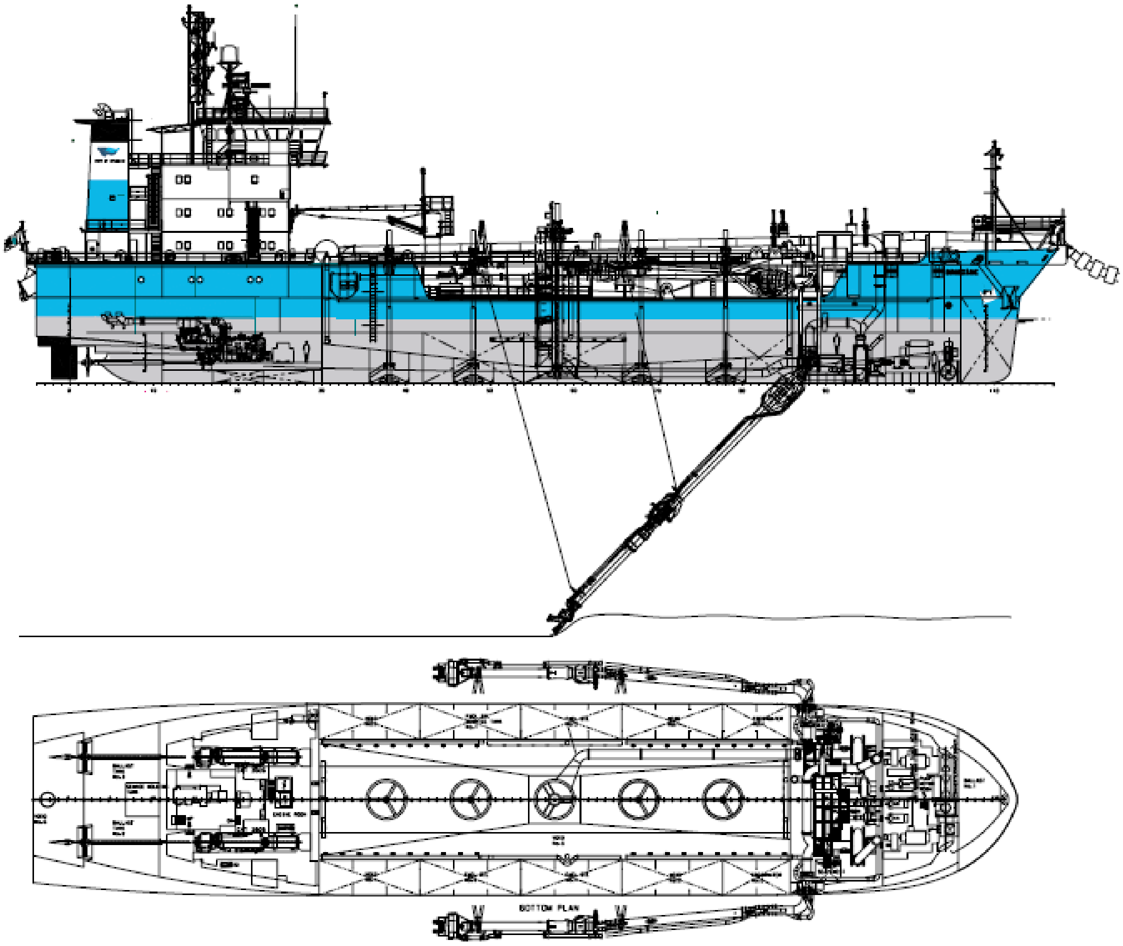


Figure 10: Technical drawing of the TSHD Brisbane.

Capabilities

The TSHD Brisbane is equipped with dredge automation control and navigation systems. The hopper capacity is 2,900m³ and dredge material can be pumped ashore or disposed of at sea through bottom dump valves. The pumping system consists of 2 x 750kw Warman pumps, capable of pumping dredge material at least 1500 metres from the mooring location. Pumping distances of 2500 metres can be achieved depending on the characteristics of the material, and the addition of booster pumps on the discharge line can increase the achievable pumping distances. The shore disposal operation can be at berth or from a mooring through a floating pipeline.

To minimise the turbidity resulting from dredging the vessel is also equipped with a low turbidity hopper loading system and under keel discharge of overflow waters through an anti-turbidity valve. The hopper can also be pumped dry to maximise efficiency in the non-overflow dredging mode.

Methodology

The TSHD Brisbane has been historically used by the Queensland ports as the preferred vessel to address the maintenance dredging requirements, therefore, the specifications and operations of the TSHD Brisbane form the baseline for dredge specification and operational environmental management plans for the maintenance dredging programs. It is recognised that while other TSHDs may be used for maintenance dredging of the Queensland Ports, this has been very rare partially due to the ports having a long term contract with the Port of Brisbane Pty Ltd. The following methodology describes the typical Queensland maintenance dredging operations.

The dredge material is removed through two suction heads, which are lowered into position to the seabed level on either side of the vessel. As the vessel slowly moves at around 1 – 3 knots, the water and sediment mix is drawn through the heads and transported into a central collection hopper. Each excavation run takes approximately 1 hour to complete, depending on the material characteristics. Once the hopper capacity is reached the TSHD Brisbane travels to the material placement site, where it discharges the sediment before returning to the dredging area and completing the dredge cycle. The suction heads are fitted with high-pressure water jets which can be used to agitate consolidated sediment; however, the unconsolidated nature of the maintenance dredging material rarely requires this procedure.

The sediment concentration delivered to the hopper of the TSHD Brisbane is typically in the order of 10 – 30 % solids by volume. The water volumes are managed using the central column weir, which is used to dispose the excess water from the hopper and maximise dredge material capacity. The weir allows excess water to overflow to discharge whilst the majority of the sediment remains in the hopper. The overflow takes place as the hopper nears full capacity, towards the end of the typical one hour dredging duration.

The vessel travels to the designated disposal ground once the hopper is full to release the dredge material. The sediments are discharged below keel level to minimise turbidity generation. The placement of sediments is logged using satellite navigation and standard bridge equipment. The release is tracked electronically using plot marks at the start of the placement process (when the hopper is open and discharge starts), and at the end of the process (when the hopper closed and discharge ceases). The discharge process tracking ensures that the dredge material is placed within the designated discharge area boundary. The discharge process usually takes between ten and twenty minutes from the time the hopper is open and discharge starts. The data collected during the discharge operations is stored and made available to the relevant government agencies in order to comply with the conditions specified in disposal permits.

Environmental Mitigation Measures

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 the latest 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 or anti turbidity function): this system works by controlling discharge from the dredger to limit the turbidity of overflow waters entering the receiving environment. The TSHD Brisbane has 5 equally spaced conical valves in the floor of the hopper which when opened allow the material to fall to the seabed when discharging. The middle valve (DV3) is surrounded by a set of 6 cylindrical rings stacked on top of each other to form a weir of adjustable height. When dredging light material such as silts only the top ring is lifted to create the largest possible hopper capacity and settling time for the material. When the hopper reaches point of overflow DV3 is partially opened to allow excess water to escape. The aperture of DV3 is regulated to maintain a water column within the circular weir stack and thereby minimise the entrapment of air in the overflow water. This reduces the amount of air bubbles which can act to carry material to the water surface and generate excessive plumes.
- 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): The Port of Brisbane Pty Ltd. (PBPL) maintain a Dredge Management Plan which addresses standard operational procedures to minimise environmental impact. Separate EMP's are also developed by PBPL for each specific port/ project is undertakes dredge works. This EMP addresses matters specific to the project including local regulations, sensitivities and specific permit conditions. It is submitted for review and approval by the principal prior to commencement of the work.

Any other TSHDs undertaking maintenance dredging works in the future at the ports within the GBRWHA should have similar state-of-the-art systems in order to minimise environmental impacts and have confidence in the basis of any environmental risk assessment.

Dredger Schedule

The Port of Brisbane has long term contracts in place with all the ports which currently utilise the TSHD Brisbane for their maintenance dredging requirements. At present this includes five of the ports located within the GBR area, Gladstone, Port Alma, Mackay, Townsville and Cairns. Since the commissioning of the TSHD Brisbane in 2000, the contracts in general roll over to 4 year extensions at the end of each term. The TSHD Brisbane also provides services for the ports of Melbourne, Bundaberg, Karumba, Weipa and Brisbane. A summary of the time the TSHD Brisbane has spent undertaking maintenance dredging at each port since 2011 is provided in **Table 10**. It is important to note that reporting on dredging by calendar year can be misleading as the timing of the dredging will vary from year to year and this can result in some years appearing to have a greater requirement for dredging while others have no requirement for dredging. For example, if the dredging is typically undertaken in November or December each year and then for one year it is delayed until January the table indicates that there was no maintenance dredging required that year which was not the case.

The schedule of the TSHD Brisbane is based on the dredging requirements of the serviced ports. The southernmost port serviced by the TSHD Brisbane is the Port of Melbourne, which is normally dredged in the first half of the year. The dredger spends an average of 53 days in Brisbane every year to address the dredging requirements for the Port of Brisbane.

The ports located north of Brisbane are generally dredged in sequence in order to minimise mobilisation costs. A typical year for the TSHD Brisbane starts with a vessel maintenance period in Brisbane, followed by a period of dredging in Brisbane and Melbourne before heading north. The furthest destination visited by the TSHD Brisbane is Karumba, however, dredging there is only required every third year. The second furthest port dredged by the TSHD Brisbane is Weipa, where maintenance dredging happens every year and the works take approximately 28 days to be completed. Other Queensland ports are visited during the trip, with stops every year in Gladstone (29 days average), Townsville (48 days average) and Cairns (25 days average). Visits to Port Alma, Mackay and Hay Point are also included in the schedule in some years, as required.

Some ports can be visited twice during the same trip (on the way up to Weipa/Karumba and when returning to Brisbane), depending on the progress of the works, the maintenance dredging requirement, meteorological conditions and environmental windows. The TSHD Brisbane normally stops in Bundaberg during the trip, increasing the time spent there during years when floods have brought in more sediments than usual during the wet season (e.g. 2011 and 2013). It is also useful to note that, depending on the occurrence of cyclones and floods during the wet season, the maintenance dredging requirements can vary at any of the ports. Typically the TSHD Brisbane spends approximately 24 weeks per year servicing the ports located within the GBRWHA.

The most efficient manner for the dredger to address the existing maintenance dredging requirements is to travel to the ports on the western side of Cape York and have sequential stops at the other ports on the way up or way back, minimising travel time and reducing mobilisation costs. Periods when no dredging is allowed under the dredging permits can result in the dredger schedule having to be adapted and, in some cases, can result in increased travel for the dredger. When travel time is minimised, so are emissions due to minimisation of fuel consumption, which in turn minimises the environmental footprint of the dredging activity.

The planning phase of the maintenance dredging works performed by the TSHD Brisbane is heavily dependent on the permits obtained by the ports to execute the necessary works. When long term permits are issued to the ports, the preparation of the maintenance dredging schedule can be done with confidence and in advance, making the most of opportunistic windows and providing a chance for medium to long term plans which can be adapted as the works evolve, optimising the usage and time of the TSHD Brisbane. Short term permits, on the other hand, prevent the client ports and the Port of Brisbane from developing a long term strategy.

Table 10: TSHD Brisbane number of days undertaking maintenance dredging in each port.

Port	2011	2012	2013	2014	2015	Total	Average
Melbourne	0	32	0	42	86	160	32
Brisbane	115[2]	107[2]	126[2]	51	33	432	86.4
Gladstone	38	18.7	0	90.7[1]	17.3	164.7	32.9
Point Alma	2.4	0	0	0	0	2.4	0.5
Bundaberg	27.4	0	48.5	6.7	7.5	90.1	18.0
Mackay	0	0	6	0	0	6	1.2
Townsville	48	81	30	39	43	241	48.2
Cairns	22	21	27	25	29.6	124.6	24.9
Karumba	19.6	0	0	13.9	0	33.5	6.7
Weipa	26	31	32	28	24	141	28.2

[1] In 2014 additional dredging was required following the Western Basin Dredging and Disposal Project as significant volumes of material were left in the channel following the capital works. This additional dredging has therefore influenced the average number of days of maintenance dredging per year, the long term average is expected to be closer to 29 days.
[2] Includes maintenance dredging of flood induced sedimentation.

The current agreements in place keep the TSHD Brisbane busy during the whole year, maximizing its utilisation and ensuring it is economically viable. The location of the ports allow the mobilization costs to be shared between them as the TSHD Brisbane travels along the Queensland coast, providing a cost competitive solution for the maintenance dredging requirements.

Future Scheduling

The TSHD Brisbane size and production rates are currently adequate to address the needs of the ports in Queensland. At present additional work is sourced to fill the schedule of the TSHD Brisbane, such as the dredging in Melbourne, indicating that it has sufficient capacity to accommodate the future maintenance dredging requirements of the ports in Queensland. However, if a different vessel is required in the future for any reason it should be ensured that the vessel continues to have state-of-the-art environmental mitigation measures.

There are a number of ways the future maintenance dredging scheduling of the Queensland ports could be further optimised, therefore reducing environmental impact through vessel emissions:

- if the ports were granted long term permits for the maintenance dredging operations. Longer term permits give certainty to the ports that the maintenance dredging works needed can take place for a number of years, therefore allowing the schedule to be prepared in advance, reducing insecurity and increasing efficiency; and
- ensuring that any no-dredge periods and environmental windows imposed on the maintenance dredging permits are necessary and do result in reduced environmental impact and management of environmental risks.

Alternative vessels

In the future, if required, there are other TSHDs available in Australia with the characteristics necessary to perform the maintenance dredging for the Queensland Ports. The proposed dredge vessel should be considered as part of the risk assessment process to identify the confidence that can be placed in any potential impacts depending on the availability of previous monitoring data.

Rohde Nielsen Dredging has an office in Newcastle where some of its equipment is based.

- The Brage R is a TSHD with a loading capacity of 2,150m^3 (**Figure 11**). It has bottom doors used for offshore disposal and can also pump ashore. This dredger has carried out maintenance dredging in Dampier and Davenport in 2015 and in New Zealand in 2016; and

- The Balder R is a Split Trailing Suction Hopper Dredger (STSHD) with a loading capacity of 6,000m^3, the split means it can open the ship longitudinally in two parts and dispose the load. It also has pump ashore capabilities and is equipped with multi beam survey system and a dynamic position system. The Balder R has commitments scheduled until July 2016.

Both vessels are equipped with central weir discharge systems (green valves).

Figure 11: Brage R THSD based in Newcastle and owned by RN Dredging.

Table 11 presents a summary of TSHDs currently available locally and internationally. All of them are equipped and designed with similar devices to the TSHD Brisbane to reduce environmental impacts during the dredging works.

Table 11: Comparison of Similar TSHDs

Dredger	Owner	Country of Origin	Length overall (m)	Beam (m)	Draft (m)	Dredging depth (m)	Hopper capacity (m^3)	Max speed loaded (knots)
Brisbane	Port of Brisbane	Australia	84.1	16.0	6.2 max 3 min	25	2,900	11
Brage R	Rohde Nielsen	Australia	89.9	13.6	5.7 max 2.1min	30	2,150	7.5
Balder R	Rohde Nielsen	Australia	111.3	19.4	7 max 3.7 min	35/54	6,000	14
River Bee	WA Dredging	Australia	80.0	13.8	5.6 max 4.5 min	20	1,895	8.8
Volvox Olympia	Van Oord	Holland	96.6	19.9	7.2	32	4,871	12.5
Jade River	DI	Bahrain	100.4	16.4	7.3	31	3,281	11.9
Alvar Nunez Cabeca de vaca	Jan de Nul	Argentina	93.3	19.8	5	26.5	3,400	11.5

4.2.2 Smaller Dredgers

In shallow areas, or in areas with limited accessibility/manoeuvrability, it is often necessary for the ports to use small dredgers. In these cases it is not possible for the TSHD Brisbane to undertake the dredging so the ports will either use a small CSD (cutter suction dredger) or a grab or backhoe dredger. If required, these dredgers are able to operate all year round to maintain design depths in inner port areas. Typically these smaller dredgers remove relatively small volumes of sediment compared to the larger TSHD.

Cutter Suction Dredger

CSD are not frequently used for maintenance dredging. CSD are not mobile and so they are better suited to dredging restricted areas (e.g. shallow) with relatively large volumes (i.e. capital dredging). Material dredged by a CSD is usually pumped onshore as slurry where it can either be stored or used for reclamation. Material can also be pumped to offshore areas, but due to limits on the distance the vessels can pump, this is uncommon.

The Port of Townsville is the only port in the GBRWHA which regularly uses a CSD for maintenance dredging purposes. The Ross River is regularly dredged (on average every 2 years) using a CSD and occasionally the Ross Creek is also dredged. Historically, the material from the dredging has been pumped onshore and placed in a reclamation area. A CSD was also used for maintenance dredging at Cooktown in 2015. The majority of the sediment was pumped onshore and placed in a reclamation area, while the remainder was pumped to an offshore placement site. A small CSD was also used to dredge a marina at the Port of Gladstone twice over the last 25 years, the sediment was pumped onshore.

Grab & Backhoe Dredger

For minor dredging work where small volumes need to be removed or in locations with limited accessibility/manoeuvrability, small grab or backhoe dredgers are often used. The dredged sediment is loaded into barges where it can either be transported to an offshore placement site or discharged to land if the barge has a slurry pump.

In cases where sediment has been identified as having elevated levels of contaminants, as defined in the NAGD guidelines, grab and backhoe dredgers are typically used in order to minimise sediment release into the water column during dredging. Over the last 10 years no sediment removed by maintenance dredging at any of the ports within the GBRWHA has been identified as contaminated based on the NAGD guidelines. At the Port of Townsville, sediment in some of the berths of the Inner harbour have exceeded the screening levels as defined in the NAGD guidelines, but have then passed the Phase III testing and so were considered suitable for ocean disposal. The PoTL has historically adopted a precautionary approach by placing this sediment onshore.

This type of dredger has historically been regularly used at Mackay Port, the Port of Townsville and the Port of Cairns.

4.2.3 Bed Levelling

Bed levelling can be an important operation to assist in maintaining declared depths without requiring additional maintenance dredging. The operation involves lowering a heavy metal bar to a set depth (e.g. the channel design depth) and then dragging the bar across the seabed. This removes any high points and redistributes the material to surrounding lower areas. This represents a very efficient way of removing high points in aprons and channels which can otherwise result in a reduction in the declared depth of the channel, berth or swing basin. This operation has historically been adopted in the Port of Gladstone, Hay Point Port, Mackay Port, Port of Townsville, Port of Mourilyan, Port of Karumba and Port of Cairns.

4.3 Existing Strategies to Minimise Maintenance Dredging

The London Protocol details that appropriate measures to prevent, reduce and where practical eliminate the relocation of dredge material should be taken by the ports. Ports therefore aim to reduce their maintenance dredging requirements as much as possible and will only undertake dredging when necessary. It is also worth noting that maintenance dredging is considered an expensive and inconvenient requirement for many ports.

Optimising the original design of dredged channels, basins, aprons and berths relative to the natural sediment transport and sedimentation processes represents an opportunity to minimise future maintenance dredging volumes. However, these areas have already been created at most ports within the GBRWHA and there are limited opportunities to further reduce future maintenance dredging requirements through the configuration of existing dredged areas. The design of any future proposed capital dredging works should be considered in terms of the future maintenance dredging requirements and optimised wherever possible.

Ports within Queensland currently undertake a number of strategies to help minimise maintenance dredging activities:

- Hydrographic survey. Repeat hydrographic surveys ensure that maintenance dredging is focused on the areas where sedimentation has occurred and that maintenance dredging is only undertaken when and where it is required. It is common practise for ports to vary the areas where maintenance dredging is carried out from campaign to campaign depending on the sedimentation. Surveys are typically undertaken at those ports which require frequent maintenance dredging at the end of the wet season each year, to identify the maintenance dredging requirements following the period of the year when the highest rates of sedimentation occur.
- Bed levelling. Bed levelling is undertaken at a number of ports in Queensland to help reduce the requirement and frequency of maintenance dredging. Bed levelling can be used to level out high points in a channel, berth, basin or apron and, therefore, help to reduce the frequency of maintenance dredging.
- Local interception strategies. Some of the ports either utilise existing deep areas or have created insurance trenches adjacent to berths and channels. Bed levelling can then be used to move sediment from the berths and channels and into the adjacent deep areas. Although this approach does not specifically reduce maintenance dredging volumes (as the material still needs to be dredged) it can be used to reduce the dredging frequency at locations which are subject to higher sedimentation rates. Use of insurance trenches results in improved dredging efficiency (hence reduced costs),
- Tidal windows. Using tidal windows involves vessels navigating shallower areas during higher stages of the tide to ensure sufficient under keel clearance. This has been occurring at the Port of Hay Point where maintenance dredging has recently not been permitted (due to approval and legal issues). This approach has resulted in operational inefficiencies and has the potential to result in safety and environmental implications (i.e. if a fully laden vessel breaks down in a shallow area and there is insufficient time for tugs to move the vessel prior to low water).
- Dynamic under keel clearance systems (DUKCS). Implementation of a dynamic under keel clearance system can help to promote safe navigation and improved overall efficiency of the port and has the potential of allowing for reduced bed levels in channels. Therefore it can potentially reduce the frequency of maintenance dredging but ultimately dredging is still required in the ports. The system can be beneficial in environments which are: exposed to waves; large tidal range; and/or where there are long navigation channels. In addition, the associated near-real time and forecast data streams associated with the DUKCS can be of direct application in operational management of dredging activities by characterising the temporal and spatial variabilities of zones

of impact during dredging campaigns. The Ports of Hay Point and Weipa use a dynamic under keel clearance system.

- Catchment Management. The port authorities who operate the ports within the GBRWHA are members of various taskforces, committees and associations that implement measures to improve the management of sediment in catchments and, therefore, reduce the land based sediment inputs to the GBR lagoon (albeit that river inputs are considered to play an insignificant role in the sedimentation of the vast majority of GBR ports, as detailed in **Section 2.6**).
- Port Management. Ports will typically manage their infrastructure and operations to minimise the requirement for future maintenance dredging including working with port tenants and customers.

In addition, the ports regularly review proven overseas technologies in terms of their benefits and risks with a view to trying to reduce future maintenance dredging requirements (e.g. fluidisation of silts for tidal current removal, silt deflection techniques, etc.).

4.4 Measures of Maintenance Dredging Quantities

There are a number of different measures which are adopted to describe dredged quantities. These are described in more detail in the following sections.

4.4.1 In-situ Volume

The in-situ volume represents the material actually removed by the dredging. It is calculated based on pre and post dredging campaign hydrographic surveys. The in-situ volume of material required to be removed by maintenance dredging to reach the target depths can be calculated prior to dredging. The in-situ volume is the only parameter which can be established both before and after dredging.

The measure can have limitations associated with the timing of the hydrographic surveys relative to the dredging campaign. This is particularly an issue when maintenance dredging is carried out through multiple campaigns in a year, as sedimentation can occur between the campaigns. The accuracy of the hydrographic survey can also be influenced by the type and density of the sediments being dredged, although modern survey vessels should be able to achieve accurate surveys when the expected properties of the bed material are known prior to the survey. It is noted that, for navigational safety, the frequency set for the sounding equipment is prescribed to detect a density of fluid/solid mix that may affect ship manoeuvring and this may be as little as 1.1 tonnes per cubic metre. Hence the volume measures may include some volume of water however this would be expected to be insignificant in the case of dredged volume determinations made by pre dredge and post dredge survey differences.

This measure is considered to provide an accurate measure of the amount of sediment dredged from port areas and it can also provide an accurate estimate of the amount of sediment required to be removed prior to dredging being undertaken.

4.4.2 Wet In-hopper Volume

The wet in-hopper volume is the mixture of sediment and water, which is contained within the dredge vessel hopper. The volume is measured at the dredge vessel based on an acoustic measurement of the hopper load, the volume typically includes a significant volume of water which is sucked into the hopper along with the sediment. The relative proportions of sediment and water can be highly variable depending on the properties of the sediment being dredged, the type of dredging (e.g. bulk dredging for depth compared to spot dredging high points) and the dredging methodology (e.g. overflow duration). As a result, prior to dredging it is not possible to accurately predict the wet in-hopper volume required to reach the target depths.

This measure is not considered to provide as accurate a measure of the amount of sediment dredged from port areas as the in-situ volumes.

4.4.3 Dry Weight

The dry weight (also known as dry tonnage) is the dry mass of the dredged sediment. The weight is calculated at the dredge vessel by measuring the wet mass, using pressure gauges on the hull to determine the vessel draft and calculating the seawater displaced. The dry weight of the sediment in the hopper can then be calculated by using established material specific gravities (e.g. 2.63 to 2.67 for clays, silts and sands) for the material dredged. Despite the assumptions made about the sediment specific gravity, variations from the calculated values for different sediment types are considered to be minimal.

The dry weight (or tonnage) is considered to provide an accurate measure of the actual amount of sediment dredged. It is not influenced by the properties of the in-situ sediment (e.g. consolidation) or the dredging methodology (e.g. overflow duration).

4.4.4 Summary

Table 12 details the historic maintenance dredging undertaken by the TSHD Brisbane at the Port of Cairns. The table includes the three measures of dredging quantities detailed above along with conversions to multiply the in-situ volume to calculate either wet in-hopper volume or dry weight. The conversion factors are ratios calculated by dividing the wet volume or dry weight by the in-situ volume. There is significant variability in the measures with the wet in-hopper volumes on average being 2.3 times higher than the in-situ volume while an average conversion factor 0.72 is required to convert from in-situ volume to dry weight in tonnes. The conversion factors also vary from year to year depending on the sediment properties, the type of dredging and the dredging methodology, with conversions to wet in-hopper varying from 1.55 to 3.69 and to dry weight varying from 0.52 to 1.13. In some cases recorded figures towards the extremes of these ranges can be explained and eliminated as uncharacteristic for the purposes of determining long term averages, however significant variability still remains.

Owing to the considerable variability in the conversions over time, it is not possible to accurately present all of these dredging quantity measures for all of the ports as requested in the brief. As such, this report presents historic dredge volumes using in-situ volume, as this measure is thought to be most suitable and it is also the measure which most ports adopt when reporting on maintenance dredging.

Table 12: Historic maintenance dredging quantities dredged by the TSHD Brisbane (just the channel) at the Port of Cairns from 2004 to 2014.

Year	In-Situ Volume (m^3)	Wet In-Hopper Volume (m^3)	Dry Weight (tonnes)	Conversion: In-Situ to Wet In-Hopper	Conversion: In-Situ to Dry Weight
2004	480,815	965,229	248,618	2.01	0.52
2005	355,342	655,045	221,417	1.84	0.62
2006	347,447	585,754	244,857	1.69	0.70
2007	193,708	466,098	156,377	2.41	0.81
2008	155,801	437,479	155,347	2.81	1.00
2009	244,910	594,398	150,347	2.43	0.61
2010	274,876	708,923	177,505	2.58	0.65
2011	397,568	736,631	205,990	1.85	0.52
2012	194,981	719,220	220,880	3.69	1.13
2013	366,754	866,894	283,552	2.36	0.77
2014	531,953	822,225	336,795	1.55	0.63

4.5 Historic Maintenance Volumes

Historic maintenance dredging in-situ volumes have been collated for all recognised Queensland Ports requiring maintenance dredging over the last 10 years (**Table 13**). The historic volumes show that there is significant variability in the maintenance dredging requirements of the different ports. This highlights that the local environment and, therefore, the relative importance of the processes which influence sedimentation differs between the ports; this was discussed further for the ports in the GBRWHA in **Section 2.6**. There is also noticeable temporal variability in the maintenance dredging volumes over the last 10 years; this can be due to the temporal variability in the processes which influence sedimentation and especially any extreme episodic events, such as tropical cyclones and flood events.

Historic maintenance dredging volumes can be used to assist in predicting likely ranges for future maintenance dredging volumes. However, the historic volumes need to be interpreted with care as they do not necessarily directly relate to the maintenance dredging requirement or sedimentation; this can be a result of:

- restrictions in maintenance dredging preventing target depths from being achieved. This can include maintenance dredging volume caps as part of dredging permits, dredger availability, internal budget constraints and dredge permit complications;
- the timing that maintenance dredging occurs varying from year to year. This can mean that reporting the maintenance dredging by calendar year does not represent the dredging required each year. For example, dredging may typically occur in November and December each year, but some years it might be delayed until January. For these years it would then look like no maintenance dredging was required, while the following year required twice the normal volume;
- capital dredging works or other port developments can change the sedimentation patterns and rates and can also potentially change the total area requiring maintenance dredging. In addition, maintenance dredging might be undertaken as part of the capital works; and
- in-situ volumes will vary depending on the composition of the material and for silts and clays the consolidation of the material.

Details of how the historic maintenance dredge volumes have related to sedimentation rates is provided in the following sections for each of the recognised Queensland Ports requiring maintenance dredging. Ports located outside of the GBRWHA have also been considered below, as the historic requirements are essential in the determination of future state wide maintenance dredging requirements.

Port of Brisbane

The historic maintenance dredging volumes at the Port of Brisbane typically provide a good representation of the sedimentation rates at the port; these are detailed in **Table 14**. Maintenance dredging at the port is carried out annually between Fisherman Island and the Hamilton Reach of the Brisbane River to remove naturally deposited sediments that have accumulated within the navigation channels. The increase in volumes dredged in 2011 and 2012 were a direct result of the 2011 Brisbane flood event, with two years of maintenance dredging required to restore depths in the dredged areas of the port. The increase in volume in 2013 was a result of flooding associated with TC Oswald in 2013. The volumes dredged between 2011 and 2013 highlight the variability in maintenance dredging volumes associated with significant flood events.

Bundaberg

The historic dredge volumes at the Port of Bundaberg provide a reasonable representation of the sedimentation rates at the port; these are detailed in **Table 14**. Since the Port of Bundaberg is located on the Burnett River, sedimentation at the port is primarily driven by fluvial processes. As a result, maintenance dredging volumes are variable, subject to the occurrence of flooding events. The increased volumes dredged in 2011 and 2013 correspond to significant flood events that resulted in increased volumes of fluvial sediments being deposited into the dredged areas of the port. Following both of these events, the port has yet to return to the declared depth of 9.5 m LAT, as it was prior to 2011. GPC envisages extended maintenance dredging campaigns until 2020 will be required to return the port to original pre 2011 declared depths.

Port of Gladstone

The historic volumes at Gladstone can be considered to generally provide a reasonable representation of the sedimentation which occurs. Based on these the historic sedimentation rates at Gladstone are presented in **Table 14**. However, there have been a number of years when the timing of the dredging has meant that the volumes indicate no maintenance dredging in one year and a relatively high requirement the following year. The dredging tends to be undertaken by the TSHD Brisbane in November or December each year (GPC, 2014), but the dredger was not available at the end of 2010 and so the dredging was undertaken at the start of 2011 and then the dredger was available at the end of 2011, resulting in two maintenance dredging campaigns in 2011. This also occurred in 2013 and 2014, with the added complication that towards the end of 2013, an extensive capital dredging program was completed and for the 2014 campaign, GPC took over the maintenance dredging of Jacobs Channel.

When Jacobs Channel was handed over to GPC at the end of 2013 following the capital dredging, the channel was found to require significant volumes of sediment to be removed to achieve the design depths, further increasing the maintenance required in 2014. Recent surveys indicate that the maintenance requirement for this area has started to stabilise and it will not continue to result in such a significant increase in maintenance dredging into the future. On this basis, it is likely that the additional dredging required in 2014 was not infill (due to natural sedimentation) but, rather, more likely due to capital dredge batter slopes finding their natural equilibrium.

Table 13: Historic in-situ maintenance dredging volumes (m^3) at the ports located within the GRBWHA.

Year	Brisbane	Bundaberg	Gladstone	Port Alma	Hay Point	Mackay	Abbot Point	Townsville	Lucinda	Mourilyan Harbour	Cairns	Cooktown	Cape Flattery	Quintell Beach	Weipa	Karumba
2004	766,400	22,000	174,150	0	98,900	122,760	0	492,740	0	0	531,962	0	0	0	621,650	395,000
2005	485,341	0	148,426	0	0	0	0	312,785	0	0	387,346	0	0	0	803,098	0
2006	494,312	0	225,242	0	0	520	0	156,560	0	0	378,554	0	0	0	500,000	399,370
2007	534,200	44,000	160,972	0	0	106,000	0	117,454	0	0	228,105	0	0	0	724,775	0
2008	427,100	100,000	17,995	0	192,294	3,406	<20,000[3]	339,306	0	0	201,864	0	0	0	834,281	466,200
2009	461,126	53,000	282,000	23,000	0	0	0	675,464	0	0	312,807	0	0	0	555,457	0
2010	426,000	24,767	0[1]	0	216,070	0	0	133,100	0	0	314,657[5]	0	0	0	832,780	544,200
2011	1,301,000[7]	280,000[6]	309,000	40,000	0	0	0	814,435[4]	0	0	439,443[5]	0	0	0	460,820	269,889
2012	1,160,684[7]	89,126[6]	150,000	0	0[2]	0	0	502,940	0	0	246,727[5]	0	0	0	598,658	0
2013	1,318,000[7]	300,000[6]	0[1]	0	0[2]	98,381	0	386,610	0	0	421,491[5]	0	0	0	644,525	0
2014	635,220	65,000[6]	555,107	0	0[2]	0	0	521,770	0	0	574,447[5]	0	0	0	394,524	120,924

[1] The years with no maintenance dredging in the Port of Gladstone are due to the timing of the dredging schedule, instead of dredging occurring towards the end of the year it occurred at the start of the following year.
[2] 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.
[3] At the Abbot Point Port capital dredging of 201,315m^3 to create a new berth as well as maintenance dredging of the existing berth occurred in 2008, this was the first time any maintenance had occurred since 1986. An exact maintenance dredging volume is not available but the volume was estimated to be less than 20,000m^3 (GHD, 2012a).
[4] The maintenance dredging volumes for the Port of Townsville in 2011 appear very high as the maintenance campaign was interrupted by TC Yasi, which subsequently silted up the channels and berths requiring additional maintenance dredging.
[5] At the Port of Cairns since 2010 it has not been possible to achieve the maintenance dredging target depths due to the capped dredging limits specified in the approved permit.
[6]At the Port of Bundaberg maintenance dredging target depths have not been reached following 2011 and 2013 flood events.
[7] The maintenance dredging volumes for the Port of Brisbane between 2011 and 2013 are high as a result of notable flood events.

Table 14: Estimated sedimentation rates (m^3/yr) from 2004 to 2014 at the recognised Queensland Ports which require maintenance dredging.

Siltation Rates (m^3 / year)	Brisbane	Bundaberg	Gladstone	Hay Point[1]	Mackay	Townsville	Cairns	Weipa	Karumba
Minimum	425,000	22,000[4]	105,000	95,000	20,000	120,000	200,000	395,000	120,000[4]
Average	530,000[3]	50,000[3]	200,000	130,000	32,000	405,000	390,000	635,000	200,000
Maximum	2,000,000	300,000	450,000	190,000	41,000	815,000[2]	600,000	835,000	545,000

[1] Values for Hay Point are following the 2006 capital dredging works and due to no maintenance dredging occurring since 2010 the values are based on only four years of data (and the maintenance dredging campaigns were cut short) and as such are not considered to provide an accurate representation of sedimentation rates. The maximum value has been determined based on the maintenance dredging requirement in 2012 calculated by WorleyParsons (2014).
[2] This includes some maintenance dredging that was undertaken in December the previous year and also maintenance following TC Yasi and as such is considered to provide a good indication of the worst case maintenance requirement.
[3] The calculated average volume does not consider the high volumes dredged between 2011 and 2013 as a result significant flooding.
[4] No maintenance dredging has occurred at the Ports of Bundaberg and Karumba during some years.

Port Alma

The port is located adjacent to the Fitzroy delta within the channels of Raglan and Casuarina Creeks. It is located within a natural deep section of the creeks and as such its historic maintenance requirements have been low, only requiring irregular maintenance dredging due to natural sedimentation and sediment movements in the creeks. As such, the historic maintenance volumes are considered to provide a good indication of sedimentation rates and their temporal variability.

Mackay Port

The historic dredge volumes at Mackay Port can be used to provide a reasonable indication of the sedimentation rates at Mackay Port; these are shown in **Table 14**. The volumes dredged each year are highly variable as some years only the small grab dredger is used (e.g. 2006 and 2008) while during other years both the small grab dredger and the TSHD Brisbane are used (e.g. 2004) (NQBP, 2011).

Abbot Point Port

In 2008, dredging of 201,315m^3 was undertaken to create a new berth and to maintain depths at the existing berth. The majority of the volume was for the capital works, with an estimated volume of less than 20,000m^3 being for the maintenance dredging of the existing berth. This was the first time any maintenance had occurred since 1986 at Abbot Point Port. This shows that the natural sedimentation rates at Abbot Point are very low.

Port of Townsville

The historic dredge volumes from the Port of Townsville provide a reasonable representation of the sedimentation rates; these are detailed in **Table 14**. However, the volumes in 2010 and 2011 do not provide such a clear representation of annual sedimentation rates as the main dredging campaign for 2010 commenced in December but continued in 2011 and PoTL include their dredging volumes based on when the campaign was finished. In addition, the campaign had to be stopped mid-way through due to TC Yasi which significantly increased the maintenance requirements. As such, the dredging which occurred prior to TC Yasi effectively had to be redone as the cyclone resulted in very high sedimentation.

Port of Lucinda

There has not been any maintenance dredging at the Port of Lucinda between 2004 and 2014. This is because the jetty extends to sufficiently deep water so that dredging has not been required, while the wharf located adjacent to the shore is not operational and the barge ramp sedimentation is not sufficient to require dredging. The lack of maintenance dredging does not mean that there has not been any sedimentation, rather that the vessel terminal is located in sufficiently deep water that any sedimentation has not influenced the navigability of the area.

Port of Mourilyan

The Port of Mourilyan has not required any maintenance dredging between 2004 and 2014. Even though the port is located at the mouth of the Moresby River, no net sedimentation has been observed over this period. Bed levelling has been required primarily in the swing basin as a combination of tidal currents and vessel propellers are thought to regularly resuspend and redistribute the bed sediment.

Port of Cairns

From 2004 to 2009, the historic maintenance dredge volumes provide a good representation of the sedimentation rates as the dredging was able to achieve the target depths. These years were relatively mild in weather conditions and did not include any high sedimentation events. However, since 2010 when more severe weather conditions were experienced the maintenance dredging volumes have not been able to reach the target depths and so they provide an underestimation of the sedimentation rates.

In 2010, the existing 5 year maintenance dredging permit, which allowed dredging of 350,000 dry tonnes per year, expired and a new approval was sought. In the Long Term Management Plan prepared as part of the approval process for a new 10 year permit a wet in-hopper volume of 550,000m^3 per year was specified as the ongoing maintenance volume along with an additional 1,100,000m^3 as cyclone contingency for two years (WorleyParsons, 2010a). The 10 year permit was approved in 2010 and it was subsequently identified by Ports North that a mistake had been made when calculating the wet in-hopper volumes and as a result an artificially low annual maintenance dredging limit had been implemented. The error resulted from the conversion from dry tonnes to wet in-hopper volume, as a conversion factor from the previous dredger, the Sir Thomas Hiley, was used instead of the TSHD Brisbane. As the Hiley operated in continuous overflow mode is was able to achieve a greater hopper density than the TSHD Brisbane. In 2013 a variation to the permit was approved, this allowed the dry tonnes values specified in the permit to be adopted rather than the in-hopper wet volumes.

Figure 12 shows the historic maintenance dredging undertaken by the TSHD Brisbane along with the in-situ volume of material requiring dredging for the target depths to be achieved. The difference between the in-situ volume to target depth prior to dredging and the in-situ volume removed since 2010 represents the shortfall in dredging volumes. From 2010 to 2014, the maintenance dredging undertaken has been 90,000 to 250,000m^3 per year below what is required to achieve the target depths (despite the cyclone contingency having been used over this period). Despite the change in the permit in 2013, along with the remaining cyclone contingency included in the permit being used, the in-situ volume required to reach the target depths has continued to increase (**Figure 12**). As such, re-declaration of the channel with a reduced depth has occurred resulting in shipping inefficiencies due to a need to short load sugar ships by several thousand tonnes, a reduced load capability for fuel imports and reduced hours of visits by cruise ships reliant on tides for entry and exit. This has also caused inefficiencies in both survey and dredging programs with a resulting need for additional monitoring surveys and split dredging campaigns to facilitate the seasonality in the trades at the port (sugar and cruise). At some stage a larger than normal dredging campaign will be required to catch up and re-instate the required depths and up to this point there will be increases in the generation of turbidity from vessel wash due to the reduced channel depths.

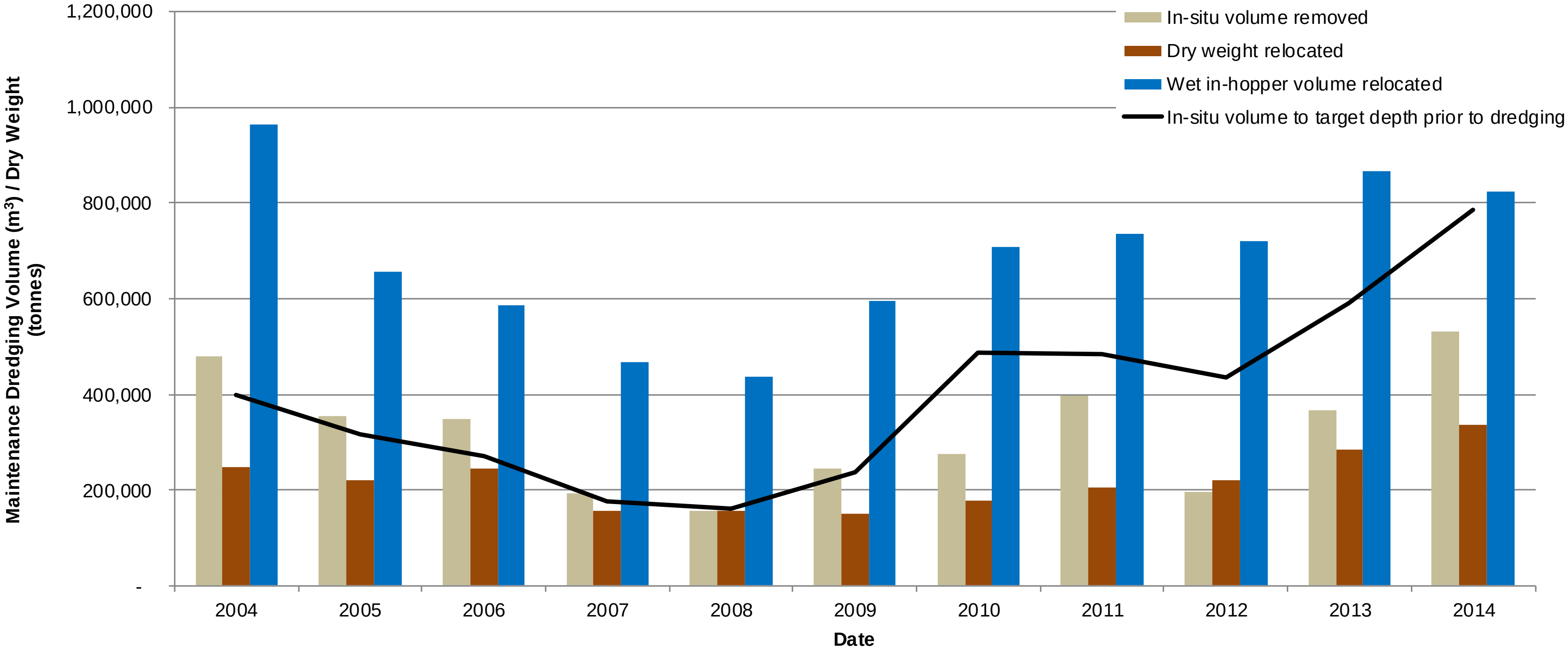
A summary of the historic sedimentation calculated for the Port of Cairns is provided in **Table 14**.

Port of Cooktown

The Port of Cooktown has not required any maintenance dredging between 2004 and 2014. Even though the port is located at the mouth of the Endeavour River, no net sedimentation has been observed over this period. Maintenance dredging has been required on two occasions since capital dredging in 1997, which was undertaken to initiate commercial management of the harbour by Cook Shire Council. In 2015, a total of 44,141m^3 was removed following TC Nathan and in 1999 a total of 26,000m^3 was removed after the channel silted up due to a cyclone. This demonstrates that the sedimentation at the Port of Cooktown is driven by extreme cyclonic events and ambient sedimentation rates are negligible.

Port of Cape Flattery

There has not been any historic maintenance dredging required at the Port of Cape Flattery, due to the relatively deep water at the berth locations. The lack of maintenance dredging does not mean that there has not been any sedimentation; rather that the berth locations are located in sufficiently deep water that any sedimentation has not influenced the navigability of the area.



Total Permit Limits	500,000 dry tonnes per year (including contingency)	350,000 dry tonnes per year (plus access to some contingency over life of permit)	550,000 wet cubic metres per year (plus access to some contingency)	350,000 dry tonnes per year (contingency consumed)

Figure 12: Historic maintenance dredging at the Port of Cairns (shown in in-situ volume, wet in-hopper volume and dry weight) along with the in-situ volume required to achieve the target depth and the corresponding permit details over the period. Note: the total permit limits are for the channel and inner harbour, while the graph relates to just the channel. In-situ volume is the only parameter that can be established both before and after dredging.

Port of Quintell Beach

This is no reported historic maintenance dredging at the Port of Quintell Beach. The port consists of a barge ramp located on a sandy foreshore and as such it is likely that sediment will have been cleared from the ramp and placed adjacent to it historically but that the scale of this work did not constitute dredging. As such, the lack of any historical maintenance dredging does not mean that there has not been any sedimentation in this area, but that rather the natural sedimentation at the port is relatively low and is accommodated by minor ramp clearance works.

Port of Weipa

The historic maintenance dredging volumes at the Port of Weipa can be used to provide a very good indication of the sedimentation rates, as shown in **Table 14**. Maintenance dredging volumes increased slightly since capital dredging works were undertaken in 2006, which included widening of the main navigational channel. Since 2006, maintenance requirements have remained relatively constant with the exception of years coinciding with cyclones and prolonged wet seasons which have had higher requirements. For example, the largest maintenance dredging requirement of 2008 was influenced by the passing of TC Helen which resulted in notable flooding and the erosion of local beaches. Capital dredging works were also undertaken at the port in 2012 which involved a 2.4 km extension of the existing channel; however a review of historical dredge volumes suggests that this did not result in any notable increase in average maintenance dredging requirements (Ports and Coastal Environmental, 2013).

Port of Karumba

The historic maintenance dredging volumes at the Port of Karumba reflect the varying requirements of the port and as such do not provide a good representation of sedimentation, which is estimated based on the available information in **Table 14**. Between 2004 and 2011 dredging was undertaken bi-annually with channel depths returned to design depths to accommodate vessels facilitating the export of zinc concentrate. The higher volumes dredged in 2010 and 2011 were due to prolonged wet seasons depositing increased volumes of sediment at the port and navigational channels. As a result of recent mine closures, the ports maintenance dredging requirements have reduced substantially as the port now primarily accommodates for the export of cattle and the local commercial fishing industry. Ports North foresees limited to no future maintenance dredging requirements at the port in the foreseeable future.

4.5.1 Comparison with Natural Sediment Transport

It is important to consider the historical maintenance dredging volumes relative to the natural sediment budget to put the activity into the context of the natural environment. This is particularly important within the GBRWHA to allow an understanding of the relative influence of maintenance dredging in this area. As discussed in **Section 2**, sediment can be input into the inner-shelf region of the GBR through river discharges and cyclonic activity. Resuspension and transport of sediment within the inner-shelf of the GBR is dominated by wave and wind induced currents. As such, the natural input of sediment to the inner-shelf of the GBR and the natural resuspension of sediment is compared relative to the contributions from maintenance dredging.

A comparison of the input of sediment to the GBRWHA from terrestrial run-off to the predicted total future maintenance dredging volumes at the ports located within the GBRWHA found that the maintenance dredging was 5-10% of the catchment input (McCook et al., 2015). However, it was also noted that the comparison was for broad context only and the dredge amounts released into the ecosystem will only be a proportion of the total maintenance dredging volumes. Due to a lack of available quantitative data it is not possible to provide a comparison with the input of sediment due to cyclonic activity.

To put the maintenance dredging volumes into context with the natural sediment transport, it is necessary to compare the mass of sediment from maintenance dredging with the mass of sediment naturally resuspended in the area of the ports. It is very difficult to accurately quantify the amount of sediment resuspended by waves and wind induced currents and there is limited existing information available. Lambrechts et al. (2010) calculated the fluxes of fine sediment for Cleveland Bay, finding that 34,500 tonnes/yr was transported around Cape Cleveland from the Burdekin River and 25,900 tonnes/yr came from the Ross River and Alligator Creek. They also noted that TSS of 50mg/l typically occur within Cleveland Bay during periods of high energy wind and waves and that this can reach up to 200mg/l in some areas, this agrees with previous water quality monitoring by Cooper et al. (2008).

Investigations by Orpin et al. (1999) found that high energy wind and waves occur for approximately 40 days per year in Townsville and during these events sediment can be resuspended in water depths of up to around 15m. Aerial photography showing the spatial extent of resuspension from a high energy wind and wave event was presented by Orpin and Ridd (2012), this shows that the plume encompasses Cleveland Bay and it extends offshore to the approximate location of the 15m depth contour (**Figure 4**).

Using the information detailed above it is possible to provide a broad estimate of the quantity of sediment resuspended by wind and wave action in Cleveland Bay. The following assumptions have been made:

- The area of Cleveland Bay to the 15m offshore depth contour is 300km^2, an average depth of 7.5m has been used to calculate the volume of water in the bay; and
- A depth averaged TSS of 50mg/l throughout the bay. This has been assumed to represent a peak value and so even though the temporal variability in resuspension through an event is not considered it is still possible to estimate the total volume of sediment resuspended by the event.

Based on these assumptions, approximately 112,500 tonnes is estimated to be resuspended by a single high energy wind and wave event in Cleveland Bay.

Based on the finding by Orpin et al. (1999) that these events occur for approximately 40 days per year, the total quantity of sediment resuspended by high energy wind and wave events in Cleveland Bay is estimated to be in the order of 4,500,000 tonnes/yr. This can be compared with the annual maintenance dredging by using an approximate conversion factor of 0.7 to convert from in-situ volume to dry tonnes as noted by McCook et al. (2015). Based on this factor the average annual maintenance dredging at the Port of Townsville is 280,000 tonnes and, of this, it can be assumed that up to 15% could be suspended during the dredging and disposal activity (rather than being transported into the hopper of the dredger), resulting in approximately 42,500 tonnes of material per annum being resuspended due to maintenance dredging.

This shows that the amount of sediment resuspended by a single high energy wind and wave event in Cleveland Bay (which occur approximately 40 days per year) is more than double the amount resuspended by the annual maintenance dredging. In addition, the total volume of material resuspended by high energy wind and wave event in Cleveland Bay per year is more than **100 times greater** than the amount resuspended each year by maintenance dredging.

Numerical modelling and measured data have been used at the Port of Cairns to quantify the amount of sediment naturally resuspended within Trinity Bay during a strong wind event. The results predicted that approximately 1.2 Million tonnes of sediment is naturally resuspended within Trinity Bay (BMT WBM, 2014a and 2014b). When compared to the estimated annual quantity of sediment suspended by maintenance dredging of 41,000 tonnes, it shows that the amount of sediment suspended by maintenance dredging is relatively small compared to the sediment resuspended by natural processes in Trinity Bay.

It is also important to consider that the quantity of sediment resuspended by an extreme event such as a tropical cyclone would be much higher than the amounts detailed in these examples. Based on the available data Carter et al (2009) and Larcombe and Ridd (2015) estimated that 140Mm^3 (100 million tonnes) was suspended by TC Winifred (1986) and 500Mm^3 (350 million tonnes) was suspended by TC Yasi (2011), respectively. It is important to note that these should only be considered rough estimates due to the significant uncertainties associated with predicting sediment suspended by extreme events.

4.5.2 Variability in Maintenance Dredging Requirements

As noted in the previous section, as well as there being significant variability in maintenance dredging requirements between the different ports due to the different locations and processes, there is also significant variability in the requirements from year to year. In addition, spatial variability in the maintenance dredging requirements also occurs at each port with different rates of sedimentation occurring at the different areas of the ports such as in the channels and berths.

The temporal patterns in historic maintenance dredging volumes can be influenced by seasonal and annual climatic variability. This includes the El Nino Southern Oscillation (ENSO) which can influence the relative importance of different processes. For example, the large flood events in 2010 which resulted in increased maintenance dredging at the Ports of Brisbane and Bundaberg occurred during a strong La Niña event which is typically associated with increased rainfall. In addition, strong La Niña events can also be associated with increased wind energy (and therefore increased current and wave energy) along with an increased risk of cyclones compared to the other phases of the ENSO.

The relative importance of these processes on the maintenance dredging requirements will vary between the ports depending on the location, configuration and the dominant sedimentation processes at the ports. Although the ENSO can influence the maintenance dredging requirements at the ports where annual maintenance dredging is required, the processes which control the sedimentation are much more complicated and do not correlate to just the ENSO (**Figure 13**). The plots show no clear correlation between maintenance dredging volumes and the ENSO at the Ports of Gladstone and Cairns, while at the Port of Townsville a correlation is evident with the maintenance dredging requirement being at its highest in the years immediately after strong La Niña events (positive SOI) in 2009 and 2011. These years also correlate to the largest wave heights which have been recorded at the Port of Townsville wave buoy (**Figure 14**), with a maximum wave height (H_{max}) of 10.1m recorded in February 2011 during TC Yasi and a H_{max} of 6.6m recorded in January 2009 (likely to be related to a number of tropical lows which occurred around this time). This also highlights that the occurrence of extreme events, such as tropical cyclones, can result in significant changes in maintenance dredging requirements at the ports.

The risk of these events occurring is influenced by the ENSO. For example, the risk of tropical cyclones and flood events increase during La Nina phases of the ENSO, but there is a risk that these events could occur during any year (and could occur multiple times in one year, in consecutive years or not at all for a number of years) and it is not possible to accurately predict when and where the events will occur. This highlights why the maintenance dredging requirements of the ports vary temporally from year to year and why the individual ports do not exhibit the same temporal variability. This highlights that port specific investigations are required to fully understand the drivers which result in the temporal variability in maintenance dredging at each port.

Spatial variability in maintenance dredging requirements occurs at all ports due to variability in the port configuration, natural environment and associated processes and therefore the sedimentation patterns. Sedimentation tends to occur in dredged areas such as berths, aprons, basins and channels as the artificially deeper areas are subject to lower energy (both from currents and waves) than the adjacent naturally higher areas. As a result, the deeper areas act as sediment sinks with increased sedimentation and less potential for resuspension than the adjacent natural areas.

The sedimentation rate is controlled by the coastal processes, the sediment transport rates and the 'trapping efficiency' of the dredged area, with deeper and wider channels increasing the efficiency and resulting in higher sedimentation rates. The orientation of the dredged area relative to the dominant current and wave directions can also influence the sedimentation rates. Sedimentation can also occur as adjacent shallow shoals and intertidal flats prograde and gradually encroach on adjacent dredged areas. Ports typically have a good understanding of the spatial variability in sedimentation around the ports from historic bathymetric surveys as well as previous maintenance dredging campaigns. As an example, the spatial variability in historic sedimentation and maintenance dredging is shown in **Figure 15** for the Port of Gladstone. The plot highlights how the majority of the dredged channels do not require regular maintenance dredging, it is only specific areas which are prone to regular sedimentation which require annual maintenance dredging.

As a result of the spatial variability in sedimentation rates, it is common for maintenance dredging campaigns to target different areas as the maintenance dredging frequency will differ spatially. For example, sections of the channel may be subject to high rates of sedimentation and require annual maintenance dredging, while other areas of the channel may have lower rates of sedimentation and only require maintenance dredging every few years and other areas could be self-cleaning or eroding and never require maintenance dredging.

Based on the historic maintenance dredging volumes, the local environment and port configuration the Queensland Ports can be classified by maintenance dredging frequency to better relate the ports to the dominant processes and their interaction with the dredged areas which result in sedimentation:

- **Frequent Maintenance Dredging (annual dredging)**: Annual maintenance dredging is required at the Ports of Brisbane, Bundaberg, Gladstone, Townsville, Cairns and Weipa. Natural processes result in high sediment transport rates in the vicinity of the ports which, combined with the port configuration, result in regular sedimentation and therefore maintenance dredging is required annually to maintain design depths. Sedimentation at the Ports of Brisbane and Bundaberg is primarily caused by fluvial processes. The sedimentation at the Ports of Gladstone, Townsville, Cairns and Weipa is primarily caused by regular sediment transport from the resuspension of natural bed sediment by waves and currents, combined with possible input of sediment from adjacent riverine sources. The sedimentation rates at all the ports can be significantly increased by episodic extreme events such as tropical cyclones and large floods.
- **Regular Maintenance Dredging (dredging every two to five years)**: Regular maintenance dredging is required at Hay Point Port and Mackay Port. These areas experience relatively high rates of natural sediment transport but the dredged areas are not as effective sediment traps as the ports which require annual maintenance dredging potentially due to the port configuration, the adjacent natural environment (or both) or lower natural sediment transport rates. Regular sedimentation does occur but at a rate which typically only requires maintenance dredging every two to five years. However, the areas can also be influenced by extreme events which can significantly increase the sedimentation rates and potentially result in the maintenance dredging frequency being increased.
- **Episodic Maintenance Dredging due to extreme events**: Episodic maintenance dredging is required at the Port of Cooktown. The sedimentation associated with maintenance dredging at this port results from episodic extreme tropical cyclone events. It is not possible to predict the frequency of these events, they could occur in consecutive years or only every few decades.

- **Infrequent Maintenance Dredging due to low sedimentation rates**: Infrequent maintenance dredging is required at Port Alma, Abbot Point Port and the Port of Karumba. The natural processes at Port Alma limit sedimentation, with only coarser material accumulating over time. The natural processes at Abbot Point result in low sediment transport rates in the vicinity of the port, which combined with the naturally deep water where the port is located, results in very low sedimentation rates and infrequent maintenance dredging. Over the last thirty years maintenance dredging has been undertaken once, when the maintenance work was undertaken as part of a capital dredging campaign. Over this period a number of tropical cyclones have affected the area but these have not resulted in the requirement for maintenance dredging. A reduction in the required declared depth at Karumba has meant that there is expected to be limited to no maintenance dredging requirement in the foreseeable future.
- **No Maintenance Dredging**: No Maintenance dredging is required at the Ports of Maryborough, Lucinda, Mourilyan, Cape Flattery, Quintell Beach, Thursday Island, Skardon River and Burketown. The configurations of these ports have meant that maintenance dredging is not required regardless of the natural sedimentation rates. At the Port of Lucinda and the Port of Cape Flattery this is because the berths are located in deep water, while at the Port of Quintell Beach it is because the port only consists of a barge ramp which does not require an access channel. There has not been any requirement for historic maintenance dredging at the Port of Mourilyan, but if a large flood event occurred there is the possibility that future maintenance dredging could be required.

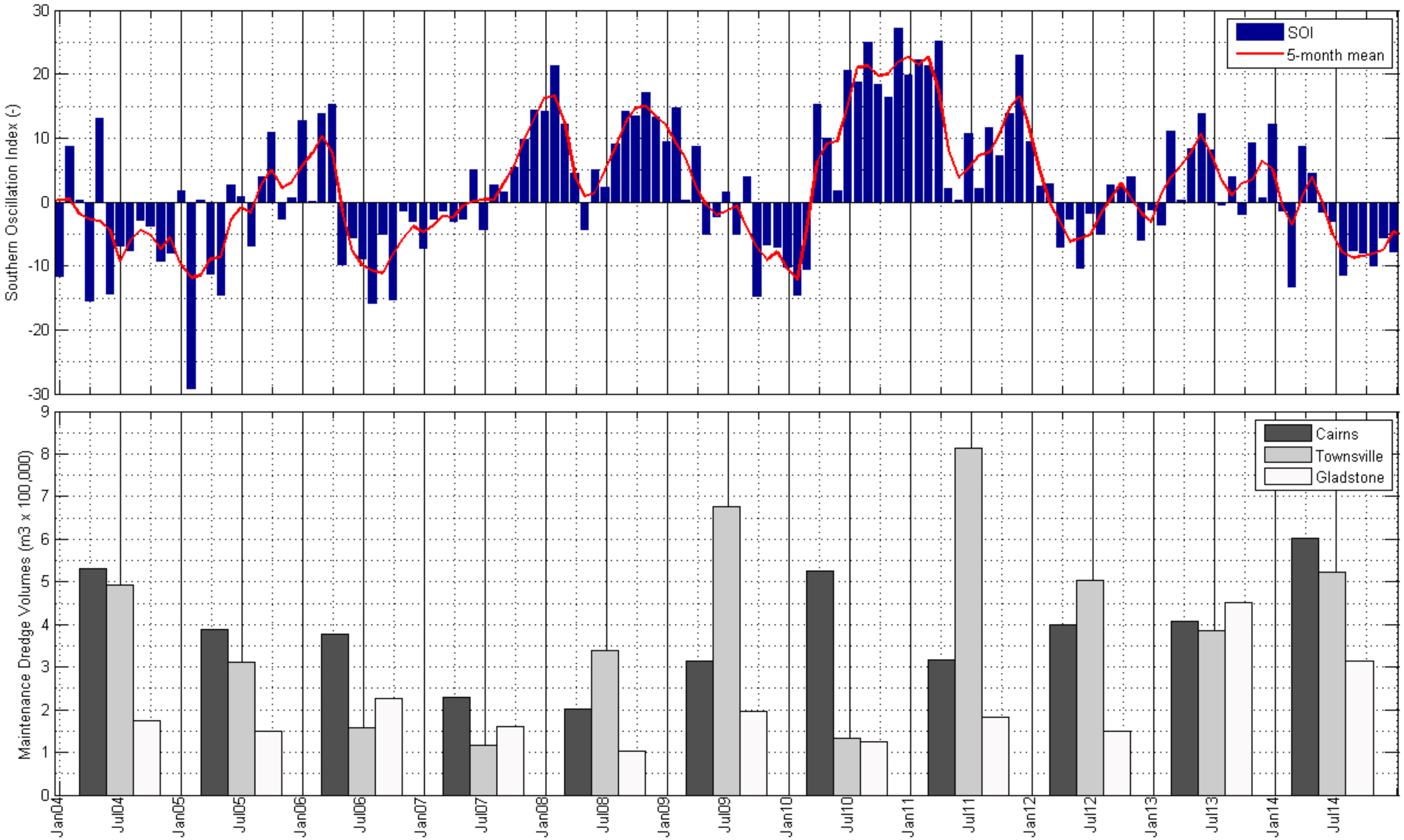


Figure 13: Monthly average Southern Oscillation Index values from 2004 to 2014 (top plot) and annual variability in sedimentation volumes from 2004 to 2014 at Gladstone, Townsville and Cairns (bottom plot).

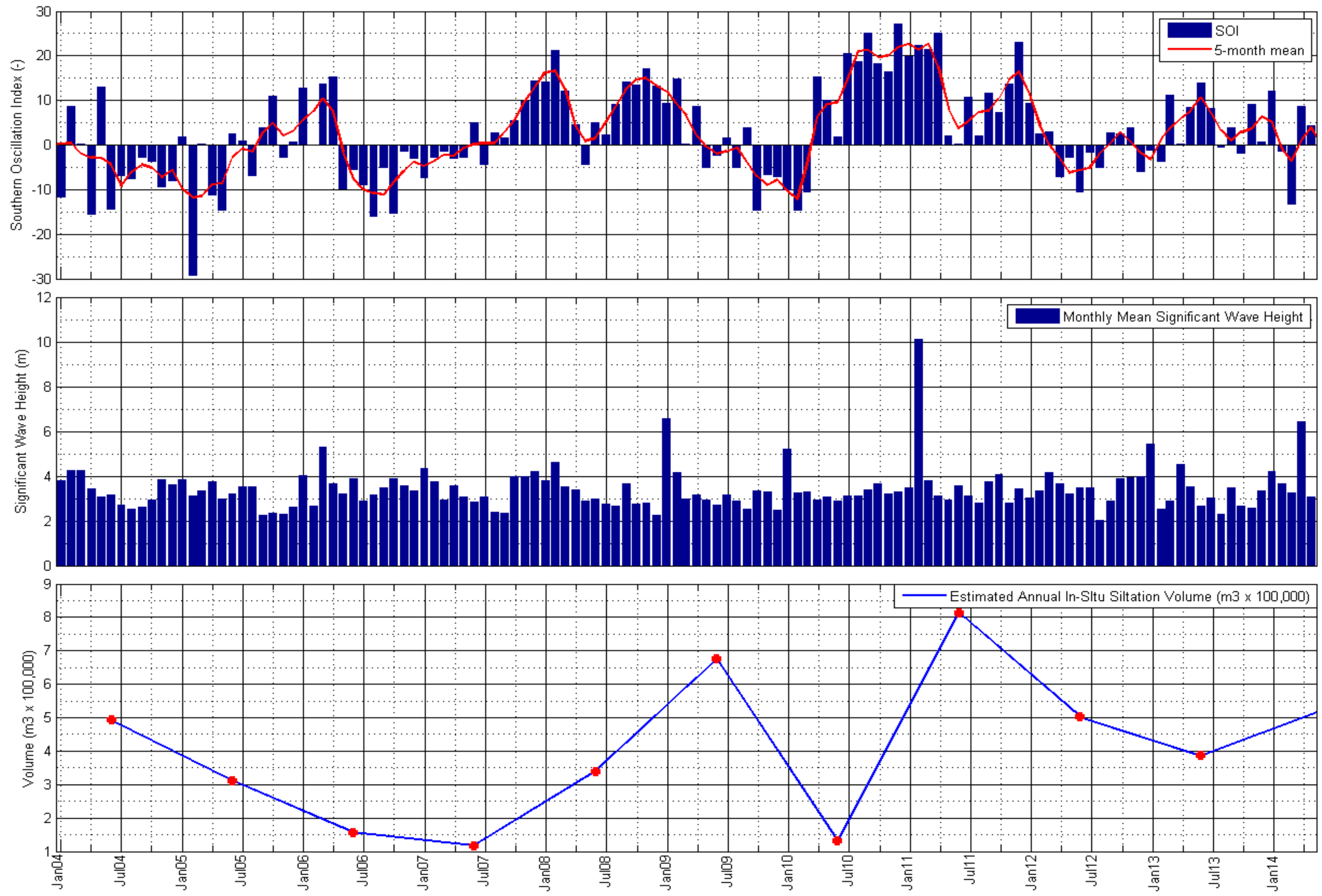


Figure 14: Monthly average Southern Oscillation Index values from 2004 to 2014 (top plot), monthly maximum wave heights at Townsville (middle plot) and the annual in-situ volume sedimentation at the Port of Townsville (bottom plot).

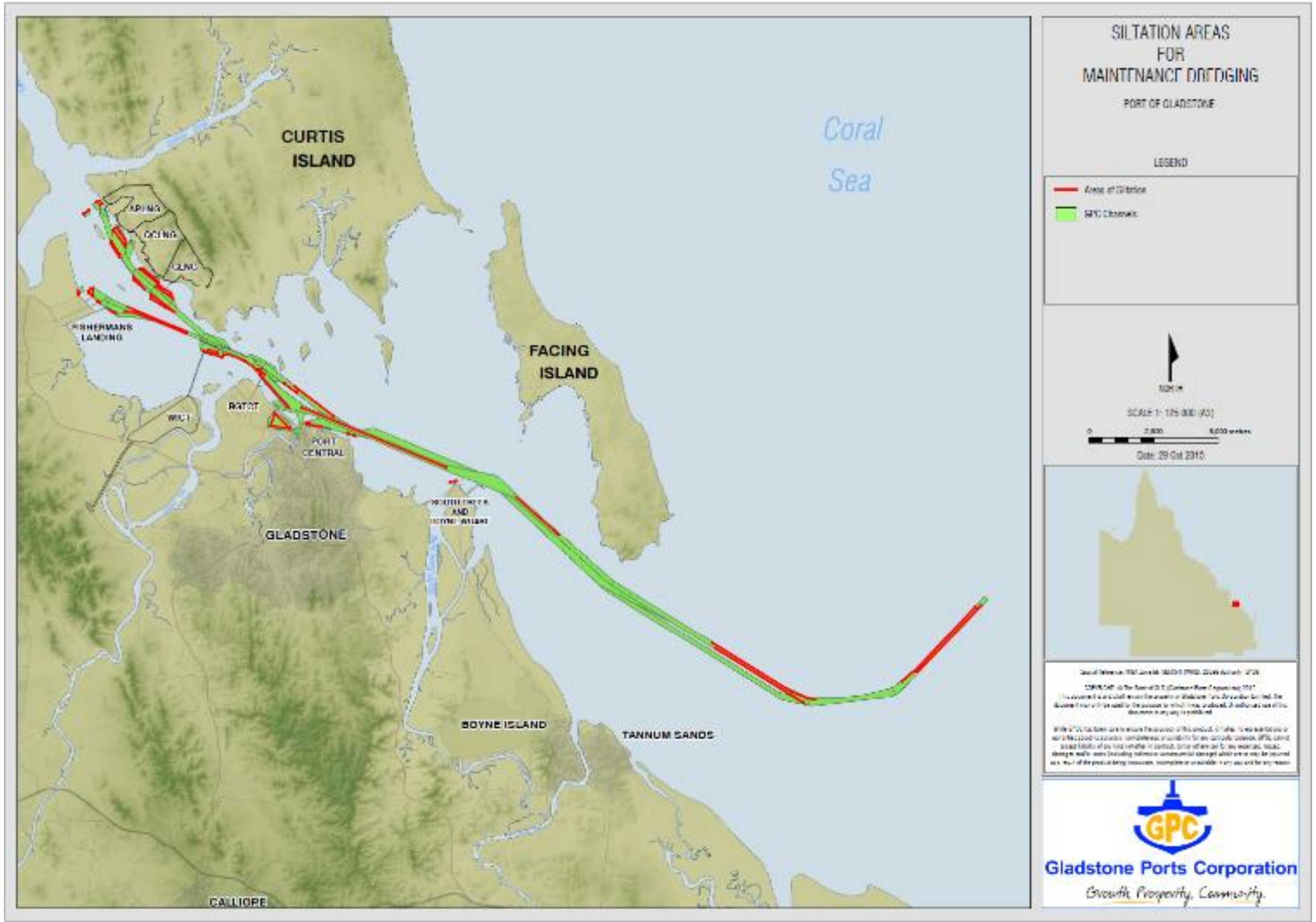


Figure 15: Map showing the areas of the Port of Gladstone which require maintenance dredging due to sedimentation (red lines).

4.5.3 Historic Material Placement

Historically the majority of sediment dredged during maintenance campaigns at the ports within the GBRWHA has been placed in offshore material placement sites, with only small quantities being placed on land. The only ports where significant on land placement has occurred are the Port of Townsville and the Port of Cooktown.

At Sea Placement

Offshore placement of dredge material has been the primary relocation approach adopted at all the ports where regular maintenance dredging has been required. Details of the material placement sites are provided in **Table 15**, this shows that the existing sites **are both retentive and dispersive in character**.

It is important to note that, in some cases, it is not possible to choose the character of the material placement site. For example, due to the large tidal range and resultant strong tidal currents at Hay Point and Mackay Ports, the majority of the area surrounding the ports is dispersive and it would be very difficult to identify a retentive site in the area. There can be positives and negatives associated with both characters of placement site and the applicability of the character needs to be assessed on a case by case basis. The important requirement in all cases is to have a sound knowledge of the fate of the dredge material when placed in the offshore material placement site.

Table 15: Details of the existing offshore material placement sites at ports within the GBRWHA where regular maintenance dredging has been required.

Port	Location	Description
Gladstone	within Port Limits	**Predominantly Retentive**. Coarse material remains but silts and clays are winnowed out (BMT WBM, 2012a).
Hay Point	within GBRMP	**Predominantly Retentive**. Approximately 65% of the sediment from historic capital and maintenance dredging has remained at the site (RHDHV, 2016).
Mackay	within Port Limits	**Highly Dispersive**. Approximately 70% of material effectively mobilised in 8 week (SKM, 2005).
Townsville	within Port Limits	**Dispersive**. Tracer studies showed that sediment erodes during moderate wave events (ETS, 2012).
Cairns	within GBRMP[1]	**Retentive**. A retentive site was chosen and regular sedimentation has been observed (WorleyParsons, 2010a).

[1] the Port of Cairns placement site was originally located outside the GBRMP, but the park boundaries were expanded in 2001 by GBRMPA and have included the site ever since.

On Land Placement

Details of the on land placement of sediment at the Port of Townsville and the Port of Cooktown are provided below.

Port of Townsville

At the Port of Townsville a portion of the sediment from maintenance dredging has regularly been placed on land in reclamation areas (**Table 16**). There have been two main reasons for the material to be placed on land:

- Contaminant risk: in the Inner Harbour area there have been two areas of the berths where the NAGD screening levels for the upper 95% confidence limit of mean contaminant concentrations in the sediment have been exceeded (PoTL, 2013). This material has typically been dredged by a mechanical grab dredge and placed in a barge with a slurry pump allowing it to discharge to land; and
- Dredging method and location: typically the maintenance dredging of the Ross River (and to a lesser extent the Ross Creek) has made up the majority of the sediment placed on land (PoTL, 2013). The material has been defined as suitable for at sea disposal based on the NAGD guidelines. However, these areas are not accessible by the TSHD Brisbane as they are too shallow and as a result the areas have been dredged by a small cutter suction dredger (CSD) which can pump directly to the reclamation area. In addition, the material has a higher sand content than most of the other maintenance dredging material and it therefore has better engineering properties. Some spot dredging has also been undertaken using PoTL's grab dredger in areas that are inaccessible to a TSHD or a CSD and these small volumes have typically been placed on land.

Table 16: Historic in-situ maintenance dredging volumes (m^3) and the distribution of sediment that was placed at sea and land at the Port of Townsville.

Year	Total Dredging (m^3)	Total Sea Placement (m^3)	Total Land Placement (m^3)
2004	**492,740**	489,240	3,500
2005	**312,785**	300,785	12,000
2006	**156,560**	151,000	5,560
2007	**117,454**	117,454	0
2008	**339,306**	338,050	1,256
2009	**675,464**	612,284	63,180
2010	**133,100**	55,300	77,800
2011	**814,435**	809,135	5,300
2012	**502,940**	424,950	77,990
2013	**386,610**	369,684	16,926
2014	**521,770**	516,060	5,710

Port of Cooktown

Out of the 44,141m^3 of sediment removed during maintenance dredging in 2015, approximately 30,000m^3 was placed on land and the remainder was placed at sea (Voisey, 2015, pers. comm., 22 October). The on land material was placed in a foreshore reclamation site and filled the site to capacity. As the requirement for maintenance dredging at the Port of Cooktown is driven by high energy tropical cyclones, the material which accumulates is predominantly made up of sand and as such is suitable for on land beneficial reuse.

4.6 Future Maintenance Dredging Requirements

The historic maintenance dredging volumes detailed in **Section 4.5** can be used to provide an indication of the future requirements and the historic natural variability at the ports. The volume of sediment which accumulates in dredged areas of the ports and requires removal through maintenance dredging cannot be directly reduced by the ports as they are caused by the preceding metocean conditions and associated natural sediment transport rates. However, the volumes can be influenced by future changes to the port such as future capital dredging or port expansions. The impacts of these types of projects on maintenance dredging requirements is typically addressed as part of the project approvals process and future predictions should therefore be understood prior to approval of the project.

The predicted future sea level rise due to climate change has the potential to progressively decrease maintenance dredge volumes into the future. However, without detailed numerical modelling it is not possible to quantify these reductions and so they have not been included in the future maintenance dredging volumes detailed in **Section 4.6.2**.

4.6.1 Future Port Expansion Works

Details of any proposed future port expansion projects which could influence the maintenance dredging requirements are detailed in **Table 17**. The table shows that the ports with expansion projects proposed over the next 10 years are the Port of Gladstone, Abbot Point Port, Port of Townsville and Port of Cairns. The influence of the proposed port expansion works on future maintenance dredging requirements is a key component of the approval process for future projects and should be detailed in the approval documentation for these projects. Details of how these proposed projects are expected to influence future maintenance dredging requirements are as follows:

- Port of Gladstone: the maintenance dredging requirement is not predicted to be significantly increased by works in the Clinton Channel. The additional depth of the channel could increase the trapping efficiency of the channel, but as the existing maintenance dredging requirements for this area are low any increases will be minor. The Gatcombe and Golding Cutting Channel Duplication works will have the potential to increase the total future maintenance dredging requirements. As the channel will be adjacent to an existing channel and the sedimentation in that area is a result of longshore sediment transport the Channel Duplication works are not predicted to result in a significant increase in maintenance dredging requirement. The current maintenance contribution of the channels to be duplicated accounts for approximately12% of the total maintenance dredging requirement and, as suc,h an increase of 6% is considered realistic. In addition, it has been identified by GPC (2015) that following the Western Basin capital dredging the maintenance dredging requirement was expected to increase by 185,000m^3 in 2014/15 and then 140,000m^3 in 2015/16 and gradually reduce until 2017/18 when it reaches a constant ongoing increased requirement of 60,000m^3. The gradual reduction in volumes over time is due to the predicted natural stabilising of the sea bed and batter slopes of the channel following the capital dredging.
- Abbot Point Port: based on the negligible historic maintenance dredging requirement at Abbot Point Port, it is not expected that the proposed capital dredging will result in significant increases in maintenance dredging.
- Port of Townsville: the Berth 12 capital dredging has been predicted to result in an increase in maintenance dredging of 250,000m^3 over five years (PoTL, 2013). The additional berths and Outer Harbour reclamation associated with the Port Expansion Project is predicted to result in a 25% reduction in existing maintenance requirements as it will restrict sedimentation in the Inner Harbour (BMT WBM, 2012e). The proposed capital dredging of the Platypus and Sea Channels

has been predicted to result in an increase in maintenance dredging of 100,000m^3 of sediment over 5 years.

- Port of Cairns: the port had pursued an EIS for a major channel expansion project which included 4.4Mm^3 of capital dredging. However, since the offshore placement of capital dredge material in the GBRMP was banned, the scale of the project was not deemed feasible for land based placement of the material. As a result the port is looking to identify a feasible project with significantly less capital dredging than the previous proposed expansion. The proposed channel expansion is expected to result in limited additional maintenance dredging as the proposed expansion areas are generally located in areas of the channel which are currently self-cleaning. The proposed minor inner port developments are expected to result in a small increase in the maintenance dredging volumes. For both of the proposed projects an increase in the maintenance dredging requirement of 10% has been assumed.

In addition to the above existing ports, Rio Tinto is currently in the process of developing a bauxite mine located to the south of Weipa. This development will include the construction of a new port facility on the Gulf of Carpentaria coastline. The proposed Amrun port development will involve the capital dredging of approximately 230,000m^3 for a berth pocket and departure area and is expected to require maintenance dredging on an annual or bi-annual basis. The first bauxite exports are expected in 2019.

Table 17: Port expansion projects proposed over the next 10 years.

Port	Future Expansion Works	Details
Brisbane	No	The Port of Brisbane currently holds a permit for the progressive dredging of spitfire channel, however, this will not have any effect on the future maintenance dredging requirements at the port.
Bundaberg	No	-
Gladstone	Yes	1) Works in Clinton Channel. The channel would have approximately the same footprint but would be deepened. 2) Gatcombe and Golding Cutting Channel Duplication Project. This would involve the creation of a new channel. Estimated capital dredging of 12Mm^3.
Port Alma	No	-
Hay Point	No	-
Mackay	No	-
Abbot Point	Yes	1) Terminal 0 and Terminal 3 Expansion. The creation of new berths and extension of the apron. Estimated capital dredging of 1.7Mm^3.
Townsville	Yes	1) Berth 12. The creation of a new berth on the northern side of the existing reclamation, this project has been approved but it has not commenced to date. 2) Port Expansion Project. The creation of six additional berths and a 100ha land reclamation to create a new outer harbour. Also minor deepening and modifications to the approach channels. Estimated capital dredging of 10Mm^3.
Lucinda	No	-

Port	Future Expansion Works	Details
Mourilyan Harbour	No	-
Cairns	Yes	1) Channel Expansion. The widening of the existing approach channel. Exact details of the works are not available but it would involve significantly less capital dredging than the 4.4Mm^3 proposed for the Cairns Shipping Development Project. 2) Inner Port Developments. Over the next 10 to 20 years up to 300,000m^3 of capital dredging is proposed in the inner port area as part of numerous minor port developments along the 3km waterfront.
Cooktown	No	-
Cape Flattery	No	-
Quintell Beach	No	-
Weipa	No	-
Karumba	No	-
Amrun Port	Yes	1) A new port is planned to be developed as part of the Rio Tinto Amrun project. This new port facility is likely to require maintenance dredging on an annual/bi-annual basis.

4.6.2 Future Maintenance Dredging Estimations

Future maintenance dredging volumes are expected to generally be similar to historical volumes, with annual variability continuing to occur as a result of natural variation in the sediment transport and sedimentation drivers. Estimates of the future maintenance dredging requirements for all Queensland Ports are shown in **Table 18**. The estimates are based on historic maintenance dredging volumes and estimated sedimentation volumes. The annual mean volumes represent the average sedimentation which has occurred over the historic period, while the annual maximum volumes show the highest annual volume which has been dredged over the historic period. The table also includes a prediction of future increases in maintenance dredging requirements due to future port expansions, these should be added to the annual mean and maximum predicted maintenance requirements to calculate the future range of requirements following the proposed port expansion works.

Any increases in maintenance dredging requirement are likely to be higher than the values included in the table for one to two years immediately after any capital dredging as the material on the seabed will be significantly disturbed following dredging and will therefore have the potential to be relocated until a stable configuration of the bed is achieved. For example, the maintenance dredging requirement in 2014 at the Port of Gladstone was increased as a result of the completion of the Western Basin Dredging and Disposal Project in September 2013. As such, the estimated ongoing maintenance dredging increase in Jacobs Channel in 2015 of 60,000m^3, as detailed in GPC (2015), has been added to the calculated annual mean volume shown in **Table 18**.

The estimates presented in **Table 18** assume that the current level of sediment supply and sediment transport continue into the future. As detailed in **Section 2.6**, the inner shelf area of the GBR Lagoon is not considered to be sediment-supply limited and, therefore, any change in riverine sediment supply (increases or decreases) is likely to be masked by natural resuspension processes as this is the dominant driver for elevated TSS. Therefore, any future reductions in sediment loads input from river systems are not expected to have a measurable change to maintenance dredging requirements at the majority of the ports over the next 10 to 20 years. The exception to this are ports located close to the mouths of large rivers, such as Port Alma, although as the maintenance dredging at the port is related to extreme flood events it is unlikely that future maintenance dredging requirements will be significantly reduced.

The historic maintenance dredging records show that annual variability in volumes regularly occurs. This is a result of variability in the natural processes which influence sediment transport and sedimentation. The occurrence of extreme events such as tropical cyclones and large floods can significantly influence the sedimentation rates. It is generally as a result of these events that the maximum maintenance dredging volumes are required. Due to the unpredictable nature of these extreme events, in terms of their intensity, frequency and spatial influence, it is not possible to reliably estimate future maintenance dredging volumes and their variability.

Historically, maintenance dredging has had a volume limit applied, which has typically been based on the historic annual average volume, and a cyclone/flood contingency volume also included to allow extra volume to be dredged in years when these extreme events occur. Based on the natural variability in sedimentation rates and the resulting variability in maintenance dredging requirements, adopting an annual maintenance dredging volume limit based on historic annual average volumes is not considered to be an appropriate management approach. As maintenance dredging requirements are primarily controlled by the natural processes, it is not possible to accurately predict future requirements. Therefore, continuing to adopt annual maintenance dredging limits could result in shipping inefficiencies, safety risks and potential increases in suspended sediment due to propeller wash as a result of channel, apron and berth depths reducing as has occurred at the Port of Cairns (see **Section 4.5**). In addition, the exact timing of the dredging is often dictated by the availability of the TSHD Brisbane. In some cases, resultant delays in the dredging can cause the dredging to occur in a different calendar year (e.g. if dredging is delayed from December to January) which, if an annual limit is imposed, could limit or prevent subsequent scheduled dredging at the end of the calendar year. This would cause additional unnecessary complications and restrictions on the schedule of the TSHD Brisbane.

Historic maintenance dredging volumes demonstrate the natural variability of sedimentation and it is expected that future maintenance dredging volumes will be just as variable. Hence, from a coastal processes perspective approvals based on mean annual dredge volumes are not an appropriate method to manage maintenance dredging for the GBR ports.

Due to the natural variability in the coastal processes a more appropriate approach would be to allow maintenance dredging to return the channels, aprons and berths to an agreed (e.g. design + insurance) depth and to use pre and post maintenance dredging surveys to demonstrate that these dredge depths had not been exceeded, within an agreed dredging tolerance. Insurance (or sedimentation) depths should also be determined with consideration of both historical areas of dredging as well as any changes that may affect sedimentation rates, to ensure that sedimentation of any part of the channel and basins does not result in a reduction in the declared depth of the entire navigational area.

Table 18: Predicted requirement for future maintenance dredging volumes (in-situ volume).

Port	Average Campaign (m^3 / campaign)	Annual Max (m^3 / yr)	Predicted Increase from Future Projects (m^3 / yr)	Typical Maintenance Dredging Frequency (years)
Brisbane	530,000	2,000,000	-	1
Bundaberg	80,000[5]	300,000[5]	-	1
Gladstone	250,000[4]	315,000	11,500[4]	1
Port Alma	30,000	40,000	-	5
Hay Point	300,000[1]	380,000[1]	-	3
Mackay	90,000	120,000	-	3
Abbot Point	<20,000	<20,000	5,000	20
Townsville	400,000	815,000	0[2]	1
Lucinda	0	0	-	0
Mourilyan Harbour	0	0	-	0
Cairns	400,000	600,000	40,000	1
Cooktown	45,000[3]	45,000	-	10
Cape Flattery	0	0	-	0
Quintell Beach	0	0	-	0
Weipa	635,000	835,000	-	1
Karumba	120,000[6]	120,000[6]	-	4[6]

[1] the annual mean and maximum maintenance dredging volumes at the Port of Hay Point are based on two maintenance dredging campaigns which both ended before the maintenance dredging was complete and an a calculated maintenance dredging volume based on 2012 MSQ surveys (WorleyParsons, 2014). NQBP are undertaking a detailed investigation into historical sedimentation based on bathymetric survey data at the Port of Hay Point which should provide additional information to inform future maintenance dredging volume requirements.

[2] there is no predicted increase in maintenance dredging volumes from future projects at the Port of Townsville as the 25% reduction in volumes predicted as a result of the reclamation associated with the Port Expansion Project is larger than the increases resulting from the additional berths and channel enlargement.

[3] the sedimentation at the Port of Cooktown is the result of extreme events and as such the annual mean future maintenance dredging requirement is misleading as it indicates the port is gradually silting up. However, the sedimentation occurs during an extreme event, with very little sedimentation occurring at other times.

[4] the annual mean is the mean based on the historic volumes plus 60,000m^3 to represent the measured increase in maintenance dredging requirement resulting from the Western Basin works.

[5] Based on information provided by GPC, in an attempt to reach pre 2011 declared depths the Port of Bundaberg will undertake the maintenance dredging of 420,000m^3 up to 2020 (possibly sooner pending demand). Beyond 2020 an average annual maintenance dredging volume of 80,000m^3 is anticipated (Carter, 2015, pers. comm., 10 March).

[6] Ports North anticipate limited to no maintenance dredging will be undertaken at Karumba in the immediate future. Minimal maintenance dredging maybe required to sustain cattle export and fishing trades (Vico, 2015, pers. comm., 9 March).

4.6.3 Management or Engineering Maintenance Dredging Reduction Options

Both PIANC and the USACE have produced documents providing guidelines for the best practise approaches to minimising harbour and channel sedimentation (USACE, 2003; PIANC, 2008a). Both guidelines note that port specific investigations are required to assess the applicability of the approaches on a case by case basis as the suitability is dependent on the port configuration, sediment type, natural environment and processes.

A summary of the approaches which the guidelines recommend is provided in **Table 19**.

Table 19: Outline of strategies to reduce future maintenance dredging requirements.

Strategy	Approach	Example
Keep Sediment Out	Stabilise sediment sources	Reduce sediment input through better catchment management.
	Diverting sediment-laden flows	Diverting river inputs away from port.
	Trapping sediment before it enters port	Sediment traps and insurance trenches.
	Blocking sediment entry	Pneumatic barrier, silt screen, barrier curtain.
Keep Sediment Moving	Structural solutions to train natural flows	Training walls/dikes to divert flow and prevent local deposition of sediment.
	Devices to increase bed shear stresses	Hydraulic jets, vortex foil arrays, mechanical agitators (e.g. spider dredging system).
	Methods to reduce sediment flocculation	Adopting designs which reduce turbulence (e.g. solid wharf walls instead of piling supported wharfs).
Keep Sediment Navigable	Adopt a ‘nautical depth’ navigation approach which includes fluid mud	Nautical depth is the distance from the water surface to a given wet density, typically in the range of 1100 to 1300 kg/m^3.

As detailed in **Section 4.3**, the ports already adopt a number of the approaches detailed in **Table 19** to try and reduce their maintenance dredging volumes. A number of the approaches detailed in **Table 19** which the ports do not currently adopt could be considered in the future as possible approaches to further reduce maintenance dredging:

- Keep Sediment Moving
    - Training structures: these are used worldwide to help prevent deposition and help keep sediment in suspension. The structures could include transverse training walls and specialised training structures such as curved deflector walls. This approach could be applicable in a range of environments but a detailed understanding of the existing tidal currents and sediment transport pathways would be required to determine if the approach would be suitable.
    - Increase bed shear stresses: this approach aims to minimise the time that deposited material remains on the bed by artificially increasing the bed shear stress and therefore promoting resuspension. The bed material can be agitated by a variety of ways, including hydraulic jets, vortex foil arrays and mechanical agitators. The material would typically be resuspended during a certain stage of the tide to allow the tidal currents to remove the

sediment from the area. This approach is aimed at replicating the natural resuspension which would occur if the dredged areas were not present; as such it does result in a local increase in turbidity. The approach is only applicable in berths and harbours; it would not be feasible in aprons or channels.

- Keep Sediment Navigable: extensive testing in Rotterdam and Antwerp harbours demonstrated that vessels can safely navigate through layers of fluid mud more than 1.8m thick when the wet density is less than 1200kg/m^3 (Johnson et al., 2010). Based on this the seabed is described on navigation charts as being where the wet density is more than 1200kg/m^3. This approach could be applicable in some areas of the ports within the GBRWHA where the sedimentation is predominantly fine silt and clays (typically only localised areas of any port). In areas where the deposited sediment is made up of coarser material this approach is not applicable. However, this approach will disturb the fluid mud deposits and result in localised turbidity plumes. Monitoring of pilot studies would be required to determine if the frequency and intensity of these plumes pose a greater risk to local environmental values compared to the plumes resulting from periodic maintenance dredging.

Detailed site specific investigations would be required to determine if any of these approaches could be beneficial at any of the ports in Queensland. As part of these investigations, indicative costs, timings and any potential impacts should be outlined to assess the relative feasibility of the options. Due to the site specific nature of the Keep Sediment Moving options and their relative scale it is not possible to provide costs or timings at this stage.

Detailed site specific investigations would be required for the Keep Sediment Navigable option, but if this approach to navigation was deemed feasible and did not result in increased environmental impacts compared to maintenance dredging then the option would not have any additional costs as it is just a change in the navigational approach.

These options have already been considered by a number of ports as part of previous approvals applications and will continue to be reviewed as part of any future applications. If any are deemed appropriate from a cost, timing, environment and safety perspective then they may be adopted.

4.7 Summary

Based on the existing requirements of the maintenance dredging in Queensland, and specifically the GBRWHA, the TSHD Brisbane is well suited as it is based locally and therefore well placed to respond to post cyclone restoration if necessary. The vessel has been subject to regular improvement since it was built in 2000 and as such it has state of the art environmental mitigation measures, including a green valve to minimise turbidity plumes while operating in overflow mode, which are similar to other modern TSHD vessels. If the maintenance dredging requirements of the ports in Queensland increase significantly in the future (this is further discussed in **Section 4.6**) then a larger TSHD which is capable of dredging at a faster rate could be beneficial over the TSHD Brisbane, to ensure the vessel can meet the dredging requirements.

There has been significant inter-annual variability in the historical maintenance dredging requirements at the majority of the ports within the GBRWHA which require regular maintenance dredging. The variability is driven by the metocean conditions and the occurrence of extreme events such as cyclones and in some cases flood events and as such it is not possible for the ports to control or accurately predict their future maintenance dredging requirements. The frequency of maintenance dredging at the different Queensland Ports are as follows:

- Frequent (annual): at six ports, the Ports of Brisbane, Bundaberg, Gladstone, Townsville, Cairns and Weipa;

- Regular (2 – 5 years): at two ports, the Port of Hay Point and Mackay;
- Episodic (extreme events): at one port, Port of Cooktown;
- Irregular (>5 years): at three ports Port Alma, Abbot Point Port and Karumba; and
- No maintenance dredging: at eight ports, Ports of Maryborough, Lucinda, Mourilyan, Cape Flattery, Quintell Beach, Thursday Island, Skardon River and Burketown.

The maintenance dredging volumes over the last 10 years should be used as an indicator of the likely range and frequency of future maintenance dredging requirements at the ports. However, it is not possible to use the historic volumes alone to accurately predict the future requirements and so it is not considered realistic to adopt them to define future maintenance dredging limits. It is also important to understand how the volumes relate to sedimentation in order to estimate future requirements, as in some cases the annual volumes can be misleading. There are a number of proposed capital dredging projects which have the potential to increase future maintenance dredging at the ports. The predicted increases in future maintenance requirements range from 10% at the Port of Cairns to a predicted reduction due to associated reclamation works at the Port of Townsville.

Historically, the majority of sediment dredged during maintenance activities has been placed at offshore placement sites, with only a small amount placed in reclamations at the Ports of Townsville and Cooktown. The offshore placement sites which have been used at the ports to date have been a mix of retentive and dispersive sites.

The ports are proactive and already adopt a number of strategies to try to minimise maintenance dredging requirements. There are limited additional options which could be adopted in the ports in the GBRWHA to try to reduce future maintenance dredging requirements. Details of a few possibilities which could be applicable at some locations have been provided. Detailed site specific investigations would be required and possible trialling prior to the implementation of these options since if they were wrongly adopted, they could potentially increase the maintenance dredging requirements or result in adverse environmental impacts.

Based on the results of this section the following observations are made:

- in-situ volumes would be the most suitable standard measure to describe maintenance dredging quantities in the future. This volume can be accurately measured before and after the dredging and can be used to provide an accurate measure of maintenance dredging. However, in some cases, such as when determining volumes for long channels which require limited maintenance dredging, it may be more applicable to adopt the in hopper volume;
- measures to incorporate environmental windows into the maintenance dredging schedule should be implemented in situations where there is significant potential to reduce environmental impacts;
- it is important to have an understanding of the sediment transport processes at the ports which have a regular maintenance requirement to put the maintenance dredging into context with the natural environment. This should consider all significant sediment sources and historic changes in bathymetry and shoreline position;
- the prevailing metocean conditions control the maintenance dredging volumes and these cannot be controlled or predicted by the ports. Historical volumes can be used to indicate the likely volumes and dredging frequency required for the ports to maintain design depths but cannot be used to completely predict future requirements;
- future maintenance dredging volume estimates need to take into account the spatial and temporal variability in sedimentation rates at the ports and, even so, flexibility should be retained so that applications for adjustments to volumes can be considered in the event of extreme situations, such as the occurrence of cyclones; and

* the existing approvals process includes assessment of changes (future maintenance dredging requirements) resulting from proposed development projects, which is considered a suitably robust approach to understand any increases in future maintenance dredging.

5 Beneficial Reuse and On-land Disposal of Dredge material

5.1 Introduction

Beneficial reuse can be defined as using dredge material for a purpose that provides social, economic or environmental benefits (or a combination of these). That is, the dredge material is managed as a valuable resource rather than a product destined for disposal. Beneficial reuse can involve the placement of dredge material on-land and in the aquatic zone (i.e. underwater or in intertidal areas). Consideration of beneficial reuse in the Queensland context to date has been focused on applications that provided economic benefits such as on-land processing and industry reuse or land reclamation.

It is important to note that the on-land placement of dredge material does not always constitute beneficial reuse. On-land disposal of dredge material can be defined as the placement of material on-land in a way that does not provide any wider benefit other than finding a destination for long-term or permanent storage of the material. Examples of on-land disposal include placement of dredge material within a licenced landfill site or a purpose-built confined disposal facility (e.g. large bunded area established for dewatering, settling and permanent containment of dredge material). It should be noted that on-land disposal generally involves bringing ashore significant quantities of maintenance dredge material (primarily fine sediments) for storage, which can result in the receiving lands being sterilised for decades and the requirement for costly ground improvement measures to be implemented to enable future land use.

It should be noted that sea disposal of dredge material under certain conditions can be considered as beneficial reuse. This could be due to environmental benefits derived from:

- sustaining natural processes of sediment supply and movement by returning sediments into the active coastal system (e.g. dispersive placement sites);
- strategic placement in specific seabed areas to benefit nearby foreshore areas by using natural sediment transport processes to rework and redistribute the material (e.g. to progressively build up intertidal mudflats or sand reserves on beaches); and,
- creation of topographic relief with dredge material placed on the seabed to establish aquatic habitat.

As such, current practices which involve the disposal of maintenance dredge material at dispersive offshore DMPA's[1] may therefore be viewed as beneficial reuse provided that the dispersion of placed dredge material is not having an adverse effect on the surrounding natural environment.

Recent legislative requirements banning the offshore disposal of capital dredge material in the GBRWHA has placed focus on the consideration of opportunities for maintenance dredge material to also be disposed of on-land. When considering this, it is important to keep in mind that capital dredging involves the removal of deep, hemmed sediments from the seabed, whereas a significant proportion of maintenance dredging material will occur within the dynamic sediment zone.

Maintenance dredge material should not be considered as 'spoil', but rather be considered an integral part of the natural sediment system. Therefore, the consequences of the net removal of natural material from the active sediment system need to be assessed in detail when considering the on-land disposal of

[1] *DMPA refers to a Dredge Material Placement Area and, in the context of this report, is exclusively referring to an offshore disposal location. Whilst an onshore disposal site could also, technically, be referred to as an onshore DMPA, this is not common practice and, hence, when an onshore disposal site is discussed, it is noted as such.*

maintenance dredge material, particularly where this material may otherwise provide net environmental benefit.

The following sections evaluate the potential for beneficial reuse of maintenance dredge material within ports adjoining the GBRWHA, including both on land and at sea options. In addressing this, the sections include:

- a review of dredge material sediment properties at each port;
- a review of constraints and opportunities applicable to beneficial reuse in the GBRWHA;
- a review of international best practice and current Australian practices;
- a review of on-land disposal limitations for GBR Ports;
- an assessment of both on-land and aquatic beneficial reuse opportunities at GBR ports; and,
- an appraisal of environmental impacts associated with different disposal options.

5.2 Dredged Sediment Characteristics

The opportunity for beneficial reuse of maintenance dredge material is highly dependent on the sediment properties of the materials dredged. This includes the engineering properties of the sediment as well as the presence of any contaminants/toxins or acid sulfate soils (ASS).

The sediment characteristics of maintenance dredge material found within selected ports where regular maintenance dredging has occurred is summarised in this section, with further details provided in **Appendix C**. This includes physical, geochemical and acid sulfate soils properties, and is based on a review of relevant documents including Long Term Dredging Management Plans, Sediment SAP (Sampling and Analysis Program) Implementation Reports and Sea Dumping Permit Applications available from each of these ports. The data presented in the sediment SAP's provides the best current available information on the properties of the sediments that may be dredged within port areas.

A high level summary of the sediment characteristics within the above ports is provided in **Table 20**. This indicates that most ports have areas where sandy material (typically with a significant clay/silt content) exists within maintained navigation areas. However, this information needs to be interpreted with care as it includes sediment data from the entire port footprint, and is not limited to typical maintenance dredging areas that are susceptible to sedimentation. Typically, when the results from the sediment sampling are considered in relation to the areas where historic sedimentation has occurred, the areas where sedimentation has occurred are predominantly made up of fine sediments (silts and clays) with only small amounts of coarser material. Furthermore, where sandy sediments exist it may not be possible to efficiently selectively dredge these areas or to separate the sand from any fine grained material also present in the sediment.

Table 20: Summary of maintenance dredged sediment characteristics at selected ports

Port	Sand/Gravel[1]	Clay/Silt	Suitable for Unconfined Sea Disposal	PASS Identified
Port of Gladstone	Yes	Yes	Yes, all areas.	Yes
Hay Point Port	Yes	Yes	Yes, subject to current GBRMPA review.	Unknown
Mackay Port	No	Yes	Yes, all areas.	Yes
Port of Townsville	Yes	Yes	Yes, except some berth areas within the Inner Harbour due to elevated levels of heavy metals (Copper and Nickel)[2], and within the Marine Precinct and Ross Creek due to assumed high levels of contaminants (not tested).	Yes
Port of Cairns	Yes	Yes	Yes, all areas.	Yes

[1] Typically this only represents a relatively minor percentage of overall maintenance dredge volumes.
[2] Elutriate testing determined that contaminants were predominantly bound to particulate matter and so would have been suitable for unconfined sea disposal, but PoTL adopted a precautionary approach and placed this material on land.

All of the ports have areas where soft clay/silt material exists. When tested, this fine material is often characterised as potential acid sulfate soil (PASS). Based on the results of sampling and testing regularly undertaken by ports, maintenance dredge material is generally considered to be uncontaminated and suitable for unconfined sea disposal in accordance with the NAGD. Some exceptions exist in localised areas, typically adjacent to berths, where elevated levels of TBT and heavy metals have resulted in the material being considered unsuitable for unconfined sea disposal.

Given that variability is evident in the composition of sediments that exist in port areas, it is considered that it would be beneficial to develop port and regional sediment distribution maps. This information would benefit the understanding of sediment transport and deposition processes suggested in **Section 4.7** and could potentially allow for planning of maintenance dredging activities to facilitate implementation of customised beneficial reuse and disposal outcomes in specific port areas. Mapping of sediment distribution can be achieved by targeted sediment sampling programs or by geophysical investigation techniques. The value of these sediment distribution maps will vary between each port as intermixing of different material pathways at different times can result in thin/irregular layers of opportunistic materials. These thin layers of usable material can be difficult to map and furthermore be difficult and inefficient to extract with typical dredging equipment.

5.3 Opportunities and Constraints

The consideration of alternatives to sea disposal is a requirement of the application process under the *Environment Protection (Sea Dumping) Act 1981*. As such, the identification of opportunities and constraints for beneficial reuse of dredge material is included in Sea Dumping Permit Applications and is also typically contained within Long Term Monitoring and Management Plans and Sampling and Analysis Plan Implementation Reports that document the assessment process for the disposal of maintenance dredging material.

Through the detailed review of dredged sediment characteristics provided in the previous section, the following realistic opportunities and constraints may apply to the management of dredge material in GBRWHA ports.

Opportunities

- existing sites that have been approved or established for land reclamation activities (e.g. existing bunded areas);
- sandy maintenance dredging material that has suitable engineering properties for use as fill in port development;
- small-scale reclamation along developed waterfront areas to create foreshore parks;
- creation or restoration of coastal habitats with dredge material (e.g. bird roosting areas, intertidal areas, wetlands); and,
- returning dredged sediments back to the active coastal/estuary system (e.g. downstream/downdrift placement of materials, beach nourishment).

It is important to note that these particular opportunities may not all prove to be viable at this point in time. However, under changes in factors such as: environmental values, port development requirements or advancements in material processing technology, these opportunities may become credible options in the future and should be continually reassessed.

Constraints

- **Sediment characteristics:**
  - silts and clays that have poor engineering properties for use as fill in port development and have limited application for agricultural reuse due to fine grain size and salinity;
  - geochemical properties of maintenance dredge material (i.e. comparison against applicable best practice guidelines for sediment and elutriate water quality, refer **Section 3.4**);
  - maintenance dredge material that is PASS would acidify once exposed to air unless neutralised with additives such as agricultural lime; and,
  - maintenance dredge material that is PASS and is exposed to oxygenated waters can also acidify.

- **Environmental issues:**
  - land reclamation over intertidal and sub-tidal coastal lands can result in habitat loss and the requirement for compensatory measures such as payment of compensation fees, provision of offsets (e.g. creation of compensatory habitat elsewhere), monitoring and research programs, and provision of public facilities;
  - land reclamation of coastal lands can reduce public access to habitats (e.g. mudflats and mangroves), potentially affect recreational fishing and reduce the aesthetic appeal of the waterfront;
  - potential impacts of the disposal of saline dredging waters into terrestrial and freshwater environments (e.g. groundwater interaction);
  - mobility of elevated turbidity plumes created during subaqueous disposal activities and proximity to sensitive environmental areas;
  - turtle nesting areas on beaches;
  - high environmental values of shoreline areas surrounding ports (World Heritage Area);
  - limited availability of degraded habitats requiring restoration in close proximity to port areas;
  - requirement for a unique regulatory process as the current approvals process would constrain the opportunity for coastal habitat creation/regeneration within both the GBRWHA and the GBRMP;

    - trialling of new disposal methods which focus on keeping the material active in the sediment system through disposal in the aquatic zone will require a comprehensive approval assessment and significant collaboration with regulatory authorities; and,
    - complete life cycle (long term) impacts resulting from the on-land relocation of dredged material (e.g. additional greenhouse gas emissions, resource consumption, and adverse human health impacts).

- **Coastal/estuary processes:**
    - fate of material resuspended from dispersive subaqueous disposal areas;
    - compatibility of dredged sediments with the grain size distribution of natural beach sands (i.e. beach nourishment applications);
    - impacts of removing sediments from the active coastal system and placement in non-dispersive subaqueous disposal areas or within on-land disposal and reclamation areas; and,
    - ecological connectivity between the catchments and the reef (coastal ecosystems, including the terrestrial-side of the coastal fringe in the form of wetlands, play a critical role in the long-term health and sustainability of the reef through improving water quality, providing nurseries for juvenile stages of keystone reef fish species, and a suite of other contributing functions and processes. By utilising coastal lands for land-based disposal of dredge material, these areas could suffer further losses.).

- **Land availability:**
    - restrictions on clearing vegetation onshore under the *Vegetation Management Act 1999*;
    - on-land disposal can result in sterilisation of valuable industrial and agricultural land for extended periods of time;
    - existence of conservation areas, national parks, state parks, marine parks and heritage sites;
    - existing and planned future land use (e.g. industrial, commercial and residential development);
    - steepness of local land topography;
    - large quantities of maintenance dredge material that needs to be managed; and,
    - availability of extensive land areas required for creation of settlement ponds and drying of dredge material in close proximity to ports.

- **Operational constraints:**
    - operational limitations of the TSHD Brisbane to pump maintenance dredge material into reclamation areas (e.g. pumping distance limitations, availability of wharf facilities for tie up);
    - high mobilisation/demobilisation costs and uncertain availability associated with using dredgers other than the TSHD Brisbane;
    - unfavourable climate for evaporative drying of dredge material disposed on-land;
    - availability and proximity of drainage channels, creeks, rivers or waterbodies for discharge of turbid and saline return water during on-land sediment dewatering activities and potential environmental impacts;
    - remote location of ports and logistical challenges and required infrastructure associated with transporting material to developed areas for beneficial reuse applications; and,
    - proximity of existing landfill sites and sustainability issues associated with disposal of dredge material within landfill sites with finite capacity for receipt of material.

- **Economic constraints:**
    - costs of on-land disposal or reclamation are often significantly higher than sea disposal;
    - limited demand within local industry (e.g. high value of regional agricultural soils and adequate supply from existing extractive industries) and poor price competitiveness of products created from processed dredge material;
    - high cost of ground improvement measures associated with land reclamation with fine grained material (e.g. surcharging, wick drains); and,
    - high cost of protecting land reclamation areas from storm surge and cyclonic activity (e.g. rock protection).

In summary, the nature of the dredged sediments results in greater constraints than opportunities. These constraints particularly relate to the ability to develop beneficial reuse opportunities that may have direct economic benefit, such as being able to commercialise (i.e. sell on) the material and/or use it for land/port reclamation activities which could further enhance economic growth.

The relatively poor physical properties of the dredge material limit its applicability for reuse applications without significant improvement involving on-land processing. In addition, the significant volume of fine materials dredged at the ports on a regular basis would present significant logistical challenges related to identification of suitable locations for disposal and the large areas required to manage the material on-land (refer **Section 5.5**). Hence, on-land disposal is likely to be a difficult, expensive and unsustainable process for maintenance dredged materials.

5.4 Review of International and National Best Practice

5.4.1 International Practice

Beneficial reuse and on-land disposal of dredge material is practiced worldwide, with guidance and case studies documented in a number of publications. This international guidance material has been prepared by large industry bodies including Construction Industry Research and Information Association (CIRIA), Permanent International Association of Navigational Congresses (PIANC), U.S. Army Corps of Engineers (USACE) and International Association of Dredging Companies (IADC). These organisations have been promoting the consideration of beneficial uses for dredge material over several decades. A selection of relevant guidance documents include:

- *Beneficial Uses of Dredge material (USACE, 1987);*
- *Beneficial Uses of Dredge material: A Practical Guide* (PIANC, 1992);
- *Dredge material Management Guide* (PIANC, 1997);
- *Summary of Available Guidance and Best Practices for Determining Suitability of Dredge material for Beneficial Uses* (USACE, 2007a); and,
- *Dredge material as a Resource: Options and Constraints* (PIANC, 2009a).

A recent international focus has been on 'Working with Nature' principles. The 'Working with Nature' concept was developed by PIANC (2008b) and calls for the consideration of project objectives firstly from the perspective of the natural system rather than from the perspective of technical design. This approach necessitates an in-depth understanding of the natural environment, including the natural processes that support ecosystems and maintain the physical environment. In the context of dredge material disposal, this could involve using natural processes to dictate where material moves and deposits to provide positive environmental outcomes. There are a number of examples where this approach has been applied successfully in European ports, particularly in the United Kingdom and The Netherlands.

A similar philosophy is promoted as 'Building with Nature' by IADC (2010) and as 'Engineering with Nature' by USACE. USACE has a dedicated Engineering with Nature program, which has supported numerous dredge material disposal projects involving restoration and rehabilitation of degraded environmental habitats. In the United States, USACE is responsible for the maintenance of federal navigation channels and is able to use available research and project funding to implement and monitor beneficial reuse schemes in collaboration with the US Environmental Protection Agency (USEPA).

Beneficial reuse applications can be considered within three categories that comprise: Engineered and Product Uses; Agricultural and Related Uses; and Environmental Enhancement (SKM, 2013). The feasibility of dredge material reuse options is highly dependent on the physical and geochemical properties of the material. As outlined previously, maintenance dredge material within the main ports adjoining the GBRWHA typically consists of soft silts and clays, some areas of sand containing a significant fines content, and is generally uncontaminated. **Table 21** has been adapted from USACE (2007a) and summarises potentially suitable reuse applications for dredge material according to sediment type.

Table 21: Suitability of dredge material sediment types for beneficial reuse applications

Beneficial Reuse Application	Dredge material Sediment Type	
	Silt / Soft Clay	Sand & Gravel
Engineered and Product Uses		
Land creation	PS	PS
Land improvement	PS	PS
Berm creation	NS	PS
Shore protection	NS	PS
Replacement fill	NS	PS
Beach nourishment	NS	PS
Capping	NS	PS
Construction materials	PS	PS
Agricultural and Related Uses		
Aquaculture	PS	NS
Topsoil	PS	NS
Environmental Enhancement		
Wildlife habitats	PS	PS
Fisheries improvement	PS	PS
Wetland restoration	PS	NS
Sustainable Relocation	PS	PS

PS = Potentially Suitable
NS = Not suitable

Example applications are outlined below for each beneficial reuse category. When reviewing international practices, it is important to note that the GBRWHA is not directly comparable to most other international settings where on-land disposal or beneficial reuse practices have been adopted. Most coastal fringe land in the GBRWHA has relatively high conservation value and there is a lack of degraded ecosystems providing opportunities for restoration or rehabilitation. As such, practices involving the placement of dredge material onshore are generally not suitable options for GBR ports.

Engineered and Product Uses

Engineered and product uses include a wide range of applications that make use of dredge material as a resource in construction for commercial, industrial or project-specific engineering purposes. Examples of these uses include:

- **Land creation** – Filling, raising and protecting an area which is otherwise periodically or permanently submerged, otherwise known as land reclamation. This practice involves significant economic investment (generally above the expenditure that would be considered appropriate for maintenance dredging works) and therefore is only viable when coupled with larger port development projects.
- **Land improvement** – Filling of land that is not currently adequate for a planned use or that requires raising of existing levels for the purpose of flood mitigation or to create elevated land in low-lying areas for recreational, residential, commercial, or industrial use.
- **Berm creation** – The creation of offshore berms to modify nearshore wave climate and improve shoreline stability.
- **Shore protection** – A typical application is beach nourishment, where sandy material that is compatible with the natural beach sand is placed to restore retreating shoreline areas, provide additional protection of foreshore development or assets from storm erosion events, maintain continuity of sediment supply, create new beach areas or to improve recreational amenity (e.g. increased beach width). In some cases, the construction of breakwater structures and shipping channel dredging associated with port development can be the cause of foreshore erosion due to disruption of sediment transport pathways or modification of wave and current patterns.
- **Replacement fill** – Replacement of weak soils or contaminated soils, or filling of holes in the landscape from mining to improve the amenity of land. Sandy material is typically used for these applications as fine grained material (soft silts and clays) does not have suitable strength properties for most end-use requirements.
- **Capping** – Placement of a continuous layer of clean sediment over contaminated material that needs to be isolated. This may be required at confined disposal facilities (bunded areas) that have been established for storage of contaminated material on-land or below water.
- **Construction materials** – Dredge material can be used in a range of construction products including concrete aggregates, backfill material, production of bituminous mixtures and mortar, construction of impermeable layers, and as raw material for manufacture of cement, bricks, rip rap, blocks, and tile. All of these applications will require significant on-land processing of the material to achieve the desired end product, which may include dewatering, drying, stabilisation with cement or blending with other additives, mechanical screening to achieve required grading, salinity management, contamination treatment and ceramic processes.

Case Study: Pasir Panjang Terminal Land Reclamation, Singapore (Loh et al, 2011)

To satisfy the demand for container port facilities the Government of Singapore decided to expand the Pasir Panang Terminal. This required the creation of 200ha of land reclamation over naturally deep waters ranging from 20m to 30m below chart datum to create areas for landside infrastructure and 14 new berths to accommodate Ultra Large Container Ships (ULCS). The Maritime and Port Authority of Singapore (MPA) had the objective of sustainable port development that reduced reliance on sand as engineering fill material, which had also become more difficult and expensive to obtain.

The reclamation was established within a containment area created by a caisson wharf line and a landward geobund created from geotextile tubes filled with dredge material. Sand was placed in critical areas of the reclamation design including a sand key below the caisson wall, caisson infill and backfill and for capping of the land reclamation area. Approximately 45% of the reclamation volume comprised soft clays and silts from maintenance and capital dredging of the port fairways, and a proportion of land-based excavation material from major underground road and rail projects.

Dredged and excavated soft silts and clays were placed directly into the reclamation area and significant primary and residual settlements of over 2m were accelerated by using Prefabricated Vertical Drains (PVD) and surcharge preloading. Slurry clay infill within the reclamation area was avoided by using Grab or clam shell dredgers to dredge clayey materials. A pilot testing area was established within a geobund enclosure at an early stage in the project to test the performance of the proposed PVD grid spacing and surcharge load.

Cement Mix Soil (CMS) was also used to fill the geotextile tubes used to construct geobunds around the perimeter of the site. Dredged clayey material was blended with Portland Blast Furnace slag Cement (PBFC) within a cement mix barge and pumped directly into geotextile tubes. Each geotextile tube as 5m to 6m in diameter and 25m long, and was either bottom dumped onto the seabed with a modified hopper barge of lowered into the sea using a purpose-built barge. CMS was also pumped to fill between the geotextile tubes as part of geobund construction.

Agriculture and Related Uses

Beneficial reuse of dredge material for agricultural and related uses includes its use in topsoil for agriculture, and aquaculture activities in dredge material containment areas.

Dredge material that contains a mixture of sand, silt, clay and organic matter can be used to improve the soil structure for agriculture. The most productive properties of topsoil for a particular application can also be achieved by blending dredge material with other soil and the addition of reusable organic materials, such as sewage sludge or manure. Significant on-land processing of dredge material is required before it can be used as productive topsoil. This includes placement within large containment areas for dewatering and drying in thin layers (0.5m to 1.0m), blending with other soils and organic additives, and transport and mechanical spreading in thin layers over the area to be top soiled. A major limitation of dredge material from marine and estuarine environments is its inherent salt content (salinity), as practically no agricultural species can grow in salty soils and few in brackish soils. As such, seeding and planting would need to be delayed until a sufficient period of drainage and natural desalination (i.e. rainfall). The presence of PASS within dredge material is also likely to be problematic for agricultural applications due to the effect of oxidisation on the acidity of these soils.

On-land dredge material containment facilities have been used around the world for aquaculture as they share many common design characteristics, including perimeter bunds to retain water, construction on relatively impervious soils and hydraulic control structures for discharge and drainage. Demand for on-land aquaculture impoundments is driven by local and regional factors including decline of commercial fisheries, expansion of aquaculture industries resulting in a shortage of suitable sites, and limitation of aquaculture development in otherwise suitable locations due to lack of access, legal constraints, competing land uses and high land costs. In both of the above applications, dredged sediment used in the production of products for human consumption would need to be uncontaminated or contain only very low levels of contaminants.

Case Study: 'Mud to Parks' Project, Chicago, United States (Great Lakes Commission, 2013)

The Peoria Lakes are located within the Illinois River and receive sedimentation from an upstream drainage area containing some of Illinois' richest agricultural land. This sedimentation had reduced the volume of the lakes by 77 percent and was adversely affecting navigation and recreational boating activity. Although the sediment dredged from Peoria Lakes comprised rich agricultural soils, the demand for local deposition as topsoil was limited due to the abundance of fertile farm land in the surrounding areas of central Illinois.

However, a beneficial reuse application for the material was identified in Chicago following the closure of the Chicago South Works plant by US Steel, which left a 573 acre site at the mouth of Calumet River covered largely with slag. The site was approved for redevelopment and the muddy sediment dredged from the Peoria Lakes was barged up the river to Lake Michigan and to the South Works site as part of a project named 'Mud to Parks'. The mud was offloaded from the barges, trucked on to the site and spread over the slag. The sediment was then left to dry and subsequently graded to the desired park profile. Following commencement of the project in 2004, 25 acres of the site was covered with dredge material and within a year the former brownfield site was blanketed with native grasses and plants.

This practice is not viable for ports within the GBRWHA as maintenance dredge material is saline and practically no agricultural species can grow in salty soils and only few in brackish soils.

Environmental Enhancement

The use of dredge material for environmental enhancement has been widely practiced worldwide, particularly in the United States and United Kingdom where the long history of industrial activity and port development has resulted in substantial modification and degradation of coastal and estuarine environments.

The identification of opportunities for environmental enhancement is site-specific and a critical success factor in such projects is the early and continued collaboration with permit agencies, local interest groups and environmental protection agencies. In addition to the initial identification of opportunities, these stakeholder groups can provide valuable input into the design of dredge material placement strategies, long-term management plans and field monitoring programs.

Examples of environmental enhancement include:

- **Wetland restoration or creation** – Dredge material can be used to stabilise eroding natural wetland shorelines, nourish or create intertidal mudflat areas, or nourish subsiding wetlands. These applications are best suited to fine grained sediments (silts and clays, and silty sand), which can be placed directly by pipeline or indirectly by using natural processes to gradually redistribute material from subtidal areas to intertidal areas (i.e. trickle charge or sustainable relocation). Dewatered dredge material can also be used to construct protective wind and wave barriers to allow native vegetation to regrow in wetland areas.
- **Thin layer placement** – There are a number of case studies in United States which have involved 'thin layer placement' of dredge materials on coastal wetlands that have deteriorated due to sediment depletion, subsidence and sea level rise. This technique involves deposition of thin layers of sediment by spraying a dredged sediment slurry under high pressure over the wetland surface. This method improves the recovery of natural wetland vegetation and benthic organisms, and prevents smothering of existing vegetation.
- **Wildlife habitats** – A common example is the creation of bird nesting islands with dredge material. This involves the creation of artificial islands by placement of dredge material in a suitable location and at sufficient elevation and topography to provide substrate for establishment of vegetation and support bird nesting.
- **Fisheries improvement** – Improvements to fisheries habitat can be provided by seabed relief created by mounding of dredge material, which has a similar effect to creation of artificial reefs. Fish habitat can also be created by placement of dredge material to restore former seabed levels in deep artificial depressions (e.g. borrow pits) that have developed a stagnant anoxic (i.e. depleted of dissolved oxygen) zone that does not support aquatic life. Improvement of fish habitat could also be provided by using dredged sediment to create new sediment platforms to act as substrate for establishment of seagrass meadows. However, the approvals for this application, involving unconfined shallow water disposal of dredge material, would require assessment of impacts associated with the loss of existing habitat and are likely to be complex and lengthy. Habitat creation has previously been proposed for beneficial reuse of sediments from capital dredging projects at Sandringham Bay (near Hay Point) and the approvals process had a 5 year lead time.
- **Sustainable Relocation** – The introduction of dredge material into aquatic systems to maintain and/or supplement sediment supply, in order to sustain the natural processes within the system (PIANC, 2009a). This can be achieved through deliberate overflow during dredger loading, discharge into the water column at selected sites, or the placement of the dredge material on the bed of the aquatic system. Existing hydrodynamic processes (e.g. waves and currents) are used to redistribute the placed material within the natural system.

Case Study: Harwich Haven, United Kingdom (RHDHV, 2007)

The Harwich Haven is formed by the confluence of the estuaries of the River Orwell and River Stour and has a long maritime history with significant development of port facilities at Felixstowe and Harwich. There are a number of sites designated for their nature conservation significance within the Orwell and Stour estuaries and both estuaries are designated as Sites of Special Scientific Interest (SSSI) under UK legislation, Special Protection Area (SPA) under European legislation and are a Ramsar wetland site.

The environment studies undertaken for the 1998 to 2000 deepening of the approach channel into the Harwich Haven identified that the effect of the deepening on tidal propagation would result in a reduced exposure of intertidal areas. In addition, the trapping of muddy material within the deepened shipping channel that would have otherwise been transported further into the estuary system and deposited on to intertidal areas, was predicted to increase the rate of intertidal erosion.

In order to mitigate the predicted impacts of sediment trapping, a number of different 'sediment replacement' approaches were implemented during maintenance dredging of the channel including:

- Subtidal placement of fine material – placement of dredged fine sediments on to the seabed to act as a feed of material into the estuary system;
- Water column recharge – discharge of maintenance dredge material from the dredger at defined placement locations within the estuary system that are adjacent to intertidal areas; placements are made under specific tidal conditions that encourage material to disperse over intertidal areas; and,
- Increased overflow during maintenance dredging – increasing of overflow above the normal rate to return fine material within the estuary system.

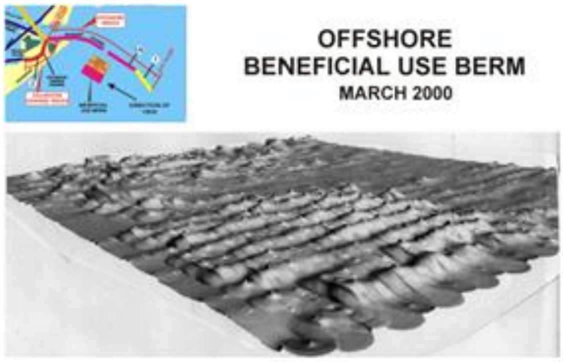
Following trial placements and monitoring the most effective strategy was considered to rely heavily on water column recharge at a number of licenced sites for placement of maintenance dredge material. This water column recharge has been ongoing since the completion of the approach channel deepening project. In addition, compensatory measures for the predicted effect on intertidal areas comprised the creation of an intertidal area at Trimley Marshes through managed realignment of a seawall and placement of maintenance dredged silt within the site (see photograph, below left). This realignment site has been demonstrated through monitoring to have developed a high ecological value, and now forms part of the designated site (SSSI, SPA and Ramsar site). As part of subsequent projects within the estuary system, degraded/eroded intertidal areas in the lower Orwell estuary have been improved through the placement of dredged clay and gravel at around the mean low water mark to form bunds along the estuary foreshore and backfilling with maintenance dredged mud.

Case Study: Galveston Harbour, United States (PIANC, 2009a)

Navigational improvements (widening and deepening) and maintenance dredging of the Houston Ship Channel and Galveston Harbour and Channel have generated large quantities of dredge material. This material has been beneficially reused in a range of environmental enhancement projects to restore birdlife habitats that have been lost due to erosion of natural islands in the area since the early 1990s.

In addition to the creation of bird islands with dredge material, other environmental enhancement projects have involved:

- construction of offshore berms by controlled placement of dredge material with hopper barges to create seabed relief;
- creation of extensive areas of saltwater marshes by constructing bunds with stiffer dredge material and filling cells with soft sediments; and,
- creation of habitat for birds and other inhabitants.



Both of the above case studies (Harwich Haven and Galveston Harbour) resulted in beneficial outcomes for degraded environmental settings that had previously lost large areas of coastal habitat to erosion. Few similar degraded coastal habitats exist along the GBRWHA coastline and many areas have high conservation value, meaning that opportunities for habitat rehabilitation are limited. However, both case studies (particularly Harwich Haven) highlight the opportunity to create benefit by keeping the material in the active sediment system. The case study below (Mobile Bay) further highlights the opportunity that sustainable relocation in the aquatic system can provide to achieve beneficial environmental outcomes.

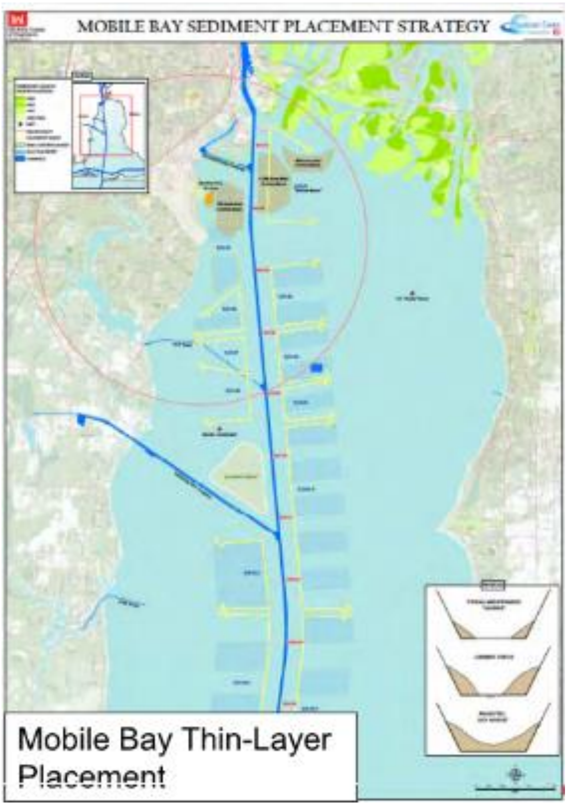
Case Study: Mobile Bay, United States (U.S. Army Corps of Engineers, 2015)

Mobile Bay, Alabama is the second largest estuary in the U.S. and the primary depositional basin for the sixth largest river system in the U.S. The bay also houses the 12th largest port in the US which includes a 15 m deep by 130 m wide shipping channel extending northward from the mouth of Mobile Bay for 29 miles to the mouth of the Mobile River. Maintenance dredging requirements at the port averages approximately 4 million cubic metres per year.

In November 1986, the Water Resources Development Act (WRDA 86) completely changed dredging and material placement practices in the bay by banning the in-bay disposal of maintenance dredge material. It was observed that over the years following that this change in practice contributed to shoreline recession and the loss of habitat in the region. Twenty five years after the banning of in-bay disposal, beneficial reuse options were considered in detail and it was determined that keeping the material in the bays active sediment system would act to limit the erosion and habitat loss experienced in the region.

A method was developed whereby a thin layer of dredge material was placed on either side of the shipping channel and in doing so this retained sediment in the local system. It was determined that disposal in thin layers had limited effects on the benthic environment as benthic communities were able to recover relatively quickly to thin layer placement. Monitoring showed that the thin layer placement approach restored natural sediment processes in the Bay as well as creating positive benefits to the local ecosystem.

This particular case study highlights the importance of keeping sediment in the active system by avoiding on-land or offshore disposal options under certain circumstances. Sustainable sediment relocation may prove to be a feasible option for some ports within the GBRWHA, subject to detailed investigations and trials.



On-land Disposal

On-land disposal options include placement within a Confined Disposal Facility (CDF) or disposal within a licenced landfill. CDFs comprise bunded containment areas that are purpose-built for dredge material disposal and can be located in open waters (island CDFs), nearshore sites or on-land. The function of CDFs is to receive dredge material, facilitate drainage of excess water (dewatering) and long term storage of dredge material. CDFs can be constructed as a system of several different containment cells that are linked by hydraulic control structures to facilitate dewatering processes and rotation of dredge material discharge. Design features of CDFs can include impermeable lining, return water treatment, leachate drainage provisions, internal bunding, ground improvement measures and capping material.

On-land CDFs are common in the United States where they are used to store dredge material from inland waterways in areas where underwater disposal is impractical, and are referred to as 'upland' CDFs. In many cases worldwide, CDFs have been constructed to isolate contaminated dredged sediment that is not suitable for sea disposal. Placement of dredge material within CDFs is generally considered to be a non-beneficial disposal option, unless ground improvement measures and/or capping are used to facilitate future use of land that would otherwise be sterilised.

Disposal of dredge material to licenced landfill sites is not a sustainable option for large quantities of material that would occupy valuable space reserved for other waste. As such, landfills are generally only used as a destination for small quantities of contaminated dredge material. Disposal to landfills typically requires the dredge material to be in a 'spadable' physical condition (i.e. capable of being handled and stockpiled by common earthmoving equipment). To achieve this, dewatering of the dredge material is required by the construction of settlement ponds and drying areas, or by the use of mechanical dewatering techniques (e.g. mesh screens, hydrocyclones, centrifuges) and the blending of additives (e.g. cement, absorbent polymers) to take up excess water content. Treatment of the dredge material to neutralise acid sulfate soils may also be required. Due to the significant processing and rehandling of the dredge material required, disposal to landfill is a high cost operation and usually only practiced for management of contaminated sediments.

Case Study: The Slufter, The Netherlands (PIANC, 2009b)

The Slufter is a large-scale CDF that was constructed in 1987 to service the dredge material disposal needs of the Port of Rotterdam. The facility is located near the shore of the Maaslakte industrial area and comprises a large bunded area that encloses an area of around 200 hectares and has a capacity of around 150 million m^3. Management of the CDF has been undertaken by dredging contractors through issue of contracts extending over several years by the Port of Rotterdam.

The Slufter receives sandy and contaminated (with heavy metals, TBT and PAHs) silty dredge material from Port of Rotterdam maintenance dredging activities and also receives dredge material from other parts of the Netherlands. Contaminated dredge material that complies with acceptance criteria can be delivered to the facility by hopper, barge or road/rail. Locally dredge material from the Port of Rotterdam is discharged by transhipment using a barge unloading suction dredger or is discharged directly from trailer suction hopper dredgers.

In the future, the facility will be filled to a maximum level of 25 metres above sea level. After this capacity is reached, it is planned that the land occupied by the CDF will be utilised as a recreational and leisure area.

It is important to note that the Slufter has been designed to only accommodate highly contaminated material that cannot be placed at sea. Establishment and operational costs were very high but necessary as few other options existed for such contaminated material.

5.4.3 Australian Practice

In the Australian context, unconfined sea disposal is a widely practiced disposal method for maintenance dredge material. This is due to a number of factors including: close proximity of many ports to the open sea; sediments being clean or containing low levels of contaminants in accordance with the NAGD; poor properties of soft sediments (silt and clays) for beneficial reuse; limited availability of land areas for on-land disposal; and economic benefits. Maintenance dredge material has typically been placed in both non-dispersive and dispersive DMPAs, with a well-established example of the latter being the DMPA used by the Port of Newcastle, NSW.

The Port of Newcastle DMPA has been used for over a century for offshore dredge material placement and has been the subject of numerous studies to develop and verify a conceptual model for far field dispersion of dredge material, and to monitor environmental characteristics of the seabed. Investigations have been completed both within the DMPA boundary and surrounding areas and have included extensive sediment sampling and physical and chemical testing, sampling of benthic communities, remote operated vehicle (ROV) video surveys, hydrographic surveys and sidescan sonar imagery. These studies have determined that the mud fraction within the dredged sediments disperses from the DMPA in a south-easterly direction before settling in water depths of 60 to 100 metres. The studies have not indicated adverse environmental impacts from ongoing placement activities. ROV investigations determined that the placement of dredged rock from capital dredging activities had, in fact, resulted in environmental enhancement by providing habitat for sponges, moss animals and filamentous algae. Juvenile snapper were also observed in the vicinity of the rocks and boulders. The Port of Newcastle currently holds a 10 year sea disposal permit for maintenance dredge material.

The Port of Newcastle's DMPA is highly dispersive as a result of its location on the continental shelf where there is considerable wave energy at the seabed. It is an example of sustainable relocation where material is placed with the knowledge it will be shifted by natural processes which is acceptable because the fate and consequences of the material movement are well understood.

Confined sea disposal has been used by several ports as a method to isolate contaminated sediments. This practice involves 'clean' capping material being dredged as part of the maintenance dredging campaign for placement on top of the disposed contaminated dredge material. Examples of this include disposal of dredge material within underwater bunded areas constructed within the inner harbour of Port Kembla, and the establishment of a large confined disposal facility within Port Phillip Bay, Victoria to receive dredge material from the Port of Melbourne Channel Deepening Project and ongoing maintenance dredge material.

Engineered and product uses have been limited to the creation of land reclamation areas. This is typically associated with port development, where capital dredging undertaken for navigation access yields sand, stiff clay and rock materials that have suitable engineering properties for incorporation into land reclamation. However, there are some cases where muddy maintenance dredge material has been placed into large bunded areas that have been established with a long-term view of future land use. An example of this approach includes the creation of reclaimed land areas at Fishermans Island by the Port of Brisbane, where ground improvement measures such as surcharging and wick drains are being utilised to progressively create and release land for industrial use. Land reclamation works at Fishermans Island also rely heavily on capital dredging of large volumes of clean sand from Moreton Bay for use as surcharge material to enable ground improvement works to be feasible. This surcharge material is typically 1.5 to 2.5 metres thick with a portion of this surface material being left on the surface following ground improvement. The restricted ability to undertake capital dredging of sands for surcharging works is a significant limitation in undertaking such land reclamation activities at GBR ports.

Beach nourishment has been implemented opportunistically by ports that are situated on the open coast or have entrances that are maintained by engineered structures (e.g. breakwaters) and interrupt the transport of marine sediments. An example of this is the periodic placement of sandy maintenance dredge material accumulating within the entrance breakwaters at the Port of Newcastle in the nearshore zone of Stockton Beach. Stockton Beach is located to the north of the harbour entrance and is nourished with the natural movement of the deposited sand onshore by wave action. This activity has been found to be more economical than unconfined sea disposal further offshore and increases sand reserves to combat storm erosion on Stockton Beach.

In comparison to the United States and Europe, the use of maintenance dredge material for environmental enhancement has not been widely practiced in Australia. This is due to lack of degraded ecosystems providing opportunities for restoration or rehabilitation and the establishment of designated unconfined sea disposal sites at most major ports. In addition, some ports are located in areas that have high conservation and environmental values where there is a concern that placement of dredge material within these ecosystems may not be beneficial. While European ports are also often located in sensitive environments covered by national and international nature conservation designations, the use of maintenance dredged silts to improve intertidal mudflats or restore eroded areas saltmarsh areas is often considered beneficial and preferable to offshore disposal, particularly in the UK and the Netherlands. Many of these initiatives tend only to require a modest amount of dredge material in the context of the maintenance dredging commitment for a particular port or harbour area.

On-land disposal or landfill disposal is considered to be uneconomic by most GBR ports that manage significant quantities of maintenance dredge material. In cases where on-land disposal has been implemented, it has typically involved small quantities of dredge material, management of contaminated sediments, and/or the opportunistic use of existing containment structures (e.g. associated with land reclamation from capital dredging projects).

5.5 Potential Capacity Requirements of Land Disposal

As discussed in **Section 5.3**, one of the major constraints for implementation of beneficial reuse and on-land disposal options is the availability of suitable land for placement and/or processing of dredge material. In many cases, although permanent on-land disposal of material may not be proposed, dewatering, drying and treatment of dredge material is required before dredge material can be used in beneficial reuse applications. Sites for dewatering and drying of dredge material that is hydraulically pumped onshore comprise large bunded areas that are constructed over available land with the following characteristics:

- relatively flat land;
- close to existing drainage, creeks or waterbodies that can receive saline return water with a suspended sediment load;
- distant from areas subject to coastal erosion or storm surge;
- have limited adverse effects on environmental values of the area;
- within a reasonable distance from the dredging site to enable pumping of dredge material;
- secured by fencing to address public safety issues associated with large areas of soft sediments in the process of drying; and,
- ideally located close to the final beneficial reuse site to minimise transport logistics and associated costs.

Research undertaken by the Port of Brisbane (Fishermans Island reclamation area) and other ports (RMC, 2012) has determined that dredge material placed into drying areas in layers 1 to 1.5 metres thick will achieve a consistency that will allow rehandling within 9 to 12 months. If the material is placed in thicker layers that are several metres thick, this period could extend to 5 to 10 years (RMC, 2012). It is important to note that dredge material at the Port of Brisbane contains significant fractions of fine silt which enhances its ability to dry. In GBR ports, subject to sediment and wet season characteristics, dredge material would need to be placed in layer thicknesses of 1.5 metres or less to facilitate drying within a practical timeframe.

The annual mean future maintenance dredging volumes from **Section 4.6.2** have been used to estimate the potential land area requirements for on-land processing of this material over 5 year and 10 year planning horizons. These land areas have been determined for each port that has periodic maintenance dredging requirement and are summarised in **Table 22**. The indicative land area requirements are based on placement of a 1m thick layer of settled silt/clay material with a bulking factor of 2 to 3 relative to its in-situ volume.

Table 22: Estimated land area requirements for land disposal over 5 year and 10 year planning horizons

Port	Annual Mean (m^3 / yr)	Typical Maintenance Dredging Frequency (years)	Indicative Land Area Requirement (ha)	
			5 years	10 years
Gladstone	190,000	1	240	480
Port Alma	10,000	5	3	6
Hay Point	100,000	3	45	90
Mackay	30,000	3	13	25
Townsville	400,000	1	500	1000
Cairns	400,000	1	500	1000
Cooktown	5,000	10	1	2

It is evident from **Table 22** that ports which have relatively high maintenance dredging needs (Gladstone, Hay Point, Townsville and Cairns) require significantly large on-land receiving facilities. When the high environmental value associated with the GBRWHA coastal areas is considered, the construction of large on-land receiving areas in close proximity to the coast would raise a wide range of environmental issues.

In addition to the significant land areas required, the timeframe for design, documentation, approvals and construction of on-land disposal facilities could be in the order of 18 to 24 months (NQBP, 2011). This is significantly longer than the typical period of 6 months required to obtain the necessary approvals for placement of maintenance dredge material within an existing DMPA (NQBP, 2011).

5.6 Beneficial Reuse and On-land Disposal Options for GBR Ports

An assessment of the applicability of beneficial reuse and on-land disposal options was commissioned by GBRMPA as part of the *Improved Dredge Material Management for the Great Barrier Reef Region* investigation (SKM, 2013). This assessment involved the completion of a multi criteria analysis for four (4) of the GBR ports and the short-listing of disposal options for management of dredge material that were considered to be potentially suitable at each port. The results of this assessment are reproduced in **Table 23**.

Table 23: Summary of port-specific options for beneficial reuse or on-land disposal (SKM, 2013)

Disposal Option	Port of Gladstone	Hay Point Port	Port of Townsville	Port of Cairns
Land reclamation	**PS (mixture clay, silt, sand, gravel)**	**PS (rock only)[2]**	**PS (sand, silt, clay)**	NS
Construction fill (load bearing above high tide mark)	**PS (mixture clay, silt, sand, gravel)**	**PS (rock only)[2]**	NS	**PS[1]**
Mine rehabilitation (filling)	NS	NS	NS	NS
Shore protection (hard structures)	NS	NS	NS	NS
Beach nourishment	NS	NS	NS	NS
Construction material (product use)	**PS (gravel, sand)**	NS	NS	NS
Parks and Recreation fill material	**PS**	NS	NS	NS
Agriculture/Forestry/Aquaculture	NS	NS	NS	NS
Habitat restoration	**PS**	NS	NS	NS
Landfill site capping	NS	NS	**PS (clay)**	NS
Permanent disposal in landfill	NS	NS	NS	NS
Permanent disposal in CDF	NS	NS	NS	NS

[1] Material is of low load bearing capability and would require significant periods of drying and or treatment processes to enable use.
[2] Only applicable to capital dredging materials.
PS = Potentially Suitable, NS = Not Suitable

It should be noted that the above assessment considered the management of both capital and maintenance dredge material. As such, some of the disposal options considered to be viable for capital dredge material may not be applicable for maintenance dredged sediments. Notably, the reuse of rock at Hay Point for land reclamation and construction fill would only apply to capital dredge material.

A number of disposal options were eliminated from further consideration at all ports, including:

- Mine rehabilitation – Due to limited availability of suitable areas for dewatering and drying, transportation of material over large distances to mine sites, existing sources of fill material available from local extractive industries, high salinity of material prevents re-vegetation.
- Shore protection (hard structures) – Maintenance dredge material comprises only soft sediments.

- Beach nourishment – Maintenance dredge material consists of a high proportion of silts and clays, which are not suitable for nourishment of sandy beaches.
- Agriculture/Forestry/Aquaculture – Due to high salt content, need for dewatering and processing, and insufficient demand.
- Permanent disposal in landfill – Due to limited availability of suitable areas for dewatering and drying, logistics of transportation of material to landfill sites, limited landfill capacity and priority storage for other waste materials rather than clean sediments.
- Permanent disposal in CDF – Due to limited availability of land for construction of large permanent containment areas and high environmental and industrial value of surrounding land areas.

The remaining disposal options were considered to be potentially suitable for some ports (refer **Table 23**) subject to site specific technical feasibility, environmental assessment and detailed cost-benefit evaluation. These included;

- Land reclamation;
- Construction fill (load bearing above high tide mark);
- Construction material (product use);
- Parks and recreation fill material;
- Habitat restoration; and,
- Landfill site capping.

It is important to note that the above listed options are not potentially suitable at all GBR ports and as such need to be considered in the context of **Table 23**. If an option is listed as being potentially suitable in **Table 23** this does not necessarily imply it is a viable option either, as detailed site specific assessment of technical, economic or environmental factors may limit its feasibility at a particular port. For example, the *Improved Dredge Material Management for the Great Barrier Reef Region* investigation concluded that at the Port of Cairns the only option that could feasibly be considered for land-based uses of dredge material was its use as construction fill (SKM, 2013). However, due to the low load bearing capability and the potential for ASS, significant periods of drying and/or treatment processes would be required to enable this use. Further investigations by Ports North (2014) noted that quarry resources and cut to fill operations in the Cairns region currently adequately meet demand for fill material and are less expensive than processed dredge material. This demonstrates a case when a beneficial reuse option was considered to be potentially suitable but was not found to be viable.

The above is reiterated in the findings of the SKM (2013) report which states that beneficial reuse or land disposal at the ports listed in **Table 23** is unlikely to be viable as a strategy for overall management of dredge material in the long term. Nevertheless, it is important that site specific on-land disposal and beneficial reuse options continue to be reassessed through applications for sea dumping permits, as changes to environmental, technological and economic factors may render previously unsuitable practices suitable or even viable in the future.

Based on the above review of maintenance dredged sediment characteristics and best practice, it is considered that the concept of 'sustainable relocation' as an environmental enhancement measure (refer Section 5.4.1) should be further considered as a potentially feasible disposal option for GBR Ports. As discussed, the approach of sustainable relocation of dredge material aims to maintain existing sediment supply within the natural system as the accumulated maintenance dredge material is part of the natural sediment system. Therefore, any adverse effects caused by the removal of naturally active sediment needs to be a key consideration for any on-land disposal practises, offshore disposal or disposal occurring at non-dispersive DMPAs.

For sustainable relocation practices to be considered as a progressive beneficial reuse option for maintenance dredging at GBR ports, port/region specific investigations will need to be undertaken. These investigations will likely need to involve detailed environmental assessments, numerical modelling investigations, community consultations and potential trial campaigns. It is also understood there may be some significant legislative and regulatory challenges to overcome. However, these obstacles have been overcome elsewhere in the world (including other environmentally valuable areas) and have resulted in successful applications with significant demonstrated environmental and operational benefits.

5.7 Beneficial Reuse and On-land Disposal Environmental Impacts

There are additional potential environmental impacts associated with different disposal options, many of which are project-specific and require site based risk assessment of impacts and development of appropriate mitigation and management measures. A high level overview of potential environmental impacts under various categories, including water quality, ecological, social, physical environment, and air/noise/odour impacts, is provided in **Table 24**. The table also provides high level guidance on possible mitigation and management measures to address different impacts. It is evident that in comparison to the potential environmental impacts within the aquatic zone that may be associated with sea disposal, there are also a significant number of potential environmental impacts associated with beneficial reuse and on-land disposal options.

As part of an independent synthesis of the current knowledge of the effects of dredging, a number of potential impacts and challenges involved in disposing of dredge material on-land or in reclamations were identified as follows (McCook et al., 2015):

- Loss of coastal habitats due to the large areas required to process dredged sediment;
- Run-off of seawater from the dredge material, which may contain large amounts of fine sediment, into freshwater and coastal ecosystems; and,
- Potential acid sulfate soils, with associated risks of production of sulphuric acid and the release of quantities of potentially toxic metals such as iron and aluminium.

As such, the environmental impacts associated with beneficial reuse and on-land disposal options often influence both the terrestrial and aquatic environment, whilst the potential impacts of sea disposal are typically limited to the aquatic environment.

In addition to the environmental impacts presented in **Table 24**, it is important that impacts which may not immediately occur are still considered (e.g. net removal of sediment from the active sediment system or greenhouse gas emissions associated with material handling). Current dredge material placement decisions largely focus on local and immediate environmental effects from the sediment itself. For example, concerns for the GBRWHA are primarily focused on the immediate effects dredge material has on corals, seagrasses and other marine life. Concentrating on immediate environmental effects can result in wider long term effects arising from transportation and placement activities of dredge material onshore not being adequately considered. These wider affects can have implications on climate change, resource consumption, and environmental and human health.

Studies undertaken by Bates (2014) assess the complete lifecycle for dredged sediment placement strategies to account for this wider range of impacts and over longer time horizons. Findings from these works suggested that cases dealing with on-land placement options of uncontaminated sediments may be the most environmentally burdensome alternative (per ton of placed material) due to the additional emissions associated with additional handling of material.

Table 24: Potential environmental impacts and mitigation/management measures associated with disposal options

Environmental Impact	Disposal Option: Land Reclamation	Construction Fill	Construction Material (product use)	Parks and Recreation Fill	Habitat Restoration	Landfill site capping	Sustainable Relocation	Sea Disposal	Possible Mitigation / Management Measures
Water Quality Impacts									
Saline return water discharge	Y	Y	Y	Y	N	Y	N	N	• locate settlement ponds adjacent to salt water creek, river or waterbodies • direct return water flow away from known groundwater recharge areas • water quality monitoring in salinity sensitive areas
Groundwater interaction	Y	Y	Y	Y	Y	Y	N	N	• identify known areas of ground contamination and modelling of potential for groundwater interactions to mobilise contaminants • construct impermeable membranes in settlement ponds • groundwater monitoring
Oxidisation of acid sulfate soils	Y	Y	Y	Y	Y	Y	U[1]	U[1]	• complete PASS testing in accordance with relevant guidelines • neutralisation by blending with agricultural lime and soil pH testing • maintain material in a wet condition • water quality monitoring of pH • site specific assessment of the potential for submarine acid formation should be undertaken in accordance with QASSTM guidance.

Environmental Impact	Disposal Option								Possible Mitigation / Management Measures
	Land Reclamation	Construction Fill	Construction Material (product use)	Parks and Recreation Fill	Habitat Restoration	Landfill site capping	Sustainable Relocation	Sea Disposal	
Release of contaminants into water column	Y	Y	Y	Y	Y	Y	Y	Y	• complete geochemical testing in accordance with the NAGD to determine potential for release of contaminants
Surface water and leaching from on-land disposal site	Y	Y	Y	Y	Y	Y	N	N	• complete geochemical testing in accordance with relevant classification guidelines • install leachate drainage provisions at disposal site • water quality monitoring of water discharge
Turbidity plumes generated during placement and/or resuspension of material	N	N	N	N	Y	N	Y	Y	• undertake numerical modelling and/or sediment tracing studies to understand the fate of dredge material • undertake numerical modelling to predict potential impacts on environmental values. • restrictions on overflow including time limitations, tidal windows or no overflow • selection of disposal site to minimise adverse impacts of plumes/resuspension • monitoring of turbidity levels during disposal activities and comparison against ambient levels and trigger levels for environmental impact
Receiving water quality impacts from material dewatering for secondary uses	Y	Y	Y	Y	Y	Y	N	N	• water quality monitoring of water discharge • construct impermeable bunds for drying/dewatering areas.

Environmental Impact	Disposal Option								Possible Mitigation / Management Measures
	Land Reclamation	Construction Fill	Construction Material (product use)	Parks and Recreation Fill	Habitat Restoration	Landfill site capping	Sustainable Relocation	Sea Disposal	
Ecological Impacts									
Loss of terrestrial habitat (land clearing)	Y	Y	Y	Y	N	Y	N	N	• selection of dredge material processing, reclamation and disposal sites with low ecological value • provision of compensatory habitat • site restoration and revegetation following completion of disposal activities
Loss of intertidal habitat	Y	N	N	N	N	N	N	N	• selection of dredge material processing, reclamation and disposal sites with low ecological value • provision of compensatory habitat • site restoration and revegetation following completion of disposal activities
Loss of subtidal habitat	Y	N	N	N	Y	N	N	Y	• selection of dredge material processing, reclamation and disposal sites with low ecological value • provision of compensatory habitat • placement of dredge material in areas of similar sediment composition • placement of dredge material in thin layers to minimise smothering and enhance the rate of vegetation recovery • monitoring of habitat loss/mortality • monitoring of recovery following disposal activities

Environmental Impact	Disposal Option								Possible Mitigation / Management Measures
	Land Reclamation	Construction Fill	Construction Material (product use)	Parks and Recreation Fill	Habitat Restoration	Landfill site capping	Sustainable Relocation	Sea Disposal	
Smothering of benthic flora and fauna	N	N	N	N	Y	N	Y	Y	• undertake numerical modelling and/or sediment tracing studies to understand the fate of dredge material • selection of material placement sites with low ecological value • provision of compensatory habitat • placement of dredge material in thin layers to minimise smothering and enhance the rate of vegetation recovery and recolonisation by benthic organisms • monitoring of habitat loss/recovery • monitoring of recovery and recolonisation following disposal activities
Displacement of species (e.g. shore/wader birds attracted to settling ponds)	Y	Y	Y	Y	N	Y	N	N	• conduct studies to understand species behaviour • minimise time period for settling pond operations • restoration of settling pond site (filling and revegetation)
Pest introduction and attraction (e.g. mosquitoes, weeds at settling ponds)	Y	Y	Y	Y	N	Y	N	N	• minimise time period for settling pond operations • restoration of settling pond site (filling and revegetation)

Environmental Impact	Disposal Option								Possible Mitigation / Management Measures
	Land Reclamation	Construction Fill	Construction Material (product use)	Parks and Recreation Fill	Habitat Restoration	Landfill site capping	Sustainable Relocation	Sea Disposal	
Injury/fatality of marine mammals (e.g. whales, dolphins, turtles)	N	N	N	N	N	N	Y	Y	• identification of beaches used for turtle nesting • undertake disposal activities outside of known periods of high marine mammal activity • cease disposal activities when marine mammals are spotted by trained observers
Social Impacts									
Human health/safety impacts (e.g. settling pond access)	Y	Y	Y	Y	N	Y	N	N	• locate settling ponds away from developed areas • install fencing, security guards and warning signage around settling ponds during operations • restoration of settling pond site (filling and revegetation)
Loss of land for industrial, commercial, or agricultural use	N	Y	Y	Y	N	Y	N	N	• undertake site constraints and opportunities mapping to determine settling pond location
Reduced visual amenity of foreshore/land areas	Y	Y	Y	Y	N	Y	N	N	• minimise time period for settling pond operations • restoration of settling pond site (filling and revegetation)

Environmental Impact	Disposal Option								Possible Mitigation / Management Measures
	Land Reclamation	Construction Fill	Construction Material (product use)	Parks and Recreation Fill	Habitat Restoration	Landfill site capping	Sustainable Relocation	Sea Disposal	
Impacts on recreational or commercial activities (e.g. fishing)	Y	N	N	N	N	N	N	Y	• undertake site constraints and opportunities mapping to determine settling pond location • undertake site constraints and opportunities mapping to determine sea disposal location • consult with local stakeholder groups to understand nature of activities
Impacts on cultural heritage (indigenous/non-indigenous)	Y	Y	Y	Y	Y	Y	Y	Y	• undertake site constraints and opportunities mapping to determine settling pond location • undertake site constraints and opportunities mapping to determine sea disposal location • consult with local stakeholder groups to understand potential cultural heritage significance impacts
Increased vehicular traffic	N	Y	Y	Y	N	Y	N	N	• develop and designate specific haulage routes to minimise impacts on local traffic
Physical Environment Impacts									
Alteration of coastal/estuarine processes	Y	N	N	N	Y	N	N	Y	• complete coastal/estuarine processes studies • undertake numerical modelling of hydrodynamic and sediment transport processes to determine the extent of potential impacts

Environmental Impact	Disposal Option								Possible Mitigation / Management Measures
	Land Reclamation	Construction Fill	Construction Material (product use)	Parks and Recreation Fill	Habitat Restoration	Landfill site capping	Sustainable Relocation	Sea Disposal	
Morphological change	Y	N	N	N	Y	N	Y	Y	• complete coastal/estuarine processes studies • undertake numerical modelling of hydrodynamic and sediment transport processes to determine the extent of potential impacts • thin layer placement of material to minimise morphological change • sustainable relocation involving the use of natural processes to redistribute dredge material
Altered hydrology and salinity regime	Y	N	N	N	N	N	N	N	• complete coastal/estuarine processes studies • undertake numerical modelling of hydrodynamic and water quality processes to determine the extent of potential impacts
Air/Noise/Odour Impacts									
Noise generation	Y	Y	Y	Y	Y	Y	N	N	• locate settling ponds away from developed areas • undertake modelling of noise attenuation from source(s) to determine extent of potential impacts • limit operational hours • establish complaints management protocols • noise monitoring at environmental values and background measurement locations

Environmental Impact	Disposal Option								Possible Mitigation / Management Measures
	Land Reclamation	Construction Fill	Construction Material (product use)	Parks and Recreation Fill	Habitat Restoration	Landfill site capping	Sustainable Relocation	Sea Disposal	
Dust generation	Y	Y	Y	Y	Y	Y	N	N	• locate settling ponds away from developed areas • use water sprays to maintain surface moisture on material stockpiles • air quality monitoring at environmental values and background measurement locations • restoration of settling pond site (filling and revegetation)
Odour generation	Y	Y	Y	Y	Y	Y	N	N	• locate settling ponds away from developed areas • undertake modelling of odour generation and propagation to determine extent of potential impacts • odour monitoring at environmental values and background measurement locations • restoration of settling pond site (filling and revegetation)
High carbon emissions (transportation)	Y	Y	Y	Y	N	Y	N	N	• locate material processing site in close proximity to end-use location • ensure plant/equipment is maintained in good working order

Y = potential impact, N = unlikely to be a potential impact, U[1] = unknown.

[1] There currently exists some unknowns as to whether oxidisation of ASS is a potential risk during the sea disposal of sediments containing ASS. The Queensland Acid Sulfate Soil Technical Manual (QASSTM) suggests that exposing ASS to oxygenated surface waters can still lead to (submarine) acid formation. While independent advice obtained by the Gladstone Independent Inquiry noted that dredging and disposal of potential acid sulfate soil in the marine environment is unlikely to result in either significant oxidation, acid production, or release of significant quantities of heavy metals (Commonwealth Australia, 2013).

An overall consideration is that all on-land disposal techniques: require significant areas of land; are visually intrusive; and can take an extended length of time to complete, particularly if the material has poor physical properties and requires a significant amount of reworking effort and ground improvement measures. These are sizeable operations to undertake and would significantly impair the visual amenity at the processing and disposal site for long periods of time. In addition, the ongoing nature of maintenance dredging activities at some ports may require such on-land disposal facilities to operate on a near-continuous basis. As such, maintenance dredge material is typically managed in a different manner to capital dredge material as the latter tends to be: dredged in once-off campaigns; often involves removal of deeper in-situ materials which may be more suitable for this purpose; and of a known quantity (maintenance dredging volumes can vary considerably from year to year).

The costs of different disposal options are also project-specific and can be influenced by a range of factors including sediment type, geochemical properties (e.g. contamination, PASS), pumping/transport distance, dredging equipment used, quantity of dredging, prevailing environmental conditions, degree of material processing required (e.g. dewatering, drying, blending with additives, separation), and construction of supporting infrastructure (e.g. reclamation bunds, containment areas). An appraisal of the range of unit rates that could be applied to different disposal activities has previously been undertaken by GBRMPA (SKM, 2013) as part of the *Improved Dredge Material Management for the Great Barrier Reef Region* study.

This information has been reviewed in conjunction with data obtained from other cost assessments completed by ports, typically for the purposes of environmental assessment documentation, applications for sea dumping permits or long term monitoring and management plans for dredge material management. The unit rates obtained from these sources have been compiled and adjusted to 2015 dollars using variations observed in the *Non-residential Building Price Index* for Queensland. Comparative unit rates are summarised in **Table 25** and demonstrate that in comparison to sea disposal, the costs of on-land disposal would be several times higher. This is mainly due to the additional costs of processing the material to achieve a suitable state for its end use and construction of associated containment structures (e.g. bunded areas). This presents economic justification for ports to select sea disposal or sustainable sediment relocation as their preferred dredge material management practices.

A recent case study for comparison of land placement and sea disposal costs is provided within the Cairns Shipping Development Project EIS (Ports North, 2014). This concluded that the costs of land placement of capital dredge material, comprising mainly marine mud and silt, would range from $306M to $545M. The costs of sea disposal at the existing DMPA were estimated to be $60M, subject to approved overflow conditions and type of dredge used. In this case, the cost of land placement was 5 to 9 times higher than sea disposal.

Table 25: Comparative Unit Rates for Different Dredge material Disposal Options

Cost Item	Disposal Option							
	Land Reclamation	Construction Fill	Construction Material (product use)	Parks and Recreation Fill	Habitat Restoration	Landfill site capping	Sustainable Relocation	Sea Disposal
Site Clearance	N/A	$3,200 to $4,800/ha	$3,200 to $4,800/ha	$3,200 to $4,800/ha	N/A	$3,200 to $4,800/ha	N/A	N/A
Transport[1]								
Pump/pipeline transport to on-land disposal site	$4.4 to $8/cum	$4.4 to $8/cum	$4.4 to $8/cum	$4.4 to $8/cum	N/A	$4.4 to $8/cum	N/A	N/A
Hopper transport and offshore disposal	N/A	N/A	N/A	N/A	N/A	N/A	N/A	$2.7 to $3.7/cum
Small CSD pumping to underwater placement area	N/A	N/A	N/A	N/A	$4.3/cum	N/A	$4.3/cum	N/A
On-road transport by truck	N/A	$0.0085 to $0.35/cum/km	$0.0085 to $0.35/cum/km	$0.0085 to $0.35/cum/km	N/A	$0.0085 to $0.35/cum/km	N/A	N/A
Processing Costs								
Dewatering (land farming, evaporation, natural/artificial compaction, geobags etc.)	$7 to $112/cum	$7 to $112/cum	$7 to $112/cum	$7 to $112/cum	N/A	$7 to $112/cum	N/A	N/A
Stabilisation of PASS[2]	$33 to $169/cum	$33 to $169/cum	$33 to $169/cum	$33 to $169/cum	N/A	$33 to $169/cum	N/A	N/A
Separation[2] (settling ponds, sieves, hydrocylones etc.)	$7 to $27/cum	$7 to $27/cum	$7 to $27/cum	$7 to $27/cum	N/A	$7 to $27/cum	N/A	N/A

Cost Item	Disposal Option							
	Land Reclamation	Construction Fill	Construction Material (product use)	Parks and Recreation Fill	Habitat Restoration	Landfill site capping	Sustainable Relocation	Sea Disposal
Other infrastructure costs								
Land reclamation site construction	$7.5 to $13/cum	N/A	N/A	N/A	N/A	N/A	N/A	N/A
On-land containment area	N/A	$9.3/cum	$9.3/cum	$9.3/cum	N/A	$9.3/cum	N/A	
Bunded facility for artificial habitat	N/A	N/A	N/A	N/A	$69 to $213/cum[3]	N/A	N/A	N/A
Sand dispersion/shaping	N/A	N/A	N/A	N/A	$11.4/cum	N/A	$11.4/cum	N/A

[1] Unit rates are for transport/disposal only and exclude dredging costs.
[2] If required.
[3] Rate per cubic metre of bund material.

5.8 Summary

This review of opportunities for beneficial reuse and on-land disposal of maintenance dredge material has determined that significant constraints exist for options requiring dewatering of dredge material. These constraints are primarily related to: the predominance of silts and clays within the maintenance dredging areas (poor engineering qualities for reuse); the volume of material involved; coastal environmental impacts; the unavailability of large areas of nearby land for dewatering of the sediments; additional permitting processes (separate to sea disposal); and the economic impacts of additional processing and management required.

A review of maintenance dredged sediment characteristics indicated that some ports that require regular maintenance dredging have some limited areas of predominantly sandy sediment which may provide greater opportunities for beneficial reuse than silts and clays. It is considered that the development of port and regional sediment distribution maps would assist with understanding sediment movement pathways and deposition areas for different sediment types at each port. This could potentially allow for planning of customised beneficial reuse and disposal outcomes for each specific port area. The value of these sediment distribution maps will vary between each port as intermixing of different material pathways at different times can result in thin/irregular layers of opportunistic materials. These thin layers of usable material can be difficult to map and, furthermore, be difficult and inefficient to extract with typical dredging equipment.

A review of international best practice identified a wide range of beneficial reuse applications, many of which are not widely practiced in Australia or particularly feasible for GBR ports. Previous studies commissioned by GBRMPA as part of the *Improved Dredge Material Management for the Great Barrier Reef Region* investigation (SKM, 2013) investigated on-land beneficial reuse disposal options for GBR ports that have the largest maintenance dredging requirements (Gladstone, Hay Point Townsville and Cairns). From this detailed assessment only a limited number of options were identified as being potentially suitable for some specific ports. If options are listed as being potentially suitable this does not necessarily imply they are viable options, as detailed site specific assessment of technical, economic or environmental factors may limit their feasibility at a particular port. Nevertheless, it is important that site specific on-land disposal and beneficial reuse options continue to be reassessed through applications for sea dumping permits, as changes to environmental, technological and economic factors may render previously unsuitable practices suitable or even viable in the future.

Based on the review of maintenance dredged sediment characteristics, it is considered that the concept of 'sustainable relocation' as an environmental enhancement measure (refer **Section 5.4.1**) should be further considered as a potentially feasible disposal option for GBR Ports. Sustainable relocation should be considered for maintenance dredge material in order to retain the material in the active natural system. This is in keeping with best practice worldwide (e.g. PIANC's Working with Nature approach). For this practice to be considered at GBR ports, port/region specific investigations will need to be undertaken. These investigations will likely need to involve detailed environmental assessments, numerical modelling investigations, community consultations and potential trial campaigns.

It is also understood there may be some legislative and regulatory challenges with such practices. However, these obstacles have been overcome elsewhere in the world (including other environmentally valuable areas) and have resulted in successful applications with significant demonstrated environmental and operational benefits.

6 Environmental Values

6.1 Introduction

This section describes the marine environmental values that occur within the vicinity of the Ports that operate within the GBRWHA, which may be influenced by maintenance dredging activities. Environmental values (EVs) are defined as particular values or uses of the environment that are important for a healthy ecosystem or for public benefit, welfare, safety or health and that require protection from the effects of pollution, waste discharges and deposits (ANZECC/ARMCANZ, 2000). In Queensland, EVs are described as the qualities that make water suitable for supporting aquatic ecosystems and human use (DEHP, 2015).

6.2 Key Marine Habitats and Communities

A site-specific description of the distribution and temporal trends for each environmental value at each of the Ports has been tabulated and summarised in **Appendix D**. Only ports within the broader GBRWHA region with a history of maintenance dredging, or a likely future need for maintenance dredging, have been considered. These ports include: the Port of Gladstone, Port Alma, Hay Point, Mackay, Abbot Point, Townsville, Cairns and Cooktown. The ports with no history of maintenance dredging and no future need include: Quintell, Cape Flattery, Mourilyan and Lucinda.

Environmental values include the marine habitats that need to be protected and maintained within the GBRWHA to maintain a healthy ecosystem, as well as the marine flora and fauna communities, which inhabit these environments. This section defines the key marine habitats and communities and provides a short discussion on how maintenance dredging may influence these EVs, where applicable. Environmental windows are also described in this section and are discussed in detail in **Appendix D**.

6.2.1 Seagrass

Seagrass meadows are found intertidally, within the coastal environments that support port infrastructure, as well as subtidally, adjacent to shipping channels and offshore disposal grounds. Seagrass meadows play a vital role in the community ecology of the nearshore zone, providing refuge habitat for a range of juvenile life stages (including many recreationally and commercially important species) and a resource for grazers that range from invertebrates to dugongs. Seagrass meadows can also occur as dense meadows that help stabilise the seabed and influence overall intertidal zone stability.

A total of 10 seagrass species have been recorded across the Ports within the GBRWHA. There has been significant temporal fluctuation in seagrass biomass reported; however the species that dominate these sandy seabed environments have remained relatively consistent. The seagrass meadows in the Port of Gladstone are dominated by *Zostera capricorni*, which occurs within the intertidal and shallow subtidal areas and *Halophila ovalis*, which occurs subtidally (McCorrmick *et al*., 2012). Two distinct habitats (coastal and offshore) have been reported at Hay Point and Mackay Ports over the years, where the offshore seagrass meadows were dominated by light *Halophila decipiens*, while the coastal meadows comprised *H. ovalis* and *Halodule uninervis* (NQBP, 2011; Rasheed *et al*., (2011*). H. uninervis* also dominated the coastal meadows at Abbot Point (McKenna and Rasheed, 2013).

Following the La Niña-related events of 2010/11 and severe TC Yasi in February 2011, total seagrass meadow area and mean above-ground biomass in a number of the major Ports declined to the lowest recorded values since annual monitoring began in 2001 (Rasheed *et al*., 2013; McKenna and Rasheed, 2013). By 2012, there was considerable loss of *Z. capricorni* from Cairns Harbour and Trinity Inlet

(PIANC, 1997). Seagrass recovery however, was recorded at Abbot Point and Gladstone (McCormick *et al*., 2013; Rasheed *et al*., 2014).

At seasonal scales, seagrass meadows in near shore waters of the Great Barrier Reef region, typically display a seasonal growth cycle in intertidal and shallow subtidal seagrass meadows (Waycott *et al*. 2005; Unsworth *et al.* 2009), with higher percentage cover of seagrass in late spring-summer than winter (Ports North, 2014). The 'growing' season occurs during these warmer months of the year and this is when seagrass meadows have the greatest capacity to grow and store nutrients. The spring and summer months are likely to be the most sensitive time of year, compared to the senescent period, when seagrass lays relatively dormant during autumn and winter.

The action of maintenance dredging and dredge material disposal activities has the potential to introduce additional suspended sediment into the water column. The presence of additional suspended sediment in the water column can cause an increase in light attenuation and reduce the available light for seagrass photosynthesis and growth. These mobilised sediments eventually settle out from the water column and can contribute to the process of sedimentation, which also presents a potential risk to seagrass.

The seagrass growing season during spring and summer is the environmental window, which needs to be considered by the Ports during their risk assessments for scheduling and managing maintenance dredging activities. Seagrass may also be more sensitive immediately after major storm events and tropical cyclone activities. **Appendix D** provides further commentary on the potential risks to seagrass from maintenance dredging activities.

6.2.2 Coral Reefs and Rocky Reef Communities

The port facilities along the Queensland coast largely operate within the GBRWHA or adjacent to the GBRMP. The GBR is considered to be the largest living thing on Earth and is visible from outer space. The 2,300 km long ecosystem comprises thousands of reefs and hundreds of islands made of over 600 types of hard and soft coral, with a total area of ~344,400 km2.

The GBR is home to numerous species of tropical fish, molluscs and starfish, plus turtles, dolphins and sharks. The reef can be divided into three primary regions, the Tropical North Island, Whitsunday Islands and Southern Reef Islands. The GBR creates a natural barrier sheltering the Queensland coastline from ocean wave energy, and the area between the reef and the mainland is known as the inner GBR lagoon. The inner lagoon, within 5 nautical miles of the coast, is where the Queensland ports undertake maintenance dredging and dredge material disposal. This is an important distinction, as there is no maintenance dredge material disposal on coral reefs.

The closest intact nearshore coral reef communities reported within the vicinity of the Ports in the GBRWHA occur adjacent to Port of Mackay and Port of Hay Point. Fringing coral reefs at Slade Islet, Round Top Island, Flat Top Island and Victor Islet contain similar species diversity and coverage. Notable species include *Porites* colonies, *Montipora* and *Acropora* corals (NQBP, 2011). Hard coral cover on these Islands and Inlets is however, generally lower than other fringing reefs in the GBR region and hence they are not considered regionally significant (Trimarchi and Keane, 2007 in NQBP, 2009).

Hard and soft corals have also been recorded within Mackay Harbour along the seawalls, which provide hard substrate for colonisation (NQBP, 2011). The fringing reefs on the intertidal and subtidal platforms and inshore rocky shoals in the Port of Hay Point also support sediment tolerant hard corals (URS, 2000 in NQBP, 2009).

There are reef communities along the eastern side of Facing Island, along the open coastline from the Port of Gladstone (Sea Research, 2013). These reefs have recently been monitored and the overall coral cover is low (< 20%); however an increasing trend between 2011 and 2013 was observed (i.e. 7.8 to 15.3%).

At the Port of Townsville, reef habitats in Cleveland Bay include shallow fringing reefs and rocky shores around Magnetic Island; the well-developed reef platform of Middle Reef; and smaller, less developed reef areas between the mainland and Magnetic Island (e.g. Virago Shoal) (AECOM & BMT WBM, 2012).

Further afield from the Port of Cairns, Double Island (Double Island and Haycock Reefs: GBR Gazetteer number 16-047 and 16-048) contains a narrow fringing reef to the north and an extensive reef platform to the south and has a total mapped area of 185 ha. This represents the largest reef in the broader area (Ports North, 2014). The only other reefs and rocky shores mapped by the GBRMPA Gazetteer include the reefs south of the Port of Cairns. i.e. Rocky Island Reef and an associated unnamed fringing reef in Mission Bay (Ports North, 2014).

On an inter-annual time scale, seasonal reductions in coral cover usually occur during the austral summer months. During summer months severe monsoonal weather conditions can cause stress to inshore ecosystems through reduced salinity, increased turbidity and elevated nutrient loads. The inner-shelf (where all dredging occurs) is naturally turbid with wave action frequently suspending muddy seabed sediments, producing environmental conditions different from the out-shelf 'blue-water' reefs. Inner-shelf reefs are adapted to highly turbid conditions (Larcombe and Ridd, 2015).

Figure 16: Great Barrier Reef region along the Queensland Coast (source: ATN, 2015 & Google Earth Pro)

Macroalgal communities have been previously reported on sandy/mud seabed and also on inshore rocky reefs at some of the key Ports. Previous benthic habitat surveys in the Port of Hay Point reported erect macrophytes on open sandy seabed, including Udotea and Sargassum and other mixed red and brown macrophytes, with isolated benthic macro-invertebrates (Thomas and Rasheed, 2010).

Macroalgal communities of *Sargassum* have been reported on the fringing coral reef and near shore rocky reef areas in the vicinity of the Port of Mackay. At the existing dredge material placement area low densities of the red algae, *Galaxaura marginata* have also been identified (Rasheed *et al*, 2001). The impact of seasonal cyclonic weather conditions on coral reefs is suggested to be the most important driver of macroalgal turf growth (Chin et al., 2006). This indirect effect from severe weather conditions enables the colonisation of macroalgae on top dead corals (Chin et al., 2006). Additionally it has been suggested that the re-suspension of sediments, into the water column, potentially adds to the rapid growth of turf algae (Rogers, 1997). The response of fleshy macrolagae however, to severe weather conditions is similar to corals, where they are often displaced due to increased wave action (Rogers, 1996; 1997).

The presence of additional suspended sediment in the water column from maintenance dredging activities has the potential like seagrass, to influence coral and macroalgal growth rates, through increased light attenuation, sedimentation and smothering. The environmental window for corals is during the spawning season. The time of year that corals spawn depends on their location, where on the inshore reefs, corals usually start spawning one to six nights after the first full moon in October, whereas those in the outer reefs spawn during November or December.

The spawning season between October and December is the environmental window, which needs to be considered by the Ports during their risk assessments for scheduling and managing maintenance dredging activities. Macroalgal communities and coral reefs, like seagrass may also be more sensitive immediately after major tropical cyclone activities. **Appendix D** provides further commentary on the potential risks to macroalgae and corals from maintenance dredging activities.

6.2.3 Marine Turtles

Marine turtles have been previously recorded within port limits in the majority of Queensland Ports within the GBRWHA. Six species of sea turtles are known to occur in the Port of Gladstone region (Limpus *et. al.,* 2013a). These species have also been recorded utilising the offshore, intertidal, estuarine and shoreline habitats in the Hay Point area. These species primarily use the near shore marine environments surrounding the Ports as a feeding ground, as well as a transit area between other parts of the Queensland coast and the GBR (Ports North, 2014).

Turtle nesting varies between regions. For example, turtle nesting on beaches within the Hay Point area occurs between October and February, with the hatchlings emerging from January to March (NQBP, 2009) and turtle-nesting season in Mackay occurs from the middle of October to early January, with hatchling emergence continuing until April (Limpus *et al*., 2013). Green turtles are historically the most common marine turtle species reported, but in recent years, since TC Yasi in 2007, there has been increased strandings and mortality for this species (Ports North, 2014).

The biggest potential risk to turtles is from vessel strike and being entrained in the trailing suction hopper drag head during maintenance dredging activities. The turtle-nesting season, which generally occurs between October and February, is the environmental window that needs to be considered by the port managers during their risk assessment. **Appendix D** provides further commentary on the potential risks to sea turtles from maintenance dredging activities.

6.2.4 Dugongs

Dugongs can be common in Trinity Bay, Cairns; however it is thought that current population numbers are low due to the reduction in the extent and condition of local seagrass meadows (Ports North, 2014). Dugongs in the Port of Abbot Point have been recorded primarily foraging within habitat associated with extensive seagrass meadows consisting of *H. uninervis* and *H. spinulosa* (GHD, 2009a). Dugongs and their feeding trails are commonly noted in the seagrass meadows of Port of Gladstone (i.e. Wiggins Island and Pelican Banks) and in Cleveland Bay, Townsville. The main risk to dugongs is from vessel strike. There is no evidence to date that maintenance dredging vessel strike has impacted dugongs at any of the ports within the GBRWHA. **Appendix D** provides further commentary on the potential risks to dugongs from maintenance dredging activities.

6.2.5 Cetaceans

The two threatened dolphin species likely to occur within the vicinity of the Ports within the GBRWHA include the Snubfin, *Orcaella heinsohnri* and Indo-Pacific humpback dolphins, *Sousa chinensis*. These species have been previously recorded in the Port of Cairns (Ports North, 2014) and throughout Cleveland Bay in Townsville (BMT WBM, 2012d). The Keppel Bay region, in close proximity to the Port Alma, is known as an important habitat for the Snubfin dolphin (Cagnazzi, 2013). The main risk to cetaceans is from vessel strike. There is no evidence to date that maintenance dredging vessel strike has impacted marine megafauna at any of the ports within the GBRWHA. **Appendix D** provides further commentary on the potential risks to cetaceans from maintenance dredging activities.

6.2.6 Benthic Infauna and Epifauna

Benthic infauna is defined as the organisms that live within the seabed, most commonly within the first 150-200 mm from the seabed surface and epifauna occurs on the seabed. i.e. sea stars. These organisms are highly diverse and facilitate a key part of the nearshore marine food chain, supporting higher trophic levels (i.e. fish and crustaceans). The species abundance and diversity is heavily influenced by the sediment grain size (Currie and Small, 2002), which provides the physical medium in which the infauna move through and forage for food. Furthermore, there have been strong correlations for infauna population dynamics and regional rainfall, freshwater inflow, nutrient and chlorophyll a concentrations. These relationships supported the hypothesis that changes in total abundance are mostly the result of long-term climatic cycles including El Niño events (Currie and Small, 2002).

Traditionally, ports along the Queensland coast have examined the benthic infauna community composition before and after offshore disposal activities. These data have demonstrated that the benthic infauna communities often have a strong capacity to recolonise the disposal sites following disposal activities.

6.3 Summary

As the world's most extensive coral reef ecosystem, the Great Barrier Reef (GBR) is a globally outstanding and significant entity. Environmental values include the marine habitats, which need to be protected and maintained within the GBRWHA, as well as the key marine flora and fauna communities, which inhabit these environments.

The marine habitats that occur within the vicinity of maintenance dredging and dredge material disposal activities are located within the GBR Inner Lagoon. These habitats include seagrass meadows, coastal embayments, intertidal and subtidal reefs and sandy seabed communities.

Seagrass meadows are found intertidally around nearshore port infrastructure, as well as subtidally, adjacent to shipping channels and offshore disposal sites. Rocky reef and coral reef communities occur on intertidal rocky foreshores, as fringing reefs along the coastline, as well as around Islands and Inlets on the inner reef. Macroalgal communities dominate some of these near shore rocky reef environments.

Maintenance dredging activities have the potential to influence suspended sediment concentrations in the water column, which in turn can influence the primary productivity of these benthic primary producer communities. Port managers during their risk assessments for prioritising the timing and management of maintenance dredging activities should consider the potential risks to these communities, the environmental windows (i.e. times where the communities are most susceptible) and any major storm or cyclone events that have preceded maintenance dredging.

The sandy seabed communities dominated by benthic epifauna and infauna communities provide the lower trophic levels of marine food chains and are critical to marine ecosystem function. These communities have the potential to be smothered from dredge material disposal activities.

The higher order trophic levels, including the marine megafauna, such as sea turtles, dugongs and cetaceans also play an important role in marine ecosystem functioning and have the potential to be influenced by maintenance dredging activities, by entrainment in the trailer suction drag head (i.e. turtles) and from vessel strike. The environmental window, which is the turtle-nesting season, is the most sensitive time when turtles may be influenced from dredging activities.

Further risk assessment discussion is provided in **Appendix D**, which may assist the Ports with identifying the key risks and making these critical decisions regarding the scheduling of maintenance dredging.

Section 7 provides a summary of the available scientifically derived data for maintenance dredging and disposal activities in Queensland ports, which aids in providing an understanding of how changes in water quality and incident light levels influence key ecosystem processes and importantly, the environmental values described here.

7 Environmental Monitoring for Maintenance Dredging

7.1 Introduction

In recent years, there has been more emphasis placed on collecting quantitative field data for maintenance dredging and disposal activities and the following sections provide a summary of these field-based measurements. This quantitative data helps to define the extent of maintenance dredging related impacts and provide the necessary data to allow an adaptive management approach to dredging works and the risk assessment process. This section introduces potential impacts associated with changes in water quality, light and suspended solid concentrations from maintenance dredging and presents a summary of the available environmental monitoring data that focus on this activity. This data contributes to the quantitative basis for the risk assessment presented in **Section 8** of this report.

7.2 Turbidity & Total Suspended Solids

The action of dredging and disposal introduces suspended solids into the water column, changing the water clarity, which can reduce the amount of light on the seabed and influence sedimentation rates. Suspended solids are introduced into the water column as a result of:

- Direct disturbance of the seabed from dredging and during overflow of sediment-laden waters from the dredge hopper;
- Dredge propeller wash and wake disturbance of the seabed which can mobilise suspended solids;
- Placement of dredge material at the dredge material placement area; and
- Remobilisation of sediment deposited on the seabed following disposal and during onshore dewatering activities.

Turbidity is an optical measure of water clarity, commonly measured in Nephelometric Turbidity Units (NTU) and is used as a surrogate for total suspended solids (TSS), which is a quantitative measure of the amount of solid material in suspension (commonly inorganic dry mass in mg/L). Turbidity levels and TSS concentrations are commonly the focus of monitoring programs, to understand the potential risks to the marine environment. The followings sections describe how these parameters are integrated into field based monitoring, how the results are used and the outcomes from a range of historic monitoring activities.

7.2.1 Active Dredging and Disposal Monitoring

Many Queensland Ports have undertaken a series of targeted monitoring programs, to provide an understanding of the fate of suspended solids in the water column during maintenance dredging activities (BMT WBM, 2011; BMT WBM, 2013; BMT WBM, 2014f; BMT WBM, 2014g; BMT WBM, 2014h; BMT WBM, 2010, JCU, 2015). In many cases the *in-situ* measurements were performed using boat mounted, downward facing Acoustic Doppler Current Profiler (ADCP) instrumentation, which was used to undertake transects through the dredge plumes. In addition, discrete TSS water sampling and in-situ water quality logging (at sensitive receptors) was undertaken to aid in the interpretation of ADCP backscatter throughout the water column.

The plume-monitoring activities were undertaken whilst the TSHD Brisbane completed maintenance dredging and disposal activities in the Port of Gladstone, Port of Cairns, Port of Townsville and Port of Cooktown. During the execution of these environmental monitoring programs, spring tides and medium to strong winds played a key role in influencing the observed TSS levels. In some instances, the TSS generated by the maintenance dredging was undetectable over natural background levels, but this was not the case during all of the plume monitoring events.

The plumes that were detected were generally transient and dissipated to background concentrations mostly within two hours after cessation of the dredging or placement activities (BMT WBM, 2011; BMT WBM, 2014e). There were instances of maintenance dredging related turbidity which extended beyond the immediate dredge area into areas with known sensitive receivers (e.g. seagrass in Gladstone and reef in Townsville); however the intensity and duration of the maintenance dredging related turbidity was low and short lived (hours to days) (BMT WBM, 2014e; BMT WBM, 2013). Other notable observations made during the maintenance dredging plume monitoring included:

Gladstone:

- Dredge plume TSS concentrations during neap tides remained below 100 mg/L and were therefore, within the limits of concentrations typically observed within the inner Gladstone Harbour during spring tide conditions;
- Dredge plumes moved between 0.5 and 1.5 km from the dredging location before reaching background turbidity levels after approximately two hours. The plumes were generally parallel to the channel and advected along the channel; and
- At East Banks Disposal Site disposal plumes were distinguishable from background up to approximately 1.5 km from the release location.

Cairns:

- It was primarily the surface component of the dredging plume created by the hopper overflow, which was available for advection by the tidal currents beyond (east or west of) the channel alignment;
- On the ebb tide, the surface component of the dredge plume was advected west of the channel alignment up to a maximum distance of 650-700m from the channel;
- Conversely, on the flooding tide the surface plume was displaced to the east side of the channel, though the distance was shorter, being a maximum of 150-200m from the channel;
- Initial plume turbidity of up to 160 NTU was measured in the centre of the placement plume at depth and up to 100 NTU near the water surface. Within approximately 35 minutes, the turbidity within the placement plume had reduced to less than 25 NTU; and
- See **Figure 17** for further visual insight into the natural turbidity versus maintenance dredging related additions.

Townsville:

- Strong ENE winds occurred during the dredge campaign, which resulted in natural re-suspension of sediment throughout Cleveland Bay;
- Short term spikes in turbidity and light attenuation occurred during the maintenance dredging campaign (except 23/24 September) along the east coast of Magnetic Island and nearshore sites. These turbidity spikes were likely driven by natural re-suspension of bed sediments, with some contribution from plumes generated by dredging; and
- The observed change in turbidity due to dredging at sensitive receptor locations was well within the range of natural variability during the monitoring period.

Cooktown:

- During the 2014/15 maintenance dredging works automated water quality monitoring equipment was deployed, capable of autonomously measuring sediment deposition, turbidity, temperature, water depth, RMS water depth and light (PAR);

- One site was located adjacent to the Port of Cooktown channel (WQ3) and the other further afield offshore (2km). Importantly, during the extended intermittent dredging works (i.e. due to weather delays) the primary driver for observed changes in water quality conditions was related to natural weather event, and in particular Tropical Cyclone Marcia (18-20th February 2015) and TC Nathan (10-24th March 2015); and
- The monitoring data generated during the 12 month period was very useful for placing the dredging works in context with natural events and highlights the insignificant nature of the maintenance dredging and the significance of weather (cyclone) events on suspended solids concentrations.

7.2.2 Turbidity Monitoring and Environmental Values

In addition to the maintenance dredging and plume fate monitoring activities, a range of targeted environmental monitoring programs have been implemented which have focussed on measuring water quality parameters within areas containing environmental values (i.e. seagrass meadows and corals) (BMT WBM, 2011; BMT WBM, 2013; BMT WBM, 2014f; BMT WBM, 2014g; BMT WBM, 2014h). In many of these programs, continuous measurement of turbidity (i.e. measured every 5-10 minutes) was a key requirement. Having access to continuous measurements of turbidity within a seagrass meadow provides valuable empirical data for assessing the influence of the maintenance dredging works, including before, during and after the event (including understanding long term TSS trends).

Continuous turbidity measurements at predetermined sensitive receiver locations (i.e. seagrass meadows in Gladstone and Cairns) demonstrated that the maintenance dredging activities had little influence on turbidity at these locations (BMT WBM, 2011; GPC, 2014). The monitoring program in the Port of Gladstone supported previous findings that changes in turbidity in the Port of Gladstone are largely driven by tidal range, with wind and wave action also making significant contributions. The effects of maintenance dredging on turbidity levels were not discernible from these key drivers and were likely to be very small or very localised such that impacts were not detected within the monitored seagrass meadows (GPC, 2014). A similar trend was observed at the offshore disposal site, where turbidity levels were largely unrelated to disposal activities and more closely linked to tidal currents (spring/neap cycles) (GPC, 2015). An illustration of this trend is provided in **Figure 18.**

Consistent with the observations from Gladstone, continuous turbidity measurements from two water quality instruments placed adjacent to the seagrass communities within the Port of Cairns demonstrated there was no increase in turbidity, which could be correlated with the maintenance dredging operations within the port (BMT WBM, 2014).

Continuous turbidity monitoring during the 2012/13 maintenance dredging campaigns at known environmental values in Cleveland Bay, Townsville (i.e. reef communities), demonstrated that spikes in turbidity may be linked to maintenance dredging activities (BMT WBM, 2013). It should be acknowledged that the 2012/13 maintenance dredging campaign was undertaken in parallel with capital dredging works and that during high winds the TSHD Brisbane was specifically targeting maintenance dredging because of its more sheltered location. In summary BMT WBM (2013) made the following key observations from the data:

- The turbidity regime during the dredging period (capital and maintenance) is generally similar to the non-dredging period (i.e. after 28 Nov 2012).
- The three Magnetic Island sites displayed a similar pattern, where spikes in turbidity occurred
- during periods of maintenance dredging in October 2012, but not in September 2012.
- It was noted that the turbidity spikes were likely driven by natural resuspension events during higher wind periods.

- The two nearshore sites (Strand and Virago Shoal) both recorded a turbidity spike during maintenance dredging in early July 2012, with Virago Shoal the most pronounced.
- Virago Shoal and the Strand had small turbidity spikes during maintenance dredging in October 2012.

There is no data available however at Cooktown, during dredging at known environmental value sites (i.e. seagrass meadows). The risk assessment process would benefit from undertaking future monitoring within the vicinity of these environmental values.

Figure 17. Aerial images during maintenance dredging and disposal activities in Cairns 2015 (source: Robert Gesink). Top: dredging from Beacon C15 to Beacon C11 at the Port of Cairns, tide was flooding and wind speeds was 28km/hr (15kts). Bottom: maintenance dredge material disposal at Port of Cairns on 23 March 2015.

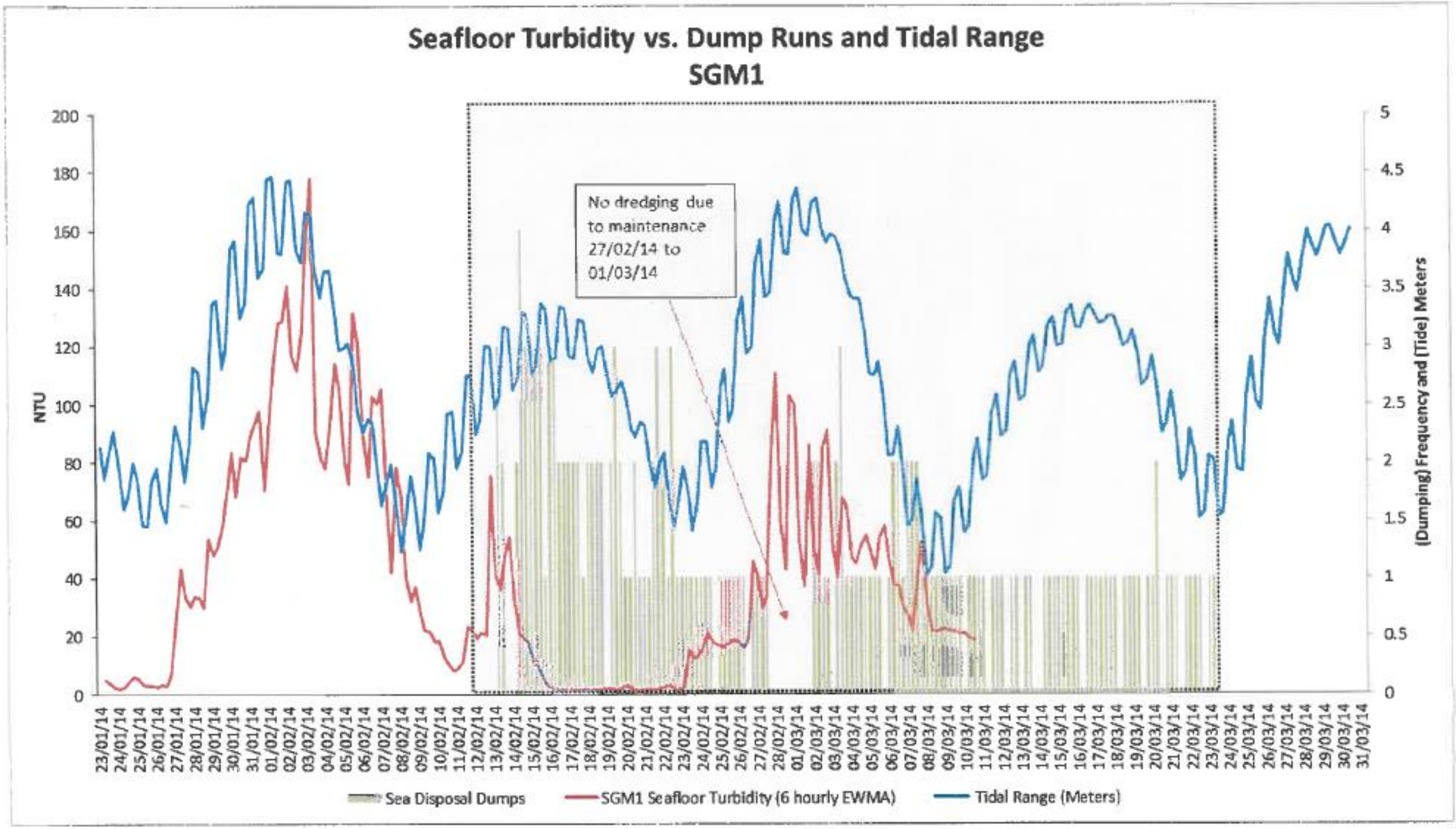


Figure 18. Offshore monitoring at site SGM1 East Banks Disposal Site, Gladstone. Hashed box area shows disposal activity, disposal corrected to align with 6 hourly EWMA.

7.3 Predictive Modelling

The data generated from the BMT WBM dredging and disposal plume intensity and extent monitoring events provided a useful basis for calibrating and updating the assumptions within the numerical models. The modelling suite, once suitably calibrated using field data, offers insight into the likely plume behaviour both during maintenance dredging and disposal activities. Dredging programs when active are used to inform and improve material source term in models or terms to validate model predictions. Other ways modelling outputs can be improved include gathering additional sediment grain size data, especially in the particle size classes <75 µm (very fine sands, silt and clay) and gathering site data on local current and tidal conditions, to improve model accuracy.

This verification work has been undertaken at the Port of Townsville (BMT WBM, 2013) and the Port of Gladstone (BMT WBM, 2014c) and the following sections provide a summary of the insights gained. The modelling outputs were used to inform water quality assessments and ecological assessments (both acute and chronic) of potential impacts. The following provide a summary of key model observations:

Townsville:

- An assessment of modelled turbidity and sediment deposition, together with water quality monitoring data was compared against preliminary impact thresholds, which suggested that it was highly unlikely that mortality to environmental values (seagrass and corals) would occur. This was primarily because of the short duration of the campaign (five weeks), and the short duration and intensity of dredge plumes and the low rates of sediment deposition;
- The observed change in turbidity due to dredging at environmental value locations was well within the range of natural variability during the monitoring period;
- During the period when the water quality monitoring was carried out, including the 2012 maintenance dredging campaign, there was seagrass expansion (not contraction) throughout Cleveland Bay;
- Given the short duration (typically up to five weeks) of maintenance dredging campaigns, the short term nature of dredge plumes and the tolerance of biota to short term increases in turbidity, it was not expected that total mortality thresholds would be exceeded during maintenance dredging at areas containing environmental values;
- Based on worse case modelling results, it was predicted that low intensity turbid plumes resulting from dredging could last for several days under windy conditions at locations containing seagrass meadows (i.e. the Strand and Cape Pallarenda). Based on a comparison of modelling results to preliminary impact thresholds (derived from biological tolerance data), it was predicted that stress (e.g. reduced growth, loss of carbohydrate) could occur under windy conditions to sensitive seagrass species (*Halophila ovalis*). This would particularly be the case if seagrass was in poor condition in the period leading up to dredging.

Gladstone:

- Based on model outputs and field validation, most environmental values surrounding the channel will not be affected by plumes. The modelling projected possible low light due to turbid plumes may result in some reduction in cover at seagrass meadows surrounding the Passage Islands during some model simulations (maintenance dredging of 400,000m^3 and 320,000m^3).
- These simulations had longer continuous dredging of the inner harbour channels than the other simulations. This was not observed during the 2014 – 2015 dredging campaign. Instead, measurement of the plume during this campaign indicated that the plume from maintenance dredging in Jacobs Channel may have travelled southward along the shoreline of Curtis Island corresponding with previously mapped meadows. The plume in this area was discernible above background for 2 hours.

- Due to the short duration of dredge plumes (measured in hours compared to seagrass light requirements being measured over a period of 14 days) adverse impacts to seagrasses are unlikely in the event that plumes do coincide with these environmental values; and
- As a worst-case and unmitigated scenario, any impacts to seagrass would be expected to manifest as a reduction in cover rather than complete meadow loss, given the relatively short duration of plumes associated with the largest modelled campaign of 400,000m^3 (up to several weeks). To date, plume influence at the Passage Island seagrasses has not been detected by water quality monitoring during maintenance dredging campaigns.

7.4 Dredge Material Resuspension and Deposition

Dredge material disposed of at the approved disposal locations along the Queensland GBRWHA are subject to different metocean processes and therefore, differing potential for bed shear stress to result in resuspension and deposition of disposed material (see **Section 4.5.3**). Loss of sediment from the approved disposal sites has the potential to increase turbidity and reduce BPAR and potentially impact upon nearby environmental values. Calibrated hydrodynamic modelling has been used to gain insights into this process (BMT WBM, 2013; BMT WBM, 2014c). The following provides a summary of the key model observations made by BMT WBM:

Townsville:

- Modelling was carried out to predict sediment resuspension over a 12-month period, to determine potential long-term impacts of dredge material placement. The modelled change in the 95th percentile turbidity from background (i.e. the turbidity value exceeded 5% of the time, or 18 days in the year) was less than 2 NTU, while the modelled change in the 50th percentile turbidity (representing changes in turbidity for 50% of the time) was less than 0.05 NTU throughout the model domain.
- This very small change to ambient turbidity is highly unlikely to cause measurable changes to biota or ecosystems. In terms of sediment deposition, the change in the 95th percentile deposition rate and the 50th percentile deposition rate would be less than 1 mg/cm^2/day and less than 0.01 mg/cm^2/day respectively throughout the entire model domain; and
- These small changes to sedimentation rates are also very small compared to background variability (e.g. 2.9-7.4 mg/cm2/day recorded at Middle Reef; Browne et al. 2012) and are highly unlikely to cause adverse effects to environmental values.

Gladstone:

- The results indicate that TSS generated by re-suspension of placed sediments would typically be low (<15 mg/l) outside the DMPA, even during the extreme events modelled. It should be noted that natural re-suspension from weather events such as tropical cyclones and gale force winds, which drive these patterns, would also result in extensive natural re-suspension of bed sediments;
- Sediment deposition from re-suspended maintenance dredging material was generally predicted to be in the fractions of millimetres. The predicted levels of sediment deposition were very low in the context of potential impacts, and would be insignificant relative to natural background sediment deposition levels.

7.5 Photosynthetically Available Radiation (Light)

The previous sections discussed monitoring of turbidity, TSS and sedimentation and considered the impacts to marine environmental values (i.e. seagrass meadows). The amount of light reaching the seabed also influences the primary productivity of these benthic communities. In recent years, there has been a substantial amount of industry and scientific research undertaken for establishing the relationship between benthic photosynthetically available radiation (BPAR) and seagrass health (Chartrand, 2012; Bryant, 2014). These studies have been specifically designed to examine the light requirements of various seagrass species (i.e. *Zostera* and *Halodule*).

The outcomes are designed to provide guidance tools for activities that influence light availability (i.e. dredging works). It should also be acknowledged that management of seagrass meadows based on BPAR requirements alone may be ineffective, because one needs to consider the temporal trends in seagrass cover/ health and other environmental factors that can impact on seagrass growth and health potential. For example, the seagrass communities in Cairns sustained significant decreases in cover since the 2010/11 La Niña events and TC Yasi and their carbohydrate stores were likely to be low and contributing to slow recovery rates and high light requirements to rebuild the deficit (Jarvis, 2015).

The BPAR thresholds derived from the examination of light requirements of seagrass varies between locations and species and was summarised for Port of Abbot Point as follows:

Abbot Point:

- For the offshore areas of deep *Halophila* beds, the modelling threshold was 1.5 mol m^{-2} day^{-1} over a rolling 7 day average.
- For the shallow inshore seagrass meadows, dominated by *H. uninervis*, the modelling threshold was 3.5 - 5 mol m^{-2} day^{-1} over a rolling 14 day average.

York and Smith (2013) summarised the minimum light requirements (MLR) for the six species of seagrass occurring in Gladstone Harbour. When seagrasses experience MLR below these limits it can lead to loss or decline (Longstaff and Dennison 1999). York and Smith (2013) express the MLR as a percentage of surface irradiance (%SI) and daily dosage displayed as mol quanta m^{-2} day^{-1} (see **Table 26**).

Table 26: Critical threshold of seagrasses for light availability ('minimum light requirements' expressed as % of surface irradiance SI and daily dose mol quanta m-2 d -1) (York and Smith, 2013).

Species	Location	% SI	Reference		Daily dose	
Cymodocea rotundata		20-37	Collier & Waycott 2009†			
Halodule uninervis	Gulf of Carpentaria	14-19	Longstaff & Dennison (1999)	Moreton Bay, Qld	9	Longstaff (2003)
				Green, Dunk & Magnetic Islands, Qld	5-9.7	Collier et al (2012)
Zostera muelleri	Moreton Bay, Qld	30	Longstaff et al. (1999)	Moreton Bay, QLD	10	Longstaff (2003)
		30	Abal and Dennison (1996)	Gladstone, Qld	4.5-12	Chartrand et al. (2012)
		31-36	Longstaff (2003)			
Halophila decipiens	Hobe Sound, Florida USA	2.5	Dennison 1987			
	St.Croix, Caribbean	4.4	Williams & Dennison 1990			
	Northwest Cuba	8.8	Duarte 1991			
Halophila ovalis	Zanzibar, Tanzania	16	Schwarz et al. (2000)	Hervey Bay, Qld	>2.8	Longstaff (2003)
Halophila spinulosa	Moreton Bay, Qld	<6	Collier & Waycott 2009*			

During the 2014 maintenance dredging campaign at the Port of Gladstone, BPAR monitoring at nearby seagrass meadows was undertaken, both within the Port of Gladstone and adjacent to the East Banks Dredge Material Placement Area (GPC, 2015). At both the Port of Gladstone and offshore seagrass BPAR monitoring sites, the primary drivers for the observed trends were the available sunlight (i.e. strong relationship between land based measurement and benthic intensities), tidal cycles and wind and wave action. Pre, during and post dredging observations did not provide any evidence that the maintenance dredging activities impacted on BPAR at environmental value sites (GPC, 2015).

Whilst these thresholds have been developed for the target species, it is also important to note that it can take extended time periods to see any physiological, morphological response or measured change in seagrass biomass from reduced light levels. For example, Collier *et al*. (2012) reported that *H. uninervis* took 46 days to show a significantly reduced leaf size, leaf thickness in the lowest light treatment investigated and Longstaff (2003) and Longstaff and Dennison (1999) reported H. uninervis took more than three months for seagrass mortality to occur following light deprivation. This is in contrast with many of the maintenance dredging campaigns in Queensland, which generally take between 7 and 53 days on average to complete (see **Table 10**) and the dredge is also working for only short periods of time in one place. Monitoring programs if and when implemented should be designed to account for an organisms physiological response. i.e. monitoring of seagrass needs to occur before, during and after dredging to understand long term temporal changes in seagrass health.

7.6 Nutrients

A review of the potential for the release of nutrients during dredging and dredge material disposal at sites in the GBRWHA, to determine the likelihood of any adverse impacts on aquatic ecosystem health was recently undertaken by CSIRO (Batley *et. al*., 2015). Some of the key findings from this review included:

- Dissolved ammonium was shown to be released in measurably high concentrations during disturbance of sediments (around the dredge), together with total phosphorus (mostly orthophosphate), while there was typically a reduction in nitrate and nitrite;
- Resuspension by tidal motion results in detectable releases of all species, which are enhanced by the greater disturbance of dredging. Greatest releases are expected during capital dredging compared to maintenance dredging;
- Measured nutrient concentrations in Queensland estuarine sediments and associated pore waters were not as high as those reported for estuaries undergoing dredging in the US, where findings were that they were unlikely to result in eutrophication or algal blooms at disposal sites or in open coastal areas; and
- Measured ammonium concentrations at the dredging and disposal sites are likely to exceed default water quality guideline values (within the vicinity of these activities), based on the 80th percentile of reference site data for Queensland near-shore waters. These guideline values however, are not intended to be protective against algal blooms. Ammonia concentrations were well below guideline values for toxicity.

More broadly, nutrient releases from dredging operations and placement of dredge material at sea are negligible and are one to two orders of magnitude lower than riverine fluxes (Larcombe and Ridd, 2015).

7.7 Contaminants

Prior to the execution of maintenance dredging programs, characterisation of the proposed dredge material is required (NAGD, 2009). A key component of this work is developing a list of contaminants of potential concern. Broadly, the sediments targeted for maintenance dredging across the ports do not contain elevated concentrations of contaminants of concern; however there have been several instances where exceedances of a NAGD (2009) screening level has been recorded (i.e. 95% Upper Confidence Limit of data exceeds screening level) (See **Section 5.2.1** for further detail). Instances of Copper, Arsenic, Nickel, Chromium, Lead and Tributyltin (TBT) have been observed in some of the ports; however these are often associated with specific locations and are not widespread (See **Appendix D**).

In all instances, the port corporations have followed the NAGD (2009) requirements to further examine the bioavailability of any exceedances. This has involved elutriate testing and/or weak acid extractions to determine the fraction of the contaminant that is of biological relevance to the marine organisms. In most cases, the biologically available fractions did not exceed the NAGD (2009) or ANZECC/ARMCANZ triggers and therefore, the maintenance dredge material was considered suitable for unconfined disposal at sea. In some instances (i.e. Townsville), a precautionary approach was adopted and onshore disposal had occurred (i.e. due to copper contamination).

During the 2014 Port of Gladstone maintenance dredging and disposal program for example, a targeted metals and TBT water quality sampling program was completed. This was not a requirement of the permitting process, but rather a due diligence exercise to provide additional data on maintenance dredging and its potential impacts on the Port of Gladstone ecosystem.

The data demonstrated observable increases in total concentrations for a few metals/metalloids during dredging, compared to baseline. Dissolved metal and metalloid concentrations however, were below ANZECC/ARMCANZ (2000) toxicity trigger levels (TTVs) during both baseline and dredging conditions. It should be noted that increases in metal concentrations during suspension of seabed sediment is not unexpected, as a number of metals are ubiquitous within soils. More importantly, all total and dissolved metals/metalloids during both baseline monitoring and during dredging were either below the Limit of Reporting (LOR) or ANZECC/ARMCANZ (2000) TTVs (GPC, 2014).

7.8 Summary

The scientific knowledge of maintenance dredging and disposal within Queensland ports is growing. There have been numerous studies which have focused on the suspended sediment plumes generated by the TSHD Brisbane, and importantly, the fate of these plumes[2] and their potential to influence the key environmental values previously described.

There are also recent efforts to enhance hydrodynamic modelling outputs for maintenance dredging and disposal activities, by conducting field-based validation measurements. These models can, and have, provided a valuable tool for assessing maintenance dredging options and the potential for plumes to interact with the key environmental values. From the available measured data (not modelling), it can be confirmed that the plume intensities and extents during maintenance dredging and disposal are relatively low and localised and often dissipate within hours of the dredging and/or disposal activities.

Importantly, the environmental monitoring has shifted towards field based monitoring for detecting any potential environmental harm within seagrass meadows and this monitoring has confirmed that key thresholds for maintaining health have not been breached. When considering the need and type of monitoring undertaken in the future, the individual Ports risk assessment will be informed by considering the frequency and duration of maintenance dredging, the potential for the plumes to interact with key environmental values (i.e. seagrass, coral and rocky reef communities), the types of parameters monitored (i.e. turbidity, TSS and BPAR), when there is an interaction and potentially quantifiable risk and the acceptable endpoints (i.e. physiological, morphological, or biomass change).

The adherence to the requirements stipulated in the NAGD (2009) contaminant screening and bioavailability assessment process, and in some cases applications of the precautionary principle (i.e. some berth location in the Port of Townsville), help ensure that unacceptable concentrations of biologically available contaminants are not introduced to the marine environment.

The scientific assessment of nutrient dynamics during dredging and dredge material disposal has indicated that biologically available forms of nutrients (e.g. ammonia) can be released; however the intermittent nature of maintenance dredging is unlikely to lead to changes in nutrient cycling and

[2] It is important to note that the work executed by BMT WBM simulated the extent of resuspension based on bed shear stress and particle size distribution of the dredge material. They did not simulate the entire quantity of material being resuspended as it was not considered realistic or scientifically feasible.

eutrophication, particularly when catchment based locations are taken into consideration. It should also be acknowledged that port channels are not constrained and the accumulation of any nutrients would disperse during tidal flushing.

The available scientific field measurements focusing on dredging and disposal activities does vary across the Queensland ports, with some ports having a much more detailed understanding of maintenance dredging and ecosystem response. However, it would be acknowledged that the ports with the greatest need, largest volumes, and most frequent visits have invested the most time and resources for understanding maintenance dredging related risk to the environment. There is, however, opportunities for further field based measurements, where there is a paucity of data, to help inform risk-based monitoring and ultimately sustainable port operations. **Section 8** presents the outcomes of a preliminary risk assessment, which was supported by the quantitative data presented in this report.

8 Maintenance Dredging – Preliminary Analysis of Risks

8.1 Background

The preliminary risk assessment undertaken has adopted the risk assessment methodology used in the Great Barrier Reef Strategic Assessment (GBRMPA, 2014; Great Barrier Reef Region Strategic Assessment: Strategic assessment report, GBRMPA, Townsville, Chapter 10, page 10-9), see **Appendix D**. This approach is consistent with the Australian Standard for Risk Assessment (AS/NZS ISO 31000:2009). It is important to acknowledge that the GBRMPA (2014) strategic assessment report ranked both capital and maintenance dredging activities together, and therefore rankings in that report cannot be compared to this assessment which only ranks maintenance dredging and maintenance material placement actions.

The risk assessment draws on scientifically based information and data generated by the ports of the GBR region. Key information reviewed include the frequency, scale (volume) and durations (day or weeks) of maintenance dredging, distribution and abundance of sensitive receptors, hydrodynamic model simulations and quantitative scientifically derived monitoring data that specifically focuses on the action of maintenance dredging and disposal operations.

8.2 Risk Assessment Outcomes

8.2.1 Key Environmental Values

Risk assessments focus on the key flora and fauna that are protected under Commonwealth and State legislation. These flora and fauna represent a key component of the World Heritage Values of the Great Barrier Reef Ecosystem, and are inextricably linked to indigenous values. They are located within the inner GBR lagoon coastline and have the potential to be influenced by the actions of maintenance dredging, disposal and vessel movements. **Table 27** provides a summary of the risk assessment outcomes, and further detail on the fauna and flora species and risk assessment approach can be found within **Appendix D**.

Importantly, the outcome from the risk assessment determined that marine flora and fauna are at Low risk from maintenance dredging and placement of maintenance dredge material. The only Medium risk identified was at the Ports of Townsville during maintenance dredging for flora and key habitats (coral). This Medium risk has been identified previously and management measures are already in place to mitigate harm. Overall, the findings of the risk assessment confirm that the action of maintenance dredging and disposal in Queensland's ports is not likely to introduce a significant impact to key marine fauna or flora, and the habitats that support their life cycles.

The risk assessment also identified the level of confidence in the data, based on that which was available, to support the risk assessment. It was observed during the process of assessing the available information that the ports with the greatest need for maintenance dredging (i.e. Gladstone, Townsville and Cairns) have invested the most resources and time to establish the extent of maintenance dredging related risks (i.e. targeted measurements of maintenance dredging and disposal plume intensity and extent, combined with ecological and water quality parameter monitoring during maintenance dredging actions).

These data go beyond supporting the activity-based risk assessments, as the plume behaviours during these maintenance dredging and disposal related activities were largely confined to the shipping channels, and were short lived. These findings lend support to the assessment process for the other ports, because the same dredge is used for all maintenance dredging works. It does not negate however, the need for site-specific plume intensity and extent measurements by the other ports, where limited field-based monitoring data is available. Queensland ports are proactively looking at opportunities to invest in site-specific maintenance dredging plume intensity and extent monitoring programs to fill knowledge gaps and enhance the confidence of risk assessments outcomes.

Several of the northern Queensland port facilities (e.g. Abbot Point, Hay Point, Mackay) have invested in predictive modelling of plume intensity and extent, field based ecological monitoring to detect dredging impacts, and in some cases larger scale capital works related plume intensity and extent monitoring programs. These programs are not entirely targeted at the action of maintenance dredging, but have provided valuable insight into the plume behaviours and condition of environmental values in these ports. Some smaller ports (i.e. Port Alma) have very little scientifically based data for supporting a risk assessment of maintenance dredging actions; however, the infrequent nature (once every 10 years), short duration (days) and the relatively low volumes (10's of thousands of m^3) are not likely to create significant impacts on the local environmental values. Further discussion on the risks to environmental values and the confidence in the data available at the various Ports is provided in **Appendix D**.

8.2.2 Heritage, Biodiversity & Coastal Processes

The description of maintenance dredging was defined earlier in this report, as follows:

'Maintenance dredging involves the removal of natural sediment (e.g. clay, silt and sand) that has settled within berthing pockets, swing basins and shipping channels as a result of mostly natural sedimentary processes.'

Maintenance dredging involves the disturbance of the seabed in areas that have been previously subject to approvals in accordance with various State and Federal legislation. This is in contrast with capital dredging which requires new work approvals. During the process of securing the required capital works approvals (i.e. EIS) a detailed assessment of impacts on heritage, biodiversity and coastal processes is undertaken. Subject to sufficiently assessing the risks and following the development of mitigations measures, approvals are then issued.

The maintenance dredging of an approved channel each year does not introduce additional risks to heritage, biodiversity and coastal processes, over and above the original capital works and maintenance dredging approvals. The process of reinstating the declared depths is precisely in line with the original approval for the capital works programs for establishing the port facilities. Based on the outcomes of the environmental values risk assessment completed in **Appendix D**, maintenance dredging does not result in a significant impact to the local environmental values, and therefore broader scale impacts on GBR biodiversity values are considered highly unlikely.

8.3 Conclusion

The preliminary risk assessment has determined that the likelihood of an impact to the port specific environmental values varied across the ports, from unlikely to likely, which was heavily influenced by the historic frequency and scale of the maintenance dredging and material disposal actions. The risk assessment determined that the consequence of maintenance dredging and disposal to broader scale environmental values is insignificant to minor:

Minor - Impact is, or would be, not discernible at a wider level. Impact would not impair the overall condition of the value, including sensitive populations or communities, over a wider level; and

Insignificant - No impact or if impact is, or would be, present then only to the extent that it has no discernible effect on the overall condition of the value.

Overall, when the likelihood and consequences were combined the finding of the risk assessment suggest that the action of maintenance dredging and disposal in Queensland's ports is not likely to introduce a significant impact to key marine fauna or flora, and the habitats that support their life cycles.

The risk assessment considered a range of targeted monitoring programs and was based on the same dredge vessel, *the Brisbane*, which provided a firm foundation for informing the risk assessment across all GBR ports. Importantly, monitoring of disposal plume intensity and extent at the ports that require frequent, larger volume dredging has been a key focus. The outcomes of this work have demonstrated that maintenance dredging does not introduce persistent environmental harm and plumes do not travel far and generally dissipate quickly.

Based on the historic field observations, the actions of maintenance dredging and disposal are not considered to pose a significant risk (i.e. in the vast majority of cases risk is low), and are therefore not a threat to broader heritage, biodiversity and coastal processes. The adoption of environmental windows should not be mandatory, as in many instances they would not contribute to mitigating environmental harm to sensitive receptors (i.e. overall risk is low).

It should be acknowledged that satisfactory environmental due diligence involves planning the timing of maintenance dredging to avoid periods of high risk or greater stress and critical or sensitive phases of the life cycle of marine species (i.e. the use of environmental windows). Therefore, consideration for the adoption of environmental windows is an important management consideration, they are appropriate when risk-based assessments identify the need. Examples of where environmental windows have been implemented include the Port of Abbot Point and Hay Point, where as part of the long-term dredge management plans they have committed to undertaking maintenance dredging activities outside of the turtle nesting season (NQBP, 2009; NQBP, 2010). If adopted, it is essential that those environmental windows be of an appropriate spatial and temporal scale to minimise the potential for ecological harm, but not unnecessarily constrain dredging activities.

Environmental windows should be implemented when there is quantifiable and/ or perceived risk, recognising that in many instances stakeholder concerns and precautionary approaches are an important consideration, particularly in relation to species of high conservation value. Further discussion on the port risk-based monitoring approach is provided in the next chapter of this report.

Table 27: Summary of preliminary risk assessment outcomes (likelihood, consequences = risk) of maintenance dredging and material placement.

Sensitive Receptor	Activity	Flora & Key Habitats			Fauna			Confidence
		Likelihood	**Consequences**	**Risk**	**Likelihood**	**Consequences**	**Risk**	**Confidence**
Gladstone	Dredging	Unlikely	Minor	Low	Possible	Minor	Low	High
	Placement at Sea	Unlikely	Minor	Low	Likely	Insignificant	Low	High
Alma	Dredging	Unlikely	Insignificant	Low	Unlikely	Insignificant	Low	Medium
	Placement at Sea	Unlikely	Insignificant	Low	Unlikely	Insignificant	Low	Medium
Hay Point	Dredging	Possible	Minor	Low	Possible	Minor	Low	Medium
	Placement at Sea	Possible	Minor	Low	Possible	Minor	Low	Medium
Mackay	Dredging	Possible	Insignificant	Low	Possible	Insignificant	Low	Medium
	Placement at Sea	Possible	Insignificant	Low	Possible	Insignificant	Low	Medium
Abbot Point	Dredging	Possible	Minor	Low	Unlikely	Minor	Low	Medium
	Placement at Sea	Possible	Minor	Low	Possible	Insignificant	Low	Medium
Townsville	Dredging	Likely	Minor	Medium (Coral)	Possible	Minor	Low	High
	Placement at Sea	Likely	Minor	Medium (Coral)	Likely	Insignificant	Low	High
Cairns	Dredging	Unlikely	Insignificant	Low	Unlikely	Insignificant	Low	High
	Placement at Sea	Unlikely	Insignificant	Low	Likely	Insignificant	Low	High
Cooktown	Dredging	Possible	Insignificant	Low	Unlikely	Insignificant	Low	Medium
	Placement at Sea	Possible	Insignificant	Low	Unlikely	Insignificant	Low	Medium

9 Establishment of Risk-based Monitoring Programs

9.1 Risk Based Monitoring

The National Assessment Guidelines for Dredging sets out the framework for the environmental impact assessment and permitting of the ocean disposal of dredge material (NAGD, 2009). These guidelines are actively used by GBR ports, and form the basis of their approvals process. The initial steps for establishing risk based monitoring includes:

- Defining the physical and biological environment that the Port exists in (sediment transport processes, monitoring data, background conditions, etc.);
- Determining environmental values to be protected (sensitive ecological receptors);
- Determining level of protection;
- Identifying environmental concerns (stakeholder management);
- Determining major natural and anthropogenic factors affecting the ecosystem; and
- Determining 'management goals' and specific objectives.

Once these initial steps are complete, GBR ports:

- Define the channels and areas that require maintenance and calculate volumes;
- Assess disposal options and define preferred option;
- Define the methods and timing of maintenance dredging and disposal – This includes consideration of environmental windows and cumulative impacts;
- Define the likely duration and frequency of maintenance dredging campaigns;
- Scope an appropriate sediment sampling and analysis plan (SAP) to characterise dredge material contamination status (considering past programs to refine approach); and
- Assess suitability of material for disposal option based on the NADG (2009) assessment process.

Once the material has been defined as either i) clean and fit for unconfirmed offshore disposal site or ii) contaminated and must not be disposed offshore, each port in Queensland is committed to a tailored environmental risk management approach as an essential part of the planning and implementing of maintenance dredging. This process is guided by, and recorded within, the port management bodies Environmental Management Systems (EMS) that logs all environmental aspects, hazard and/or risk to the environment. A key component of this process is to define risk-based monitoring programs, management responses and opportunities for improvement (i.e. in accordance with ISO 14000). This management approach is considered world's best practice and ensures potential impacts on the environment are minimised and regulatory compliance is achieved.

Cumulative impacts of the proposed maintenance dredging program are also taken into considerations by each of the ports in Queensland. This is particularly important if major natural perturbations occur (i.e. cyclones, flooding, etc). Cumulative impacts may also be of relevance when port development and channel upgrades are being executed, and each port needs to place these activities in context with the temporal occurrence of the proposed maintenance dredging and the likelihood of interacting with sensitive environmental values.

It is important to acknowledge that each port occupies a different environmental setting, with different coastal processes and distribution and abundance of environmental values. Differences are not limited to spatial areas, with all ports experiencing variable sediment transport regime, loads and ecological cycles. Therefore, in many cases environmental risks associated with maintenance dredging are unique to each port and tailored risk-based assessments to establish monitoring programs are necessary. Broadly, a risk-based monitoring program is tailored for maintenance dredging at each port by considering:

- The key environmental values and environmental windows, where applicable (e.g. seagrass growing season, etc.);
- Port-specific monitoring traditionally undertaken for managing these environmental values that may be influenced by dredging (e.g. long term seagrass monitoring);
- Predictive modelling for examining potential impacts to the environmental values identified;
- Results of continuous monitoring during dredging and at-sea disposal (e.g. monitoring of turbidity,TSS and BPAR);
- Occurrence of major natural perturbation, including flood event and tropical cyclones. When these types of events occur, they have the potential to physically damage marine ecosystems and introduce prolonged periods of stress (e.g. reduced benthic light). Cumulative impacts of the proposed maintenance dredging program need to be placed in context with these types of occurrences; and
- Historical review of sediment contamination status.

These monitoring programs provide a basis to assess risks associated with future maintenance dredging and the need for adaptive management during dredging. Additional to the results of the risk-based monitoring, the risk assessment also takes account of approval conditions, the need for environmental windows and stakeholder and government agency input. A series of management actions are then identified and incorporated into a maintenance dredging Environmental Management Plan (EMP). The EMP is also supported by various other management plans and procedures to ensure all environmental risks are sufficiently managed and risk-based monitoring is complete, for example:

- Long Term Monitoring and Management Plan for Sea Disposal;
- Maintenance Dredging Environmental Monitoring Procedure;
- Dredge (TSHD Brisbane) Contractors Environmental Management Plan; and
- Land-based Placement Environmental Monitoring Procedure.

9.2 Future Innovation

Queensland Ports have made a significant contribution to the development of environmental and coastal process based scientific investigations and monitoring programs. In recent years they have identified the need to understand the sediment dynamics within their region as a prerequisite to allow adaptive long-term environmental management, supporting sustainable development and minimising environmental harm to the port and surrounding areas.

The outcomes of such works will help to inform how natural environmental variables behave, and how they interact/influence environmental values. Importantly, the outcomes of these programs will feed into the Queensland Ports annual risk assessments, helping to refining risk rating and the monitoring that is required to ensure the environmental values are maintained into the future.

This process is a fundamental component of the adaptive management approach for ensuring risk-based management of Queensland Ports is proactive and founded on the most current scientific understanding of each port marine ecosystem. Indicative steps for developing a more strategic long term plan for sediment management in GBR ports is illustrated in **Figure 19**.

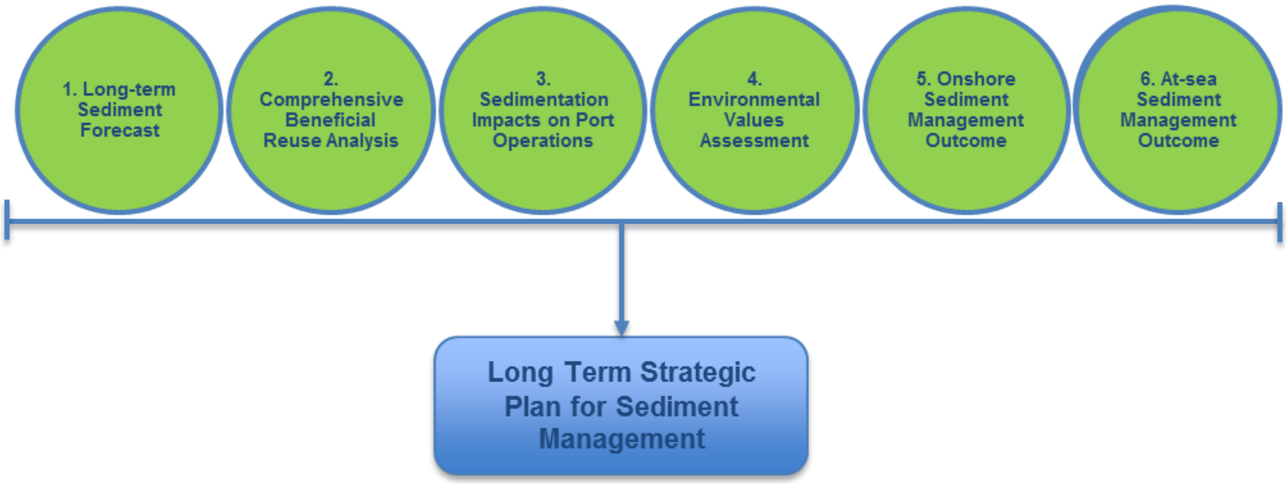


Figure 19. Key steps towards developing a long-term strategic plan for sediment management in GBR ports.

As part of an independent synthesis of the current knowledge of the effects of dredging, detailed in McCook et al. (2015), it was noted that a more open framework for data sharing should be adopted in the future. This would allow the information to be more readily available to the public and research communities, providing further data to the research community, which could help to improve our understanding of the GBRWHA such as the long-term sediment dynamics.

10 Summary and Key Findings

10.1 Introduction

Maintenance dredging is a vital component of port operations as the depths of channels, berths and swing basins may reduce over time due to natural sedimentation processes and dredging is therefore required to maintain designated depths to ensure ships can safely and efficiently access port infrastructure. Maintenance dredging has been carried out at ports within the GBRWHA since the ports were established with most dredge material being deposited in approved offshore placement areas.

Of the 20 recognised Queensland ports, 12 lie within or adjoin the GBRWHA. Of those, only 8 require some level of maintenance dredging, ranging from annually to very infrequently (10 years+). Since 2001, the majority of the maintenance dredging volume has been handled by the TSHD Brisbane which travels up and down the Queensland coast to undertake the maintenance dredging each year.

10.2 Sediment Transport Processes

Queensland ports located within the GBRWHA reside in a variety of coastal environments and are subject to variability in local metocean conditions. As a result of these variabilities, each port sees varying rates of sedimentation which is typically driven by a number of key coastal processes. For the majority of the GBR inner-shelf region and in turn the GBR ports, sediment transport and sedimentation during typical conditions is primarily a result of wave and current induced resuspension, with currents then driving the advection of the suspended sediments.

Cyclones also play an important role in the input of new sediment to the inner shelf of the GBR Lagoon through: river flooding, seabed erosion in the mid-shelf and reef breakage (Larcombe & Carter, 2004). In particular, cyclone induced waves and currents play an important role in the supply of sediment to the inner shelf through the erosion and advection of sediments away from the mid-shelf. This demonstrates that catchment runoff is not the sole source of sediment to the inner shelf of the GBR Lagoon.

At the vast majority of ports, catchment runoff plays a low to negligible role in driving sedimentation processes. Ports are either located too far from the major river systems or adjacent to rivers with relatively negligible suspended sediment discharge (with the exception of Port Alma). Any reduction in catchment sediment runoff will, in most areas of the inner shelf, be overwhelmed by the natural wave and current resuspension as the primary driver for elevated TSS. Since it is these elevated TSS events which lead to the sedimentation of dredged areas, it can therefore be determined that efforts made to reduce sediment loads discharged into the GBR, although important for many reasons, will have limited to negligible effects on the future requirement for maintenance dredging at the majority of the GBR ports.

10.3 Legislative Requirements

Legislative requirements play an important function in the management of maintenance dredging operations at all ports. Dredging activities at ports within the GBRWHA are managed under both State and Commonwealth legislation. The application of these State and Commonwealth legislations vary depending on specific legislative parameters applicable at each port.

Submissions for ocean disposal approval are subject to rigorous studies justifying why ocean disposal is the most effective solution to dredge material disposal through the consideration of both environmental and economic reasoning. The determining authority (DoE or GRBMPA) considers the application and decides whether to grant the approval. If approval is granted it can be subject to any number of conditions, which may include an approved environmental management plan, environmental site supervision and monitoring of water quality, and other factors throughout the dredging campaign.

The determining authority has the ability to grant long-term permits for maintenance dredging requirements at each of the ports. Applications for long term maintenance dredging permits are favoured by port operators as they provide for an efficient approvals process and allow for certainty around future maintenance dredging requirements and therefore the safe operation of the ports.

10.4 Maintenance Dredging

Based on the existing requirements of the maintenance dredging in Queensland, and specifically the GBRWHA, the TSHD Brisbane is well suited. The vessel has been subject to regular improvement since it was built in 2000 and as such it has state of the art environmental mitigation measures, including a green valve to minimise turbidity plumes while operating in overflow mode, which are similar to the other TSHD vessels available nationally and internationally.

There has been significant inter-annual variability in the historical maintenance dredging requirements at the majority of the ports within the GBRWHA, which require regular maintenance dredging. The variability is driven by the local metocean conditions and the occurrence of extreme events such as cyclones and (in some limited cases) flood events and, as such, it is not possible for the ports to control or accurately predict their future maintenance dredging requirements.

The maintenance dredging volumes over the last 10 years can be used as an indicator of the likely range and frequency of future maintenance dredging requirements at the ports. However, for a number of reasons, including the variability of processes that drive sedimentation, it is not possible to use the historic volumes alone to completely predict the future requirements. As such, they should not be used to necessarily pre-determine future maintenance dredging volume limits. Future volume estimates should take all reasonable factors into account and, even so, flexibility should be retained so that applications for adjustments to volumes can be considered in the event of extreme situations, such as the occurrence of cyclones.

The ports are proactive and already adopt a number of strategies to try and minimise maintenance dredging requirements. Given their natural setting, there are limited additional options which could be adopted in the ports in the GBRWHA to try and reduce future maintenance dredging requirements.

10.5 Beneficial Reuse and On-land Disposal of Dredge material

A review of opportunities for on-land disposal of maintenance dredge material has determined that significant constraints exist for options requiring dewatering of dredge material. These constraints are primarily related to: the predominance of silts and clays within the maintenance dredging areas (poor engineering qualities for reuse); the volume of material involved; coastal environmental impacts; the unavailability of large areas of nearby land for dewatering of the sediments; additional permitting processes (separate to sea disposal); and the economic impacts of additional processing and management required.

Based on the review of maintenance dredged investigations and associated sediment characteristics, it is considered that the concept of 'sustainable relocation' as an environmental enhancement measure should be further considered as a potentially feasible disposal option for GBR Ports. Sustainable relocation should be considered for maintenance dredge material in order to retain the material in the active natural system. For this practice to be considered at GBR ports, port/region specific investigations will need to be undertaken. These investigations will likely need to involve detailed environmental assessments, numerical modelling, community consultations and potential trial campaigns. It is also understood there may be some legislative and regulatory challenges with such practices. However, these obstacles have been overcome elsewhere in the world (including other environmentally valuable areas) and have resulted in successful applications with significant demonstrated environmental and operational benefits.

10.6 Environmental Values

Environmental values (EVs) are defined as particular values or uses of the environment that are important for a healthy ecosystem or for public benefit, welfare, safety or health and that require protection from the effects of pollution, waste discharges and deposits (ANZECC/ARMCANZ, 2000). In Queensland, EVs are described as the qualities that make water suitable for supporting aquatic ecosystems and human use (DEHP, 2015)

The marine habitats that occur within the vicinity of maintenance dredging and dredge material disposal activities are located within the GBR inner Lagoon. These habitats include seagrass meadows, coastal embayments, intertidal and subtidal reefs and sandy seabed communities.

Seagrass meadows are found intertidally around nearshore port infrastructure, as well as subtidally, adjacent to shipping channels and offshore disposal sites. Rocky reef and coral reef communities occur on intertidal rocky foreshores, as fringing reefs along the coastline, as well as around Islands and Inlets on the inner reef. Macroalgal communities dominate some of these near shore rocky reef environments.

Maintenance dredging activities have the potential to influence suspended sediment concentrations in the water column, which in turn can influence the primary productivity of these benthic primary producer communities. Port managers during their risk assessments for prioritising the timing and management of maintenance dredging activities should consider the potential risks to these communities, the environmental windows (i.e. times where the communities are most susceptible) and any major storm or cyclone events that have preceded maintenance dredging.

The sandy seabed communities dominated by benthic epifauna and infauna communities provide the lower trophic levels of marine food chains and are critical to marine ecosystem function. These communities have the potential to be smothered from dredge material disposal activities.

The higher order trophic levels, including the marine megafauna, such as sea turtles, dugongs and cetaceans also play an important role in marine ecosystem functioning and have the potential to be influenced by maintenance dredging activities, by entrainment in the trailer suction drag head (i.e. turtles) and from vessel strike. The environmental window, which is the turtle-nesting season, is the most sensitive time when turtles may be influenced from dredging activities.

10.7 Environmental Monitoring of Maintenance Dredging

The scientific knowledge of maintenance dredging and disposal within Queensland ports is growing. There have been numerous studies focusing on the suspended sediment plumes generated by the TSHD Brisbane, and importantly the fate of these plumes and their potential to influence sensitive receptors. There are also efforts to enhance hydrodynamic modelling for application to maintenance dredging and disposal via investment in field based measurements that can be used to enhance the reliability of the model outputs. These models can, and have, provided a valuable tool for assessing maintenance dredging options and the potential for plumes to interact with sensitive receivers.

From available measured data (not modelling) it can be confirmed that the plume intensities and extents during maintenance dredging and disposal are relatively low and localised, and often dissipate within hours of the dredging and/or disposal activities. Importantly, the environmental monitoring centred on detecting any potential environmental harm at sensitive receptor locations (i.e. seagrass meadows) has confirmed that key thresholds for maintaining health have not been breached by maintenance dredging activities. The adherence to the requirements stipulated in the NAGD (2009) contaminant screening and bioavailability assessment process, and in some cases applications of the precautionary principle (i.e. some berth locations in the Port of Townsville), help ensure that unacceptable concentrations of biologically available contaminants are not introduced to the marine environment.

The scientific assessment of nutrient dynamics during dredging and dredge material disposal has indicated that biologically available forms of nutrients (i.e. ammonia) can be released, however the intermittent nature of maintenance dredging is unlikely to lead to changes in nutrient cycling and eutrophication, particularly when catchment based locations are taken into consideration. It should also be acknowledged that port channels are not constrained and the accumulation of any nutrients will disperse during tidal flushing.

It should be acknowledged, however, that the existing knowledge base of maintenance dredging and disposal impacts does vary across the Queensland ports, with some ports having a much more detailed understanding of maintenance dredging (typically, the ports with the greatest dredging requirements).

10.8 Maintenance Dredging – Preliminary Analysis of Risks

The preliminary risk assessment has established that the action of maintenance dredging and disposal in many of Queensland's ports is not likely to introduce a significant impact to key marine fauna, and the habitats that support their life cycles. This statement, however, cannot be issued with the same level of confidence across all ports because the degree of scientifically based information to support this statement is not consistent. In many cases, however, the action of maintenance dredging and disposal does not introduce persistent environmental harm, and plumes do not travel far and dissipate quickly.

Based on scientific observations, actions of maintenance dredging and disposal are not considered stressors of primary importance for conserving key flora and fauna species. Environmental windows associated with the dredging permits which prohibit dredging activities can also restrict the ability of the TSHD Brisbane to visit the ports in the most efficient way, creating inefficiencies to the process as the vessel may not be able to continue its usual sequence of works and have to adapt its schedule to the environmental window. When travel time is minimised, so are emissions due to minimisation of fuel consumption, which in turn minimises the environmental footprint of the dredging activity.

However, consideration for the need and adoption of environmental windows during periods of greater susceptibility is, and will continue, to be considered during the annual port specific risk assessment process. A key component to sustainable port practise is a thorough annual assessment of risk. This is particularly important if major natural perturbations, including flood events and tropical cyclones, occur. When these types of events occur, they have the potential to physically damage marine ecosystems and introduce prolonged periods of stress (e.g. reduced benthic light). During these times, sensitive receptors can experience reduced spatial coverage, energy reserve losses, and overall reduced health. Ports are acutely aware of these ecosystem responses and their annual risk assessment is informed by their occurrence. In line with best management practice cumulative impacts of the maintenance dredging program for that year are assessed.

10.9 Establishment of Risk-based Monitoring Programs

Consistent with the National Assessment Guidelines for Dredging, and port specific legislative permitting requirements, all Queensland Ports scientifically examine the contamination status and physical nature of the proposed maintenance dredge material. Once the material has been defined as either i) clean and fit for unconfirmed offshore disposal site or ii) contaminated and must not be disposed offshore, each port in Queensland is committed to a tailored environmental risk management approach as an essential part of the planning and implementing of maintenance dredging. This process is guided by, and recorded within, the ports management bodies Environmental Management Systems (EMS) that logs all environmental aspects, hazard and/or risk to the environment. A key component of this process is to define risk-based monitoring programs, management responses and opportunities for improvement (i.e. in accordance with ISO 14000). This management approach is considered global best practice and ensures potential impacts on the environment are minimised and regulatory compliance is achieved.

It is important to acknowledge that each port occupies a different environmental setting, with different coastal processes and distribution and abundance of environmental values. Differences are not limited to spatial areas, with all ports experiencing variable sediment transport regimes, loads and ecological cycles. Therefore, in many cases environmental risks associated with maintenance dredging are unique to each port and tailored risk-based assessments to establish monitoring programs are necessary. Broadly, a risk-based monitoring program is tailored for maintenance dredging at each port by considering:

- The key environmental values and environmental windows, where applicable (i.e. seagrass growing season);
- Port-specific monitoring requirements traditionally undertaken for managing these environmental values that may be influenced by dredging (e.g. long term seagrass monitoring);
- Predictive modelling for examining potential impacts to the environmental values identified;
- Results of continuous monitoring during dredging and at-sea disposal (e.g. water quality monitoring of turbidity and TSS);
- Occurrence of major natural perturbation, including flood event and tropical cyclones. When these types of events occur, they have the potential to physically damage marine ecosystems and introduce prolonged periods of stress (e.g. reduced benthic light); and
- Historical review of sediment contamination status.

A series of management actions are then identified and incorporated into a maintenance dredging Environmental Management Plan (EMP). The EMP is also supported by various other management plans and procedures to ensure all environmental risks are sufficiently managed and risk-based monitoring is complete, for example:

- Long Term Monitoring and Management Plan for Sea Disposal;
- Maintenance Dredging Environmental Monitoring Procedure;
- Dredge (TSHD Brisbane) Contractors Environmental Management Plan; and
- Land-based Placement Environmental Monitoring Procedure.

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Appendix A Acronyms

Acronym	Acronym description
ADCP	Acoustic Doppler Current Profiler
AMA	Australasian Marine Associates (the “Consultant”)
AMCS	Australian Marine Conservation Society
AMSA	Australian Maritime Safety Authority
ANC	Acid Neutralising Capacity
ANZECC	Australian and New Zealand Environment Conservation Council
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
As	Arsenic
ASS	Acid Sulfate Soil
BoM	Bureau of Meteorology
BPAR	Benthic Photosynthetically Available Radiation
BTEX	Benzene, Toluene, Ethylbenzene and Xylenes
CAMBA	China-Australia Migratory Bird Agreement
Cd	Cadmium
CDF	Confined Disposal Facility
CFB	Commercial Fishing Base
CIRIA	Construction Industry Research and Information Association
CoPC	Contaminants of Potential Concern
Cr	Chromium
CSD	Cutter Suction Dredge
Cu	Copper
DBCT	Dalrymple Bay Coal Terminal
DEWHA	Department of the Environment, Water, Heritage and the Arts
DMPA	Dredge Material Placement Area
DoE	Department of Environment
DSITI	Department of Science, Information, Technology and Innovation
EHP	Department of Environment and Heritage Protection

EMP	Environmental Management Plan
ENSO	El Nino Southern Oscillation
FHA	Fish Habitat Area
GBR	Great Barrier Reef
GBRMPA	Great Barrier Reef Marine Park Authority
GBRWHA	Great Barrier Reef World Heritage Area
GPC	Gladstone Ports Corporation Limited
HAT	Highest Astronomical Tide
HKA	Haskoning Australia
HM	Harbour Master
H_{max}	Highest Maximum Wave Height
HPCT	Hay Point Coal Terminal
IADC	International Association of Dredging Companies
IDAS	Integrated Development Assessment System
JAMBA	Japan-Australia Migratory Bird Agreement
Kts	Knots
LAT	Lowest Astronomical Tide
LNG	Liquefied Natural Gas
LOR	Limit of Reporting
LTSMP	Long Term Sediment Monitoring Program
MCU	Material Change of Use
MPA	Maritime and Port Authority
MSQ	Maritime Safety Queensland
NAGD	National Assessment Guidelines for Dredging
NEPM	National Environment Protection Measure
NQBP	North Queensland Bulk Ports Corporation Limited
NQEA	North Queensland Engineers and Agents
NTU	Nephelometric Turbidity Units
PAH	Polycyclic Aromatic Hydrocarbons
PAR	Photosynthetically Available Radiation

PASS	Potential Acid Sulfate Soil
Pb	Lead
PBLP	Port of Brisbane Pty. Ltd.
PBFC	Portland Blast Furnace slag Cement
PIANC	Permanent International Association of Navigational Congresses
PLC	Programmable Logic Controller
Ports North	Far North Queensland Ports Corporation Limited
PoTL	Port of Townsville Limited
PVD	Prefabricated Vertical Drain
QPA	Queensland Ports Association
QWQG	Queensland Water Quality Guidelines
Reef 2050	Reef 2050 Long-Term Sustainability Plan
RHDHV	Royal HaskoningDHV (the "Consultant")
ROV	Remote Operated Vehicle
SOI	Southern Oscillation Index
SPA	Special Protection Area
SSSI	Sites of Special Scientific Interest
STSHD	Split Trailer Suction Hopper Dredge
TACC	Technical Advisory and Consultative Committee
TBT	Tributyltin
TMR	Department of Transport and Main Roads (the "Client")
TPH	Total Petroleum Hydrocarbon
TSHD	Trailing Suction Hopper Dredger
TSS	Total Suspended Solids
TTV	Toxicity Trigger Levels
UKC	Under Keel Clearance
ULCS	Ultra Large Container Ships
WBDDP	Western Basin Dredging and Disposal Project
WHC	World Heritage Committee of UNESCO
WQGGBRMP	Water Quality Guidelines Great Barrier Reef Marine Park

WWF	World Wildlife Fund
Zn	Zinc

Appendix B Coastal Processes Summary

Table 28: Port of Cooktown key coastal processes.

Coastal Process	Description
Tide Range	Semi-diurnal tides with a tidal range of 3.2 m. (MSQ 2015)
Wind Climate	Predominant south to east-south-easterly trade winds.
Wave Climate	Predominantly short period wind waves generated within the GBR lagoon.
Current Conditions	Current regimes at Cooktown are generated predominantly by both tidal and wind forcing's. The prevailing south easterly wind conditions can have a significant effect on currents and leads to net north westerly directed current in the region.
River Influences	The Port of Cooktown is located on the southern bank of the Endeavour River mouth.
Cyclone Influences	The Port of Cooktown is particularly susceptible to cyclonic activity and has seen 30 cyclones pass within 100km of the port between 1906 and 2007. Notable recent cyclones include TC Justine in 1999 and TC Ita in 2014 which both instigated the need for maintenance dredging at the port. (BoM 2015)
Port Configuration	The Port is located on the southern bank of the Endeavour River mouth and consists of one berth maintained to a depth of 4 m LAT and a navigational channel maintained to depth of 3.1 m LAT.
Background TSS Concentrations	Not Available
Sediment Transport Summary	Sedimentation at the Port of Cooktown is typically instigated by cyclones travelling nearby to the Port which generate flooding, significant waves and currents. Under these extreme processes sediment is mobilised into Ports channels and berths.

Table 29: Port of Cairns key coastal processes.

Coastal Process	Description
Tide Range	Semi-diurnal tides with a tidal range of 3.5 m. (MSQ, 2015)
Wind Climate	Predominant south to east-south-easterly trade winds during the dry season (May to October). During the wet season (November to April) prevailing winds are still from south to east-south-east, however there is generally greater directional variability and slightly lower wind speeds. (Ports North, 2014)
Wave Climate	The wave climate can be generally described as predominantly wind generated waves with the most common significant wave height between 0.2 to 0.4m with a wave period of 2.5 to 4 seconds. Due to the complex arrangement of reef passes, islands, local bathymetry and fetch lengths the wave climate at the Port of Cairns can be described as multi modal comprising of waves of distinct periods and directions, these include: 1. Ocean swell waves generated in the Coral Sea can reach the port

	through passages in the outer reef. These passages allow for the limited penetration of significantly attenuated swell waves. Reef passages affecting swell conditions at the port include the Trinity opening to the north-east of Cairns and Grafton Passage to the east. 2. Cape Grafton provides significant shelter to the Port from the prevailing south easterly wind waves generated within in the GBR Lagoon. These waves do still however influence wave conditions in Trinity Bay as they refract around Cape Grafton. 3. Short period wind waves generated from local winds within Trinity Bay. (Ports North, 2014)
Current Conditions	Current regimes in Trinity Bay are generated predominantly by astronomical tides and local winds. Within Trinity Bay astronomical tides represent the dominant current component. The tidal currents tend to flow in an inshore/offshore direction, perpendicular to the bathymetry contours and along the channel alignment. However, wind induced currents resulting from the prevailing south-easterly trade winds do result in a slight net cross-channel directed current component. This wind induced current component becomes more predominant in the outer areas of Trinity Bay. (Ports North, 2014)
River Influences	The Port of Cairns is situated 7 km to the south of the Barron River mouth which is the major source of sediment for Trinity Bay. Discharges from the Barron River are typically associated with flooding events caused by tropical cyclones and extreme rainfall events and contain a high discharge of fine (muddy) sediment from the catchment. The sediment is transported into the sea where it forms a substantial proportion of the seabed sediment in the bay (Ports North, 2014).
Cyclone Influences	The Port of Cairns is particularly susceptible to cyclonic activity and has seen 36 cyclones pass within 100km of the port between 1906 and 2007. Notable recent cyclones include TC Yasi in 2011 and TC Larry in 2006. (BoM, 2015)
Port Configuration	The Port of Cairns is located within Trinity Bay and Trinity Inlet. The harbour areas within the Inlet consist of a number of berths and swing basin with a maintained depth of 8.3m below LAT. The main navigational channel (Entrance Channel) also has a maintained depth of 8.3 m below LAT and traverses the relatively shallow Trinity Bay in a north-north-east orientation. The Entrance Channel represents an area of high trapping efficiency as areas adjacent to the channel are relatively shallow (0 – 2 m below LAT for the majority of the channel length).
Background TSS Concentrations	Previous water quality monitoring undertaken within the port can be summarised as: 1. Within Trinity Inlet the mean TSS concentration is 9 mg/l in the dry season and 41 mg/l in the wet season. 2. Within Trinity Bay the mean TSS concentration is 6 mg/l in the dry season and 8 mg/l in the wet season. (Ports North, 2014)
Sediment Transport Summary	Key processes driving sedimentation in the Port of Cairns dredged areas can be summarised as: 1. Wave and current influences are the primary drivers responsible for mobilising and transporting sediment into dredged areas. The

	orientation and shallow surrounding bathymetry of the Entrance Channel results in the channel being an effective sediment trap. 2. The Barron River is primarily responsible for depositing muddy (25% to 70% mud component) sediment within Trinity Bay. Resultant flood plumes can result in some direct sedimentation in the dredged areas. 3. The relatively high frequency of cyclones can result in high intensity sedimentations events, potentially causing significant annual variability in the maintenance dredging requirements.

Table 30: Port of Townsville key coastal processes.

Coastal Process	Description
Tide Range	Semi-diurnal tides with a tidal range of 4.11 m. (MSQ, 2015)
Wind Climate	The local wind climate is governed by south easterly trade winds. However, sea breezes and wet season winds do result in winds from the north east at times. (PoTL, 2013)
Wave Climate	The wave climate can be generally described as primarily 'sea waves' generated by local winds within Cleveland Bay. The wave climate can be further summarised as: 1. Cape Cleveland provides significant shelter to the port from the prevailing south easterly wind waves generated in the GBR Lagoon. However, these waves still influence wave conditions in Cleveland Bay with the more developed (longer period waves) refracting around Cape Cleveland and propagating shoreward towards the port. 2. Local sea waves generated by winds blowing across the open waters of Cleveland Bay, as well as those across West Channel between Magnetic Island and the mainland are a common occurrence in the Bay. (PoTL 2013)
Current Conditions	Current regimes in Cleveland Bay are generated predominantly by astronomical tides and local winds. Peak current speeds generally range from 0.3 to 0.6 m/s during spring tides or prolonged wind events. The prevailing south easterly wind conditions can have a significant effect on currents and at times can result in the amplification of the flood tide towards the west and the reduction or even reversing of the eastward ebb tide. This results in a net westerly directed current in the shoreward extents of Cleveland Bay. (PoTL 2013) In Cleveland Bay local features also influence the spatial variation in currents throughout the Port area. While inshore currents are generally orientated in an east-west direction (perpendicular to the channel), the influence of Magnetic Island means tidal currents in the outer reaches of the navigational channel generally flow in a north-south direction (parallel to the channel). (PoTL 2013)
River Influences	The Ross River located immediately to the south west of the port was once the primary sediment source to Cleveland Bay until the construction of weirs and the Ross River dam essentially eliminated the transport of coarser sediments to the Bay. The Port of Townsville is located about 50 km north of the Burdekin River, and is also about halfway between the Burdekin and Herbert Rivers which provide the dominant sediment supply to the central GBR region

	(Rayment, Reilly, & Best 1993). The source of the ongoing accumulation of fine sediments in Cleveland Bay is understood to predominantly originate from the Burdekin River (PoTL 2013), although much of this sediment will have been periodically resuspended and transported by waves and currents before it reaches Cleveland Bay.
Cyclone Influences	The Port of Townsville is susceptible to cyclonic activity and has seen 31 cyclones pass within 100km of the port between 1906 and 2007. A notable recent cyclone was TC Yasi in 2011 (BoM, 2015).
Port Configuration	The port is located within Cleveland Bay with the harbour areas located on the Ross Creek. Dredged areas within the harbour have a declared depth of 11.7 m below LAT. The main navigational channel (Platypus and Sea Channels) also has a maintained depth of 11.7 m below LAT and traverses the relatively shallow Cleveland Bay in a north-north-easterly orientation. The shoreward extents of the navigation channel represent an area of high trapping efficiency as areas adjacent to the dredged channel are relatively shallow (3 – 10m below LAT depths for approximately 90% of the channel length).
Background TSS Concentrations	Previous water quality monitoring undertaken within the port can be summarised as: 1. Mean TSS concentration within Cleveland Bay of 10 mg/l (POTL 2004 – 2011). 2. Mean wet season TSS concentration within Cleveland Bay of 20 mg/l (WBM Jan 09 – Feb 09). 3. Mean dry season TSS concentration within Cleveland Bay of 9 mg/l (WBM Sep 08 – May 09). 4. 80 NTU (160 mg/l) measured at Horseshoe Bay during TC Larry (expected to be higher inside Cleveland Bay), (Cooper et al. 2008).
Sediment Transport Summary	Key processes driving sedimentation in the Port of Townsville can be summarised as: 1. Residual currents in a westerly direction along with local sea and swell waves can result in the net longshore transport of sediment from the shallow eastern coastal areas of Cleveland Bay to the west, with some of the material being deposited in the dredged areas of the port. 2. Limited river fine sediment inputs are provided by the Ross River and Ross Creek. Any fine sediment discharged from the major Burdekin River catchment to the south will typically not directly influence sedimentation within Cleveland Bay, rather the material will be reworked by waves and currents before it reaches the bay. 3. The relatively high frequency of cyclones can result in short lived, high intensity sedimentations events, potentially causing significant annual variability in the maintenance dredging requirements.

Table 31: Port of Abbot Point key coastal processes.

Coastal Process	Description
Tide Range	Semi-diurnal tides with a tidal range of 3.6 m (MSQ, 2015).
Wind Climate	South east trade winds blow throughout the year but tend to be more persistent during winter months while north to north easterly winds occur predominantly in

	summer months but tend to be less frequent and lower in speed. (RHDHV, 2015)
Wave Climate	The wave climate at Abbot Point can be further summarised as: 1. The GBR generally blocks/ significantly attenuates, the majority of long period swell waves reaching the port. 2. Abbot Point is generally shielded from longer period waves developed in the GBR Lagoon as a result of sheltering effects from the Whitsundays Island group (Orpin et al,1999). 3. The wave climate at Abbot Point is variable. The port is exposed to both sea and swell (attenuated), with spectral peak periods ranging from about 2 to 13 seconds. With locally generated sea waves dominating with a wave period of 3 to 5 seconds. (GHD, 2009b)
Current Conditions	Currents at the Port of Abbot Point can be summarised as: 1. Astronomical tides provide a constant and predictable forcing with spring tidal currents at the wharf being in the order of 0.5 m/s (Hilliard et al., 1997). 2. The predominant south easterly trade winds provide a frequent and highly variable current forcing resulting in net north westerly currents. 3. Regional GBR Lagoon scale circulation provides an intermittent and variable forcing resulting in net south easterly currents. (RHDHV, 2014)
River Influences	The Don River mouth is located only a few kilometres south east of the port. Sand and mud deposits adjacent to the mouth of the Don River are deposited mainly on the northwest bank, which indicates littoral drift is in this direction. Despite being located close to the Don River very little sedimentation has been observed in the dredged areas at Abbot Point Port. (Hilliard et al., 1997)
Cyclone Influences	Abbot Point is susceptible to cyclonic activity and has seen 28 cyclones pass within 100km of the port between 1906 and 2007. Notable recent cyclones include TC Dylan and TC Ita in 2014 (BoM, 2015).
Port Configuration	The wharf and associated berths are located in relatively deep water, with the surrounding bathymetry averaging 17m below LAT and the berth pockets dredged to depths of 19.5m below LAT. The wharf is connected to the land via a 2.75 km trestle jetty and conveyor system.
Background TSS Concentrations	Previous water quality monitoring suggests the mean TSS at the port is 4.5 mg/l with a maximum TSS of 210mg/l (WorleyParsons, Feb 2013 – Jun 2014). Previous monitoring from 2008 to 2009 and 2011 to 2012 found that the mean TSS ranged from 11 – 20mg/l during the dry season and 12 – 16mg/l during the wet season. The monitoring was undertaken at eight sites which included coastal, inshore and deepwater areas (GHD, 2012b).
Sediment Transport Summary	Sedimentation in the dredged areas of the port is minimal with only one minor maintenance dredging event (in 2008) having been required since 1986. This is primarily due to the locality of the Port in relatively deep water where there is limited sediment transport during ambient conditions. The natural deep water also results in the dredged areas of the port having a relatively low trapping efficiency.

Table 32: Port of Mackay key coastal processes.

Coastal Process	Description
Tide Range	Mackay port is located in the area of the Queensland coast which experiences the highest tidal range, with semi-diurnal tides with a tidal range of 6.58m (MSQ, 2015).
Wind Climate	The local wind climate is governed by east to south east trade winds, with lighter land breezes from the south-west sector also occurring.
Wave Climate	The wave climate at Mackay can be summarised as: 1. The port is largely protected from swell waves as a result of the GBR and adjacent Islands (Whitsunday and Cumberland groups). 2. The large open fetch from the south east and predominant south easterly winds dominate local south easterly wave conditions. (NQBP, 2011)
Current Conditions	Current forcing at the Port of Mackay is predominantly driven by the large astronomical tides with tidal currents often exceeding 0.5 m/s (NQBP, 2011). The ebb tidal current to the north is slightly stronger and runs for slightly longer than the flood tidal current to the south. This results in an overall net northerly current direction. The predominant south easterly trade winds also act to reinforce the net northerly current direction.
River Influences	The Pioneer River mouth is located approximately 5 km to the south west of the Port of Mackay. The Pioneer River catchment is the major source of sediment which form the tidal flats and beaches surrounding the Port of Mackay.
Cyclone Influences	The Port of Mackay is susceptible to cyclonic activity and has seen 23 cyclones pass within 100km of the port between 1906 and 2007.
Port Configuration	The Mackay Port can be described as an artificial harbour enclosed within two northern and southern breakwaters. The harbour areas consists of a number of berths ranging between 8.8 and 13m below LAT and turning basin maintained to a depth of 8.5m below LAT. Outside of the harbour entrance, no dredging is required to maintain the port approach.
Background TSS Concentrations	Previous water quality monitoring suggests the mean suspended sediment concentration at the port (nearby to Slade Islet) as being 19 mg/l. (NQBP 2011)
Sediment Transport Summary	Maintenance dredging is only required within the harbour at the Port of Mackay. Key processes driving sedimentation can be summarised as: 1. The combination of the dominant northward ebb tidal currents and prevailing south easterly winds transport sediments in a net northerly direction with the net sediment volume transported northward being estimated as approximately 36,000 m^3. 2. Since tidal currents are the dominant current forcing, tidal driven sediment advection occurs in both the northerly and southerly direction on a daily basis. As the sediment migrates both up and down the coast sediment enters the harbour through currents which flow through the entrance. 3. The relatively high frequency of cyclones can result in short lived, high

	intensity sedimentations events, potentially causing significant annual variability in the maintenance dredging requirements. (ETS, 2012)

Table 33: Hay Point key coastal processes.

Coastal Process	Description
Tide Range	Hay Point Port is located in the area of the Queensland coast which experiences the highest tidal range, with semi-diurnal tides with a tidal range of 7.14m (MSQ, 2015).
Wind Climate	The local wind climate is governed by east to south east trade winds, with lighter land breezes from the south-west sector also occurring.
Wave Climate	The wave climate at Hay Point can be summarised as: 1. The port is largely protected from swell waves as a result of the GBR and adjacent Islands (Whitsunday and Cumberland groups). 2. The large open fetch from the south east and predominant south easterly winds dominate the local wave direction. 3. The dominant waves at the port are short period sea waves which are generated by local winds within the GBR Lagoon. (WorleyParsons, 2014)
Current Conditions	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 are slightly stronger than the flood currents to the south. The predominant south easterly trade winds also act to reinforce the net northerly current residual.
River Influences	The Pioneer River located approximately 17 km north west of Hay Point is the major source of sediment to the region. During large flood events the river has the capacity to discharge large volumes of suspended sediment into the waters surrounding the port and can result in elevated sedimentation over periods of days to weeks. (WorleyParsons, 2014)
Cyclone Influences	Hay Point is susceptible to cyclonic activity and has seen 15 cyclones pass within 100km of the port between 1906 and 2007 (BoM, 2015).
Port Configuration	Hay Point Port consists of the independently operated Hay Point and Dalrymple Bay Coal Terminals. These terminals comprise of trestle jetties extending offshore from Hay Point into Dalrymple Bay. The port has an approach channel with a maintained depth of 14.7m below LAT and berth pockets ranging in depth from 16.7m to 19.6m below LAT. Water depths surrounding the dredged area generally range between 10m and 13m below LAT.
Background TSS Concentrations	Previous water quality monitoring undertaken at Hay Point can be summarised as: 1. Median wet season suspended TSS concentrations of 16.2 mg/l (NQBP 2004 – 2012). 2. Median dry season suspended TSS concentrations of 6.6 mg/l (NQBP, 2004 – 2012). 3. Peak suspended TSS concentrations of up to 500 mg/l have been

	recorded adjacent to the port during the wet season (JCU, 2015)
Sediment Transport Summary	Key processes driving sedimentation at Hay Point can be summarised as: 1. Sediment transport surrounding the Port is predominantly driven by tidal currents in the region. 2. The combination of the dominant northward ebb tidal currents and the dominant south easterly winds result in the net migration of sediment to the north. 3. The relatively high frequency of cyclones can result in short lived, high intensity sedimentations events, potentially causing significant annual variability in the maintenance dredging requirements.

Table 34: Port Alma key coastal processes.

Coastal Process	Description
Tide Range	Semi-diurnal tides with a tidal range of 5.98m (MSQ, 2015).
Wind Climate	The prevailing winds are predominantly from the east to south east.
Wave Climate	The port is protected from wave action as it is situated within the Fitzroy River Delta in Raglan Creek.
Current Conditions	Current conditions at Port Alma are driven by both tidal and river processes. River currents at the wharf have been estimated to be in the order of 0.5 m/s at times, adding to the ebb tidal flow (Hilliard et al., 1997).
River Influences	Three natural channels influence Port Alma, two are direct feeds from the Fitzroy River, while the third is from Casuarina and Ragland Creeks. The Fitzroy River is the second largest catchment in Australia covering approximately 142,500km^2. The Fitzroy River has the second largest annual input of TSS of all river catchments discharging into the GBRWHA (Joo et al. 2012).
Cyclone Influences	Port Alma is susceptible to cyclonic activity and has seen 15 cyclones pass within 100km of the port between 1906 and 2007. (BoM 2015)
Port Configuration	Port Alma lies on the western side of Raglan Creek within the Fitzroy River Delta. The approach to the port passes through Keppel Bay and the lower Fitzroy River mouth. The port consists of three berths maintained to depths of 9.2m below LAT as well as a relatively small maintained area to 7m below LAT. The port is positioned in a naturally deep section of Raglan Creek and such requires minimal maintenance dredging.
Background TSS Concentrations	Not Available. Likely to be similar to the Port of Gladstone, averaging 10-35 NTU, and much higher during flood events.
Sediment Transport Summary	Sedimentation at Port Alma is result of local currents (both tidal and river currents) as well as episodic flood events.

Table 35: Port of Gladstone key coastal processes.

Coastal Process	Description
Tide Range	Gladstone experiences semi-diurnal tides with a tidal range of approximately 4.9m (MSQ, 2015). It should be noted that the narrowing embayment of Port of Gladstone leads to a funnelling effect with larger tides experienced at the upstream extents (i.e. Fisherman's Landing).
Wind Climate	The local wind climate can be summarised as south easterly winds in the morning which generally swing more east and north-east and become slightly stronger in the afternoon (GHD, 2009b).
Wave Climate	The Port of Gladstone sees a spatially varying wave climate as a result of the sheltering effects of Facing Island and Curtis Island. The wave climate at the Port of Gladstone can be summarised as: 1. Within the Port of Gladstone the sheltering effects of Facing Island and Curtis Island means the wave climate is dominated by locally generated sea waves influenced by local wind conditions. 2. Outside of the Port of Gladstone, both sea and swell conditions are more prominent. Developed swell waves are a common occurrence resulting from southerly swell refracting towards the Port through an opening in the reef and Islands. (BMT WBM, 2013)
Current Conditions	Currents within the Port are primarily driven by astronomical tides. Tides propagate into the Port of Gladstone via the North Channel, South Channel and The Narrow which leads to complex tidal flows throughout the port. The large tidal prism and the amplification effect of the embayment results in high current speeds throughout the port. Current speeds in excess of 2m/s have been measured within the Port of Gladstone. Within the Port depth-averaged tidal velocities are strongest during the flood tide. (GHD, 2009b)
River Influences	A number of local rivers and tributaries discharge directly into the Port of Gladstone. These include the Calliope River, Boyne River and Raglan Creek. Discharge from these systems varies throughout the year with the highest volumes experienced during the wet season when an estimated 75 – 90 % of yearly discharge occurs. (GHD, 2009b)
Cyclone Influences	Port of Gladstone is susceptible to cyclonic activity and has seen 12 cyclones pass within 100km of the port between 1906 and 2007. Notable recent cyclones include: • TC Hamish in 2009 passed along the coastline of Gladstone and resulted in the temporary closure of the Port. • TC Yasi and TC Oswald (2011 and 2013) resulted in significant flood events in the region. (GPC, 2014a)
Port Configuration	The Port of Gladstone is Queensland's largest multi-cargo port and comprises of multiple dredged channels, berths and basins. There is approximately 40km of shipping channels (with an averaged maintained depth of 16m below LAT) stretching from the Fairway Buoy to Fisherman's Island. The depths adjacent to

	the ports dredged areas range significantly throughout the port. A recent capital works project (Western Basin Dredging) has been recently completed to accommodate new Gas export facilities in the port. (GPC, 2014a)
Background Turbidity/TSS Concentrations	Turbidity/total suspended solid concentrations in Port Cutis are primarily driven by tidal resuspension and freshwater inflows. Previous water quality monitoring undertaken at the port can be summarised as: 1. Average turbidity levels in the Port of Gladstone are between 10-35 NTUs. 2. During heavy rain and floods turbidity measurements in the port can rise to over 250 NTUs. 3. Outside of the Harbour turbidity measurements average 5 NTUs. (GPC, 2014a) A review of previous marine investigations found that the mean turbidity at a number of sites around the Port of Gladstone ranged from 10 – 47 NTU during the dry season and 29 – 161 NTU during the wet season (GPC, 2014b).
Sediment Transport Summary	Key processes driving sedimentation at the Port of Gladstone can be summarised as: 1. The principal drivers of sediment movement are the tidal currents and locally generated wind waves. 2. The highest amounts of resuspension and in turn sedimentation occur during spring tides when tidal currents are at their strongest. 3. Both temporal and spatially varying currents throughout the Port of Gladstone results in marked variation in the spatial distribution of suspended sediments throughout the port. 4. Within the inner harbour, locally generated wind waves can act to mobilise fine sediments from the shallower intertidal areas of the Port from which the prevailing currents transport the sediment into deeper maintained dredged areas. 5. Outside the harbour the presence of longer period swell waves are an important process for sediment transport. The longer period waves are effective in mobilising bed sediments allowing prevailing tidal and wind-induced currents to transport the mobilised sediment. 6. The local rivers and tributaries can supply large volumes of suspended sediment during episodic flood events. 7. Cyclonic conditions resulting in extreme wave and current conditions can drive infrequent, short duration, high intensity sedimentation events, potentially causing significant annual variability in the maintenance dredging requirements. (GPC, 2014a; GHD, 2009b)

Appendix C Port Specific Sediment Sampling

Port of Gladstone

The extent of maintenance dredging areas within the Port of Gladstone is shown on **Figure 20**.

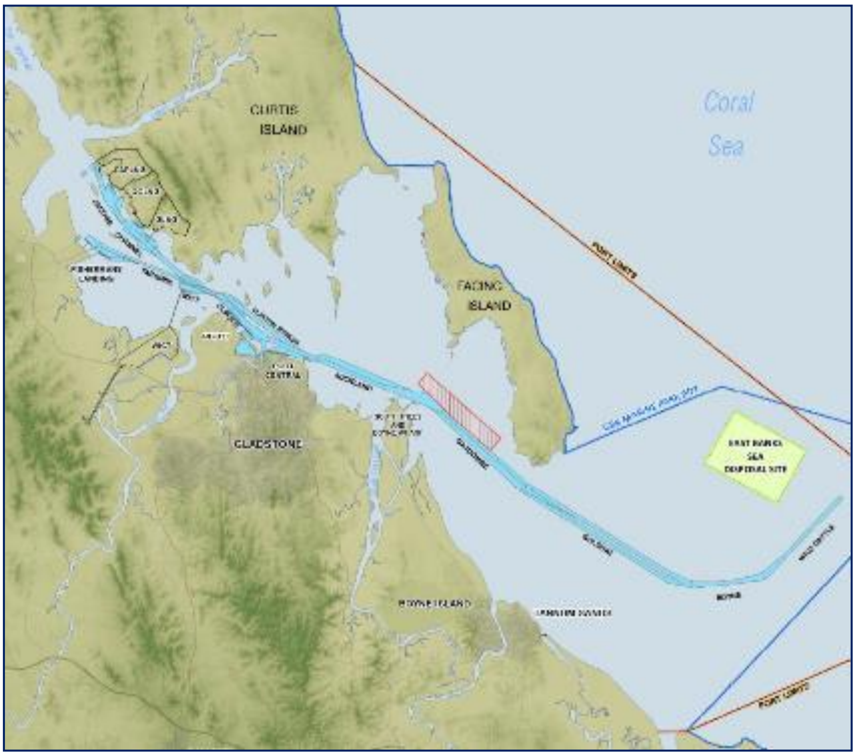

Figure 20: Extent of Maintenance Dredging Areas within the Port of Gladstone, blue area represents the gazetted channel while the red hatched area represents area of maintained depth for anchorage. (GPC, 2014b)

In 2012, a sediment sampling program (BMT WBM, 2012c) was implemented to cover the area of the main port channel, six (6) wharf sites (Fishermans Landing Wharf, Clinton Wharf, Auckland Wharf, Barney Point Wharf, South Trees Wharf, and Boyne Wharf) and the East Banks Sea Disposal Site. This involved the collection of sediment samples from 51 locations as shown on **Figure 21**. It is important to note that historical sediment sampling programs have provided coverage over the entire channel footprint, including areas that may not require maintenance dredging. The areas which have historically been prone to accretion are shown in **Figure 15**.

The results of the sampling program indicated that the sediments within the main channel were predominantly coarse grained with 54% of all locations sampled having a combined gravel and sand fraction of greater than 90%. This included some very coarse sediments inshore of Facing Island (sampling site S17) to the channel approach to Fishermans Landing Wharf (sampling site S38), which had gravel contents exceeding 30% and up to 70% to 80% at some locations. Finer sediments were found within the outer sections of the channel between sampling sites S10 to S16 as well as sites S1 to S3, where surface sediments were characterised as soft silts with fines (silt and clay) contents of up to 50%. Fine sediments were also found at sampling sites S39 and S41 on the channel approach to Fishermans Landing Wharf, where surface sediments with fines contents of up to 40% and 60% respectively were sampled.

Predominantly coarse grained sediments were sampled at Fishermans Landing Wharf, Clinton Wharf, Barney Point Wharf and Boyne Wharf, with combined gravel and sand contents between 73% and 86%. Sediments at Auckland Wharf and South Trees Wharf were silts and clays with fines contents of 93% and 50% respectively.

Figure 21: 2012 Sediment Sampling Locations in Port of Gladstone (BMT WBM, 2012c)

In 2014, sampling of new maintenance dredging areas created by the Western Basin Dredging and Disposal Project (WBDDP) was undertaken (BMT WBM, 2014d). This investigation comprised 17 sampling locations (refer **Figure 22**) and found that sediments:

- in the northern part of the WBDDP area (Jacobs Channel) were characterised by high proportions of silts and clays (often greater than 90% silts and clays);
- in the southern part of the WBDDP area (Clinton Channel) were generally characterised by coarser sediments (greater than 90% sand and gravel); and,
- at the Tug Base at RG Tanna coal terminal were characterised by fine sediments (greater than 90% silts and clays at all sampling locations).

When the results of the sediment sampling are considered in relation to the areas where historic sedimentation has occurred the sediment accumulating predominantly comprise fine sediments (silts and clays) with some sands. Although identified in previous sampling campaigns, GPC have advised that gravels have not been found to accumulate in areas where maintenance dredging has been required.

Maintenance dredging sediments within the Port of Gladstone have consistently been found to not exceed NAGD screening levels and suitable for disposal at sea in accordance with the NAGD (BMT WBM, 2014e). While past studies have found occasional exceedances in arsenic and tributyltin (TBT), elutriate testing showed that these contaminants were predominantly bound to particulate material and were not bioavailable for organisms.

Exceedances in arsenic have been observed several times since 1992 and are thought to be naturally occurring as reference sampling sites occasionally also have concentrations of arsenic above NAGD screening levels. The most recent sediment quality assessments (BMT WBM, 2012c and BMT WBM, 2014e) did not find any parameters that exceeded the NAGD screening levels.

Although not an issue for unconfined sea disposal, 3 out of the 17 sites sampled for potential acid sulfate soil (PASS) testing within the WBDDP dredging area (BMT WBM, 2014e) were found to require management of the acid generating potential. It was noted however, that most samples had sufficient acid neutralising capacity to neutralise acids upon oxidisation and therefore could be placed on-land with minimal acid generation issues. PASS testing was not undertaken as part of the 2012 sediment sampling program.

Figure 22: 2014 Sediment Sampling Locations in Port of Gladstone (BMT WBM, 2014e)

Port of Hay Point

The extent of maintenance dredging areas within Hay Point Port is shown on **Figure 23**. This includes the following main areas:

- Departure Path and Apron areas;
- Half Tide Tug Harbour Approaches, Berths and Operations Areas;
- Hay Point Coal Terminal (HPCT) Berths 1, 2 and 3; and,
- Dalrymple Bay Coal Terminal (DBCT) Berths 1, 2, 3 and 4.

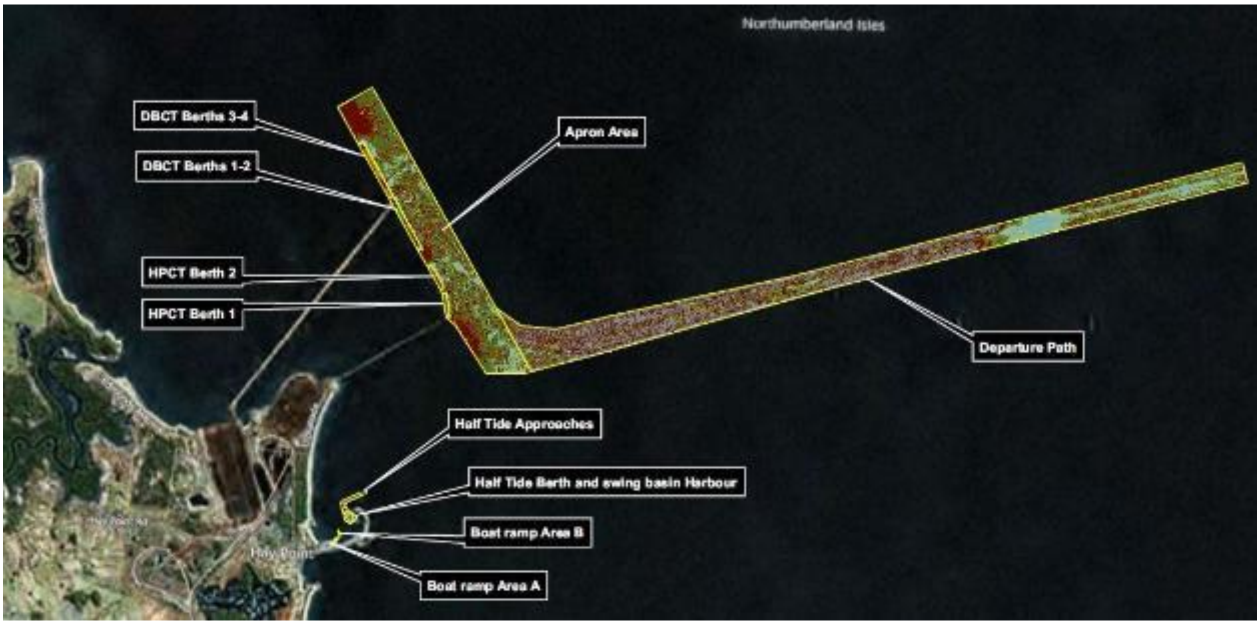

Figure 23: Extent of Maintenance Dredging Areas within Hay Point Port (Ports and Coastal Pty Ltd, 2012)

The most recent sediment sampling program was completed in 2012 (Ports and Coastal Environmental Pty Ltd, 2012) and comprised sampling at the above maintenance dredging areas in accordance with NAGD requirements.

The 2012 investigation determined that the following distribution of sediment types existed within maintenance dredging areas:

- sediments within DBCT Berths 3 and 4 comprised silty clays with an average of around 80% clay/silt content and 20% sand/gravel content;
- sediments within HPCT Berth 1 comprised clayey sands with an average of around 80% sand/gravel content and 20% clay/silt content;
- sediments within HPCT Berth 2 comprised silty clays and clayey sands with an average of around 50% sand/gravel content and 50% clay/silt content;
- sediments within the Apron Area comprised silty clays and clayey sands with an average of around 50% sand/gravel content and 50% clay/silt content;
- sediments within the Departure Path comprised clayey sands with an average of around 80% sand/gravel content and 20% clay/silt content; and,
- sediments with the Half Tide Tug Harbour Approaches and Berths comprised silty clays with an average of around 80% clay/silt content and 20% sand/gravel content.

The sediment samples obtained from the 2012 investigation were tested for the following analytes: TBT, heavy metals, hydrocarbons and polycyclic aromatic hydrocarbons (PAHs). The following is a summary of the geochemical properties of sediments:

- sediments within the Half Tide Tug Harbour Approaches and Berths satisfied NAGD screening criteria with the exception of arsenic, however when considering the approach channel and berth area as a single dredge unit, it was found to be below the NAGD limit and considered to be suitable for unconfined sea disposal. Sediments of the Central Queensland coast are known to contain naturally elevated arsenic due to the mineralogy of adjacent catchments;
- sediments within HPCT Berths 1 and 2 exceeded NAGD screening criteria for TBT (Berth 1 and 2), and arsenic, copper, lead and zinc (Berth 2), and it was concluded that the sediment was not suitable for unconfined sea disposal in accordance with the NAGD;

- at the time of sampling HPCT Berth 3 was under construction and was not included within the 2012 investigation;
- past sampling (2010) within DBCT Berth 1 and 2 identified potentially elevated concentrations of TBT, however recent investigations undertaken in 2015 concluded that TBT concentrations within these berths are below the NAGD screening levels, these findings are currently being reviewed by GBRMPA to confirm the materials are suitable for at-sea disposal; and,
- sediments within DBCT Berth 3 and 4, Apron Area and Departure Path satisfied NAGD screening criteria for all analytes and were considered to be suitable for unconfined sea disposal in accordance with the NAGD.

Mackay Port

The extent of maintenance dredging areas within Mackay Port is shown on **Figure 24**.

Figure 24: Extent of Maintenance Dredging Areas within Mackay Port (NQBP, 2011)

The most recent available sediment sampling program was completed in 2009 and involved the separate assessment of the ‘channel and swing basin’ and ‘berth pockets’ maintenance dredging areas. The 2009 investigation (WorleyParsons, 2010a) determined that sediments within the channel and swing basin comprised sandy clays and silty clays with an average of 38% clay, 36% silt and 23% sand content. Two samples located near the northern breakwater and the entrance to the harbour were characterised as clayey sands and had a higher sand content (65% sand) in comparison to the remainder of the maintenance dredging area. Field assessment of sediments indicated that the berth pockets were dominated by clays and silts with very little sand (similar to the channel and swing basin areas). Sediments within the Tug Berth were noted to have a high sand content in comparison to other berth areas due to the frequent passage of tug traffic.

Based on the results of previous sediment sampling and testing and historical industrial activities, Primary Contaminants of Potential Concern (CoPCs) within maintenance dredged sediments include TBT, heavy metals (arsenic, chromium, copper, lead, mercury, nickel and zinc) and polycyclic aromatic hydrocarbons (PAHs). The results of the 2009 sediment assessment determined that contamination levels were below relevant screening levels with the exception of TBT detected within the berth pockets. Further elutriate and pore water analysis at elevated TBT locations determined that water quality would be unlikely to be impacted at the offshore disposal site and that TBT is also unlikely to be bioavailable to benthic infauna at the disposal site. As such, it was concluded that the maintenance dredged sediment from all areas was suitable for unconfined sea disposal in accordance with the NAGD.

The 2009 sediment assessment included acid sulfate soils testing of surface sediments at 4 sites within the berth pockets. The test results indicated that potential acid sulfate soils (PASS) existed at all locations. However, the sediment contained sufficient Acid Neutralising Capacity (ANC) such that liming would not be required if the material was disposed of on-land. It was noted that sampling of deeper sediments was required to definitively assess the maintenance dredging areas for PASS.

Port of Townsville

The extent of maintenance dredging areas within the Port of Townsville is shown on **Figure 25**.

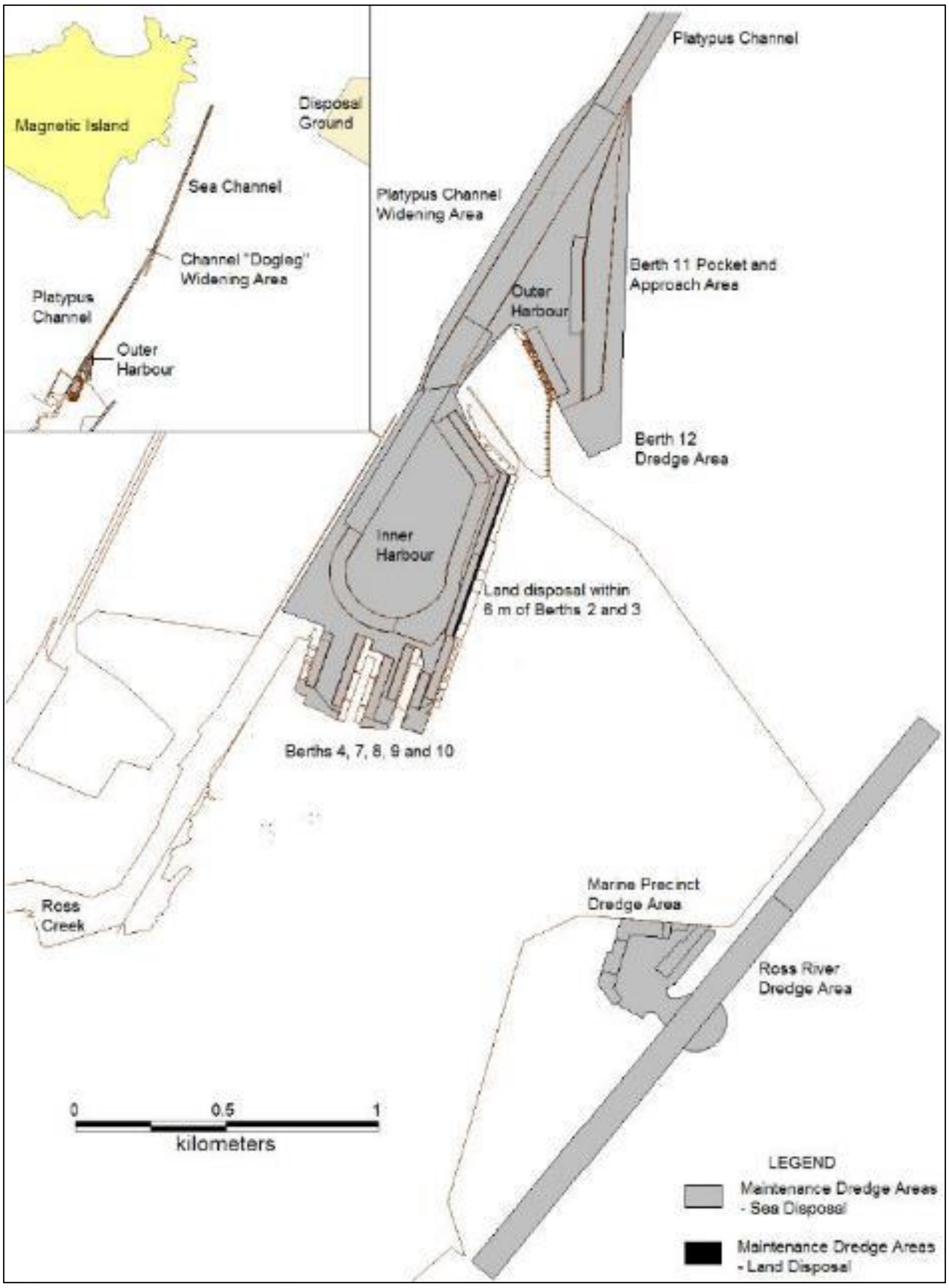

Figure 25: Extent of Maintenance Dredging Areas within the Port of Townsville (Geochemical Assessments, 2013)

The soft surface sediments within maintenance dredging areas generally comprise sandy muds. The most recent maintenance dredging sediment quality assessment was completed in 2012 and comprised sampling within the Platypus Channel, Sea Channel, Inner Harbour, Outer Harbour and Ross River maintenance dredging areas (PoTL, 2013). The 2012 sediment quality assessment (Geochemical Assessments, 2013) determined that:

- sediments in the Platypus Channel and Sea Channel were found to be muddy with variable sand content (up to 43%) and gravel at some locations;

- sediments in the Inner Harbour area were found to be silts and clays with trace to minor amounts of sand;
- silts and clays were found in deep water areas of the Outer Harbour (greater than 10 metres), whilst fine sand was found in shallow water areas;
- sediment in the Ross River comprised coarse sand that accumulates in prominent sand banks and fine grained muddy sediments (i.e. greater than 90% fines content) that exist within deeper sections of the Ross River channel; and,
- greater than 50% of the fines content in the 15 samples analysed consisted of clay material (i.e. grain size less than 4 microns).

Ross Creek and the Marine Precinct were excluded from the 2012 sampling program as these areas are infrequently dredged and maintenance dredging was not planned in these areas at the time. However, it was reported that sediments within Ross Creek comprised silts and muds and that muddy sands exist within the Marine Precinct (PoTL, 2013).

PoTL has been implementing a comprehensive “surveillance” sediment sampling program involving 247 sites throughout the port that are sampled quarterly. The Long Term Sediment Monitoring Program (LTSMP) has been in place since 1994 and is supplemented by more detailed sampling of areas subject to maintenance dredging consistent with the NAGD.

Based on the results of previous sediment sampling and testing and historical industrial activities, Primary Contaminants of Potential Concern (CoPCs) within maintenance dredged sediments include Arsenic (As), Cadmium (Cd), Chromium (Cr), Copper (Cu), Lead (Pb), Zinc (Zn) and TBT.

Levels of contamination are highest within the Inner Harbour, where concentrations of Cu and Ni have exceeded NAGD screening levels. However, subsequent elutriate testing undertaken as part of the 2012 sampling campaign for maintenance dredging sediment quality assessment determined that these contaminants were predominantly bound to particulate material and are not bioavailable for organisms at unacceptable concentrations in accordance with the NAGD. It was concluded that these sediments were suitable for unconfined sea disposal.

However, the 2012 assessment of Inner Harbour sediment excluded two small areas, which included a 6 metre strip along the quay line of Berths 2 and 3 and the southern area between Berths 7 and 8. Some of these areas have been influenced by product loading/unloading spillage as indicated by the historical results of quarterly collection and analysis of surface samples from these areas as part of the LTSMP undertaken by PoTL. The LTSMP has shown that contamination levels of Cu, Ni, Pb and Zn and in these areas are sufficiently high to trigger ecotoxicity testing within the NAGD testing hierarchy. As such, PoTL and port users have adopted a precautionary approach by placing material from these areas on-land. The LTSMP has also identified sediments containing relatively high concentrations of Cu south of Berth 4.

The 2012 sampling campaign determined that the concentrations of trace metals in maintenance dredging areas beyond the Inner Harbour did not exceed NAGD screening levels. It was concluded that sediment in the Outer Harbour, Platypus Channel, Sea Channel and Ross River was classified as suitable for unconfined sea disposal.

Previous sampling in the Marine Precinct area was undertaken prior to its development in 2011, which indicated that sediment quality was relatively good with negligible exceedances of NAGD screening levels (PoTL, 2013). However, it is considered that contaminants released by refuelling, abrasive blasting, painting and minor transfer of hazardous goods (e.g. batteries) associated with its current use as a commercial maritime facility have the potential to accumulate with the muddy sands within the Marine

Precinct under its low energy conditions. Due to the absence of current sediment quality data since development of the area and shallow water depth making the area inaccessible for operation of a TSHD, PoTL maintenance dredging strategies have allocated this material for disposal on-land.

The sediments within Ross Creek are known to have been subject to industrial and stormwater discharges over a long period of time as the area is infrequently dredged. In the absence of current sediment quality data, PoTL maintenance dredging strategies have assumed that this material is unsuitable for unconfined sea disposal and would be disposed on-land.

In light of the above, PoTL has proposed that future testing of sediments in the Marine Precinct and Ross Creek should include PAHs (Polycyclic Aromatic Hydrocarbons), TPH (Total Petroleum Hydrocarbon), BTEX (benzene, toluene, ethylbenzene and xylenes) and organochlorine pesticide residues in addition to the primary CoPCs.

Potential acid sulfate soils (PASS) have been identified at the port. Although not an issue for unconfined sea disposal, sediment disposed of this material to land may require management of the acid generating potential.

Port of Cairns

The extent of maintenance dredging areas within the Port of Cairns is shown on **Figure 26**. The port is divided into several dredging management areas that comprise:

- Outer Channel;
- Inner Port (including the Inner Channel, main wharves and swing basins);
- Navy Base;
- Marlin Marina;
- Commercial Fishing Base 1 (CFB1); and,
- Commercial Fishing Base 2 (CFB2).

It is important to note that the majority (approximately 90%) of maintenance dredge material volume is removed from the Outer Channel, in comparison to the other areas of the port.

Figure 26: Extent of Maintenance Dredging Areas within the Port of Cairns (WorleyParsons, 2010b)

The Port of Cairns prepares comprehensive sediment SAP's on an annual basis for intended maintenance dredging areas. These sediment SAP's are approved by GBRMPA and the sampling and testing is then completed. Prior to commencement of dredging, sediment SAP implementation reports are submitted to GBRMPA for approval that the material is sufficiently free of contaminants and suitable for unconfined sea disposal. The sediment information presented below has been obtained from the 2008 sediment sampling program whereby sediment sampling occurred across all dredging management areas (WorleyParsons, 2010b).

The 2008 investigation determined that the following distribution of sediment types existed within dredging management areas:

- sediments within the Outer Channel and Inner Port had variable sand (1% to 71%) and gravel (1% to 12%) content and an average clay/silt content of 82% to 89%, sands and gravels were most prevalent in sediments near the mouth Trinity Inlet;
- sediments within the Navy Base comprised silts and clays with minor sand content (1% to 7%);
- sediments within the Marlin Marina comprised silts and clays with an average sand content of around 8% and gravel content of around 4%;

- sediments within Commercial Fishing Base 1 comprised silts and clays with minor sand content (2%); and,
- sediments within Commercial Fishing Base 2 comprised silts and clays with minor sand content (8%).

An extensive program of sediment contamination assessment has been implemented by the operators of Port of Cairns since 1995 (BMT WBM, 2014b). Sediments within the Port of Cairns are typically uncontaminated, with the majority of contaminant substances not exceeding NAGD screening levels at 95 per cent UCL (BMT WBM, 2014b).

The few exceptions involve arsenic, tributylin (TBT), copper and diuron (WorleyParsons 2010b). Additional testing has been undertaken during the implementation of past Sampling and Analysis Plans (SAPs) and levels present in elutriate and porewater tests have indicated that no significant impact to water quality or benthic communities was likely (BMT WBM, 2014b). Similar to other parts of Eastern Australia, arsenic is naturally elevated in the Cairns region due to the presence of natural mineralisation in metamorphic rocks. As such, arsenic has exceeded the NAGD screening level in most Port of Cairns dredge areas except Marlin Marina within the past five years (BMT WBM, 2014b). Any exceedances have tended to be marginal over the screening level and further testing using DAE and elutriate analysis has indicated that impacts to water quality and benthic communities are highly unlikely. Therefore, the local arsenic screening level has been increased by the Determining Authority from 20 mg/kg to 30 mg/kg (WorleyParsons 2010b).

For all studies undertaken between 1995 and 2013, dredge material has been considered suitable for unconfined sea placement on the basis of contaminant levels (BMT WBM, 2014b). Further sediment quality testing was undertaken as part of the sediment SAP developed for the Cairns Shipping Development Project (BMT WBM, 2014b). The findings of the sediment SAP have confirmed that the dredge material is considered suitable for unconfined sea placement. Sampling was undertaken in accordance with the NAGD, and details are provided in BMT WBM, 2014b. The sediment investigation also identified PASS within the top 1 metre of soft sediments (silts and clays) in the Inner Port and Outer Channel.

Appendix D Environmental Review and Risk Assessment

REPORT APPENDIX – ENVIRONMENTAL REVIEW & RISK ASSESSMENT

Maintenance Dredging Strategy

Client: Dept. of Transport and Main Roads

Reference: M&WPA1184R002F03

Revision: 03/Final

Date: 23 September 2016

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Table of Contents

1 Environmental Review and Risk Assessment of Maintenance Dredging

This Appendix provides supporting information for the Maintenance Dredging Strategy commissioned by the Queensland Department of Transport and Main Roads. The strategy focuses on the existing Queensland port facilities adjoining the GBRWHA between Gladstone in central Queensland to Quintell Beach in northern Queensland (i.e. Gladstone, Port Alma, Hay Point, Mackay, Abbot Point, Townsville, Lucinda, Mourilyan, Cairns, Cooktown, Quintell Beach and Cape Flattery). A review of historical maintenance dredging activities for these ports demonstrated that the needs vary, from annually to no specific need at all. The ports that have no history, or a likely need for maintenance dredging into the future, include Quintell, Cape Flattery, Mourilyan and Lucinda. For the purposes of this environmental review and risk assessment only ports with a history of maintenance dredging, or a likely need into the future, will be considered.

The following sections introduce the ecological setting of each relevant port, and the extent of the known environmental values that have the potential to be impacted by maintenance dredging related activities. Consistent with the approach presented in the GBRMPA (2009) Risk Framework; a preliminary analysis of the environmental – ecosystem level risks posed by maintenance dredging is presented. This assessment draws on the available information to describe the nature and extent of the maintenance dredging in each port and the potential for these activities to impact environmental values.

1.1 Port of Gladstone

The Port of Gladstone is located in Port of Gladstone, which contains a mosaic of marine and coastal wetlands that include mangrove, seagrass, saltmarsh, rocky and sandy shore, open water and sub-tidal benthic habitats. The Port of Gladstone has recently experienced substantial growth, with the establishment of the Liquefied Natural Gas (LNG) industries on Curtis Island. The scale of the development, and the requirement to dredge new channels to facilitate the shipping access, triggered the need for an Environmental Impact Statement (GHD, 2009a; GHD, 2009b), suitable environmental permitting conditions which included the establishment of the Ecosystem Research and Monitoring Program (ERMP). The scientific outputs drawn together from the EIS and ERMP provide the foundation for understanding the nature and current status of the marine ecology in Port of Gladstone.

The material targeted during maintenance dredging in the Port of Gladstone channels has consistently been found to be uncontaminated (BMT WBM, 2014a). While past studies have found occasional exceedances in arsenic and TBT, elutriate testing showed that these concentrations would not result in water column impacts. Exceedances in arsenic have been observed several times since 1992 and are thought to be naturally occurring as reference sites occasionally also have concentrations of arsenic above screening levels. The most recent sediment quality assessments (BMT WBM, 2012a; BMT WBM, 2014b) did not find any parameters that exceeded the ANZECC (2000), NODGDM (2002) or the NAGD (2009) screening levels.

More recently the Port of Gladstone has invested time and resources to enhance their understanding of maintenance dredging and disposal operations. This work has centred on three key areas, including:

- Targeted monitoring of the plume intensity and extent when the TSHD Brisbane is dredging and also during disposal activities;
- Continuous monitoring of turbidity and benthic light (BPAR) at key environmental value locations (seagrass meadows); and

- Hydrodynamic modelling of various maintenance dredging scenarios to ascertain the potential for plumes to interact with environmental values.

1.1.1 Environmental Values

Table 1 provides a list of the environmental values in Port of Gladstone, including a summary of their known distribution and temporal trends.

Table 1. Summary of environmental value distribution and temporal trends in the Port of Gladstone area.

Environmental Value	Distribution	Temporal Trends – Environmental Windows
HABITATS		
Seagrass Meadows	Six species of seagrass have been identified in Port of Gladstone by the Department of Agriculture Forestry and Fisheries DAFF (formerly DEEDI), namely: *Zostera muelleri, Halodule uninervis, Cymodocea serrulata, Halophila spinulosa, Halophila ovalis*, and *Halophila decipiens*. More generally, the intertidal seagrass communities in Port of Gladstone are *Zostera capricorni* and the deepwater meadows (>5 m deep) are typically sparser than coastal meadows and are typically dominated by Halophila species. (McCormack *et al.*, 2013). Long term monitoring of this seagrass species in Port of Gladstone has identified several key meadows, with Pelican Banks comprising the most dense and annually persistent cover (**Figure 1**).	Bi-annual surveys of seagrass distribution have shown that seagrasses in the Gladstone region are generally at their peak in distribution and abundance during the late spring/early summer and decline (senesce) during the winter months (Chartrand et al., 2011, Chartrand et al. 2012, Rasheed et al. 2012) consistent with seagrasses in other tropical and subtropical areas of Queensland (Mellors et al. 1993; McKenzie 1994; Rasheed 1999; 2004). Flood events have been demonstrated to have a significant impact on seagrass meadows in Port of Gladstone, in some cases reducing cover to zero (Chartrand *et al.*, 2012).
Coral Reefs	The GBRMPA Gazetteer maps nineteen reefs within Port of Gladstone, most of which are intertidal rocky shores or shallow subtidal reefs (BMT WBM, 2013) **(Figure 2).** The reefs include fringing, platform, and headland reefs, as well as rubble fields. Of the unsurveyed reefs, Seal Rocks is the most likely to support significant reef communities given its size and position (BMT WBM, 2013)	There is limited temporal data for coral reef communities in the inner harbour area. The reef communities along the eastern side of Facing Island have been monitored during 2011 to 2013 (Sea Research, 2013). The coral cover along Facing Island is low (< 20%), however an increasing trend between 2011 and 2013 was observed (i.e. 7.8 to 15.3%).
FAUNA		
Sea Turtles	Six species of sea turtles are known to occur in the Port of Gladstone region. Loggerhead turtle (*Caretta caretta*) occurs in the region, (Limpus et al., 2013a). Green turtle (*Chelonia mydas*) are common in the region (Limpus et al., 2013b). Hawksbill turtle	Loggerhead turtle (*C. caretta*) population has been declining since 1970's, the closest nesting site is Heron Island (>60 km east of Gladstone) during Dec – Feb (Limpus et al., 2013a). Green turtle (*C. mydas*) populations are increasing, the closest primary nesting site is Wreck Island and North West Island (>60km east of Gladstone). However, nesting is possible in

	(*Eretmochelys imbricate*) are occasionally sighted (Limpus et al., 2013c). Olive ridley turtle *(Lepidochelys olivacea*) are rarely seen in the region (Limpus et al., 2013d). Flatback turtle (*Natator depressus*) are common in the region, especially during nesting season (Limpus et al., 2013e). Leatherback turtle (*Dermochelys coreacea)* are occasionally sighted (Limpus et al., 2013f).	Port of Gladstone (Limpus et al., 2013b). Hawksbill turtle (*E. imbricate*) populations are declining, the closest nesting beach in Milman Island in northern QLD (>1500 km north of Gladstone) (Limpus et al., 2013c). Olive ridley turtle (*L. olivacea*) population dynamics in the region are unknown, there are no known nesting beaches in the GBR region (Limpus et al., 2013d). Flatback turtle (N. depressus) populations are stable, however the trends vary with location, there is a known nesting site on the southern shoreline of Curtis Island. Recent tagging data has also demonstrated the interesting behaviour of the females that use this nesting site (**Figure 3** and **Figure 4**). Leatherback turtle (*D. coreacea*) populations are in decline both within the region and more broadly, the closest nesting site is Wreck Rock (> 60km south of Gladstone) (Limpus et al., 2013f).
Dugongs	Port of Gladstone provides important habitat for a relatively small population of dugongs (*Dugong dugon*) (Sobtzick et al., 2013). Animals are sighted in varying locations, showing a wide use of the area (Sobtzick et al., 2013). Density estimates have been generated for the region (**Figure 5**).	Sobtzick *et al.* (2013) found that a long-term decline in dugong abundance was present at a regional scale along the urban coast. This contrasted with shorter-term fluctuation at local scales due to animal movements. However, the specific population numbers and dynamics through time for the Port of Gladstone population are unknown.
Cetaceans	Indo-Pacific humpback dolphins (*Sousa chinensis*) are the primary dolphin species that inhabits Port of Gladstone. They have been observed through the area engaged in various activities (**Figure 6**) (Cagnazzi, 2013). Overall, abundance estimates indicate that less than 200 humpback dolphins inhabit the Capricorn-Curtis coast region.	Humpback dolphins (*S. chinensis*) are resident in Port of Gladstone, using the habitat all year (Cagnazzi, 2013). Population estimates suggest that there is an overall decline in numbers (Cagnazzi, 2013).
Benthic fauna and epifauna	Currie and Small (2002) investigated changes in macroinvertebrates at 30 sites in Port of Gladstone, twice yearly, over 6 years between 1995 and 2001. Gradients in abundance and species richness were principally driven by depth and sediment grain size, with extremely fine or extremely coarse sediments having the lowest richness and abundance. Bivalve molluscs, ascidians, polychaetes and pistol shrimp (Alpheus sp.) were among the most important taxa defining the difference between intertidal and subtidal sediments.	From the work that Currie and Small (2002) completed, richness and abundance were positively correlated with turbidity measurements made 4 months previously. They suggested that high turbidity promotes recruitment and growth of benthic organisms in Port of Gladstone. Strong correlations between regional rainfall, freshwater inflow, nutrient and chlorophyll a concentrations, also supported the hypothesis that changes in total abundance were mostly the result of long-term climatic cycles including El Niño events (Currie and Small, 2002). Long-term, broad-scale changes in macroinvertebrate communities were also observed in the offshore monitoring program (BMT WBM 2012b), including a strong seasonal pattern, where richness and abundance were higher during winter and spring and lower in summer and autumn. In this case, the largest declines in abundance and richness were observed after extremely large rainfall associated with tropical cyclone Yasi. Thus, it appears that increasing rainfall

		(and associated environmental changes) stimulate macroinvertebrate communities to a point, but extreme rainfall events and associated turbidity can be detrimental. The benthic communities of the sea disposal site have been examined during a number of surveys between 1992 and 2011. The site has been characterised as sparsely populated with all of the studies finding that, even prior to disposal events, both species abundance and species richness is generally lower in the sea disposal site compared to the surrounding area (Aurecon, 2010). More broadly, benthic fauna regions have been defined based on substrate type (**Figure 7**).

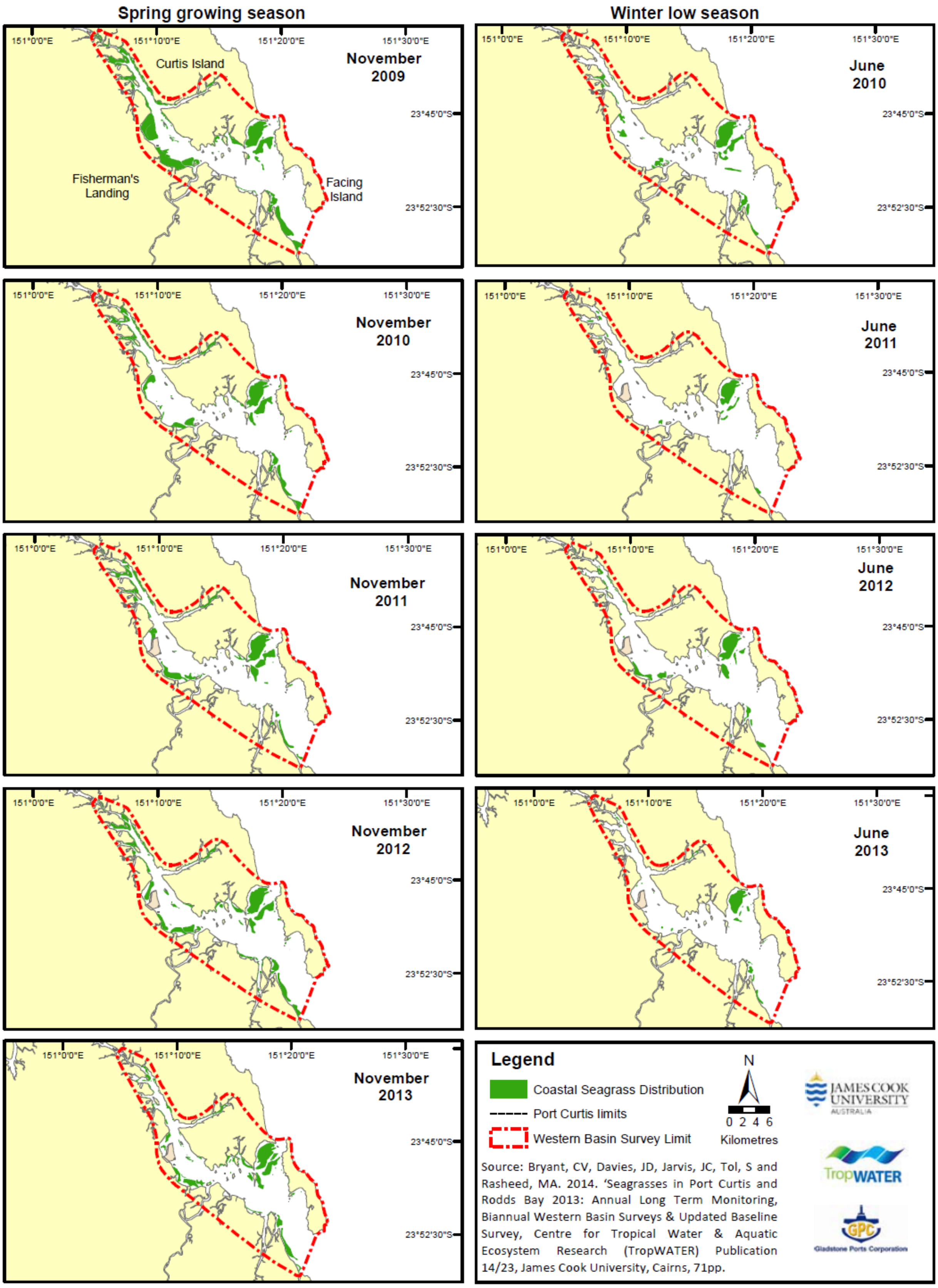

Figure 1. Temporal seagrass distribution in Gladstone (Bryant et. al. 2013)

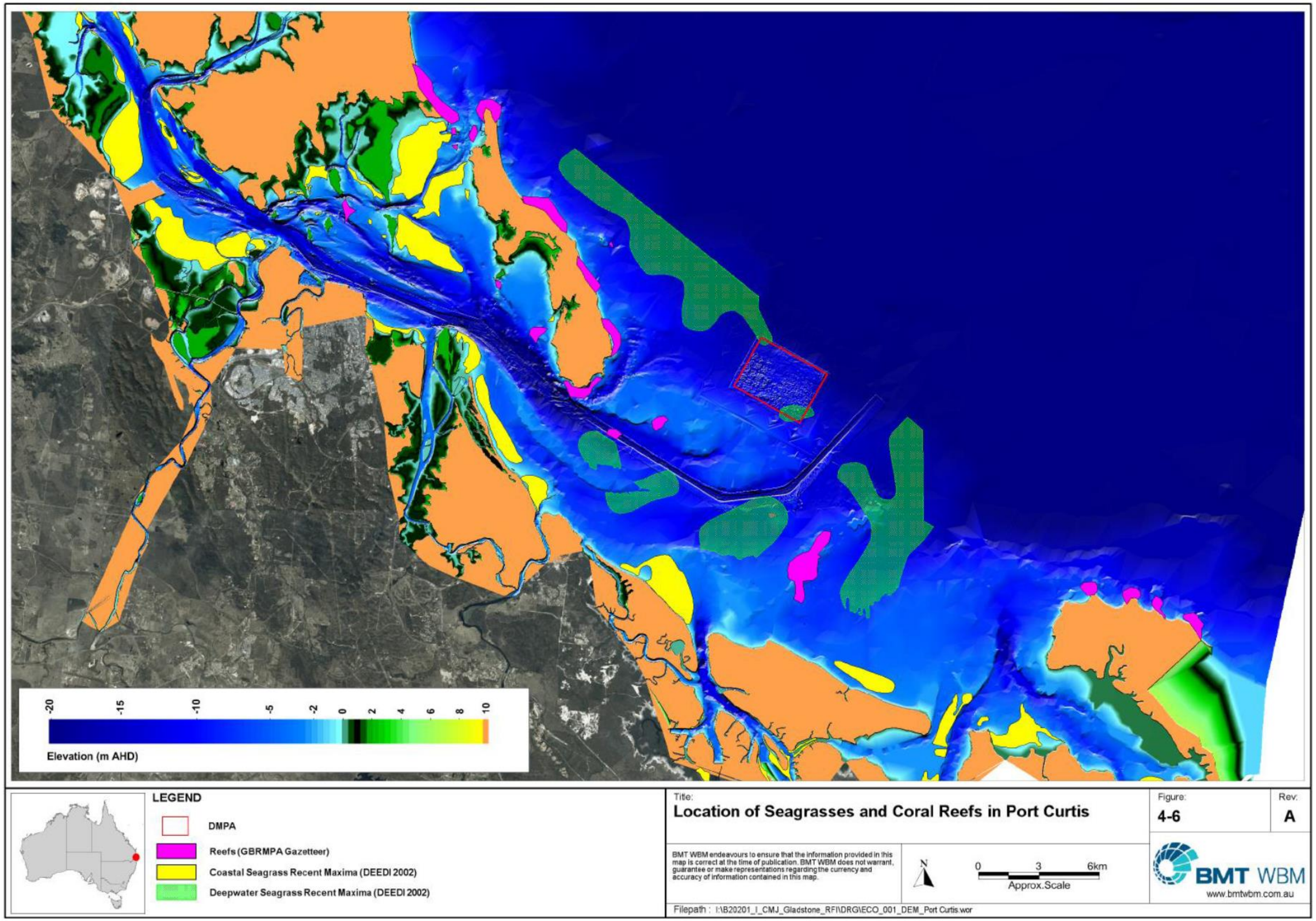

Figure 2. Location of Seagrass and Coral Reef in Port of Gladstone region (BMT WBM, 2014e).

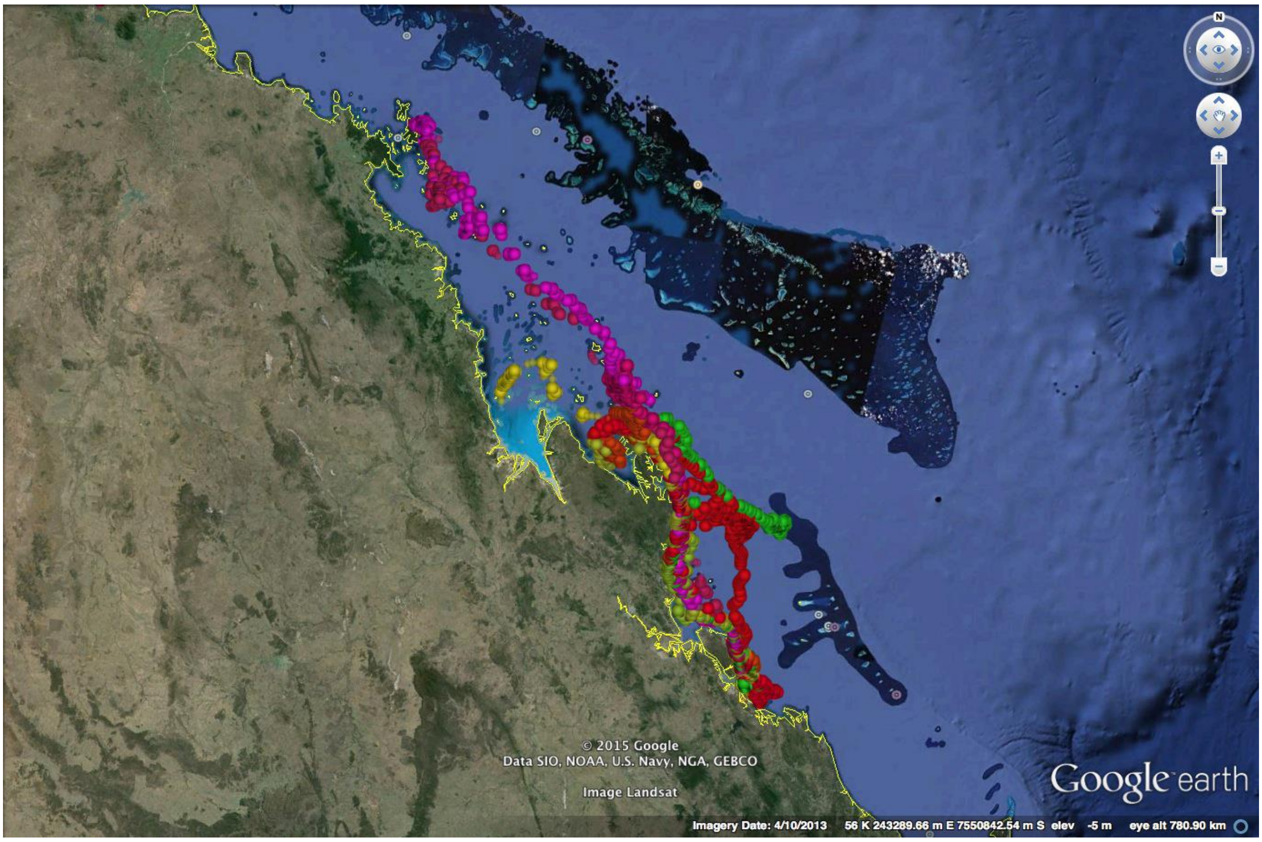

Figure 3. Migration routes and destinations for eleven female flatback turtles tracked from their nesting beach at Curtis Island in November 2013 (Hamman et. al., 2015)

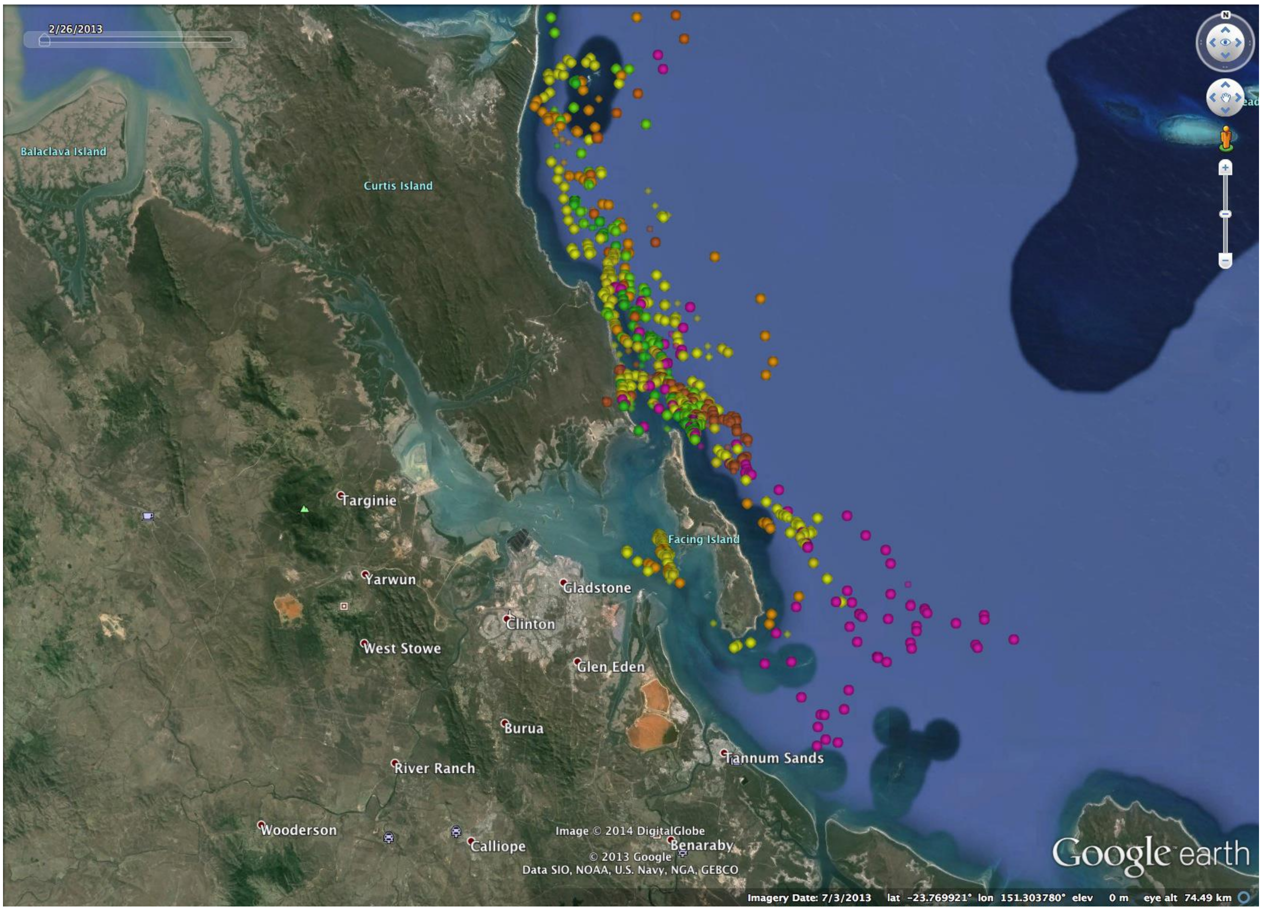

Figure 4. GPS Location points for eight flatback turtles tracked during their interesting period between November to December 2013. Each of the turtles was tagged after nesting on South End beach of Curtis Island (Hamman et. al, 2015)

The Hamman *et. al.* (2015) study reported that seven of the eight turtles spent time within the waters of the Port of Gladstone. Three had 50% core use areas in the middle harbour region of the Port, and another four turtles used habitat within the limits of the Port of Gladstone, but outside of the middle harbour. Overall, approximately 20% of all habitat used by the seven turtles was located within the Port of Gladstone limits.

Turtles spent 91% of their time in water depths less than 25 m, 41% of time in water depths between 15 and 20 m and 11% of their time in water <2 m deep. A comparison of home range area and bathymetry indicates that the turtles spent most of their time on the bottom.

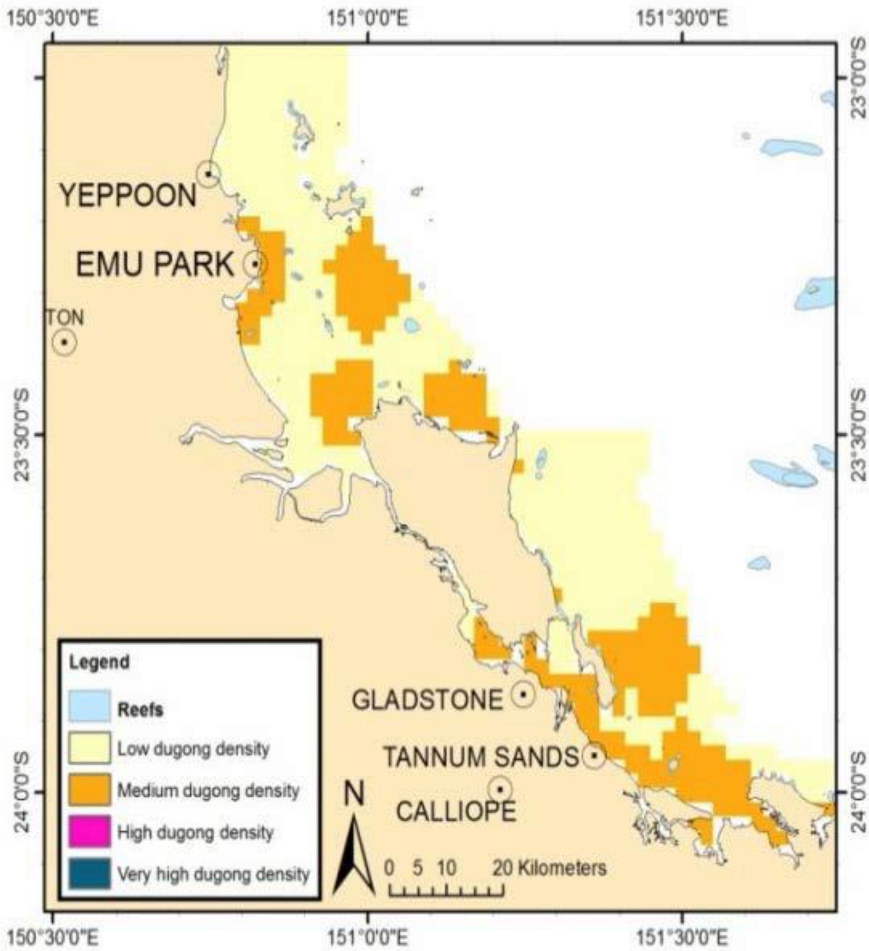

Figure 5. Relative dugong density in the Gladstone – Yapoon region Modelled distribution of relative animal density covers the spatial extend of aerial surveys conducted by James Cook University 1986-2005 (from Sobtzick et al 2013)

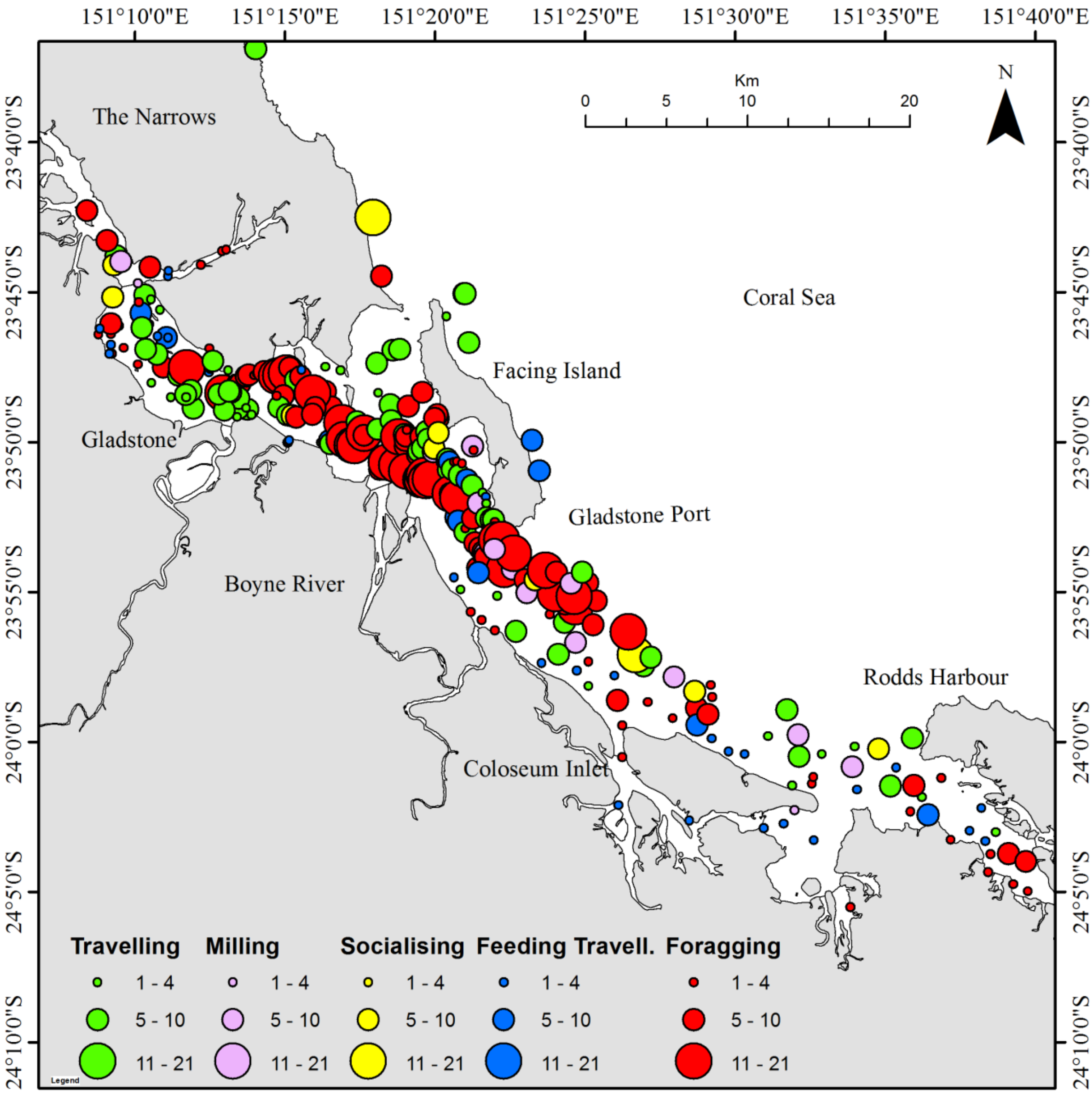

Figure 6. Sightings of humpback dolphin schools in the Curtis region showed in relation to the group size (dot size) and behavioural types (dot colours) (Cagnazzi, 2013).

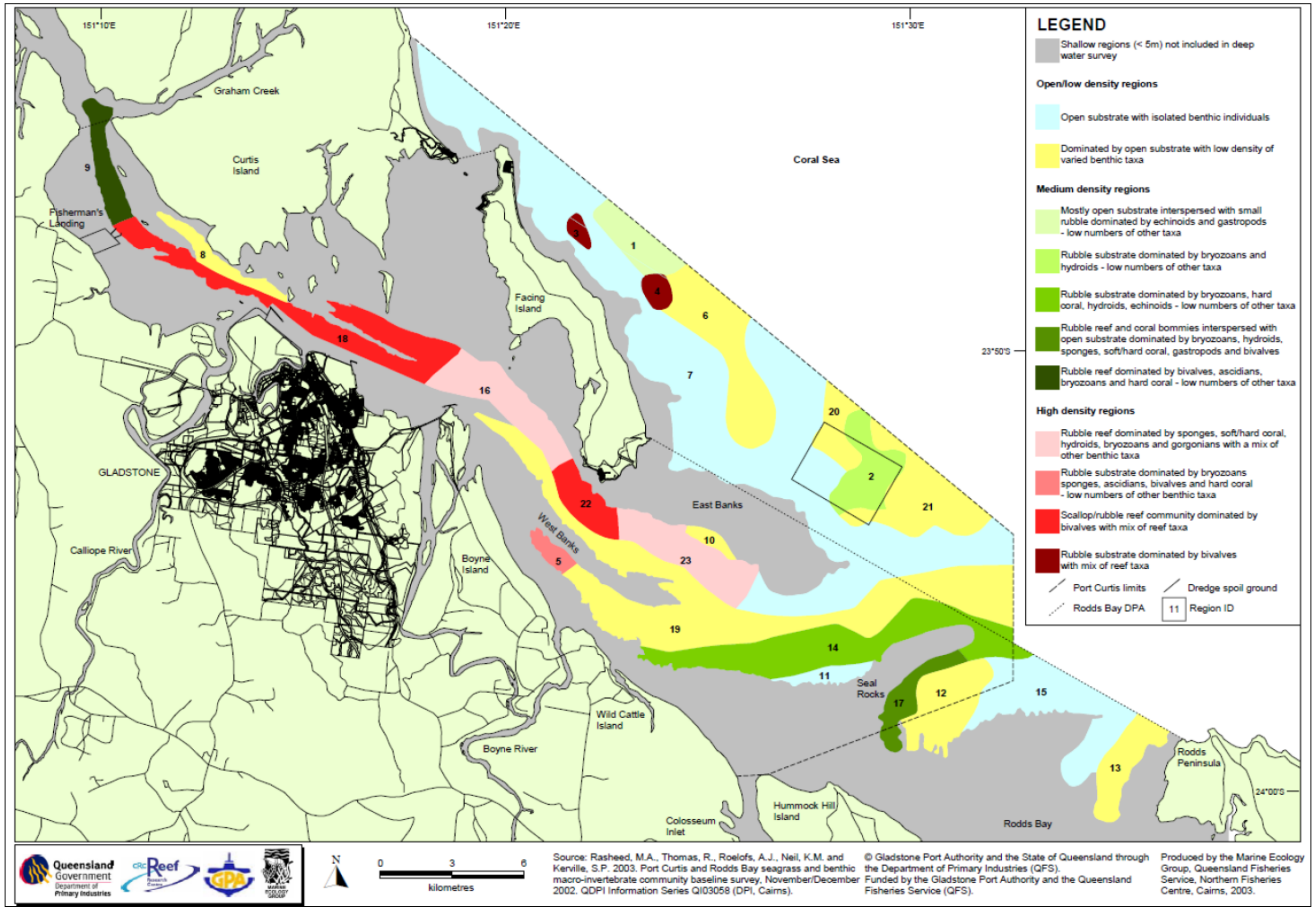

Figure 7. Deepwater Benthic Macro-Invertebrate Regions in Port of Gladstone, November/December 2002 (Source: Rasheed et al. 2003)

1.2 Port Alma

The Port of Rockhampton is located in lower reaches of the Fitzroy River Delta (Queensland's largest catchment) and experience pulsed disturbances associated with quasi-annual flooding (BMT WBM, 2015a). The Fitzroy River has a major influence on the coastal processes (erosion and deposition) and ultimately the biological environments. Historically, there has been little need for maintenance dredging i.e. 2000, 2009 and most recently in 2011. The 2009 and 2011 maintenance dredging campaigns have taken less than a week to conduct where dredged volumes consisted of 23,000 m^2 and 40,000 m^2 of material, respectively (BMT WBM, 2015a). Based on these small scale sporadic requirements there has been little environmental characterisation for the purpose of assessing the impact of maintenance dredging on the receiving environment. Recently, however, BMT WBM (2015a) was commissioned by GPC to deliver a receiving environment monitoring program for the Port of Alma, and the information collated by BMT WBM has been used to generate a summary for the environmental values.

As part of the BMT WBM work, maintenance dredging plume intensity and extent was assessed and provided insight into the potential for plumes to interact with sensitive receptors. The primary objective of their works was to design a monitoring program that seeks to understand the intensity and extent of potential impacts related to maintenance dredging at Port of Rockhampton, in order to protect the environmental values of the surrounding environment (BMT WBM, 2015a).

1.2.1 Environmental Values

Table 2 provides a list of the key environmental values in Port Alma, including a summary of their known distribution and temporal trends.

Table 2. Summary of environmental value distribution and temporal trends in the Port of Rockhampton area.

Environmental Values	Distribution	Temporal Trends – Environmental Windows
HABITATS		
Seagrass Meadows	Historical mapping and monitoring of seagrasses in the Port Alma area, including outside the mouth of the Fitzroy River, did not detect large areas of seagrass habitat (York and Smith, 2013) and seagrass has not been observed in the Port Alma area in recent monitoring (M. Rasheed, James Cook University pers. comm. from BMT WBM, 2015a)	NA
Coral Reefs	The closest significant coral reef communities to Port Alma are located at Peak Island which are approximately 25 km north-east of the port facilities (BMT WBM, 2013). Extensive coral reef communities can be found in the northern parts of Keppel Bay, with occasional corals and soft corals found on hard substrates such as rock shelves, around the northern tip of Curtis Island (BMT WBM unpublished). The north western tip of Curtis Island is 10km from the approved offshore disposal area.	NA
FAUNA		
Sea Turtles	Six species of sea turtles are known to occur in the Port of Gladstone region. Loggerhead turtle (*C. caretta*) occurs in the region, (Limpus et. al., 2013a).	NA

	Green turtle (*C. mydas*) are common in the region (Limpus et. al., 2013b). Hawksbill turtle (*E. imbricate*) are occasionally sighted (Limpus et. al., 2013c). Olive ridley turtle (*L. olivacea*) are rarely seen in the region (Limpus et. al., 2013d). Flatback turtle (N. depressus) are common in the region, especially during nesting season (Limpus et. al., 2013e). Leatherback turtle (*D. coreacea*) are occasionally sighted (Limpus et. al., 2013f).	
Dugongs	Marsh et al., (2007) has modelled the relative density of dugongs across the Great Barrier Reef World Heritage Area (GBRWHA). The model outputs indicate that dugong management units within the Port Alma region, are of medium conservation value. This is of particular relevance along the north western coastline of Curtis Island and the remaining areas including the Fitzroy River delta and Fitzroy estuary are of low conservation value (GHD 2009a). The lower Fitzroy estuary accommodates a low number of dugongs due to the turbid waters limiting seagrass habitat.	NA
Cetaceans	Three species of inshore dolphins have been recorded inhabiting Port of Gladstone and Port Alma and include Australian snubfin (Orcaella heinsohni), Indo-Pacific humpback (Sousa chinensis chinensis) and the inshore bottlenose dolphin (Cagnazzi 2013). The Fitzroy estuary supports the three inshore dolphin species, all of which are reported to be found in small groups (Cagnazzi 2013). All three dolphins are listed as migratory under the EPBC Act and the snubfin and Indo-Pacific humpback dolphins are listed as 'near threatened' under the Queensland NC Act.	NA
Benthic fauna and epifauna	In 2015, a pilot study to examine the benthic community within and immediately adjacent to the maintenance dredge area and the Dredge Material Placement Area (DMPA) was commissioned by GPC (BMT WBM, 2015b). A total of 2874 individuals were recorded in the study, comprising 144 taxa from 87 families, 13 classes and 11 phyla. The most abundant group were the polychaete worms (42% of individuals), followed by malacostracan crustaceans (27% of individuals), acorn worms (11% of individuals), nemertean worms (5% of individuals), ostracod seed shrimps (3% of individuals) and gastropod molluscs (2% of individuals). Benthic communities within the study area were characterised by having the following attributes: • Comprised exclusively of marine/estuarine species, with no freshwater species recorded • Comprised exclusively of small opportunistic and/or mobile taxa	NA

	• Abundance dominated by a few taxa • A large proportion of uncommon taxa (93% of taxa were recorded in one or two samples).	

1.3 Port of Hay Point

An EIS was undertaken for the Port of Hay Point in 2005, as part of the development of the Apron Area and Departure Path Capital Dredging. This EIS reported on the surrounding cultural heritage values, dredge material geochemical characteristics, hydrodynamics and water quality conditions and coral reef communities. Routine seagrass, algae and benthic infauna and coral reef surveys have also been undertaken over the past decade (Thomas and Rasheed, 2011; Thomas et al., 2011; WorleyParsons, 2010) in areas adjacent to the Port of Hay Point.

The coastal environment surrounding the Port of Hay Point consists of wetlands, mangroves and saltmarsh communities. The Sandringham Bay-Bakers Creek Aggregation is located north of the terminals. These coastal wetlands are listed on the Directory of Important Wetlands of Australia and encompass an area of 7,367 hectares. Seagrass meadows and macroalgal communities are present immediately offshore of the Port of Hay Point, within Port limits. Fringing reefs are also located subtidally along the foreshore, within Dalrymple Bay and also north and south of the Port limits, on Flat Top Island and Round Top Islands (to the north) and Victor Islet (to the south) (**Figure 8**) (NQBP, 2009).

Sediment quality was previously investigated as part of the Hay Point EIS and the 95% Upper Confidence Limits (UCLs) of the contaminants of interest were below the relevant screening levels and therefore, the sediments were considered non-toxic and suitable for unconfined ocean disposal (GHD, 2005). Nutrient levels in the sediments were reported at low concentrations, compared with concentrations reported in estuary sediments at Shoalwater Bay (GHD, 2005). Sediment at the Port of Hay Point was categorised as silts and fine sands of variable thickness (1-30 cm) underlain by stiff clay.

The most recent survey undertaken for maintenance dredging was in 2012, which reported that, with the exception of HPCT Berths 1 and 2, the chemical nature of all dredge areas nominated met the National Assessment Guidelines for Dredging (Commonwealth of Australia, 2009) screening levels for unconfined ocean disposal of maintenance dredge material (Ports and Coastal Environmental, 2013).

The waters of Hay Point contain low turbidity, particularly during the winter months; however high turbidity is experienced during storm events (GHD 2005). NQBP is required to undertake water quality monitoring during dredging campaigns, which measure turbidity, light and sediment deposition. More recently, NQBP engaged James Cook University to undertake an extensive ambient marine water quality monitoring program. Loggers will be installed to monitor water quality 24/7 and a complete water quality analysis program will be undertaken on a quarterly basis with at least two survey events conducted prior to the commencement of dredging (NQBP, 2014).

Detailed impact monitoring will be undertaken for a period of four to six weeks around the actual dredging campaign, which provides detailed daily records. The water monitoring will continue for a period of 12 months after dredging is completed. There are 14 locations proposed for ambient monitoring and 25 locations where impact monitoring is proposed. James Cook University is also advising NQBP on the selection of three monitoring locations in the southern Whitsundays. NQBP also undertake a social impact study to cover fishing (commercial and recreational), diving and tourism (NQBP, 2014). With regards to inshore water quality, in a study conducted in 2000, water quality at Grendon and Sandfly Creeks and in

Lake Barfield was found to meet the ANZECC (2000) water quality guidelines.

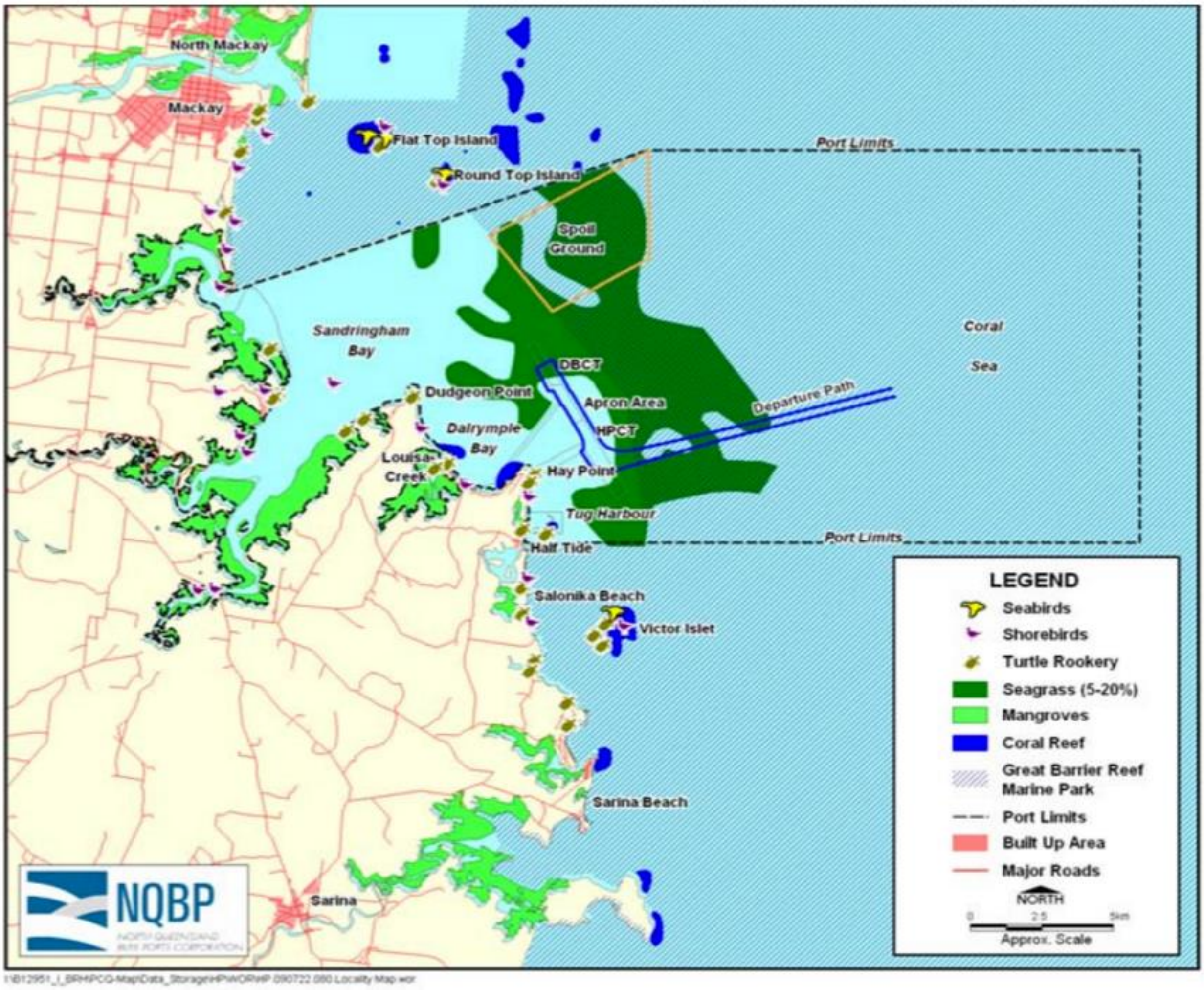

Figure 8. Port of Hay Point Marine Habitat Map (NQBP, 2009).

1.3.1 Environmental Values

Table 3 provides a list of the key sensitive receptors and communities previously reported at the Port of Hay Point, including a summary of known distribution and seasonal and temporal trends.

Table 3. Summary of environmental values distribution and temporal trends in the Port of Hay Point area.

Environmental Values	Distribution	Temporal Trends – Environmental Windows
HABITATS		
Seagrass Meadows	The most recent seagrass survey of the Port of Hay Point was conducted in 2011 (NQBP, 2011a). Two distinct seagrass habitats (coastal and offshore) were surveyed and two seagrass species (representing two families) were observed *Halophila decipiens* and *Halodule uninervis*. The offshore seagrass area was described	There was a marked decline in offshore seagrass meadows in 2011, compared to previous years. These large seagrass declines were reflected throughout much of the urbanised east coast of Queensland (Thomas et al., 2011). The seagrass surveys undertaken in July 2004, December 2005, October 2009, October 2010 and

	by light *Halophila decipiens* while the coastal meadows comprised *Halophila ovalis* and *Halodule uninervis*.	November 2011 (Rasheed et al. 2004b; Chartrand et al. 2008; Thomas and Rasheed 2011) reported that offshore seagrasses at the Port of Hay Point were naturally highly variable with peak abundances and distribution occurring in winter and spring before seasonal declines over summer. Seagrasses were absent from the survey area between December and June of each year (Chartrand et al. 2008).
Coral Reefs	Hard coral cover on the Islands and Inlet immediately north and south of the Port limits is generally lower than other fringing reefs in the GBR region and hence they were considered to be not regionally significant (Trimarchi and Keane 2007 in NQBP, 2009). The fringing reefs on the intertidal and subtidal platforms and inshore rocky shoals support sediment tolerant hard corals (URS 2000 in NQBP, 2009a).	NA
Macroalgal Beds	The macroalgal community was reported at very low per cent coverage (≤1%) in the Port of Hay Point survey area. The only functional group identified was erect macrophytic algae. Whilst not all species were identified, the most common types of erect macrophytes present were species of *Udotea*, *Sargassum* and other mixed red and brown macrophytes. These algae generally occurred on open sand/mud sediment with isolated benthic macro-invertebrates (Thomas and Rasheed, 2011).	The macroalgal community in 2010 was substantially reduced, compared to the baseline survey conducted in 2004 (Thomas and Rasheed, 2011). In 2004, low density macro-algae communities covered 80% of the survey area and were represented by species from four functional groups; however in 2010, macro-algae only formed 10% of the survey area and were represented by species from only one functional group, namely erect macrophytes (Thomas and Rasheed, 2011).
FAUNA		
Sea Turtles	Six species of turtles have been recorded utilising the offshore, intertidal, estuarine and shoreline habitats in the Hay Point area, these are Flatback (*N. depressus*), Green (*C. mydas*), Loggerhead (*C. caretta*), Leatherback (*D. coriacea*), Hawksbill (*E. imbricate*) and Olive Ridley (*L. olivacea*) (NQBP, 2009a).	Turtle nesting occurs between October and February, with the hatchlings emerging from January–March (NQBP, 2009a).
Dugongs	Small populations of dugong have been reported near Port Newry (north) and Ince Bay (20 km south), with areas of Llewellyn Bay and Ince Bay having been declared Dugong Protection Areas (DPA) under the Nature Conservation Act (NC Act) and the Fisheries Act 1994 (NQBP, 2009a).	NA
Cetaceans	Seven species of dolphins and five species of whales potentially occur in waters around Hay Point (NQBP, 2009a).	The Spotted Bottlenose Dolphin (Stenella attenuate) is considered likely to occur within the area and Humpback Whales (Megaptera novaeangliae) are present offshore from the Port

		between June and August (NQBP, 2009a).
Benthic fauna and epifauna	The nearshore sandy seabed region was dominated by open substrate with isolated benthic individuals including polychaete worms, gastropods and bivalves. The habitat forming benthic macro-invertebrate communities in the survey area were typical of those found in other deep water (>10m) areas between the Great Barrier Reef and mainland coast that have been surveyed (Rasheed et al. 2001; 2003; 2004; 2005 in Thomas and Rasheed (2011).	Benthic macro-invertebrate communities found in 2010 were similar to those found in 2004 and were typical of the types of communities commonly described in deep water (>10 m) areas between the Great Barrier Reef and mainland coast (Thomas and Rasheed, 2011).

1.4 Port of Mackay

The Port of Mackay coastal environment contains a complex array of coastal dune vegetation, freshwater wetlands, estuarine plant communities and rocky outcrops (**Figure 9**). Fields for agriculture and coal mining, as well as an established marina that accesses the main harbour channel, dominate the activities operating from the Port of Mackay.

The key habitats described in previous studies include seagrass meadows, mangroves and sub-tidal and intertidal soft sand and mud substrates (NQBP 2011). Sediment quality investigations have been undertaken at the Port of Mackay since 1993.

The results of the 2009 sediment assessment determined that contamination levels were below relevant screening levels with the exception of TBT detected within the berth pockets. Further elutriate and pore water analysis at elevated TBT locations determined that water quality would be unlikely to be impacted at the offshore disposal site and that TBT is also unlikely to be bioavailable to benthic infauna at the disposal site. As such, it was concluded that the maintenance-dredged sediment from all areas was suitable for unconfined sea disposal in accordance with the NAGD. Sediments within the Channel and Swing Basin Dredge Area were dominated by even portions of clay (38%) and silt (36%), with sand making up approximately 23%.

The Mackay Port Authority commenced a regular program of water quality monitoring in 1998, as part of its commitments under their adopted Environmental Management Plan (Aurecon, 2009a). The program noted periodic elevations in various metals and nutrient analyses within the harbour basin. It was suggested that no significant issues related to water quality were identified, due to tidal range and high flow within the harbour. Additional water quality data was collected in 2009 from the offshore disposal ground (WorleyParsons, 2009), which defined all metals apart from Zinc as non-detectable. For nutrients analysis, nitrate was the only component obtained from the disposal ground with reported levels (mean concentration of 0.032 mg/L) not compliant to the assessed water quality criteria.

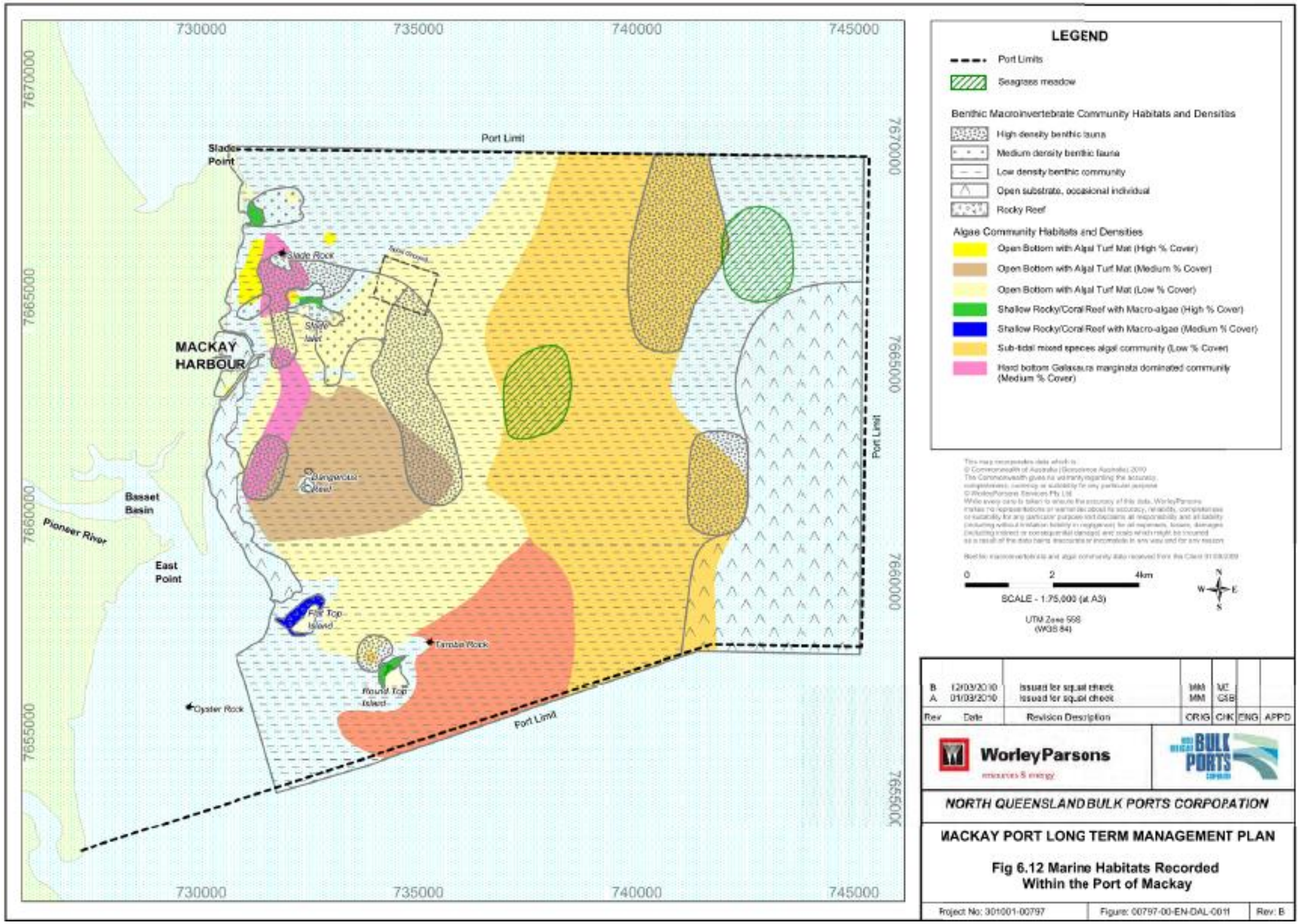

Figure 9. Mackay Ports Marine Habitats

1.4.1 Environmental Values

Table 4 provides a list of the key sensitive receptors in Port of Mackay, including a summary of their known distribution and temporal trends.

Table 4. Summary of environmental value distribution and temporal trends in the Port of Mackay area.

Environmental Values	Distribution	Temporal Trends – Environmental Windows
HABITATS		
Seagrass Meadows	The seagrass communities were first identified at Flat Top and Round Top Islands by Coles et al. (1987), which were suggested to be present in low densities (NQBP, 2011b). Rasheed *et al.,* (2011) observed additional deeper meadows at locations 3 km south east and 8 km east of the spoil ground. The offshore meadows were characterised by *Halophila decipiens*, while the more coastal community adjacent to round top island was found to be dominated by *Halodule uninervis* (wide)/ *Halophila ovalis* (Rasheed et al., 2011).	Seagrass surveys have been intermittently conducted throughout the Mackay region since 1987. Inter-annual variability in seagrass abundance was noted at the second meadow identified by Coles *et al*., (1987) which was located at the northwest of Flat Top Island. This meadow was not present in the February 2001 surveys with the seasonal and inter-annual variability typical of tropical regions suggested to be driving the absence (Rasheed et al., 2001).
Coral Reefs	Coral reef habitat has been mapped in several locations in the Port of Mackay area. (NQBP 2011). Fringing coral reefs at Slade Islet, Round Top Island, Flat Top Island and Victor Islet all exhibit similar species diversity and coverage. Notable species at the aforementioned locations include *Porites* colonies, *Macroalgae*, *Montipora* and *Acropora* corals. Hard and soft corals have also been recorded within Mackay Harbour along the seawalls, which provide hard substrate for colonisation (NQBP 2011b).	There is limited temporal data for coral reef communities in the Mackay Port region. Investigations into the impact of dredging works has documented some temporal stability at Slade Islet and Slade Rock (the two closest reefs to the disposal ground) with little impact reported at these sites during the 2006 capital dredging works or 2008 maintenance dredging program (NQBP 2011b). Victor Islet was observed to have a reduction in coral cover after 2006 activities, however no further reductions were identified in 2008.
Macroalgal Beds	Microalgae communities of *Sargassum* have been sparsely observed on the fringing coral reef and nearshore rocky reef areas in the vicinity of the Port of Mackay. At the existing spoil disposal ground, low densities of *maginata* have also been identified (Rasheed et al, 2001).	NA
FAUNA		
Sea Turtles	Four species of turtles that have been recorded utilise the area of Mackay as foraging grounds, these are Flatback (*N. depressus*), Green (C. mydas), Loggerhead (*C. caretta*), Leatherback (D. coriacea), Olive Ridley (*L. olivacea*) and Hawksbill (*E. imbricate*) (Limpus et al., 2013).	Turtle nesting season in Mackay occurs from the middle of October to early January with hatchling emergence continuing until April.

Dugongs	There are a number of Dugong Protection Areas in the Mackay region – Ince Bay, Newry region, Llewellyn Bay, Repulse Bay and Sand Bay. These areas are remote from the spoil ground. Seagrass is absent from the spoil ground and the areas directly surrounding it (Rasheed et al., 2001) and as such it does not constitute dugong foraging habitat.	NA
Cetaceans	The Indo-Pacific Humpback Dolphin (Sousa chinensis), the Australian Snubfin Dolphin (Orcaella heinsohni) are known to occur within the Port limits (Corkeron et al., 1997; Hale et al., 1998). The inshore (Tursiops aduncus) and offshore (Tursiops truncatus) forms of the Bottlenose Dolphin are also likely to occur in the surrounding estuaries and shallow offshore waters (Hale et al.,1998).	NA
Benthic fauna and epifauna	NQBP (2011b) identified that the dominant taxa within and adjacent to the offshore spoil ground were polychaete worms, although ascidians (sea squirts) were also abundant at the spoil ground. Tanaid and amphipod crustaceans were also amongst the most abundant taxa identified. Many taxa were represented by less than five individuals (NQBP, 2011b).	NA

1.5 Port of Abbot Point

Extensive environmental survey work has been performed at the Port of Abbot Point over the past decade, with the most recent work undertaken for the Abbot Point Growth Gateway Project Environmental Impact Statement (WorleyParsons, 2015). The port is located within the Great Barrier Reef World Heritage Area (GBRWHA), which encompasses the waters to the low water mark along the coastline in the region. The existing spoil ground is within the Marine Park and is also within Port limits and has been in use since 1982.

Middle Island and Thomas Island National Parks are located within Port limits and Gloucester Island National Park is located on the Port limit boundary. There is one listed Fish Habitat Area (FHA) within the Port of Abbot Point, Edgecumbe Bay FHA and a Dugong Sanctuary extends over most of Edgecumbe Bay and Port Denison. There are two wetlands of national importance located within the Port of Abbot Point, namely the Caley Valley Wetland Aggregation and Edgecumbe Bay Wetland. WorleyParsons (2015) describe the key environmental values of the surrounding marine environment, which include seagrass, soft bottom habitats, beaches and estuarine areas and these are illustrated in **Figure 10** and **Figure 11**.

The most recent water quality monitoring at Abbot Point was between February 2013 and June 2014 (WorleyParsons, 2014), which provided an up to date understanding regarding baseline marine water quality conditions. Wet seasons compared to dry seasons were characterised by higher sea temperatures, lower pH and DO and higher suspended solid concentrations (measured as turbidity). Sites located closest to freshwater inputs from local creeks and rivers exhibited the largest changes in salinities in the wet season. These sites also experienced the lowest pH values and largest ranges of DO concentrations (WorleyParsons, 2014).

Daily benthic light availability (photosynthetically active radiation, PAR) was higher in the wet season compared to the dry season. The increases in turbidity observed during the wet season which reduce PAR on the seabed, were offset by the longer days and more intense sunlight available to benthic organisms in this season (WorleyParsons, 2014).

The sediment properties of dredge material in the Port of Abbot Point have been analysed since 2004 for capital and maintenance dredging projects relating to the Port. The most recent sediment investigation was undertaken for Abbot Point T0, T2 and T3 capital dredging in 2012 (GHD 2012). Sediment samples were collected at 69 locations within the dredge footprint.

All TPHs, BTEX, pesticides (OCPs and OPPs), PCBs and total cyanide had concentrations less than the NAGD screening levels and the laboratory practical quantitation limits (PQL), indicating no anthropogenic sources of these contaminants within the dredging footprint (GHD 2012). All metal concentrations had 95% UCLs less than the NAGD screening levels and NEPM (1999) EILs and HIL A Guidelines (where applicable).

The sediments were found to be relatively homogenous in the 0 to 0.5 m depth interval, with less sand recorded in the T0 dredging footprint than in the T2 and T3 footprints. As depth increases to the deepest intervals between 3 and 4.5 m, clay and silt content increased and sand content decreased. Across the dredging footprint, sand (0.06-2 mm) was the predominant sediment type (54%), with high percentages of silt (2µm) and clay (<2µm) recorded (19% and 20% respectively) (GHD, 2012).

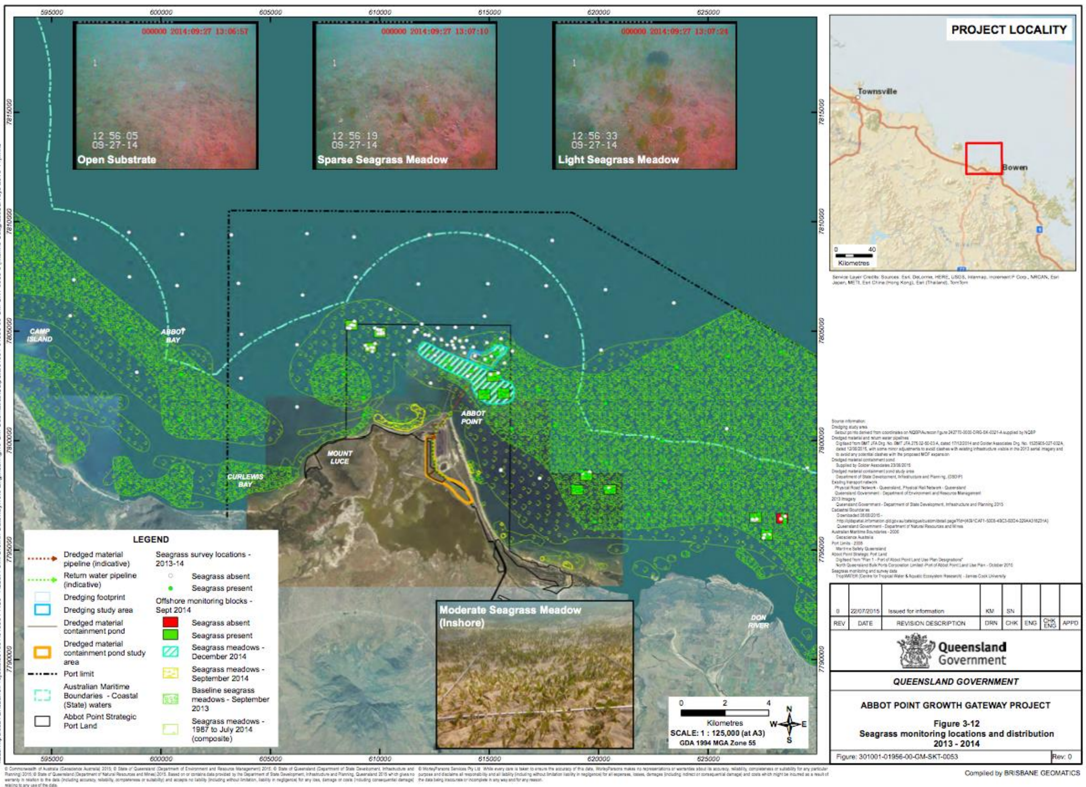

Figure 10. Abbot Point mapped seagrass distribution (Queensland Government, 2015).

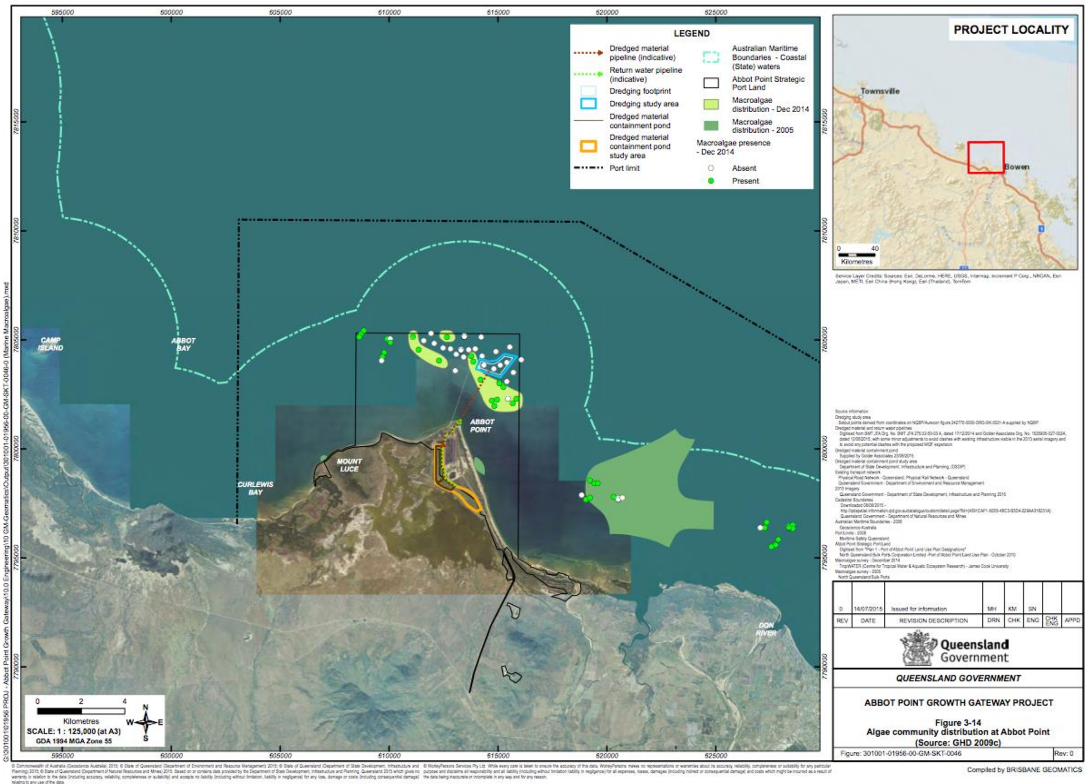

Figure 11. Abbot Point algal community distribution (Queensland Government, 2015).

1.5.1 Environmental Values

Table 5 provides a list of the key sensitive receptors and communities previously reported at the Port of Abbot Point, including a summary of known distribution and seasonal and temporal trends.

Table 5. Summary of environmental value distribution and temporal trends in the Port of Abbot Point area.

Environmental Values	Distribution	Temporal Trends – Environmental Windows
HABITATS		
Seagrass Meadows	Seven seagrass species have been identified within the Abbot Point region between February/March 2008 and September 2012 (McKenna and Rasheed, 2013). These include: *Halophila decipien, Halophila ovalis, Halophila spinulosa, Halodule uninervis Cymodocea serrulata, Cymodocea rotundata, Zostera capricorni.* Coastal meadows in the Abbot Point area generally consisted of isolated, aggregated patches of seagrass dominated by *Halodule uninervis*, although one meadow was dominated by *Zostera capricorni* (McKenna and Rasheed, 2013).	Prior to the La Niña related events of 2010/11 and severe Tropical Cyclone (TC) Yasi in February 2011, there was a broad seasonal pattern at Abbot Point for seagrass biomass and distribution to be at a minimum at the end of the wet season and a maximum in late spring/early summer. This trend is consistent with observations of seagrasses throughout Queensland (McKenna and Rasheed, 2013). Following the summer of 2010/11, significant losses in density and distribution of seagrasses at both coastal and offshore monitoring sites were observed. There is evidence of seagrass recovery at some of the deep water monitoring sites; however the coastal inshore meadows have not undergone any significant recovery (McKenna and Rasheed, 2013).
Coral Reefs	Cnidarians (soft and hard corals, jelly fish, anemones and hydrozoans) have been recorded throughout the Abbot Point area in very low densities (<10% coverage when recorded) (GHD, 2009a). Extensive hard and soft coral communities were reported growing on rocky outcrops surrounding Nares Rock and Camp Island. The most extensive coral communities were found offshore at Holbourne Island (GHD, 2009d). A similar species composition was recorded at sandy inshore locations that are consistent with the project area habitat (GHD, 2009d). These areas supported soft corals, sea pens, sub-massive corals, massive corals and mushroom corals. All corals observed were very small in size (<1 cm to 30 cm), often occurring as a single coral and were very sparsely distributed across the project area (less than one coral per ha) (GHD, 2009d).	NA
Macroalgal Beds	Macroalgal communities at Abbot Point have been identified as widespread, but patchy in distribution and typically with low	Findings indicate temporal variability in the presence of macroalgal species, with a shift in species composition observed between the 2005

	percentage cover. During surveys within the Port limits, GHD (2009e) detected algae in association with small patches of hard substrate, which were scattered across the area. Macroalgae recorded included (GHD, 2009e): • Nine green algae (phylum Chlorophyta); • Four brown algae (phylum Phaeophyta); and • Seven red algae (phylum Rhodophyta). The most commonly occurring algae were *Chondria spp., Peyssonnelia spp., Chaetomorphaspp., Acetabularia spp., Laurencia spp.* and a red filamentous alga (GHD, 2009e).	and 2009 surveys (GHD, 2009e).
FAUNA		
Sea Turtles	A 12-month study (GHD 2009d) indicated the most frequently observed turtles within the Port of Abbot Point were the green (Chelonia mydas) and the flatback (Natator depressus) turtles.	Turtles have been recorded in the area, with numbers peaking in the nesting period (November – February) (GHD 2009d). It is likely that the green turtle inhabits this area all year round, with varying abundance. The flatback turtle is likely to be a resident during the nesting period, as it generally feeds in the pelagic zone. GHD (2009d) reported the highest number of turtles in December. This month also recorded the highest species diversity.
Dugongs	Dugongs have been recorded in moderate numbers during boat-based surveys, primarily foraging within habitat associated with extensive seagrass meadow consisting of Halodule uninervis and Halophila spinulosa (GHD, 2008).	NA
Cetaceans	Some of the whales recorded in September 2008 in GHD (2008) appeared to use Abbot Point as a resting and possible calf feeding area, as whales were observed in the same location for a few hours. These observations suggest the deep water and the protected coastline of Abbot Point acts as an important refuge environment for some whales. Others were observed to swim past the area (GHD 2008).	Humpback whales were recorded in September 2008 (GHD 2008) and incidentally sighted in August 2008, which corresponds with expected seasonal migration patterns for breeding and calving.
Benthic fauna and epifauna	GHD (2009e) reported sedentary benthic macroinvertebrates during surveys of the Port limits. Ascidians were the most abundant, followed by echinoderms, molluscs, polychaetes and small crustaceans, concentrated around isolated patches of rubble and rock.	WorleyParsons (2014) reported that the dominant benthic invertebrate species from Abbot Point changed since the JCU survey 25 years ago; however the spatial findings of the earlier work is consistent with recent studies, which demonstrates that the patchy distribution of low diversity benthic communities at Abbot Point is a persistent condition of this area.

1.6 Port of Townsville

An EIS was completed for the Port of Townsville in 2012 to examine the opportunity to expand the existing Port (AECOM & BMT WBM, 2012). This EIS examined the marine ecology and described the existing marine flora, fauna and biodiversity values of environments in close proximity to the Port and the wider Cleveland Bay region. Seagrass, mangroves, saltmarsh, benthic algae, together with corals, represent benthic primary producer habitat (BPPH).

The Port of Townsville is adjacent to areas that contain matters of national environmental significance, including World Heritage Properties – specifically Great Barrier Reef World Heritage Area (GBRWHA), wetland of international importance – specifically Bowling Green Bay Ramsar site, Great Barrier Reef Marine Park – which includes most of Cleveland Bay, Commonwealth Marine Areas – which includes areas offshore of Cleveland Bay (BMT, 2012b).

Sediment quality was previously investigated as part of the Long Term Dredging and Disposal Management Plan and the 95% Upper Confidence Limits (UCLs) of most contaminants of interest were below the relevant screening levels (Port of Townsville, 2013). The exclusions were Cu and Ni in the Inner Harbour, where the 95% UCL of mean Cu and Ni concentrations exceeded NAGD Screening Levels. Phase III testing of these sediments indicated that the portion of total contaminants which are available to biota in sediment proposed for dredging, are present at less than the NAGD Screening Levels. Elutriate testing demonstrated that contaminants are predominantly bound to particulate material and only a small fraction of each contaminant would be released during dredging and disposal of the material. Toxicity assessments under Phase IV of the NAGD Dredge Spoil Assessment Framework for Ocean Disposal were not triggered. In the outer harbour there was an isolated detection of TBT exceeding the NADG trigger value, however 95% UCL was below the trigger. Overall all sediment were classified as acceptable for unconfined ocean disposal.

The more recent sediment quality observations summarised above are also consistent with the historical observation generated as part of the Port of Townsville Long Term Sediment Management Plan (Port of Townsville). Historical exceedances of Cu, Ni and Cr have been observed in the Inner Harbour (Berths 2, 7 and 8), and Port of Townsville and the relevant port users have adopted a precautionary approach by placing material from these areas on land.

Naturally high suspended sediment and turbidity can occur in Cleveland Bay due to its shallowness and the muddy nature of the central bay sediment facies and the wind regime and ensuing waves and swells (AECOM & BMT WBM, 2012). The suspended sediment concentrations vary spatially, with more turbid conditions in the Inner Harbour, compared to the Outer Harbour area. Generally, higher TSS concentrations are associated with strong winds and lower concentrations with calm conditions. Specifically, monitoring data has showed a correlation with sustained easterly wind and strong northerly winds >30 km/hr with an increased median turbidity at all sites monitored (AECOM & BMT WBM, 2012). Under suitable conditions low TSS can exist in the bay, and a natural range in the order of 4 to 30 mg/L can be expected.

In 2013, an assessment to provide supporting information to determine whether or not a referral is required under the Environment Protection and Biodiversity Conservation Act 1999, with respect to maintenance dredging activities, was completed (BMT WBM, 2013). This assessment was requested as part of an information request made by the Department of Sustainability, Environment, Water, Population and Communities, as part of its assessment of an application for a long term maintenance dredging and placement permit, under the Sea Dumping Act. The BMT WBM (2013) scope of work included assessment of water quality data and hydrodynamic modelling. There is no evidence to suggest that dredge-generated sediment plumes and subsequent deposition from the 2012 maintenance dredging campaign caused significant impacts to the GBRWHA, Natural Heritage Place, or GBRMP, or the values that underpin these matters of national environmental significance.

1.6.1 Environmental Values

Table 6 provides a list of the key sensitive receptors and communities previously reported at the Port of Abbot Point, including a summary of known distribution and seasonal and temporal trends.

Table 6. Summary of environmental values distribution and temporal trends in the Port of Townsville area.

Sensitive Receptor	Distribution	Temporal Trends – Environmental Windows
HABITATS		
Seagrass Meadows	A range of studies has investigated the seagrass communities of Cleveland Bay. To date, eight species of seagrass have been recorded in Cleveland Bay (Rasheed and Taylor 2008), namely Zostera muelleri, Halodule uninervis, Syringodium isoetifolium, Cymodocea serrulata, Halophila spinulosa, Halophila ovalis, Halophila decipiens and Thalassia hemprichii. (**Figure 12**). Cleveland Bay contains some of the most extensive and diverse seagrass meadows in north Queensland. Seagrass meadows in Cleveland Bay have high ecological significance in the context of providing habitat for a range of species of fisheries significance, and the provision of food resources for the threatened dugong and green turtle.	Monitoring studies indicate that the distribution, extent and density of seagrass assemblages within Cleveland Bay can show great variation over a range of temporal scales (particularly seasonally and inter-annually) in response to variations in a range of environmental factors (Rasheed and Taylor 2008; McKenna and Rasheed 2012). In particular, it is thought that high suspended sediment concentrations resulting from wave driven bed sediment remobilisation (together with runoff) are key drivers of temporal change in seagrass meadows. Seagrass growing season is similar to other QLD regions, with maximum growth rates in the warmer months (October to March) and senescence during the cooler months (April to September).
Coral Reefs	Based on mapping from the GBRMPA Gazetteer, the total area of reef habitat within Cleveland Bay is approximately 987 hectares (**Figure 13 & Figure 14**). Reef habitats in Cleveland Bay include shallow fringing reefs and rocky shores around Magnetic Island; the well developed reef platform of Middle Reef; and smaller, less developed reef areas between the mainland and Magnetic Island (e.g. Virago Shoal) (AECOM & BMT WBM, 2012).	There is extensive temporal data assessing the changes on coral cover and conditions (i.e. Middle Reef, Magnetic Island). The coral communities respond to high turbidity - which controls the composition and structure of corals communities, freshwater inundation and runoff - low salinity, together with high levels of nutrients and turbidity, can lead to stress and mortality of corals, and bleaching - typically occurs in response to high water temperatures, and appears to represent a key agent of change at Middle Reef (BMT, 2012b). Coral spawning occurs during the warmer months of the year between November and March (AECOM & BMT WBM, 2012).
FAUNA		
Sea Turtles	Six species of marine turtle are known to use Cleveland Bay as a feeding ground including loggerhead turtle (Caretta caretta), green turtle (Chelonia mydas), hawksbill turtle (Eretmochelys imbricate), olive ridley turtle (Lepidochelys	Cleveland Bay is not an important turtle breeding area, with most turtles in the Bay believed to have originated from rookeries elsewhere on the central and north Queensland coast and islands, or in other

	olivacea), flatback turtle (Natator depressus), leatherback turtle (Dermochelys coreacea). These species have been recorded in offshore, nearshore and intertidal habitats within Cleveland Bay (BMT WBM, 2012b). Green turtles are the most abundant turtle species within Cleveland Bay, which based on surveys undertaken in 2000 (Preen 2000), accounted for over 90% of the total abundance in the Bay.	countries (BMT WBM, 2012b). The exceptions to this are flatback and green turtles. Low density nesting for these species has been reported on a number of sandy beaches adjacent to the study area and surrounds, including Magnetic, Herald and Rattlesnake Islands, the Strand and AIMS beach (GHD 2009f). In terms of habitat use, there is little scientific data available. The Townsville region was identified as a hot-spot for strandings in 2011, with 262 marine turtle stranding's compared to 35 (2008), 44 (2009) and 93 (2010) turtles in the period 2008 to 2010 (BMT WBM, 2012).
Dugongs	Dugongs are abundant in Cleveland Bay and the Bay is thought to be an important dugong habitat at a regional scale (Sheppard 2007). Aerial survey data collected in 2008, 2010 and 2011 was modelled by James Cook University to determine relative density of dugong habitat use in Cleveland Bay (GHD, 2011). Whilst dugongs are most abundant around dense seagrass meadows, it is apparent that they move throughout Cleveland Bay, as they move between feeding sites (seagrass meadows) (**Figure 15**).	Food resource availability is thought to be a key control on dugong populations. The loss of seagrass meadows has been implicated as the major cause of dugong strandings in the region (BMT WBM, 2012). Dugong stranding reports for the GBR increased from an annual average of 63 per annum in the period 2008-2010 (BMT WBM, 2012b). It is apparent that dugong population resilience was markedly reduced because of the 2011 floods (BMT WBM, 2012b). Dugongs also breed in Cleveland Bay. While dugongs breed year round, mating and calving tend to peak in spring and summer, particularly at high latitudes (BMT WBM, 2012).
Cetaceans	Australian snubfin dolphins (*Orcaella heinsohni*) and Indo-Pacific humpback dolphins (*Sousa chinensis*) are common in nearshore environments throughout Cleveland Bay, and are likely to regularly feed in the Port area. The estimate for the Australian snubfin dolphin "sub-population" in 2002 in Cleveland Bay was 63 individuals (95% confidence interval = 51-88) (Parra et al. 2006a,b). These dolphins are opportunistic feeders, and the area near the entrance of the Townsville Harbour has been identified as an important habitat (**Figure 16**). Humpback whales (*Megaptera novaeangliae*) are not commonly present in the waters of Cleveland Bay, however they have been observed (BMT WBM, 2012b).	There is no quantitative understanding of dolphin and whale population trends in Cleveland Bay.
Benthic fauna and epifauna	Sparse and patchy epibenthic communities occurred throughout the study area and surrounds examined in the EIS (AECOM & BMT WBM, 2012), and were comprised of occasional hydrozoan and soft coral colonies to completely bare substrates. The community structure within the disposal ground has been studied in more detail as part of the sea disposal permitting process.	Temporal survey of benthic fauna across the region is not available. However, surveys of benthic macroinvertebrates and epibenthic fauna (e.g. GHD 2008b) show that the current disposal ground has been recolonised between dredging campaigns. Furthermore the species composition is similar to that present in sediment adjacent to the disposal ground. Cruz Motta (2000)

	Fifteen Phyla from 103 families and 207 species were recorded in Cruz Motta's (2000) research. The fifteen Phyla were as follows: *Annelida; Ectoprocta; Chaetognata; Foraminifera; Chelicerata; Mollusca; Chordata; Phoronida; Cnidaria; Platyhelmintes; Crustacea; Porifera; Echinodermata; Sipunculida and Echiura;*	found that the current disposal ground could be recolonised in less than three months from disposal of dredge material.

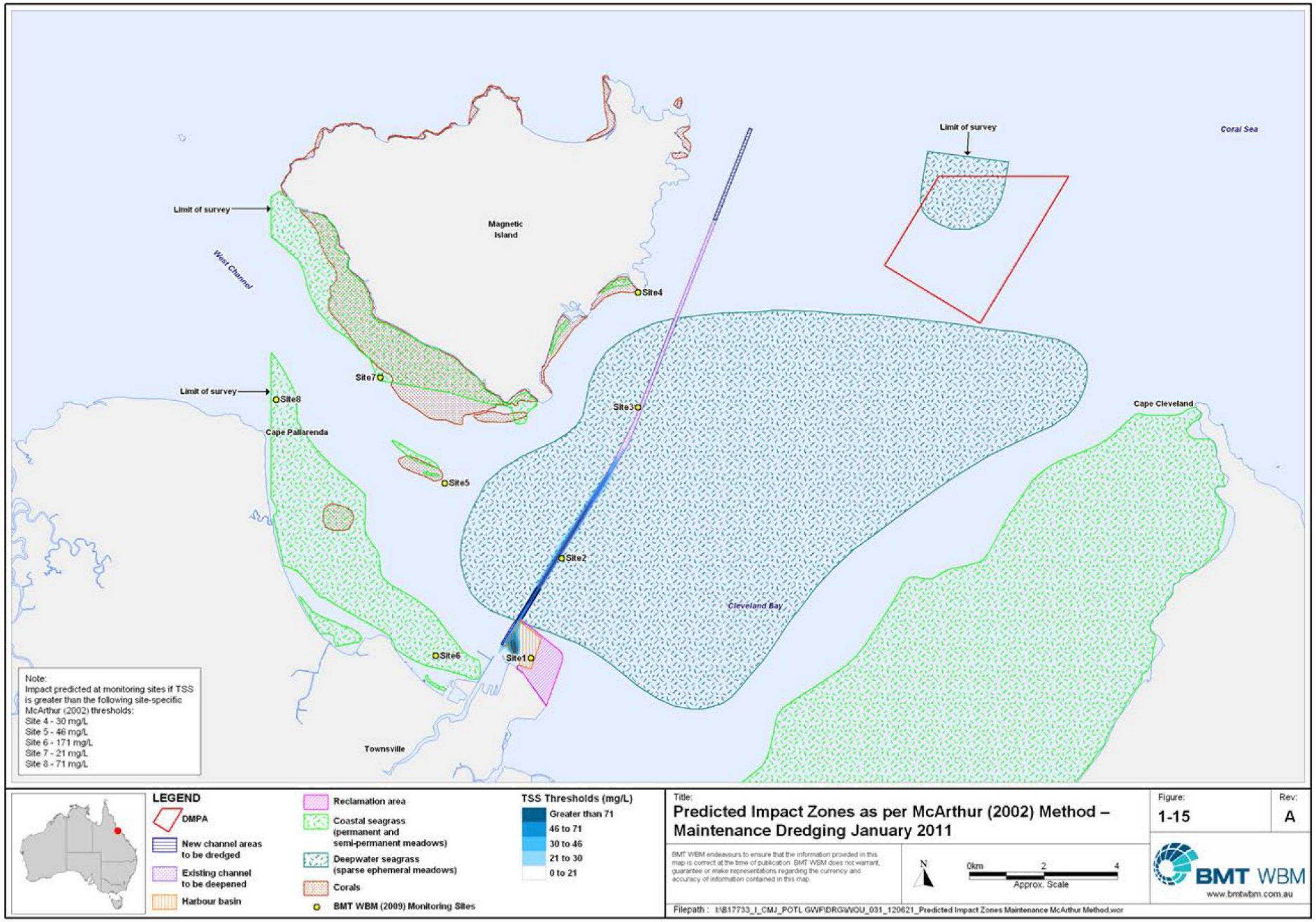

Figure 12. Seagrass distribution in Cleveland Bay, Townsville. With predicted impact zone from maintenance dredging in 2011 (BMT, 2010).

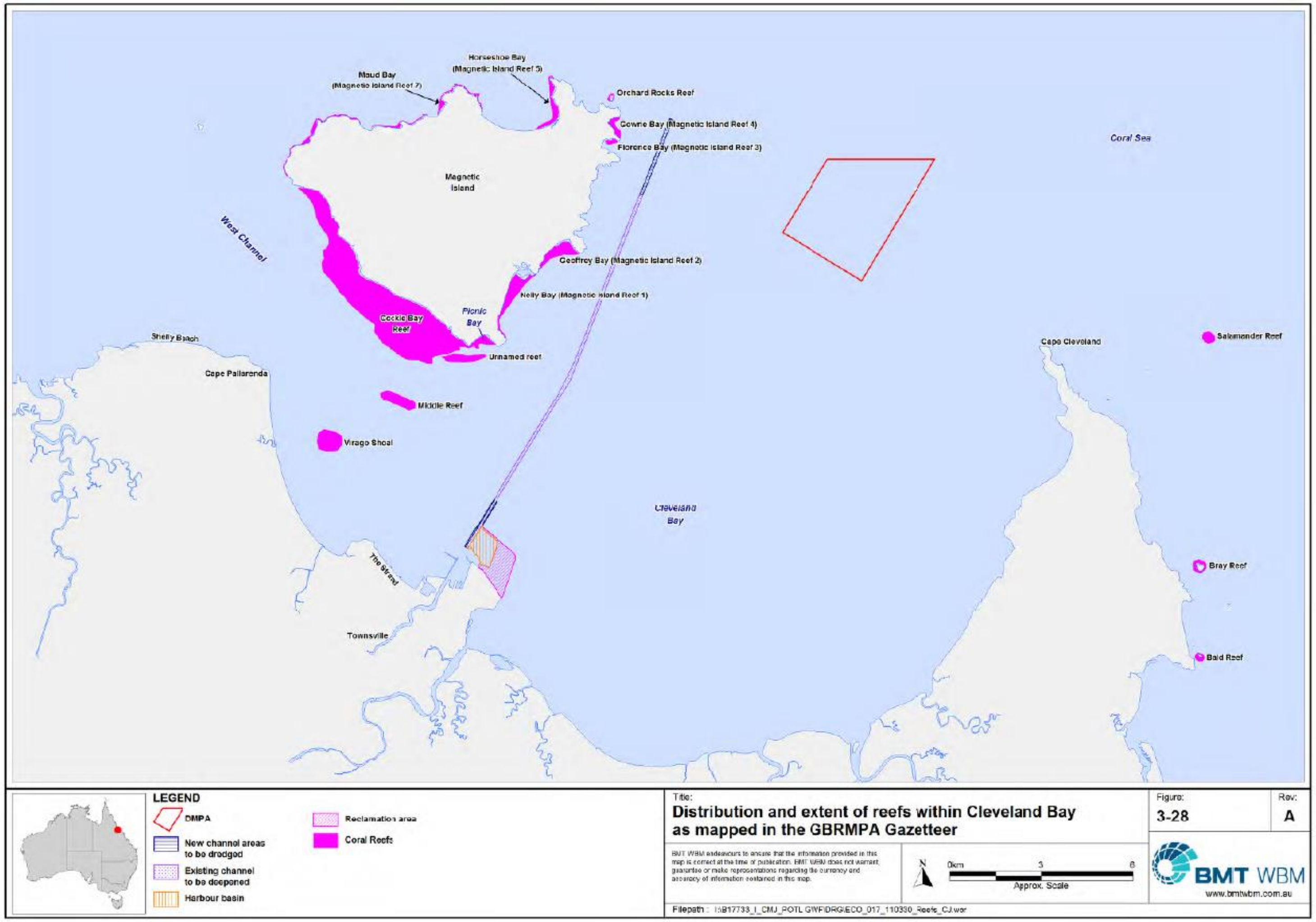

Figure 13. Coral distribution in Cleveland Bay, Townsville (BMT WBM, 2010).

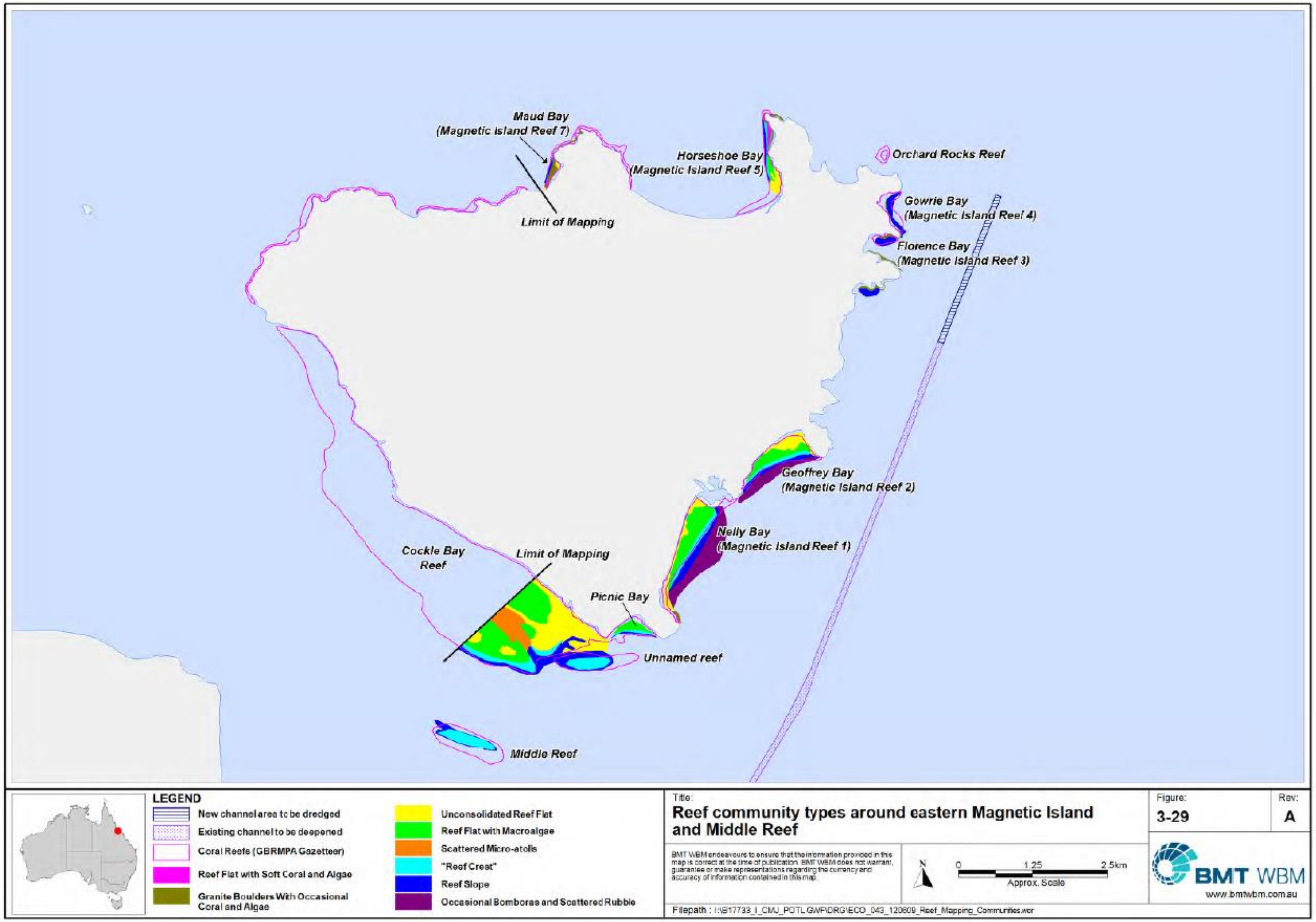

Figure 14. Common reef communities around eastern Magnetic Island, Townsville (BMT WBM, 2010)

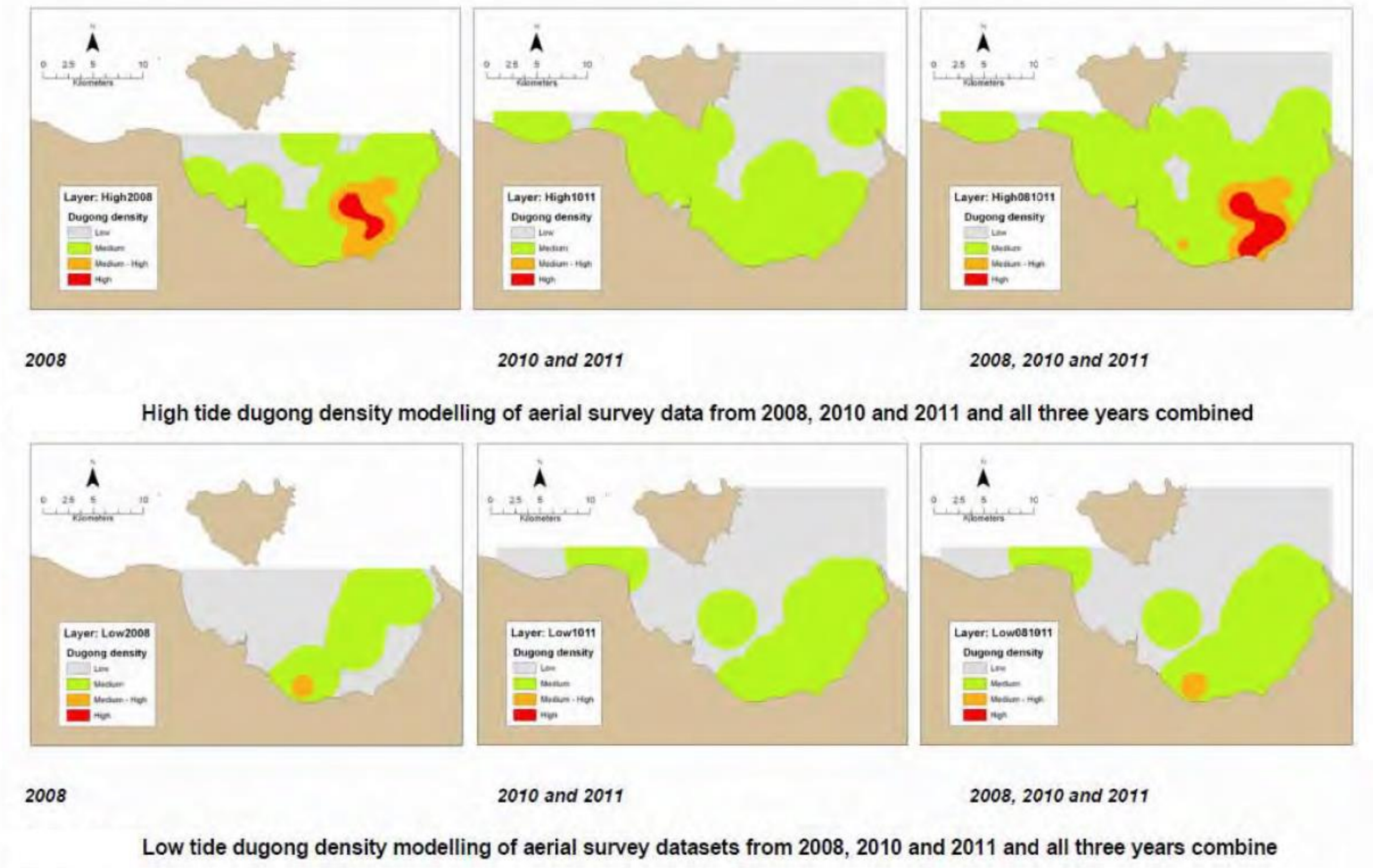

Figure 15. Dugong relative density during high and low tide survey (GHD, 2011).

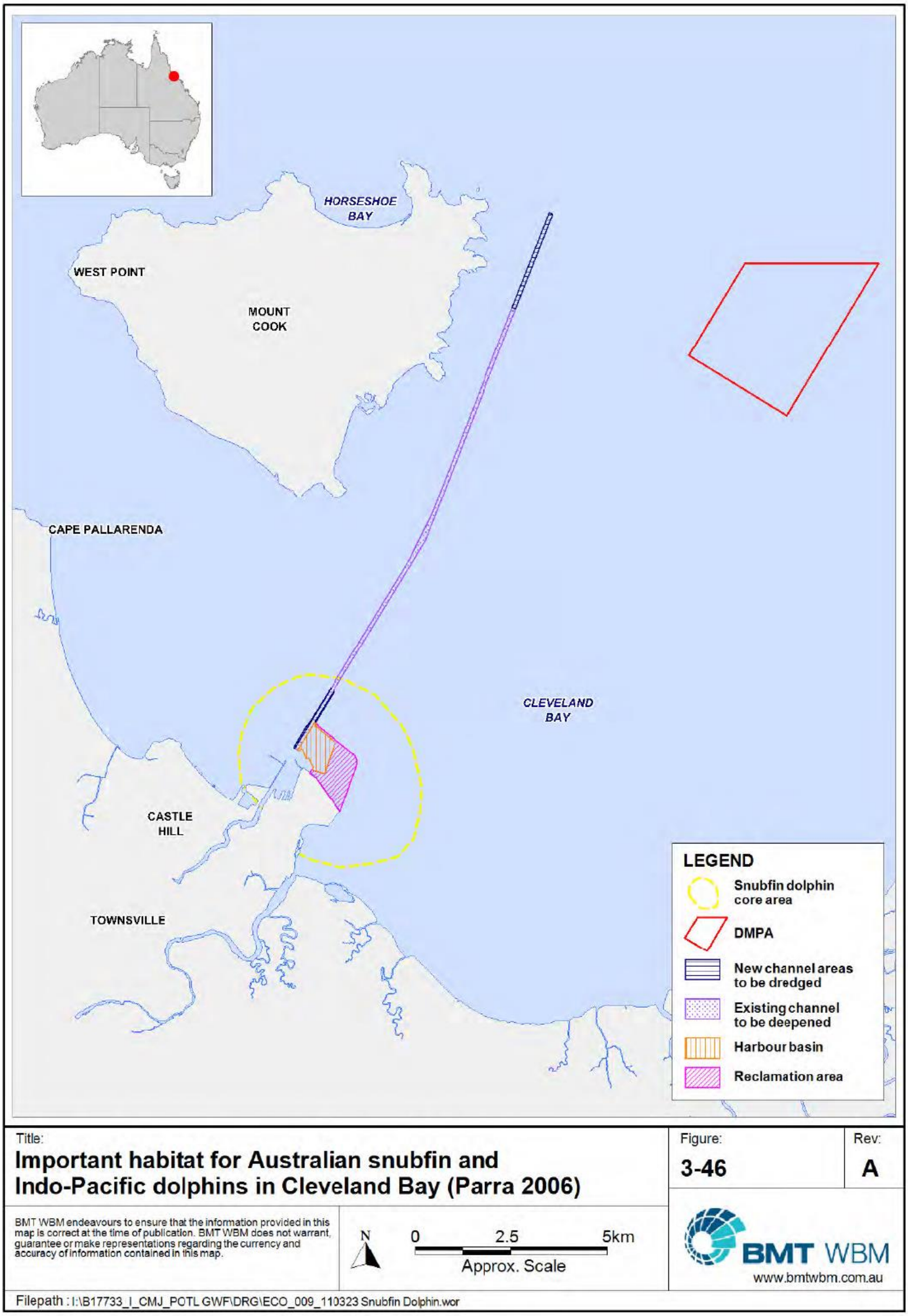

Figure 16. Important habitat for Australian snubfin and Indo-Pacific dolphins in Cleveland Bay (BMT WBM, 2010)

1.7 Port of Cairns

A significant amount of environmental data has been collected over the past decade in the Port of Cairns and most recently an Environmental Impact Assessment (EIS) was conducted for the Cairns Shipping Development Project (Ports North, 2014). Annual seagrass monitoring has also been undertaken in Cairns Harbour and Trinity Inlet since 2001, following a baseline assessment of the marine habitat within the Port limits. The most recent survey was for the Cairns Harbour and Trinity Inlet annual seagrass monitoring program and baseline survey work for the EIS, conducted between October 2012 and January 2013 (Rasheed *et al*., 2013).

WorleyParsons (2010) describe the key habitats adjacent to Port of Cairns operations, dredging, and disposal activities, as comprising seagrass meadows, mangrove communities and subtidal and intertidal soft sediment and mud substrates (**Figure 17**). Carter *et al.* (2002) documents the nearest fringing reefs to the Port of Cairns as occurring at Green Island, which is approximately 35 km offshore of the Port of Cairns.

Turbidity data from the inner port area since 2001 has recorded a mean surface turbidity of 18 NTU, increasing with depth to approximately 30 NTU and maximum turbidities were recorded between 200-300 NTU, with a peak of 700 NTU. Sediment sampling from within the inner harbour completed between 2001 and 2008 confirms an overall compliance to median zinc, chromium and cadmium guideline concentrations set out in ANZECC/ARMCANZ, 2000. Concentrations of copper, lead and TBT however, remain above guideline criteria. These findings are indicative of pollutants often associated with port operations and vessel repair facilities (WorleyParsons, 2010).

The Port North EIS reported the Inner Port sediments as generally characterised by high proportions of silt (mean 46.8%) and clay (mean 36.9%) and the Outer Channel sediments were characterised by high proportions of silt (mean 54.8%) and clay (mean 33.9%) (Ports North, 2014). Sandy and gravelly sediments contributed 10.1% and 1.3% on average, respectively. The geochemical characteristics of the sediments in both Inner Port and Outer Channel subareas were found to be suitable for ocean disposal in accordance with the NAGD (Ports North, 2014).

Ports North undertakes pest species surveys in the marine park annually for target marine pest species, given the history of detections within the port and difficulty and uncertainty of identifying perceived resident populations (WorleyParsons, 2010). In addition, spoil ground sled tows in 2014 and 2019 are documented in the Cairns Ports Long Terms Dredge Management Plan as required when pest species are reported in sediments. Ports North also undertake turbidity monitoring around the TSHD, under various tidal states during the dredging program, and target dredging in the vicinity of significant seagrass beds adjacent to the channel (WorleyParsons, 2010). In addition to the annual seagrass monitoring, as part of recent enhancements to the monitoring program, benthic light and temperature assessments were implemented in March 2013 at four locations in Cairns Harbour (Rasheed *et al*., 2013).

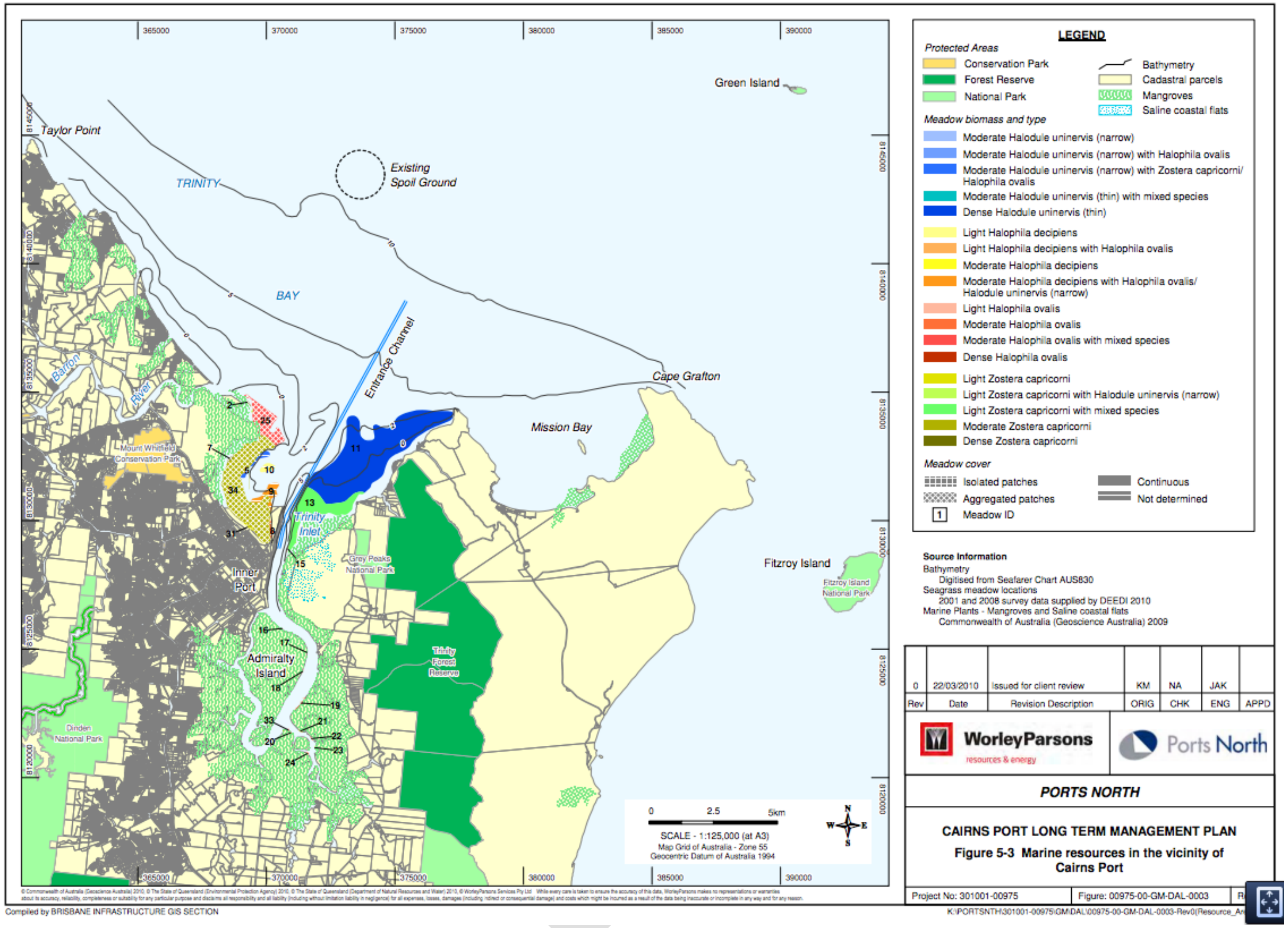

Figure 17. Port of Cairns Marine Habitat

1.7.1 Environmental Values

Table 7 provides a list of the key sensitive receptors and communities previously reported at the Port of Cairns, including a summary of known distribution and seasonal and temporal trends.

Table 7. Summary of environmental values distribution and temporal trends in the Port of Cairns area.

Environmental Values	Distribution	Temporal Trends – Environmental Windows
HABITATS		
Seagrass Meadows	A total of seven seagrass species have been recorded in Cairns Harbour and Trinity Inlet across all surveys (1984, 1988, 1993, 2001-2012), four of which were identified in 2012, namely *Halodule uninervis, Zostera capricorni, Halophila decipiens, H. ovalis* (Rasheed *et al*., 2013).	Following the La Niña-related events of 2010/11 and severe TC Yasi in February 2011, total seagrass meadow area and mean above-ground biomass in Cairns Harbour and Trinity Inlet has declined to the lowest recorded values since annual monitoring began in 2001 (**Figure 18**) (Rasheed et al., 2013). The species composition of Cairns Harbour and Trinity Inlet meadows has also remained largely consistent across all baseline surveys. By 2012, however, there was a considerable loss of *Zostera capricorni* from Cairns Harbour and Trinity Inlet (Rasheed et al., 2013). At seasonal scales, seagrass meadows in nearshore waters of the Great Barrier Reef region typically display a seasonal growth cycle in intertidal and shallow subtidal seagrass meadows (Waycott et al. 2005; Unsworth et al. 2009), with higher percentage cover of seagrass in late spring-summer than winter (Ports North, 2014).
Coral Reefs	No low-lying rocky reef or fringing coral reefs were found to be present in the harbour. Exposed rock substrate comprised entirely of massive boulders and rocky shore outcrops within the intertidal zone. Autotrophic species (i.e. hard corals) were poorly developed in the harbour and were primarily comprised of small, isolated colonies (Ports North, 2014). Further afield, Double Island (Double Island and Haycock Reefs: GBR Gazetteer number 16-047 and 16-048) contains a narrow fringing reef to the north and an extensive reef platform to the south, and has a total mapped area of 185 ha. This represents the largest reef in the broader area (Ports North, 2014).	NA

	The only reefs and rocky shores mapped by the GBRMPA Gazetteer south of the Port of Cairns are Rocky Island Reef and an associated unnamed fringing reef in Mission Bay (Ports North, 2014).	
Macroalgal Beds	The rocky shores surrounding False Cape provide a more substantial subtidal habitat than East Trinity, with continuous rocky shores along a steeper shoreline profile. A variety of macroalgal species including *Halimeda* and *Sargassum* dominated the lower intertidal area, with much of it covered in a thick turf of algae, encrusting sponges and bryozoans.	NA
FAUNA		
Sea Turtles	Marine turtles have been recorded in offshore, near-shore and intertidal habitats within the Port of Cairns. These species primarily use the area as a feeding ground, as well as a transit area between other parts of the Queensland coast and the Great Barrier Reef (Ports North, 2014). Low density nesting occurs across the region, including Green and Flatback turtles (Limpus 2008).	Green turtles are historically the most common marine turtle species in the study area, but in recent years, since Tropical Cyclone Yasi in 2007, there has been increased strandings and mortality for this species (Ports North, 2014).
Dugongs	Ports North (2014) report the targeted surveys by Marsh and Saalfeld (1990) which confirmed that the dugongs recorded in the Cairns area were sighted close to inshore seagrass beds. While dugongs can be common in Trinity Bay, it is thought that current population numbers are low due to the reduction in the extent and condition of local seagrass meadows (Ports North, 2014).	NA
Cetaceans	The two threatened dolphin species likely to occur within the vicinity of the Port of Cairns, include the Snub fin, Orcaella heinsohnri and Indo-Pacific humpback dolphins, Sousa chinensis. The Indo-Pacific humpback dolphin is occasionally recorded from the Cairns area in low numbers on the StrandNet database, with a total of four strandings from 2008 to 2010. Indo-Pacific Humpback dolphins have also recently been sighted in the project area, including two individuals at the marina in Trinity Inlet in November 2013 and two individuals swimming in shallow waters off Ellis Beach in September 2013 (Ports North, 2014).	Large numbers of whales are sighted off Cairns each winter (Ports North, 2014).

	The waters surrounding Cairns were reported to have moderate environmental suitability for humpback whales, compared to the highly suitable waters offshore from Mackay (Ports North, 2014).	
Benthic infauna and epifauna	Ports North (2014) report epibenthic communities were sparse and patchy throughout the Port of Cairns. In total, 11 fauna taxa were recorded consisting of 64 animals, without seagrass or macroalgae. The inner channel community was dominated by polychaetes (glycerids, maldanids, and capitellids) and tellnid bivalves, the outer channel was characterised by tellnids and amphipod crustaceans (Ports North, 2014). The coastal sites were characterised by large numbers of marine worms (spionids, orbininids, nemerteans) and amphipods, inshore sites were dominated by amphipods, mid-shore sites by amphipods and sea pens, while the offshore sites had large numbers of crustaceans (tanaids, amphipods, callianassids ghost shrimp) and maldanid polychaetes (Ports North, 2014).	All of the infauna community trends observed were reasonably consistent between wet and dry seasons, albeit with greater variation between sites in the wet season than during the dry season (Ports North, 2014).

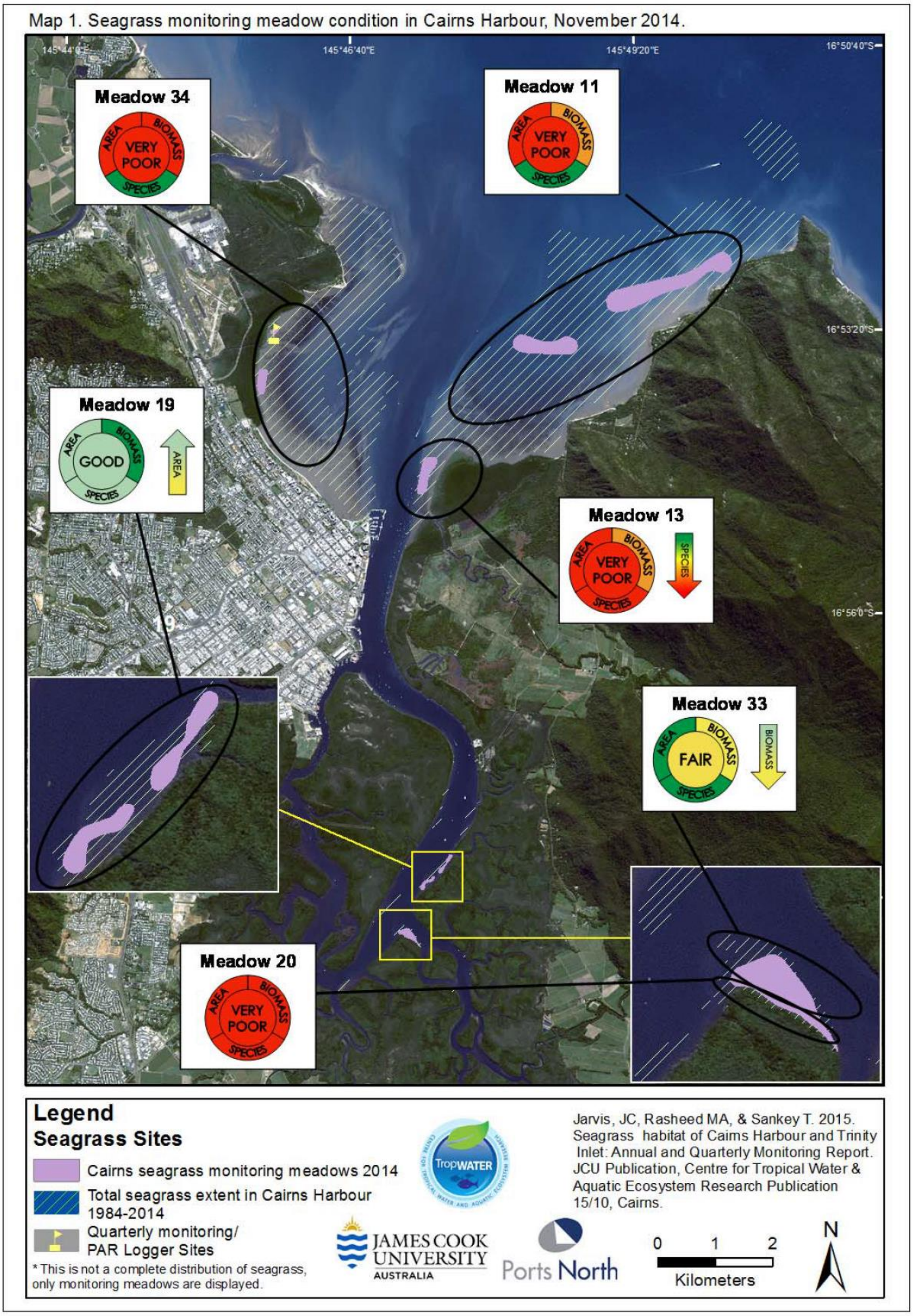

Figure 18. Cairns Harbour and Trinity Inlet seagrass total extent and recent condition classification (Jarvis et. al., 2014)

1.8 Port of Cooktown

The Port of Cooktown is the located on the Eastern Cape York region and as a result the stability of ecological communities are largely influenced by seasonal monsoon events. The primary habitat in the nearshore environment consists of seagrass, coastal dunes, mangroves and saltmarsh communities (TMR 2014). Since the original harbour dredging of the Port in 1997 a number of intermittent benthic flora and fauna monitoring surveys have been conducted.

WMB (1995) undertook a baseline EIA which identified moderate density seagrass throughout surrounding sub-tidal areas and fringing mangroves along the Cooktown foreshore (**Figure 19**). Many of these identified communities have been further characterised in subsequent surveys in 2003, 2006, 2007 and 2011 (McKenzie et al., 2007; GBRMPA, 2012). Benthic infauna assessments have been undertaken in the Port and surrounding subtidal areas. The composition of infauna in the Cooktown region is dominated by opportunistic species due to the seasonal instability of the region (WMB 1995), with temporal trends reflective similar patterns of diversity (FRC 2000). Additionally, it was suggested that the overall distribution of benthic infauna was likely to be driven by sediment grain size (FRC 2000).

The physical sediment properties throughout the endeavour river are typical of those to North Queensland. The key features across all sites surveyed include; non-cohesive fine and medium sands; coarser sand in shallow exposed areas; finer stand in deeper waters; and a monitor component of very find salt and silts (WMB 1995). Sediment sampling and analysis of the Endeavour River found all contaminant levels to be below the LOR (Coffey, 1999).

Turbidity data from the inner port area in 1995 for two weeks, recorded large variations in turbidity, ranging from 0 to 55 NTU (WMB 1995). The fluctuations in turbidity were attributed to wind and wave induced mixing. Water quality at the Port of Cooktown was suggested to be high and defined by low nutrients, chlorophyll a and phaeophytin levels. Ammonia and nitrate were the only two analytes recorded above the ANZECC threshold at some sites. High ammonia concentrations (up to 4.5µg/l) were noted near the river mouth, while no trends could be correlated among sites containing excess nitrogen.

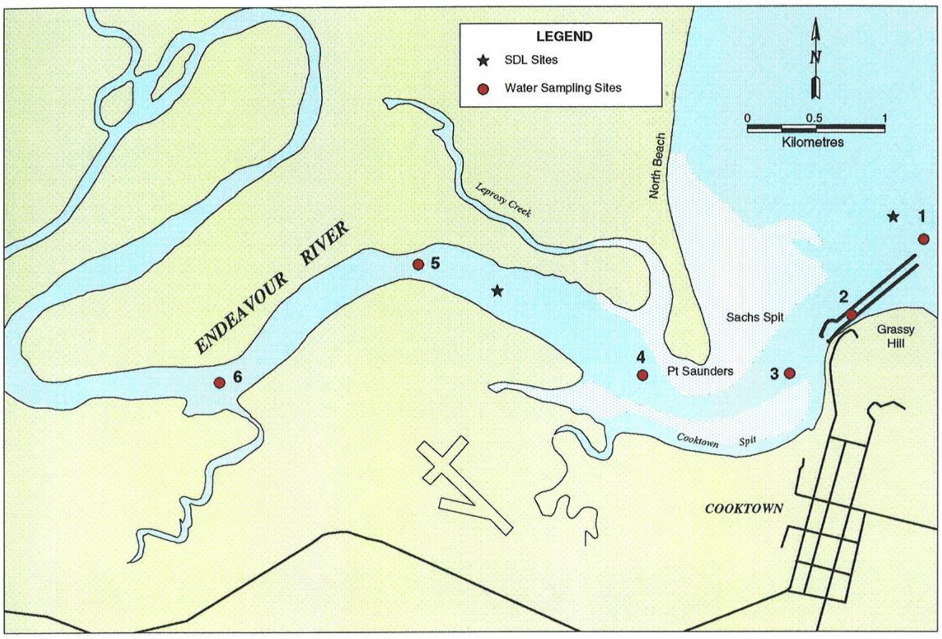

Figure 19. Water quality sampling sites within the Endeavour River undertaken by WMB (1995).

1.8.1 Environmental Values

Table 8 provides a list of the environmental values and communities previously reported at the Port of Cooktown, including a summary of known distribution and seasonal and temporal trends.

Table 8. Environmental Values for the Port of Cooktown.

Environmental Values	Distribution	Temporal Trends – Environmental Windows
HABITATS		
Seagrass Meadows	Cooktown is composed of two different intertidal communities of seagrass located near archer point. The primary community is dominated by *H. univervis/ H. ovalis* with *Cymodocea/T. hemprichii* and the second composed of *H. univervis/H. ovalis* with *C. rotundata* (McKenzie et al., 2007; GBRMPA, 2012). In 2005 a seagrass survey of the Endeavour River identified spare patches of *H. ovalis* in Chinamans creek and dense patches on the northern intertidal banks of the river (McKenzie and Yoshida, 2014). *Zostera capricorni* was also observed on the exposed banks and narrow intertidal banks known as Sash's Spit (McKenzie and Yoshida, 2014), on the southern banks of the endeavour river since 1985. There is no consistent monitoring north of Cooktown, but aerial surveys in the Princess Charlotte Bay region supports other evidence that seagrass in the northern Great Barrier Reef is stable (GBRMPA, 2012). BMT WBM (2010) presented a summary of key environmental values and a water quality monitoring program as part of a long term Dredge Strategy (**Figure 20**). Seagrass communities observed by GHD (2006) in the north-eastern corner of the DMPA were found to be of moderate density, composed of Zostera capricorni and Halodule uninervis in an area of approximately 10m^2 (BMT WBM, 2010).	Since 2003 seasonal variability has been observed within the *H. uninervis* and *H. ovalis* beds south of Cooktown ranging from 20% in winter to 35% in spring. Annual declines have also been noted in assemblages between 2003 and 2006 surveys as well as between 2009 and 2011, although the decadal trend is suggested to be relatively stable (McKenzie et al., 2007; GBRMPA, 2012).
Coral Reefs	Cooktown has a number of inshore reefs (starting ~15km from the Cooktown) which are primarily composed of hard coral (40.4%) and algae (41.5%), with a ~5% soft corals. The dominant coral assemblages are *Acroporidae, Favidae, Pocilloporidae* and *Poritidae* (Sweatman et al., 2008).	There appears to be no long-term trends with most fluctuations driven by increases or decreases in in the abundance of hard coral (Sweatman et al., 2008).
Macroalgal Beds	NA	Macroalgae generally increases in spring/early summer, but has remained well below the GBR long-term average for reef habitat since 2006 (McKenzie and Yoshida, 2014).
FAUNA		
Sea Turtles	Loggerhead, Green, Flatback and Hawksbill turtles are known to inhibit the area (Garcon et al., 2010). The Hawksbill is regularly found in the Howick reef	NA

	group to the north of Cooktown (Bell et al., 2012).	
Dugongs	The World Heritage Area has been subdivided into two parts: north of Cooktown and south of Cooktown. North of Cooktown, surveys were carried out in 1984, 1985, 1990 and 1995, suggesting that Cooktown may represent a population break (Env 2015). The extensive seagrass meadows north of Cooktown and lack of anthropogenic influences in the region are suggested to allow dugong populations to persist in strong numbers (Marsh et al., 1995).	Dugong numbers have declined significantly in recent years possibly as a consequence to both natural and human-induced changes to the health and ecology of seagrass beds. From 1984 to 1995 the northern dugong population was stable, with the minimum population estimate from 1995 being 8190 (+/- standard error of 1172) dugongs (Marsh et al., 1995; Env 2015).
Cetaceans	A number of inshore dolphins are have been recorded in the Cooktown area including; Australian snubfin (*Orcaella heinsohni*), Indo-Pacific humpback (*Sousa chinensis*) and Bottlenose dolphin (*Tursiops truncates / aduncus*) (Fisheries Queensland, 2011). The dwarf minke whale, *Balaenoptera acutorostrat* is a migratory whale species that is also known to frequent the offshore area off Cooktown, particularly Lizard Island (Britles et al., 2008; 2014).	Swim-with-whale operators in the area have undertaken ongoing monitoring of B. acutorostrat populations. The Ribbon 9/10 reefs north of Cooktown account for the majority of sightings for the species along the east coast of Australia (Britles et al., 2008; 2014). The number of encounters increased by 90% from 2003 to 2008, which are likely a reflection of increased visitation and knowledge on occurrence (Britles et al., 2008; 2014).
Benthic infauna and epifauna	The Port of Cooktown is characterised by unstable, highly turbid waters that is driven by the seasonal monsoon rains that are reflective of benthic fauna identified (FRC 2000, WMB 1996). Benthic fauna investigations undertaken by FRC (2000) identified a lack of sponges and soft coral. The benthic infauna surrounding the Port of Cooktown and spoil ground is dominated by opportunistic species such as polychaete's and amphipods (FRC 2000; WMB 1996).	There appears to be no noticeable qualitative changes between historic infauna investigations (FRC 2000, WMB 1996).

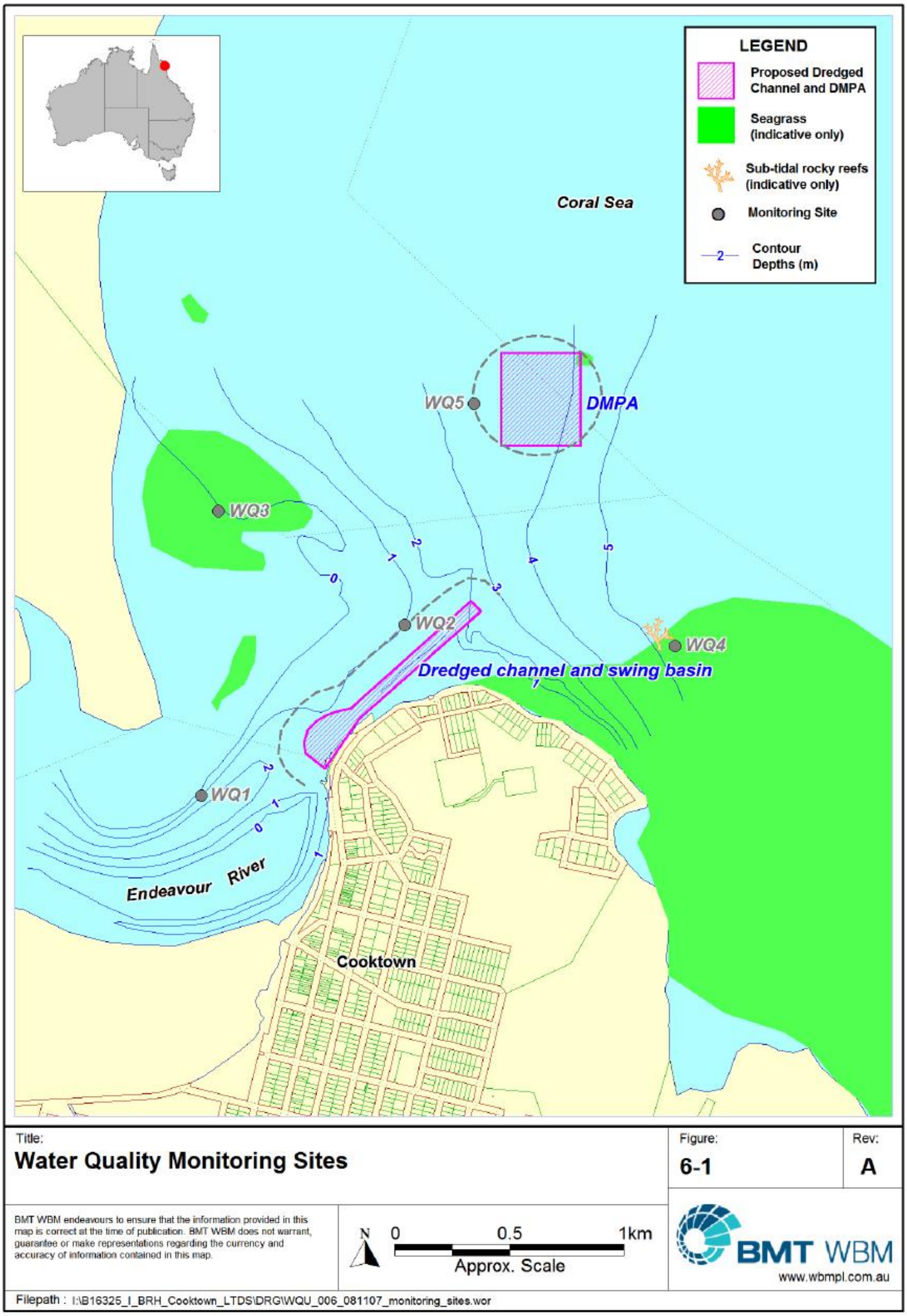

Figure 20. Proposed water quality monitoring sites and sensitive environmental values areas in the Port of Cooktown (BMT WBM, 2010).

2 Risk Assessment Approach & Assessment Outcomes

The basis of the environment – ecosystem level risk assessment approach in this report comes from the *Great Barrier Reef Marine Park Authority 2014, Great Barrier Reef Region Strategic Assessment: Strategic assessment report, GBRMPA, Townsville* (GBRMPA, 2014).

The risk assessment approach will adopt the following:

Consequence description and definition (GBRMPA, 2014):

Consequence	Extent of the impact based on current management	
	Broad scale	**Local scale**
Catastrophic	Impact is clearly affecting, or would clearly affect, the nature of the value over a wide area. Recovery periods greater than 20 years likely.	
Major	Impact is, or would be, significant at a wider level. Recovery periods of 10 to 20 years likely.	Impact is, or would be, extremely serious and possibly irreversible to the condition of a value. Condition of the affected value possibly irretrievably compromised.
Moderate	Impact is, or would be, present at a wider level. Recovery periods of 5 to 10 years likely.	Impact is, or would be, extremely serious to the condition of a value and possibly irreversible over a small area. Recovery periods of 10 to 20 years likely.
Minor	Impact is, or would be, not discernible at a wider level. Impact would not impair the overall condition of the value, including sensitive populations or communities, over a wider level.	Impact is, or would be, significant to the condition of value at a local level. Recovery periods of 5 to 10 years likely.
Insignificant	No impact or if impact is, or would be, present then only to the extent that it has no discernible effect on the overall condition of the value.	No impact or if impact is, or would be, present then only to the extent that it has no discernible effect on the overall condition of the value.

Note: Recovery periods are indicative of major capital dredging programs, and not maintenance dredging.

Likelihood description and frequency (GBRMPA, 2014):

Likelihood	Expected frequency of a given threat
Almost certain	Expected to occur more or less continuously throughout a year
Likely	Not expected to be continuous but expected to occur one or more times in a year
Possible	Not expected to occur annually but expected to occur within a 10-year period
Unlikely	Not expected to occur in a 10-year period but expected to occur in a 100-year period
Rare	Not expected to occur within the next 100 years

Consistent with the GBRMPA (2014) approach, the assessment of likelihood is based on the likelihood of the consequences of an event occurring at each Port. For example, if maintenance dredging occurs one or more times a year and there is the potential for an impact to occur (i.e. from historic turbidity monitoring or predictive plume modelling) during maintenance dredging, then the likelihood of this impact is determined to be 'Likely'. Alternatively, if maintenance dredging occurs infrequently (i.e. > annually), and there is low potential for an impact to occur (i.e. from historic turbidity monitoring or predictive plume modelling) then the likelihood of an impact is determined to be 'Unlikely'.

The assessment of consequences is based on available technical data for the dredging works. For example, where predictive modelling or field based monitoring demonstrated no interaction between plumes and environmental values then the consequence was determined to be insignificant.

In many cases field based measurements of maintenance dredging plume intensity and extent are available, and the status of environmental values are well understood. The volume of scientifically derived information however, varies across the ports and therefore, the level of confidence applied to the risk grades also varies. The table below provides guidance on the confidence levels for the risk grades. For the purpose of this risk assessment only environmental values that have the potential to be influenced by maintenance dredging and disposal plumes, and dredge movements, will be included in the assessment. These include: seagrass, coral, macro algal beds, sea turtle, dugong, cetaceans and benthic infauna communities.

Hazard Risk Grades (GBRMPA, 2014):

	Consequence				
Likelihood	**Insignificant**	**Minor**	**Moderate**	**Major**	**Catastrophic**
Almost Certain	Low	Medium	High	Very high	Very high
Likely	Low	Medium	High	High	Very high
Possible	Low	Low	Medium	High	Very high
Unlikely	Low	Low	Low	Medium	High
Rare	Low	Low	Low	Medium	High

Confidence Score Grades:

Confidence Level	Data Availability
Low	No water quality monitoring during maintenance dredging/disposal available, environmental values not well understood and are largely unknown.
Medium	Water quality monitoring during active dredging/disposal is available and ideally focuses on measuring the plume intensity and extent. Other data on water quality observations during other dredging works may be available to inform the assessment, however it's not representative of maintenance dredging (i.e. TSHD Brisbane), modelling may have been completed that is representative of maintenance dredging and disposal however no field validation has been executed, environmental values are well understood (mapped)
High	Targeted maintenance dredging/disposal plume intensity and extent monitoring available, environmental values well understood (mapped), if plume interaction is likely monitoring has been established to inform management.

2.1 Risk Assessment Summary Tables

Tables 9 to **Table 16** provide a summary of the preliminary risk assessment outcomes for the environmental values from each relevant port. The risk assessment addresses risks from maintenance dredging and dredge material placement activities to environmental values that have the greatest potential to be influenced by these activities. These include; seagrass, coral, macro algal beds, sea turtle, dugong, cetaceans and benthic infauna communities. These key environmental values have been considered in each port; however the summary tables to support the risk assessment focus on the environmental values of most relevance to each port. For example, of most relevance to the Port of Gladstone are the potential impacts of maintenance dredging activities to adjacent seagrass meadows.

For the purposes of the risk assessment, the environmental values have been grouped into two different threat categories, namely (1) maintenance dredging leading to a loss of important marine flora and key habitat; and (2) maintenance dredging leading to a loss of important marine fauna. This threat characterisation approach was adopted, as the key flora and habitats primarily consisted of benthic primary producers (namely, seagrasses, corals and macroalgal communities), whereas the important fauna primarily relate to marine megafauna.

Benthic infauna and epifauna communities have also been discussed under the important fauna threat category, as this community consists primarily of invertebrate fauna. Loss of important marine flora and fauna was considered the endpoint as this is traditionally monitored and can be quantitatively defined (i.e. loss of seagrass meadow cover, biomass and areal extent). In the case of fauna it is mortality (loss) of individuals from a defined population i.e. vessel strike and smoothing of sediment infauna communities.

The outcomes of this preliminary risk assessment are summarised in Table 27, in the Technical Supporting Document and Table 6 in the Concise Summary Document.

Table 9. Port of Gladstone risk assessment summary.

Port	Threat	Activity	Spatial Commentary	Risk Commentary	Likelihood of Consequence Occurring	Consequences of Maintenance Dredging	Risk Score	Confidence Level
Gladstone	Maintenance dredging leads to loss of marine flora and habitat caused by elevated turbidity, reduction in benthic light and sedimentation	Maintenance dredging of Port of Gladstone Channels (i.e. not all areas, just those that require maintenance)	Inner Harbour - there are seagrass meadows within close proximity to the Jacobs Channel. There are also seagrass meadows throughout Port Curtis (i.e. Pelican Banks, adjacent to Wiggin Island). The seagrass communities in Port Curtis are regionally significant, and second only to Moreton Bay meadows in terms of spatial scale. Coral communities are present in Port Curtis (Turtle Island Reef, Bushy Island Reef & Manning Reef). These reefs do not have extensive hard coral communities Extensive mangrove and saltmarsh communities exist in Port Curtis.	Seagrass meadows close to the maintenance dredging works in Jacobs Channel have the potential to be impacted. Light measurement data at this location has demonstrated that the 2014 maintenance dredging did not impact upon BPAR. All other seagrass meadows are > 100 m from the channel and based on calibrated hydrodynamic modelling simulation and importantly measured turbidity during dredging, are unlikely to be influenced by maintenance dredging. Furthermore, the maintenance dredging in the difference channel areas is of short duration, which is unlikely to introduce a period of > 14 days of light stress. Dredging plumes are low intensity and extent. The intermittent maintenance dredging plumes tend to follow the channel and only marginally move towards reef communities (i.e. > 10 mg/L for up to 1 week out of the entire program). There is no evidence that the action of maintenance dredging in Port Curtis has lead to changes in coastal processes and impact on mangrove or saltmarsh communities. These habitat are not impacted by increased turbidity or loss of light within the water column.	Unlikely	Minor	Low	High
		Offshore disposal at East Banks Spoil Disposal Area.	Deep water seagrass communities have been identified to the north west of disposal area (eg. *Halophila decipiens, H. ovalis, and H. spinulosa*). Coral communities are present along the eastern side of Facing Island, within 6km of the sea disposal area. These coral communities do have hard and soft coral cover, however hard coral cover is typically < 15 %. The closed significant reefs are those in the southern Great Barrier Reef bunker island near Heron Island (approx. 60 km east of Facing Island.	Continuous turbidity measurements at predetermined sensitive receiver locations (i.e. offshore seagrass meadows) demonstrated that the maintenance dredging activities had little influence on turbidity at these locations. Disposal plumes are low intensity and extent. The intermittent plumes do not create turbid plumes that extent to the reefs along Facing Island and sedimentation on coral reefs linked to disposal material is not expected to occur.	Unlikely	Minor	Low	High
	Maintenance dredging leads to loss of important coastal fauna caused by elevated turbidity, sedimentation, burial during disposal operations and direct interaction with the dredge.	Maintenance dredging of Port of Gladstone Channels (i.e. not all areas, just those that require maintenance)	Sea Turtles are known to frequent Port Curtis, with Flat Back turtles using southern Curtis Island as a nesting beach. Tagging of these turtles has demonstrated movement of these animals into Port Curtis during inter-nesting. Dugong populations of Port Curtis are know to frequent seagrass meadows and also transit throughout Port Curtis as they move between meadows. Indo-Pacific Humpback dolphins (*Sousa chinensis*) are resident in Port Curtis, using the habitat all year. Fish communities within Port Curtis are heavily reliant on seagrass meadows and mud flats. These habitats occur extensively along the intertidal area of the system. There is an extensive area of intertidal habitat where shorebirds frequent. There is a large number of species that frequent Port Curtis.	There is no scientific evidence to demonstrate that maintenance dredging vessel strike has impacted on marine mega fauna in Port Curtis. Advice from the operators of the TSHD Brisbane (Pers. Comm Michel Willemen, Nov 2015) suggested that over the last 10 years there have been 5 occasions when an animal has been captured by the dredge (i.e. Green Turtle or unidentified). Section 4.5 of the GPC EMP provides specific guidance on the method for managing/avoiding mega fauna impacts. A review of the contamination status of maintenance dredging material has confirmed that all material has been classified as uncontaminated and fit for unconfined offshore disposal. Therefore, the action of maintenance dredging does not introduce a risk of contaminant exposure for marine megafauna. Pelagic fish species have the ability to move away from any intermittent turbid water associated with offshore disposal plumes. There is no evidence that the action of maintenance dredging in Port Curtis has lead to changes in coastal processes and impact on intertidal communities and bird foraging capacity.	Possible	Minor	Low	High
		Offshore disposal at East Banks Spoil Disposal Area.	Sea Turtles are known to frequent the offshore area, with Flat Back turtles using southern Curtis Island as a nesting beach. Tagging of these turtles has demonstrated movement of these animals along the eastern side of Facing Island during inter-nesting. Dudongs are know to frequent the eastern side of Facing Island, but their primary habitat is within the Port Curtis harbour. Both pelagic and demersal fish species occur in the offshore zone. Benthic fauna at the offshore disposal area is not diverse and is expected to be impact during the disposal process.	During the process of disposal it is expected that sessile benthic organisms (i.e. e.g. soft corals, sea pens, gorgonians, sponges etc) will be impacted. The primary impacts of disposal have been a reduction in richness and abundance within the EBSDS, directly related to burial. These have only been observable when large quantities of dredged material have been placed over the EBSDS. While contaminated sediment disposal elsewhere in the world has resulted in community changes (a loss of sensitive species), this has not been observed on the Port Curtis EBSDS, and is probably related to a lack of contamination in disposed sediments. The biggest changes in communities appear to be the result of substrate changes, with the EBSDS becoming more heterogeneous than reference areas (more habitat diversity) and fine material increasing in areas directly adjacent to the EBSDS.	Likely	Insignificant	Low	High

Table 10. Port Alma risk assessment summary.

Port	Threat	Activity	Spatial Commentary	Risk Commentary	Likelihood of Consequence Occurring	Consequences of Maintenance Dredging	Risk Score	Confidence Level
Alma	Maintenance dredging leads to loss of marine flora and habitat caused by elevated turbidity, reduction in benthic light and sedimentation	Maintenance dredging of Port of Rockhampton Channels (i.e. not all areas, just those that require maintenance)	There is no known seagrass meadows in close proximity to the Port of Rockhampton Channels or offshore disposal area. There are no coral communities in close proximity to the Port of Rockhampton channel maintenance area (i.e. inner port channel). Extensive mangrove and saltmarsh communities exist adjacent to the inner Port of Rockhampton channel.	The Port is located in the lower Fitzroy River Delta system, which is a turbid depositional zones. The small scale nature of the maintenance dredging and disposal required in the Port of Rockhampton (i.e. days and small volumes) is not likely to results in persistent plumes. However, preliminary modelling has shows that turbid plumes could extend some distance (measured in kilometres) from the loading and placement sites. These plume are not likely to impact key flora and fauna, but have the potential to impact upon benthic fauna communities. A monitoring program aim at detecting these changes has been initiated by GPC. It should be acknowledged that any impact to benthic infauna in the vicinity of the dredging and disposal area is not likely to be significant based on the small scale nature of the maintenance dredging and disposal required in the Port of Rockhampton (i.e. days and small volumes). In fact, scientifically based differentiation of natural stressors (e.g. sediment resuspension and high flow river events) will prove challenging to distinguish from maintenance dredging and disposal impacts. There has been no recorded instances of fauna strike or hopper capture in Port Alma.	Unlikely	Insignificant	Low	Medium
		Offshore disposal at approved disposal area.	There is no known seagrass meadows in close proximity to the Port of Rockhampton offshore disposal area. The offshore disposal site is 20 km away from any significant reef communities. Extensive mangrove and saltmarsh communities exist adjacent to the offshore disposal area.		Unlikely	Insignificant	Low	Medium
	Maintenance dredging leads to loss of important coastal fauna caused by elevated turbidity, sedimentation, burial during disposal operations and direct interaction with the dredge.	Maintenance dredging of Port of Rockhampton Channels (i.e. not all areas, just those that require maintenance)	Sea Turtles are known to frequent Port of Rockhampton. Peak Island at the northern limit of Port Alma represents a key breeding habitat for flatback turtles. Peak island is approximately 20 km north east of the inner channels of the Port of Rockhampton. The lower Fitzroy estuary accommodates a low number of dugongs due to the turbid waters limiting seagrass habitat. Three species of inshore dolphins have been recorded inhabiting Port Curtis and Port Alma and include Australian snubfin (*Orcaella heinsohni*), Indo-Pacific humpback (*Sousa chinensis chinensis*) and the inshore bottlenose dolphin (*Tursiops Delphinidae*).		Unlikely	Insignificant	Low	Medium
		Offshore disposal at approved disposal area.	The offshore disposal area for the Port of Rockhampton is located < 5 km from the inner harbour. Therefore, the species described above are also of relevance to the disposal site		Unlikely	Insignificant	Low	Medium

Table 11. Port of Hay Point risk assessment summary.

Port	Threat	Activity	Spatial Commentary	Risk Commentary	Likelihood of Consequence Occurring	Consequences of Maintenance Dredging	Risk Score	Confidence Level
Hay Point	Maintenance dredging leads to loss of marine flora and habitat caused by elevated turbidity, reduction in benthic light and sedimentation	Dredging of Port of Port of Hay Point (i.e. not all areas, just those that require maintenance)	The most recent seagrass survey of the Port of Hay Point was conducted in 2011 (NQBP, 2011). Two distinct seagrass habitats (coastal and offshore) were surveyed and two seagrass species (representing two families) were observed *Halophila decipiens* and *Halodule uninervis*. The coastal meadows comprised *Halophila ovalis* and *Halodule uninervis*. The fringing reefs on the intertidal and subtidal platforms and inshore rocky shoals support sediment tolerant hard corals (URS 2000 in NQBP, 2009). There are minor stands of mostly Avicennia mangroves on the eastern and southern sides of Hay Point (NQBP, 2009).	Results of maintenance dredging model simulations indicate that the plumes are short term and disperse within hours of dredging and spoil disposal (NQBP, 2009). Water quality monitoring is undertaken before, during and after dredging campaigns at Port of Hay Point. Overall, dredging does contribute to increased turbidity in the port waters; however, impacts are relatively short term and depend on prevailing wind and wave conditions. Specifically, during dredging, there is likely to be an observable impact on the water quality at Victor Islet and Round Top Island (NQBP, 2009). NQBP monitors coral communities at Round Top Island, Victor Islet and Slade Islet (reference) before, during and after significant dredging works. Whilst turbidity increases during dredging, the fringing reefs surrounding the inshore islands are not significantly affected by sediment resuspended during dredging activities (WorleyParsons, 2008; WorleyParsons, 2009).	Possible	Minor	Low	Medium
		Offshore disposal at Hay Point Disposal Area.	The offshore seagrass area was described by light *Halophila decipiens* (NQBP, 2011). Hard coral cover occurs on the Islands and Inlet immediately north and south of the Port Limits.		Possible	Minor	Low	Medium
	Maintenance dredging leads to loss of important marine fauna caused by elevated turbidity, sedimentation, burial during disposal operations and direct interaction with the dredge.	Dredging of Port of Port of Hay Point (i.e. not all areas, just those that require maintenance)	Six species of turtles have been recorded utilising the offshore, intertidal, estuarine and shoreline habitats in the Hay Point area, these are Flatback (*Natator depressus*), Green (*Chelonia mydas*), Loggerhead (*Caretta caretta*), Leatherback (*Dermochelys coriacea*), Hawksbill (*Eretmochelys imbricate*) and Olive Ridley (*Lepidochelys olivacea*) (NQBP, 2009). Small populations of dugong have been reported near Port Newry (north) and Ince Bay (20 km south), with areas of Llewellyn Bay and Ince Bay having been declared Dugong Protection Areas (DPA) under the Nature Conservation Act (NC Act) and the Fisheries Act 1994 (NQBP, 2009).	Marine turtles and marine mammals are mobile and can generally avoid impacted areas for the duration of dredging activities. NQBP requires a turtle exclusion device to be fitted to the drag head on the dredger to reduce the risk of turtles being injured during dredging. Other turtle protection measures include conducting the campaign outside the normal nesting period of mid October to March (NQBP, 2009).	Possible	Minor	Low	Medium
		Offshore disposal at Hay Point Disposal Area.	The nearshore sandy seabed region was dominated by open substrate with isolated benthic individuals including polychaete worms, gastropods and bivalves (Rasheed et al. 2001; 2003; 2004; 2005 in Thomas and Rasheed (2010).	The nature of the benthic habitat at the spoil ground will change during and after dredging. Previous studies indicate that the spoil ground’s ability to support a benthic fauna community will not alter, although the community composition may initially not be the same (NQBP, 2009).	Possible	Minor	Low	Medium

Table 12. Port of Mackay risk assessment summary.

Port	Threat	Activity	Spatial Commentary	Risk Commentary	Likelihood of Consequence Occurring	Consequences of Maintenance Dredging	Risk Score	Confidence Level
Mackay	Maintenance dredging leads to loss of important marine flora and habitat caused by elevated turbidity, reduction in benthic light and sedimentation.	Dredging of Port of Mackay Channels (i.e. not all areas, just those that require maintenance)	The seagrass communities were first identified at Flat Top and Round Top Islands by Coles *et al*. (1987), which were present in low densities. The coastal seagrass meadows adjacent to Round Top island were found to be dominated by *Halodule uninervis* (wide)/ *Halophila ovalis*. Hard and soft corals have been recorded within Mackay Harbour along the seawalls, which provide hard substrate for colonisation. Fringing coral reefs at Slade Islet, Round Top Island, Flat Top Island and Victor Islet all exhibit similar species diversity and coverage. Notable species at the aforementioned locations include Porites colonies, Macroalgae, Montipora and Acropora corals.	Turbidity and TSS monitoring has not been previously undertaken during active dredging within the Port of Mackay or during disposal operations at the spoil ground. Whilst seagrass meadows are present within Mackay Port limits, routine maintenance dredging, disposal and day-to-day port operations are considered unlikely to impact on these sensitive receptors due to the distance from these operations (NQBP, 2011).	Possible	Insignificant	Low	Medium
		Offshore disposal at Port of Mackay Disposal Area.	Rasheed et al., (2011) observed seagrass meadows at locations 3km south east and 8 km east of the spoil ground. The offshore meadows were characterised by *Halophila decipiens* (Rasheed *et al*., (2011). At the existing spoil disposal ground low densities of the macroalgae, *Galaxaura marginata* have also been identified (Rasheed et al, 2001).	Seagrass meadows are located approximately 3 km from the spoil ground. There is limited temporal data for coral reef communities in the Mackay port region. Investigations into the impact of dredging works has documented some temporal stability at Slade Islet and Slade Rock (the two closest reefs to the disposal ground) with little impact reported at these sites during the 2006 capital dredging works or 2008 maintenance dredging program (NQBP 2011b). Victor Islet was observed to have a reduction in coral cover after 2006 activities, however no further reductions were identified in 2008.	Possible	Insignificant	Low	Medium
	Maintenance dredging leads to loss of important marine fauna caused by elevated turbidity, sedimentation, burial during disposal operations and direct interaction with the dredge.	Dredging of Port of Mackay Channels (i.e. not all areas, just those that require maintenance)	Four species of turtles have been recorded utilize the area of Mackay as foraging grounds, these are Flatback (*Natator depressus*), Green (*Chelonia mydas*), Loggerhead (*Caretta caretta*), Leatherback (*Dermochelys coriacea*), Olive Ridley (*Lepidochelys olivacea*) and Hawksbill (*Eretmochelys imbricate*) (Limpus et al., 2013).	Since 2005 only one turtle strike has been reported by the operators of the Brisbane in the Port of Mackay.	Possible	Insignificant	Low	Medium
		Offshore disposal at Port of Mackay Disposal Area.	NQBP (2012) identified that the dominant benthic infauna taxa within and adjacent to the offshore spoil ground were polychaete worms, although ascidians (sea squirts) were also abundant at the spoil ground. There are a number of Dugong Protection Areas in the Mackay region – Ince Bay, Newry region, Llewellyn Bay, Repulse Bay and Sand Bay. These areas are remote from the spoil ground.	Monitoring was undertaken at the offshore disposal ground to assess the benthic infauna assemblages, with the express objective of identifying impacts within and adjacent to the spoil ground from spoil placement or sediment remobilisation. No clear impacts on the overall structure of the macrobenthic infauna assemblage from disposal at the spoil ground were evident (NQBP, 2011).	Possible	Insignificant	Low	Medium

Table 13. Port of Abbot Point risk assessment summary.

Port	Threat	Activity	Spatial Commentary	Risk Commentary	Likelihood of Consequence Occurring	Consequences of Maintenance Dredging	Risk Score	Confidence Level
Abbot Point	Maintenance dredging leads to loss of important marine flora and habitat caused by elevated turbidity, reduction in benthic light and sedimentation.	Dredging of Abbot Point (i.e. not all areas, just those that require maintenance)	Seven seagrass species have been identified within the Abbot Point region between February/March 2008and September 2012 (McKenna and Rasheed, 2013). These include: *Halophila decipien, Halophila ovalis, Halophila spinulosa, Halodule uninervis, Cymodocea serrulata, Cymodocea rotundata, Zostera capricorni*. Coastal meadows in the Abbot Point area generally consisted of isolated to aggregated patches of seagrass dominated by *Halodule uninervis*, although one meadow was dominated by *Zostera capricorni* (McKenna and Rasheed, 2013). Mangroves are present in the tidal creek lines to the west of the Caley Valley wetland. GHD (2009c) state that samphire forbland (i.e. bare mud-flats on Quaternary estuarine deposits. Mainly saltpans and mudflats with clumps of saltbush) is widespread across the majority of the interior of the Caley Valley Wetland.	Hydrodynamic modelling predictions of the port indicate that turbid plumes generated by dredging and spoil disposal are likely to migrate over seagrass meadows located within the port limits. However, the concentration and reduction in light penetration caused by the increased turbidity will be of relatively short duration and within the natural range of turbidity. Results of model simulations indicate that the plumes are short term and disperse within hours of dredging and spoil disposal. The peak concentrations of turbidity predicted can be within the order of those recorded during high wind and wave induced mobilisation (NQBP, 2010).	Unlikely	Minor	Low	Medium
		Offshore disposal at Abbot Point.	Macroalgal communities at Abbot Point have been identified as widespread, but patchy in distribution and typically with low percentage cover. During surveys within the port limits, GHD (2009b) detected algae in association with small patches of hard substrate, which were scattered across the area. Macroalgae recorded included (GHD, 2009b): • Nine green algae (phylum Chlorophyta); • Four brown algae (phylum Phaeophyta); and • Seven red algae (phylum Rhodophyta).	Jarvis (2015) identified light thresholds for managing impacts from dredging activities. For the offshore areas of deep water *Halophila* species the modelling threshold was 1.5 mol m-2 day-1 over a rolling 7 day average (Jarvis, 2015). No water quality (turbidity) or light based monitoring has been undertaken at Abbot Point during any previous maintenance dredging campaign.	Unlikely	Minor	Low	Medium
	Maintenance dredging leads to loss of important marine fauna caused by elevated turbidity, sedimentation, burial during disposal operations and direct interaction with the dredge.	Dredging of Abbot Point (i.e. not all areas, just those that require maintenance)	A 12-month study by GHD (2009d) indicated the most frequently observed turtles within the Port of Abbot Point were the green (Chelonia mydas) and the flatback (*Natator depressus*) turtles.	Marine turtles and marine mammals are mobile and can generally avoid impacted areas for the duration of dredging activities. NQBP requires a turtle exclusion device to be fitted to the drag head on the dredger to reduce the risk of turtles being injured during dredging. Other turtle protection measures include conducting the campaigns outside the normal nesting period of mid October to March (NQBP, 2010).	Possible	Minor	Low	Medium
		Offshore disposal at Abbot Point.	GHD (2009b) reported sedentary benthic macroinvertebrates during surveys of the Port Limits. Ascidians were the most abundant, followed by echinoderms, molluscs, polychaetes and small crustaceans, concentrated around isolated patches of rubble and rock.	Although the abundance of benthic fauna at the spoil ground would temporarily decrease post dredging, the area affected by the material relocation is relatively small in the context of the total area of habitat available in the immediate surrounds. The nature of the benthic habitat at the spoil ground will change during and after dredging. Previous studies indicate that the spoil ground's ability to support a benthic fauna community will not alter, although the community composition may initially not be the same (NQBP, 2010).	Possible	Insignificant	Low	Medium

Table 14. Port of Townsville risk assessment summary

Port	Threat	Activity	Spatial Commentary	Risk Commentary	Likelihood of Consequence Occurring	Consequences of Maintenance Dredging	Risk Score	Confidence Level
Townsville	Maintenance dredging leads to loss of marine flora and habitat caused by elevated turbidity, reduction in benthic light and sedimentation	Dredging of Port of Townsville Channels (i.e. not all areas, just those that require maintenance).	Cleveland Bay contains some of the most extensive and diverse seagrass meadows in north Queensland. Seagrass meadows in Cleveland Bay have high ecological significance in the context of providing habitat for a range of species of fisheries significance, and the provision of food resources for the threatened dugong and green turtle. The Port of Townsville Channel is adjacent to known deep water seagrass meadows (ephemeral and sparse) and close to coast seagrasses (semi-permanent/permanent). Reef habitats in Cleveland Bay include shallow fringing reefs and rocky shores around Magnetic Island; the well-developed reef platform of Middle Reef; and smaller, less developed reef areas between the mainland and Magnetic Island. Large areas of mangrove and saltmarsh communities occur to the south of the Outer Harbour Project area along Ross Creek, Ross River, and the eastern shoreline of Cleveland Bay. The offshore disposal area for the Port of Townsville is located in an area know to support deepwater seagrass meadows (empheral and sparse).	Cleveland Bay is subject to natural sediment resuspension event that create turbidity within the water column. The natural event have been observed during targeted maintenance dredging works. The observed change in turbidity due to dredging at sensitive receptor locations was well within the range of natural variability during the monitoring period. Predictive Hydrodynamic modelling, together with water quality monitoring data, against preliminary impact thresholds, suggest that it is highly unlikely that mortality to sensitive ecological receptors (seagrass and corals) would occur. This is primarily because of the short duration of the campaign (five weeks), and the short duration and intensity of dredge plumes, and the low intensity of sediment deposition. However, it has been acknowledged that based on worse case modelling results, it is predicted that low intensity turbid plumes resulting from dredging could last for several days under windy conditions at locations containing seagrass meadows (i.e. the Strand and Cape Pallarenda). Stress (e.g. reduced growth, loss of carbohydrate) could occur under windy conditions to sensitive seagrass species (*Halophila ovalis*). This would particularly be the case if seagrass was in poor condition in the period leading up to dredging. The interpreted impact zones indicate that coral communities and nearshore seagrass meadows in Cleveland Bay are not expected to be adversely impacted from the maintenance dredging of Platypus Channel and the Outer Harbour. The results indicate that some deepwater seagrass meadows near the Platypus Channel may be impacted. However, recent surveys have found no marine plants at sample sites in the vicinity of the Platypus and Sea Channels (GHD 2011).	Likely - There is the potential for an impact to occur during maintenance dredging and therefore, the likelihood of this impact is determined to be Likely.	Minor	Medium - Townsville currently has a comprehensive ambient and targeted water quality monitoring dredging, where these risks are recognised and managed.	High
		Offshore disposal at Spoil Disposal Area.		Modelling was carried out to predict sediment resuspension over a 12 month period to determine potential long-term impacts of dredged material placement. The modelled change in the 95th percentile turbidity from background (i.e. the turbidity value exceeded 5% of the time, or 18 days in the year) was less than 2 NTU, while the modelled change in the 50th percentile turbidity (representing changes in turbidity for 50% of the time) was less than 0.05 NTU throughout the model domain. There is an interaction between benthic communities and turbid plumes generated from offshore disposal activities associated with maintenance dredging.	Likely - There is the potential for an impact to occur during maintenance dredging and therefore, the likelihood of this impact is determined to be Likely.	Minor	Medium - Townsville currently has a comprehensive ambient and targeted water quality monitoring dredging, where these risks are recognised and managed.	High
	Maintenance dredging leads to loss of important coastal fauna caused by elevated turbidity, sedimentation, burial during disposal operations and direct interaction with the dredge.	Dredging of Port of Townsville Channels (i.e. not all areas, just those that require maintenance)	Sea Turtle are known to frequent the waters of Cleveland Bay. Green turtles are the most abundant turtle species (~90% of sightings). Dugongs are abundant in Cleveland Bay and the Bay is thought to be an important dugong habitat at a regional scale. Australian snubfin dolphins (Orcaella heinsohni) and Indo-Pacific humpback dolphins (Sousa chinensis) are common in nearshore environments throughout Cleveland Bay, and are likely to regularly feed in the port area. There have been 253 fish species recorded from Cleveland Bay and the Ross River and Creek, representing a number of important commercial and recreational species. The wetland and mudflat habitats associated with Ross River, parts of Magnetic Island National Park, Bowling Green Bay National Park and Townsville Town Common Conservation Park provide foraging and roosting habitat for migratory shorebirds. The benthic fauna are sparse and patchy in Cleveland Bay and contain large areas of completely bare substrate.	There is no scientific evidence to demonstrate that maintenance dredging vessel strike has impacted on marine mega fauna. Advice from the operators of the TSHD Brisbane (Pers. Comm Michel Willemen, Nov 2015) suggested that over the last 10 years there have been 3 occasions when an animal has been captured by the dredge (i.e. Green Turtle or unidentified). Section 7 of the PoT EMP provides specific guidance on the method for managing/avoiding mega fauna impacts. A review of the contamination status of maintenance dredging material has confirmed that all material has been classified as uncontaminated and fit for unconfined offshore disposal. Therefore, the action of maintenance dredging does not introduce a risk of contaminant exposure for marine megafauna. Pelagic fish species have the ability to move away from any intermittent turbid water associated with offshore disposal plumes. There is no evidence that the action of maintenance dredging in Port of Townsville has lead to changes in coastal processes and impact on intertidal communities and bird foraging capacity.	Possible	Minor	Low	High
		Offshore disposal at Spoil Disposal Area.		Modelling was carried out to predict sediment resuspension over a 12 month period to determine potential long-term impacts of dredged material placement. The modelled change in the 95th percentile turbidity from background (i.e. the turbidity value exceeded 5% of the time, or 18 days in the year) was less than 2 NTU, while the modelled change in the 50th percentile turbidity (representing changes in turbidity for 50% of the time) was less than 0.05 NTU throughout the model domain. This very small change to ambient turbidity is highly unlikely to cause measurable changes to biota.	Possible	Minor	Low	High

Table 15. Port of Cairns risk assessment summary

Port	Threat	Activity	Spatial Commentary	Risk Commentary	Likelihood of Consequence Occurring	Consequences of Maintenance Dredging	Risk Score	Confidence Level
Cairns	Maintenance dredging leads to loss of marine flora and habitat caused by elevated turbidity, reduction in benthic light and sedimentation	Maintenance dredging of Port of Cairns Channels (i.e. not all areas, just those that require maintenance)	Historically the marine environment of Cairns has supported large areas of seagrass habitat, however post the TC Yasi the seagrass meadows in the Trinity Inlet area have been significantly impacted and the spatial area of the meadows has contracted. There are, however, extensive areas of macroalgal beds still present. No low-lying rocky reef or fringing coral reefs were found to be present in the harbour. Further afield, Double Island (Double Island and Haycock Reefs contains a narrow fringing reef to the north and an extensive reef platform to the south, and has a total mapped area of 185 ha. At least 24 mangrove species from 15 genera have been recorded growing within Trinity Inlet. Mangrove and clay pan/saltmarsh habitats, however, have been progressively removed in the broader Cairns Harbour and Trinity Inlet area over the past few decades	Turbid plumes formed during maintenance dredging within the Port of Cairns entrance channel were contained mainly within the channel confines because the ebb and flood tide flows were directed almost parallel with the channel (northeast and southwest respectively) whilst the surrounding shallow bathymetry limited the opportunity for sediments disturbed by the dredge heads to move beyond the channel (BMT WBM, 2011). It was primarily the surface component of the dredging plume created by the hopper overflow which was available for advection by the tidal currents beyond (east or west of) the channel alignment. On the ebb tide the surface component of the dredge plume was advected west of the channel alignment up to a maximum distance of 650-700m from the channel. Conversely, on the flooding tide the surface plume was displaced to the east side of the channel, though the distance was shorter, being a maximum of 150-200m from the channel. For each tide the result was consistent with the measurements reported previously (BMT WBM, 2011). Importantly, measurements from two recording water quality instruments placed adjacent to the seagrass communities within the Port of Cairns, there was no increase in turbidity which could be correlated with the continuous maintenance dredging operations within the Port over the corresponding time period (BMT WBM, 2011). Based upon a 4 day period of measurements from two recording water quality instruments placed adjacent to the seagrass communities within the Port of Cairns, there was no increase in turbidity which could be correlated with the continuous maintenance dredging operations within the Port over the corresponding time period (BMT WBM, 2011).	Unlikely	Insignificant	Low	High
		Offshore disposal at Spoil Disposal Area.	The offshore disposal area is known to support deep seagrass meadows (sparse and ephemeral). However, the coastal meadows are considered more important from an ecological perspective.	The turbidity and visual monitoring of maintenance dredging and disposal plumes suggests that they remained visible for up to approximately 2 hours after their formation and up to several hundred metres beyond the spoil ground boundary. However the bulk of the deposited material was retained within the bounds of the spoil ground. Plume travel distances to the boundary of the spoil ground were approximately 1km in each instance and was achieved by the selective placement of dredged material closest to the up-current side of the spoil ground in accordance with the LTMP. For each tide the plume extent measurements were consistent with the measurements previously reported in 1990.	Unlikely	Insignificant	Low	High
	Maintenance dredging leads to loss of important coastal fauna caused by elevated turbidity, sedimentation, burial during disposal operations and direct interaction with the dredge.	Maintenance dredging of Port of Cairns Channels (i.e. not all areas, just those that require maintenance)	Marine turtles have been recorded in offshore, nearshore and intertidal habitats within the Port of Cairns. Dugongs can be common in Trinity Bay, however, it is thought that current population numbers are low due to the reduction in the extent and condition of local seagrass meadows. The two threatened dolphin species likely to occur within the vicinity of the Port of Cairns, include the Snub fin, *Orcaella heinsohnri* and Indo-Pacific humpback dolphins, *Sousa chinensis*. There are a variety of fish species that frequent Cairns Harbour and Trinity Inlet, however few are of commercial importance. The shorebirds and waders that have been previously recorded within the vicinity of the Port of Cairns, have a preference for the intertidal zone across from Cairns Esplanade, the estuarine wetland area on the eastern side of Trinity Inlet and/ or surrounding marine and non-marine areas.	There is no scientific evidence to demonstrate that maintenance dredging vessel strike has impacted on marine mega fauna. Advice from the operators of the TSHD Brisbane (Pers. Comm Michel Willemen, Nov 2015) suggested that over the last 10 years there have been no occasions when an animal has been captured by the dredge. Section 6 of the PoC EMP provides specific guidance on the method for managing/avoiding mega fauna impacts. A review of the contamination status of maintenance dredging material has confirmed that all material has been classified as uncontaminated and fit for unconfined offshore disposal. Therefore, the action of maintenance dredging does not introduce a risk of contaminant exposure for marine megafauna. Pelagic fish species have the ability to move away from any intermittent turbid water associated with offshore disposal plumes. There is no evidence that the action of maintenance dredging in the Port of Cairns has lead to changes in coastal processes and impact on intertidal communities and bird foraging capacity.	Unlikely	Insignificant	Low	High
		Offshore disposal at Spoil Disposal Area.		During the process of disposal it is expected that sessile benthic organisms (i.e. e.g. soft corals, sea pens, gorgonians, sponges etc) will be impacted. The primary impacts of disposal have been a reduction in richness and abundance within the sediment, directly related to burial. Benthic fauna has been demonstrated to exhibit a capacity to recolonise the disposal site within months.	Unlikely	Insignificant	Low	High

Table 16. Port of Cooktown risk assessment summary

Threat	Activity	Spatial Commentary	Risk Commentary	Likelihood of Consequence Occurring	Consequences of Maintenance Dredging	Risk Score	Confidence Level
Maintenance dredging leads to loss of marine flora and habitat caused by elevated turbidity, reduction in benthic light and sedimentation	Maintenance dredging of Port of Cooktown Channels (i.e. not all areas, just those that require maintenance)	Cooktown is composed of two different intertidal communities of seagrass located near archer point, Sachs Spit and the base of Grassy Hill. Cooktown has a number of inshore reefs (starting ~15km from the Cooktown) which are primarily composed of hard coral (40.4%) and algae (41.5%), with a ~5% soft corals.	The need for maintenance dredging in the Port of Cooktown is intermittent, and over the past 20 years there have been only 2 occasions (1999 and 2014/15) and volume have been relatively small (25,000 and 45,000m3 respectively). The material that is removed from the port channel and swing basin is largely sand and is expected to create short lived low turbidity plumes. During the 2014/15 maintenance dredging works automated water quality monitoring equipment was deployed, capable of autonomously measuring sediment deposition, turbidity, temperature, water depth, RMS water depth and light (PAR). One site was located adjacent to the Port of Cooktown channel (WQ3) and the other further afield offshore (2km). Importantly, during the extended intermittent dredging works (i.e. due to weather delays) the primary driver for observed changes in water quality conditions was related to natural weather event, and in particular Tropical Cyclone Marcia (18-20th February 2015) and TC Nathan (10-24th March 2015). The monitoring data generated during the 12 month period is very useful for placing the dredging works in context with natural events and highlights the insignificant nature of the maintenance dredging and the significance of weather (cyclone) events on suspended solids concentrations. However, there is not data available during dredging at known environmental value sites (i.e. seagrass meadows) and the risk assessment would benefit from these data.	Possible	Insignificant	Low	Medium
	Offshore disposal at Spoil Disposal Area.	Maintenance dredge spoil is placed within the approved Dredge Material Placement Area approximately 3 km north-east of the harbour entrance, within a Conservation Park Zone of the Great Barrier Reef Marine Park. Seagrass communities observed by GHD (2006) in the north-eastern corner of the DMPA were found to be of moderate density, composed of Zostera capricorni and Halodule uninervis in an area of approximately 10m2 (BMT WBM, 2010). Seagrass communities observed by GHD (2006) in the north-eastern corner of the DMPA were found to be of moderate density, composed of *Zostera capricorni* and *Halodule uninervis* in an area of approximately 10m2 (BMT WBM, 2010).		Possible	Insignificant	Low	Medium
Maintenance dredging leads to loss of important coastal fauna caused by elevated turbidity, sedimentation, burial during disposal operations and direct interaction with the dredge.	Maintenance dredging of Port of Cooktown Channels (i.e. not all areas, just those that require maintenance)	Sea Turtle are know to frequent the Cooktown area, and Hawksbill are regularly found in the Howick reef group to the north of Cooktown. The extensive seagrass meadows north of Cooktown and lack of anthropogenic influences in the region are suggested to allow dugong populations to persist in strong numbers. A number of inshore dolphins are have been recorded in the Cooktown area including; Australian snubfin (*Orcaella heinsohn* i), Indo-Pacific humpback *(Sousa chinensis*) and Bottlenose dolphin (*Tursiops truncates / aduncu* s). The dwarf minke whale, Balaenoptera acutorostrat is a migratory whale species that is also known to frequent the offshore area off Cooktown, particularly Lizard Island. There is a commercial fishery that operates off Cooktown, primarily targets mackerels and barramundi through commercial netting operations. No significant sites for shore birds are present within the Endeavour River, however, three conservation significant species use the estuary.	There is no scientific evidence to demonstrate that maintenance dredging vessel strike has impacted on marine mega fauna in Port Cooktown. Advice from the operators of the TSHD Brisbane (Pers. Comm Michel Willemen, Nov 2015) suggested that over the last 10 years there have been no occasions when an animal has been captured by the dredge. A review of the contamination status of maintenance dredging material has confirmed that all material has been classified as uncontaminated and fit for unconfined offshore disposal. Therefore, the action of maintenance dredging does not introduce a risk of contaminant exposure for marine megafauna.	Unlikely	Insignificant	Low	Medium
	Offshore disposal at Spoil Disposal Area.	Benthic fauna investigations have demonstrated a lack of sponges and soft coral. The benthic infauna surrounding the Port of Cooktown and spoil ground are dominated by opportunistic species such as polychaete's and amphipods.	The Port of Cooktown is characterised by unstable, highly turbid waters that are driven by the seasonal monsoon rains which are reflective of benthic fauna identified. The limited available evidence does suggest that recolonisation of the disposal site is likely to occur (i.e. opportunistic species such as polychaete's and amphipods have a strong ability to recolonise disturbed seabeds.	Unlikely	Insignificant	Low	Medium

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