GBR Quantitative Sediment Budget Assessment

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Synopsis: This report details the development of a quantitative sediment budget considering both ambient and maintenance dredging related contributions to suspended sediment within the Great Barrier Reef region.		

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Executive Summary

INTRODUCTION

The Reef 2050 Long Term Sustainability Plan (Reef 2050) sets out strategies for protecting and managing the Great Barrier Reef (GBR). Queensland Ports Association is leading Water Quality Action 17 (WQA17) of Reef 2050, which has the objective to: *"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*."

To inform this action QPA has commissioned the development of a quantitative sediment budget related to maintenance dredging at each of the six GBR ports of Gladstone, Hay Point, Mackay, Abbot Point, Townsville and Cairns.

PORT SEDIMENTATION CHARACTERISTICS

The inner GBR region has an enormous store of fine sediments and nutrients, derived mostly from catchment sources over thousands of years. Within this region, net sediment transport is northward driven by prevailing winds, wave and currents. Seabed sediments are typically comprised of muddy sand and fine sandy mud, varying spatially throughout the GBR region.

The primary driver of suspended sediment at the port-scale is overwhelmingly due to natural wave and current resuspension of existing sediment that has been deposited in the GBR inner-shelf region over geological timescales. Both catchment and dredging related contributions are found to be relatively minor in the context of the natural resuspension already occurring within the inner shelf area.

Port navigation infrastructure (e.g. channels and berths) intercept and capture a proportion of this natural inner-shelf sediment transport as navigational areas are deeper and calmer than surrounding waters enabling sediment to settle. This quantity varies among ports depending on location, channel length and depth relative to the surrounding seabed.

Port maintenance dredging relocates the majority of port captured sediment to offshore dredged material placement areas (DMPA), which are also situated within the active coastal sedimentary system. The relocation of port maintenance dredging material to DMPAs located within the active coastal system maintains ongoing transport of sediment along natural sediment pathways, with maintenance dredge material gradually re-assimilated into the ambient coastal system from which it originated.

CATCHMENT LOADS

Catchments are estimated to deliver an average of 9 million tonnes per year of fine sediment into the GBR. The Burdekin and Fitzroy River catchments are the largest contributors to catchment loads, and together supply more than 50% of catchment sediments. Over thousands of years, the sediment delivered by the major GBR catchments has built up the nearshore terrigenous wedge and its associated longshore (net northward) sediment transport pathway.

Comparison of river discharge, port proximity and maintenance dredging have demonstrated that there is no evident correlation, indicating that river sources are unlikely to be a significant contributor to sedimentation within most GBR ports.

AMBIENT SEDIMENT RESUSPENSION QUANTITIES

The development of a quantitative sediment budget related to ambient resuspension of seabed sediment by tidal current action has been based on measured water quality data collected in the vicinity of the ports. The derived ambient resuspension quantities have provided a high-level point of reference for comparing the maintenance dredging quantities individually and collectively across the ports.

Within the GBR inner-shelf region natural resuspension of sediment deposits by tidal currents and episodic wave events is the primary contributor to sediment suspended into the water column. Natural suspended sediment events typically occur around 25 times per year and last for 3 to 4 days.

At a port scale the quantities being resuspended annually by natural processes are estimated to be between 1.5 million tonnes at the Port of Abbot Point and 15 million tonnes at the Port of Gladstone. At an entire GBR inner-shelf scale the quantities being resuspended annually by natural processes is estimated to be 160 million tonnes. This natural resuspension quantity is approximately 17-times higher than the input of new sediment from the catchment.

These natural resuspension processes are also the primary mechanism for sedimentation of port infrastructure. However, the quantities being trapped in port facilities and requiring maintenance dredging constitute less than 3% of the sediment being resuspended by currents and waves at a port scale.

COMPARISON WITH PORT MAINTENANCE DREDGING RESUSPENSION

To ensure that port navigation channels remain safe and useable, sediment depositing within port areas is typically managed by regular maintenance dredging. Maintenance dredging generates a mechanism for resuspension of sediment into the water column, in addition to naturally resuspended quantities. However, maintenance dredging does not introduce any additional sediment into the active system and the sediment that is resuspended by maintenance dredging into the water column will eventually settle back to the seabed.

The mass of sediment put in suspension by maintenance dredging activities was derived from numerical dredge plume modelling which were compared with ambient suspended sediment quantities. Averaged over a typical maintenance dredge campaign, dredging related suspended sediment quantities are 4 to 10% of ambient quantities at a port-scale. Over longer time-scales the relative contribution of dredging becomes even less significant compared with ambient suspended sediment quantities averaged over a similar period. Averaged over an entire year including a maintenance dredge campaign, the quantity of dredging related sediment in suspension at the port-scale ranges between 0.1 to 1% of ambient quantities.

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The Reef 2050 Long Term Sustainability Plan (Reef 2050) sets out strategies for protecting and managing the Great Barrier Reef (GBR). Queensland Ports Association is leading Water Quality Action 17 (WQA17) of Reef 2050, which has the objective to: *"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*."

To inform this action QPA has commissioned the development of a quantitative sediment budget related to maintenance dredging at each of the six GBR ports of Gladstone, Hay Point, Mackay, Abbot Point, Townsville and Cairns (Figure 1-1). These port-scale assessments have been further aggregated into an overall sediment budget for the inner-shelf region of the entire GBR. This work has been compiled by BMT based on data held for Cairns, Townsville and Gladstone and has included inputs for the Ports of Hay Point, Mackay and Abbot Point by Port and Coastal Solutions (Dr Andy Symonds).

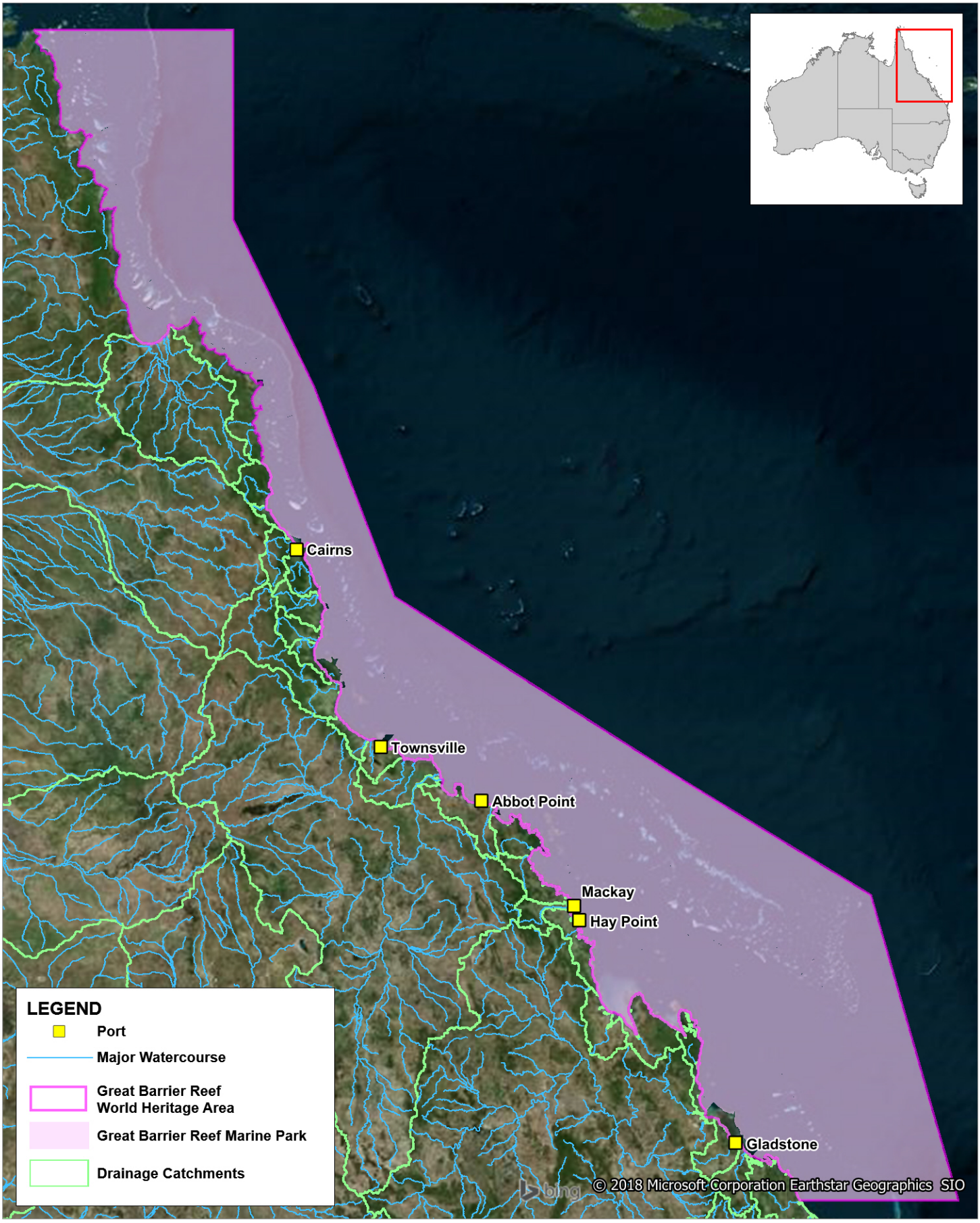
A characterisation of ambient sediment processes and properties at each of the ports is provided in Section 2, which includes consideration of the unique environmental setting of each port. The quantification of catchment contributions at the port-scale and GBR scale were made based on modelling results from the Paddock 2 Reef program. The results of which are summarised in Section 3 of this report.

The development of a quantitative sediment budget related to ambient resuspension of seabed sediment by wave and current action has primarily been based on measured water quality data collected in the vicinity of the ports. As described in Section 4, natural sediment resuspension quantities have been derived for each of the port areas, and for the entire inner-shelf GBR.

The derived ambient resuspension quantities have provided a high-level point of reference for comparing the maintenance dredging quantities individually and collectively across the ports. The derivation of port maintenance dredging resuspension quantities is described in Section 5.

The comparison of port maintenance dredging quantities with catchment and natural resuspension quantities is summarised in Section 6. The primary driver of suspended sediment at the port-scale is overwhelmingly due to natural wave and tidal current resuspension of existing sediment that has been deposited in the GBR inner-shelf region over geological timescales. Both catchment and dredging related contributions are found to be relatively minor in the context of the natural resuspension quantities.

As a secondary line of evidence, the quantitative sediment budget has been informed by numerical modelling of both ambient and dredging related sediment resuspension, where this information has been available for the GBR ports.



Title:

GBR Region and Major Port Locations

Figure: 1-1

Rev: A

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

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Approx. Scale

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2 Port Sedimentation Characteristics

As a result of their location in the inner shelf, all the GBR ports have surface sediments comprised of terrigenous origin. However, there is great variability in the environmental settings and sediment composition among and within ports. There is also great variability in maintenance dredging requirements, which depend on their physical setting, the prevailing oceanographic processes and the surrounding seabed sediment characteristics.

Port navigation channels typically traverse across-shelf from the coastline until sufficient natural depth is reached (~10-20 m depending on port shipping requirements). For naturally deep-water ports such as Abbot Point only a minimal berth footprint is required, while the Port of Gladstone maintain approximately 40km of port navigation channels within an estuarine system.

Due to their orientation, the port navigation channels typically intersect the dominant longshore sediment transport pathways. Because they are generally deeper than the surrounding seabed and are less exposed to wave and current energy, sediment is more likely to settle and less likely to resuspend in the dredged channels than in adjacent areas of the seabed. The sediment characteristics of infilling material are generally consistent with surface sediments in the surrounding seabed, reflecting the natural sediment pathway origin of the material. Sedimentation in low energy harbour areas (such as the Port of Mackay) is predominantly fine-grained material, as sand-sized material will tend to deposit within a short distance of the harbour entrance.

The majority of maintenance dredge sediments from GBR ports have been relocated to offshore Dredge Material Placement Areas (DMPAs), typically between 5 and 15 km offshore and therefore within the active nearshore sediment transport system. The relocation of port maintenance dredging material to DMPAs located within the active sedimentary system maintains ongoing transport of sediment along natural sediment pathways, with maintenance dredge material gradually re-assimilated into the ambient sedimentary system from which it originated. The retentiveness of individual port DMPAs depends both on the characteristics of the placed material and on the hydrodynamic characteristics of the site (depth, current speeds and wave climate). Where maintenance material includes a range of sediment particle sizes, the finer material may be winnowed from the DMPA surface sediments, while coarser sediment fractions remain behind.

The following sections discuss the sediment characteristics and dredging requirements of the GBR ports[1].

2.1 North Facing Embayments - Ports of Cairns and Townsville

The Ports of Cairns and Townsville are north-facing embayments that are relatively protected from the dominant SE winds. Seabed sediments in the more sheltered areas are dominated by fine mud transported predominantly by tidal fluxes, while shoals and shorelines in areas that are exposed to higher energy waves are dominated by sand fractions. Due to the relatively low energy hydrodynamic environment at these ports and the greater depth of the navigation channels and berths compared

[1] The summary outlines typical maintenance dredging requirements for each of the major GBR ports. Note that although the average campaign volumes are provided, the actual requirements at each port can vary substantially from year to year depending on the antecedent conditions. In particular, cyclone activity in the vicinity of ports can generate significant levels of siltation that may create the need for additional or unscheduled maintenance dredging campaigns.

to the adjacent seabed, significant accumulation of sediments occurs within the channels. The accumulated sediment is predominantly fine-grained and characteristic of the surrounding seabed sediment. Maintenance dredging is therefore carried out regularly (typically annually) at both ports, and the average campaign volume (~400,000m^3) is typically higher than other GBR ports (RHDHV, 2016). Most sediment removed from the channel during maintenance dredging is clay/silt (typically >90%).

The offshore DMPAs at both ports are located in offshore waters and are generally dispersive in character but noting the Cairns DMPA is far more retentive than Townsville due to its geophysical setting (POTL 2013; Ports North 2014). Sediments in the DMPAs are mostly terrigenous muds and sands, similar to the material placed there as part of maintenance dredging (POTL 2013; Ports North 2014).

2.2 Open Coast Environments – Ports of Abbot Point and Hay Point

The Port of Abbot Point is located offshore in relatively deep water and the natural sediment transport rates in the area are relatively low. Therefore, maintenance dredging requirements are low – over the last thirty years' maintenance dredging has been carried out only once, and a relatively small amount was removed (less than 20,000 m^3). Any siltation that does occur in berths is likely associated with tropical cyclone activity, and is therefore episodic in nature. The sediment composition is relatively homogenous across the dredge area comprising predominantly fine sands (54%), and silts and clays (39%), and smaller quantities of gravel (8%) (NQBP 2012).

The Port of Hay Point is also located in an open coastal environment. However, unlike the Port of Abbot Point, Hay Point has a highly active natural sediment transport mechanism driven by wave-generated resuspension and prevailing currents (AECOM 2016). Available mapping (Mathews *et al*. 2007) indicates that seabed sediments in the areas surrounding Hay Point are mostly (> 80%) sands. Maintenance dredging is typically carried out once every three to five years, with an average volume of around 300,000m^3 removed per campaign (RHDHV, 2016). A recent dredge plume modelling study by RHDHV (2018) states that the areas at the Port of Hay Point which are subject to regular sedimentation (and therefore require maintenance dredging) – the Dalrymple Bay Coal Terminal berths, North Apron and Half Tide Tug Harbour – have similar surface sediment compositions: 20% sand, 40% silt and 40% clay.

The offshore DMPAs at both ports are predominantly retentive (AECOM 2016). Sediments in the DMPAs are mostly terrigenous sands with a minor proportion of muds.

2.3 Harbour Environment – Port of Mackay

The Port of Mackay is located in an artificial harbour formed by rock breakwaters. Fine sediments are swept into the harbour during flood tides, where they tend to settle due to the relatively quiescent hydrodynamic environment. Sediments requiring maintenance dredging are therefore mostly comprised of silts and clays. Seabed sediments adjacent to the Port are mainly sandy, with some areas of 'transitional gravel, sand and mud' and nearshore mud deposits near the mouth of the Pioneer River (Jones 1987; Worley Parsons 2010). Maintenance dredging is carried out approximately once every three years, and the average volume of sediment removed is around

90,000m^3. The composition of the dredged sediments is approximately 80-97% silts and clays, with a low percentage of fine sands and gravel (NQBP, 2011).

The DMPA is located in offshore waters and is considered to be dispersive (AECOM 2016). Sediments here are mostly terrigenous sands with a minor proportion of muds.

2.4 Macro-tidal Estuary – Port of Gladstone

The Port of Gladstone is located within a macro-tidal estuary that features significant tidal currents. The energetic tidal hydrodynamic conditions play an important role in the context of natural bed remobilisation processes. The surface sediments in the main channels of the Port where tidal velocities are high are typically dominated by coarser fractions with the finer particles swept away. The shallower intertidal areas are a mixture of sands and silts with fine soft silts and clays dominating in the lower current/wave energy areas. The dredged channels are effective sediment traps, due to their increased depth relative to the surrounding seabed. Maintenance dredging is carried out on an annual basis, and the average campaign volume is now around 250,000m^3 following completion of capital dredging associated with recent LNG terminal construction. The composition of the dredged material is variable, with sediments in the main navigation channels dominated by sands and gravels (where tidal currents are energetic) and sediments in the berth pockets and closed-ended channels having a higher fines content (silts and clays) (BMT WBM 2014b).

The DMPA is located in an exposed coastal environment at the entrance to Gladstone Harbour. The DMPA is partially retentive, with sediments consisting of sands with low proportion of silts and gravel, due to winnowing by wave/current resuspension (BMT WBM 2012c).

3 Catchment Loads

Under the Paddock to Reef (P2R) program, loads of fine sediment and nutrients being contributed to the reef have been quantified through a multiple lines of evidence approach (Carroll *et al.* 2012). The results from the 2014-15 Report Card (Australian and Queensland Governments 2015) are presented in the following sections. The modelling was undertaken for the period 1990 to 2013 to give an indication of long term average catchment fine-sediment and nutrient loads across the reef regions. This section outlines the key sediment contributions from GBR catchments to provide context for the magnitude of these loads in comparison to those generated through other activities.

3.1 Modelled Loads

The modelling of these catchments over longer timeframes, and disaggregated down to finer scale catchments and associated land uses, provides the ability to understand the sediment and nutrient sources in more detail, and also the relative contributions from anthropogenic and natural sources.

The results for the 2014 modelling results are the latest publicly available, representing a 24-year modelling period (from 1990 to 2014), and are presented in Figure 3-1. Modelled average annual sediment loads were highest at the Burdekin (36% of total loads) and Fitzroy (17%) rivers, with the Burnett, Herbert and Mary River catchments each contributing approximately 5-6% of total sediment loads. The Burdekin River also accounted for the highest total nitrogen and phosphorus load to the GBR, followed by the Johnstone, Fitzroy and Herbert rivers.

Anthropogenic pollutant loads were significant, accounting for 74% of the total sediment load to the GBR, and 53 to 59% of the total nitrogen and phosphorus load respectively. This was mainly driven by the large anthropogenic loads from the Burdekin and other agricultural catchments.

3.2 Catchment Sediment Contributions at the Port Scale

The most significant supplies of fine sediment to the GBR lagoon are delivered by the Fitzroy and Burdekin Rivers, and the major ports are located some distance away from these two river mouths. The Port of Townsville is around 100km north of the Burdekin River mouth, and the Fitzroy River mouth is around 50km north of the Port of Gladstone. Over thousands of years, the sediment delivered by these rivers (and other large rivers) has built up the nearshore terrigenous wedge and its associated longshore (net northward) sediment transport pathway.

While the linkage between the ports and the major catchment loads via the longshore sediment transport pathway is apparent, it can only be described as weak. That is, loads from major catchments are not directly contributing to sediment deposited in navigational areas at the major GBR ports. This lack of connectivity is due to the vast quantities of sediment accumulated in the nearshore terrigenous wedge over geological timeframes and the dominant wave/current driven sediment transport processes which act on this abundant supply of fluvial sediment.

Comparison of river discharge, port proximity and maintenance dredging requirements (RHDHV, 2016) demonstrated that there was no evident correlation, indicating that river sources are unlikely to be a significant contributor to sedimentation within most GBR ports. While some temporal correlation would be expected between above-average wet seasons and port maintenance dredging

requirements, these will be due to the role of tropical cyclones in driving both energetic inner shelf sediment transport and catchment flooding. An example of this would be the Port of Townsville maintenance dredging campaign following Tropical Cyclone Yasi in January 2011 (RHDHV, 2016), where the volume removed increased by more than 50% relative to the long term average.

Smaller local catchments in close proximity (nominally within 20km) to the ports have a greater potential to contribute directly to maintenance dredging volumes. However, the mean annual loads delivered by local catchments (shown in Figure 3-2) are small when compared to the loads of sediment that are regularly resuspended and transported by wave and current action in nearshore areas (this comparison is considered further in Section 6).

The contribution of local scale catchments to the individual ports is summarised below:

- **Port of Cairns -** The primary contemporary source of terrigenous sediment in the immediate vicinity of the Port is the Barron River. However, the river discharge is located 7km to the north of the Port, and the natural net sediment transport in the area is from south to north. Therefore, the percentage of the maintenance dredging load that could be attributed to the Barron River discharge directly is very low, and connectivity between new fluvial inputs and maintenance dredging requirements is considered to be weak.
- **Port of Townsville -** The Ross River discharges fine sediment to the south of the Port, and the natural sediment transport processes in Cleveland Bay do allow some of this sediment supply to be transported around the Port reclamation areas and to be deposited in the approach channel to the Port. However, sediment trapping by Ross River dam and other weirs, as well as the relatively small size of the catchment, limits the significance of this load when compared to the overall nearshore sediment transport which is supplied regionally by Burdekin River catchment loads over geological timescales and driven by resuspension processes. Connectivity between new fluvial inputs and maintenance dredging requirements is considered very weak.
- **Port of Abbot Point -** The Don River discharges sediment at its mouth 19km to the south-east of the Port. The catchment draining Caley Valley wetlands is located in port waters and is estimated to export around 5,800 tonnes of fine sediment per year. This is only 2.5% of the sediment load being discharged by the Don River in the same vicinity as the port, so the degree of influence of these localised catchments in comparison to the larger sources would need to be analysed through more detailed receiving water quality analysis. As outlined in previous sections, the maintenance dredging requirements at the Port are negligible, due to the relatively low ambient sediment transport rate and the fact that the Port is situated in deep water. Connectivity between new fluvial inputs and maintenance dredging requirements is considered very weak.
- **Port of Mackay** - The Pioneer River discharges fine sediment at its mouth 5km to the south of the Port. The amount of sediment that is discharged is relatively small compared to the volume of sediment that is regionally supplied and transported along the coast by waves and currents. Connectivity between new fluvial inputs and maintenance dredging requirements is considered weak, but possibly greater than at Hay Point and Abbot Point, and to a lesser extent Townsville.
- **Port of Hay Point** - Plane Creek discharges fine sediment at its mouth 15km to the south of the Port. The amount of sediment that is discharged is relatively small compared to the volume of

sediment that is regionally supplied and transported along the coast by waves and currents. Connectivity between new fluvial inputs and maintenance dredging requirements is considered to be weak.

- **Port of Gladstone** - The Calliope River discharges sediment directly into the Port, as do smaller catchments on Curtis Island and other minor catchments such as Boat Creek and urban areas adjacent to Auckland Inlet. The Boyne River also discharges into the Port but sediment discharge is relatively minor due to sediment trapping and flow attenuation by the Awoonga Dam. Overall, the sediment fluxes contributed by these catchments are very small compared to the channel infilling that is driven by energetic spring tide currents (within the Port) and wave activity (outside the Port). Connectivity between new fluvial inputs and maintenance dredging requirements is considered to be weak.

The catchment sediment loads delivered into the GBR adjacent to the six major ports have been summarised in Table 3-1. The load contribution from local catchments (within a 20km radius of the ports) and from regionally significant catchments (defined in the table footnotes) have been separately quantified, including both the total load and estimated anthropogenic component. These tables have been prepared to support the contextualisation objective of the study (and WQA17), however it should be re-iterated that there is only a weak linkage between catchment loads and sedimentation within the six GBR ports.

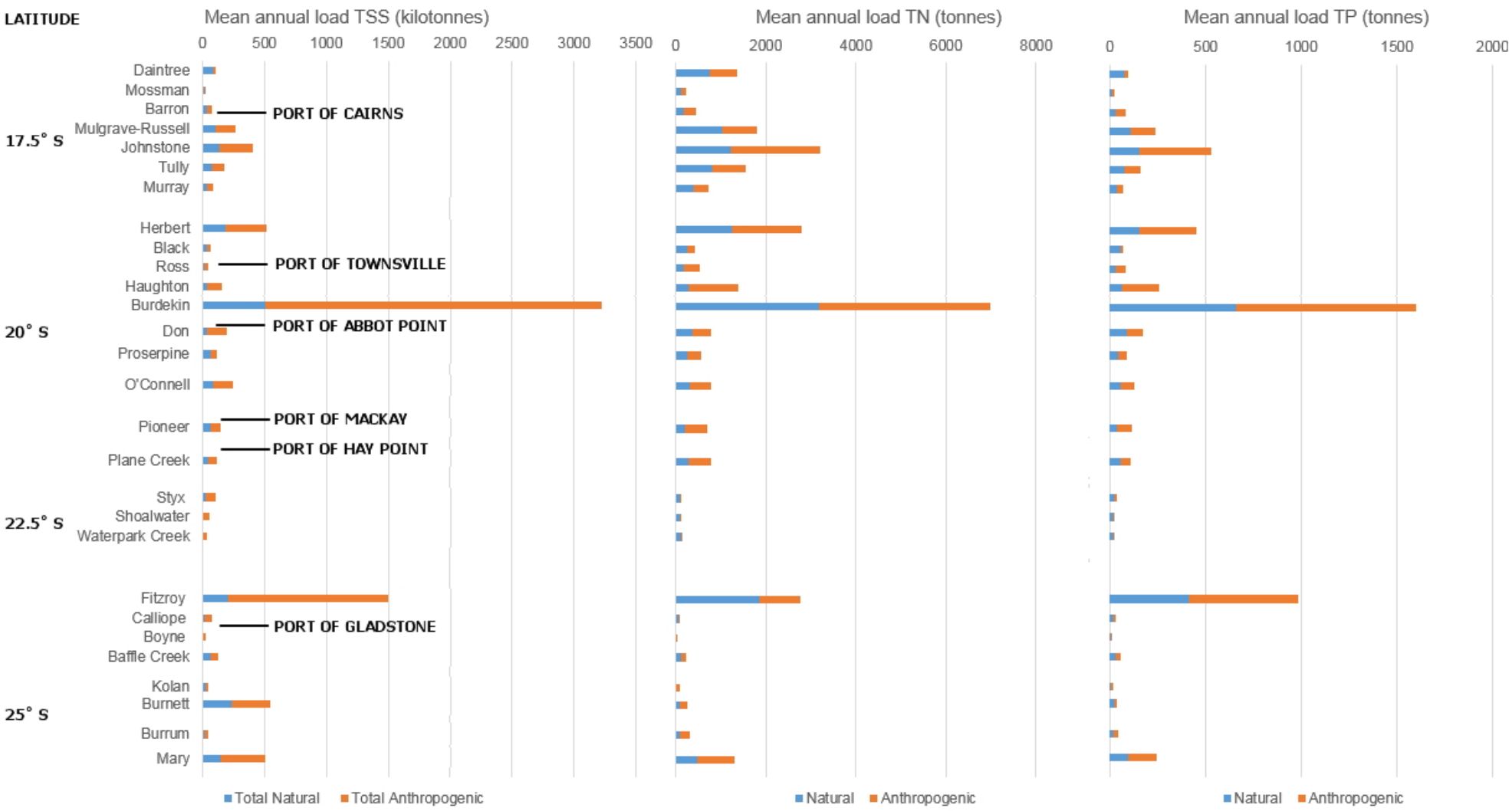

Figure 3-1 Modelled mean annual load of TSS (kilotonnes/year) and TN and TP (tonnes/year) in GBR catchments (Australian/Queensland Govt 2015).

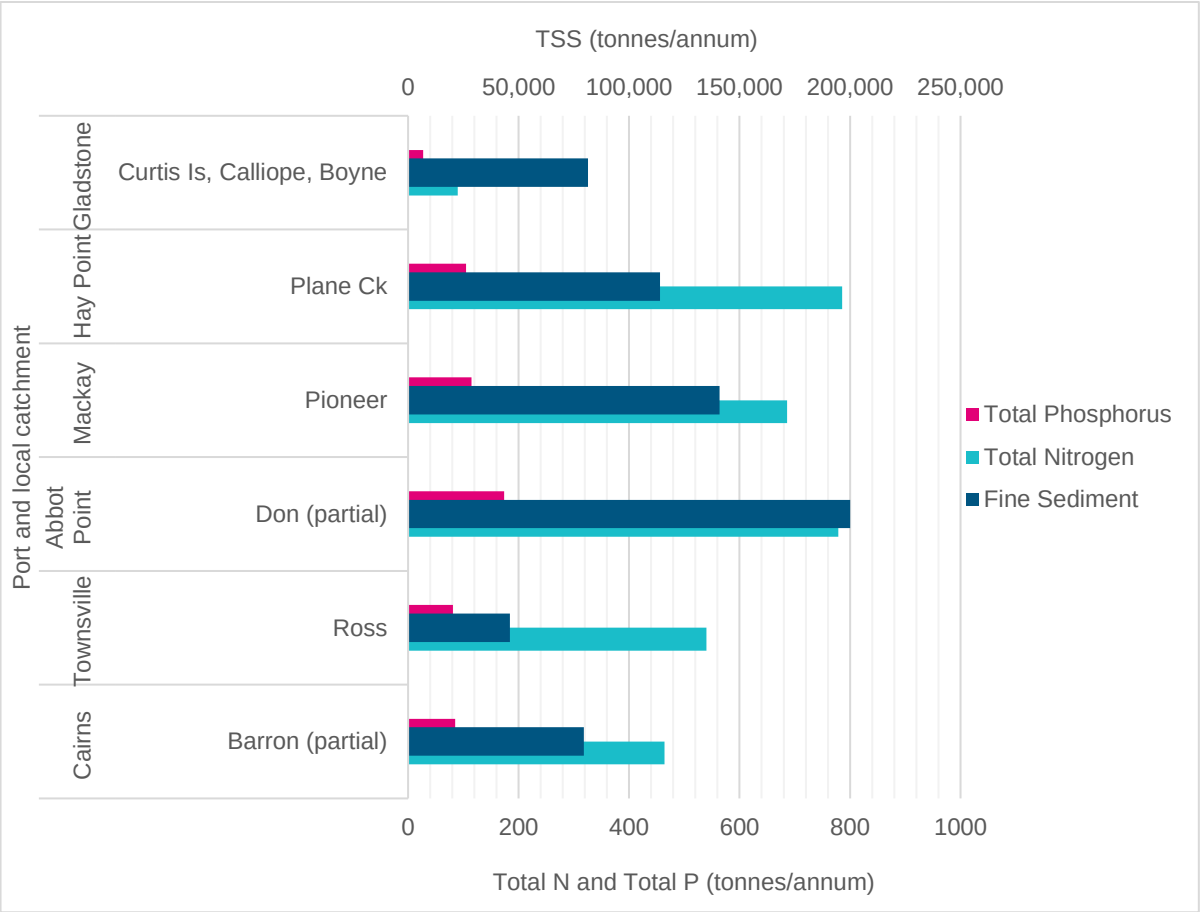

Figure 3-2 Fine sediment, total nitrogen and total phosphorus mean annual loads discharging in the direct vicinity of GBR ports

Table 3-1 Sediment Load Estimates from Catchments Adjacent to the GBR Ports

	Parameter	Units		Port of Gladstone	Port of Hay Point	Port of Mackay	Port of Abbot Point	Port of Townsville	Port of Cairns	GBR Total Load
Fine Sediment	**Local Catchment Loads** The average annual suspended sediment load delivered by catchment runoff within a nominal 20km radius of the ports.	tonnes per year	Total:	97,000 [a]	114,000 [a]	141,000 [a]	200,000 [a]	46,000 [a]	80,000 [a]	Total: 9,000,000 [a] Anthropogenic: 6,726,000 [a]
			Anthro':	79,000 [a]	67,000 [a]	79 ,000[a]	168,000 [a]	32,000 [a]	43,000 [a]	
	Regional Catchment Loads The average annual suspended load delivered regionally to the inner shelf by catchment runoff.		Total:	1,260,000 [b]	1,700,000 [c]	1,700,000 [c]	350,000 [d]	3,000,000 [e]	1,450,000 [f]	
			Anthro':	780,000 [b]	1,450,000 [c]	1,450,000 [c]	210,000 [d]	2,700,000 [e]	910,000 [f]	

[a] Alluvium (2017)
[b] Alluvium (2017) – Baffle, Kolan, Burnett, Burrum and Mary Rivers
[c] Alluvium (2017) – Fitzroy, Waterpark, Shoalwater and Styx Rivers
[d] Alluvium (2017) – Proserpine and O'Connell Rivers
[e] Alluvium (2017) – Burdekin River
[f] Alluvium (2017) – Mulgrave, Johnstone, Tully, Murray and Herbert Rivers

4 Ambient Resuspension Quantities

4.1 Overview

The development of a quantitative sediment budget related to ambient resuspension of seabed sediment by wave and current action has primarily been based on measured water quality data collected in the vicinity of the ports. Continuous turbidity measurements have typically been undertaken as part of the individual ports' water quality monitoring programs and have been collected by self-logging or telemetered turbidity sondes attached either to a seabed mounted frame or to a surface buoy. The data collection frequency typically ranges between 1 and 10-minutes and the raw data has been vetted (and where appropriate censored) prior to undertaking the analysis described below.

Continuous turbidity measurements provide an indirect measure of the quantity of sediment suspended in the water column and have been used as the primary basis for quantifying ambient resuspension processes within the GBR inner-shelf region. The temporal variability exhibited in these measurements can be used to infer the key drivers, magnitude (and other characteristics) of natural sediment resuspension events. The intensity (magnitude), frequency and duration of natural sediment resuspension events provides the necessary context for understanding the relative contribution from maintenance dredging activities.

The quantitative sediment budget derivation is based on the following analysis stages:

(1) Statistical analysis of the raw ambient turbidity data;

(2) Conversion to Suspended Sediment Concentration;

(3) Conversion to Suspended Sediment Mass;

(4) Calculation of Ambient Sediment Resuspension Quantity/s;

(5) Derivation of GBR inner-shelf region ambient quantities.

4.2 Statistical Analysis

Statistical analysis of continuous turbidity measurements was undertaken in order to derive summary metrics describing the quantity and variability of ambient turbidity in the GBR inner-shelf region.

The following steps were undertaken in processing and statistically analysing the turbidity timeseries:

(1) A moving-median filter with a 1-hour window was applied to the data to remove spurious short-duration turbidity spikes that are a common feature of turbidity sonde datasets. This hourly (filtered) turbidity data was used as the basis of all further analysis.

(2) Percentile analysis was undertaken on the median-filtered dataset to derive key turbidity percentile quantities. The median-value was a key parameter used in subsequent assessment steps.

(3) Moving-average filters corresponding to both 1-day and 30-day moving windows were applied to the hourly data in order to illustrate the degree of natural variation which occurs over varying timescales.

(4) In locations subject to significant tidal variations the sub-daily turbidity fluctuations can be a significant component of the overall variance. The sub-daily turbidity fluctuation was calculated by subtracting the 1-day moving average from the hourly turbidity data (filtered).

(5) In order to illustrate the turbidity climate at each monitoring location the filtered timeseries datasets were plotted using a log-scale turbidity axis (see Figure 4-1and Figure 4-2 for examples).

(6) Natural resuspension "events" were defined as periods when the daily-average turbidity exceeded the long-term mean, which was typically 2 to 3 times the median value or roughly similar to the 75th percentile.

(7) Key statistical quantities were derived from the turbidity climate at each monitoring location, as a basis for subsequent quantitative sediment budget development. These summary statistical quantities are described in Table 4-1.

Example turbidity timeseries from the Port of Cairns are shown in Figure 4-1and Figure 4-2 (for locations, refer to the map in Appendix F). The first shows a relatively deep water monitoring site where the resuspension mechanism is dominated by wave events and the second shows a relatively shallow site where resuspension is driven by both tidal currents and waves. Typically, around 25 turbidity "events" (as defined above) were observed to occur in a 12-month period, and these events lasted on average around 4 days (generally periods of consistent medium to strong south-easterly winds).

Both datasets (Figure 4-1 and Figure 4-2) show the natural turbidity range exceeding an order of magnitude. Because of this event driven variability, the mean turbidity is around 2-times the median value. The 30-day moving average turbidity also varies substantially (by a factor 5-10), indicating that the natural system is adapted to extended periods of elevated suspended sediment levels.

4.3 Conversion to Suspended Sediment Concentration

The next step in the quantitative assessment involved converting the turbidity values into equivalent depth-averaged Suspended Sediment Concentrations (SSC, units of *mg/L*). Turbidity measurements have historically been a key component of long term water quality datasets collected as part of ports industry and independent monitoring programs. Continuous turbidity records can be used to derive continuous estimates of SSC and are the most widely available source of data for this purpose.

Location specific relationships for converting turbidity to SSC were used (where available). In doing this conversion account was also made of instrument depth. Vertical profiles of SSC will increase from the surface towards the seabed. To account for this variation, near-bed instrument SSCs were typically factored down to an estimated depth-average, while near-surface instruments were factored up. The conversion factors applied for each port area are detailed in Appendix A to F.

4.4 Port-Area Ambient Suspended Sediment Mass

Conversion of Suspended Sediment Concentration to a mass quantity required multiplication by a water surface area and a representative depth. Port-area regions were defined to encompass the potential area of influence of maintenance dredging plumes (refer Appendix A to F for maps). The area selection was informed by port-commissioned maintenance dredging studies, but to ensure

consistency between individual ports these regions covered approximately 20km along the coast either side of the channel infrastructure and extended to approximately the 20m depth contour. The waterway area varied for individual ports primarily depending on the nearshore profile slope.

For the purpose of the quantitative sediment budget assessment, sub-regions were additionally defined within each port area. These sub-regions were selected based on common geophysical characteristics and were informed by identification of similar turbidity summary statistics at water quality monitoring locations. Most port areas were divided between inshore (depth less than 10m) and offshore (depth ~10-20m) regions. Some port areas (e.g. Gladstone) were also divided into estuarine and open coast sub-regions. Further details about the SSC logger locations and deployment periods is provided in the Appendices (A to F).

The summary statistical turbidity statistics were aggregated for each individual port sub-area and converted firstly to SSC (refer 4.3), and then to mass units by multiplying by surface area and depth. The following summary sediment mass statistics were derived for each sub-area as well as aggregated for the entire port area (refer to Table 4-1 for more detailed descriptions):

- Median sediment mass – annual median mass of suspended sediment representing relatively calm conditions
- Mean sediment mass – annual average mass of suspended sediment across both calm conditions and events
- “Event” sediment mass – average sediment mass in suspension during a typical elevated turbidity event
- “Tidal” sediment mass – average sediment mass of sediment suspended and deposited during a single tidal cycle

The total port-area ambient sediment mass estimates are summarised for each of the six GBR ports in Section 6. The detailed derivation of these estimates for each individual port is provided in the Appendices (A to F).

Table 4-1 Summary statistical quantities derived from continuous turbidity datasets

Statistical Quantity	Description
Median	The median represents the turbidity value that is exceeded 50% of the time. In general, the median is representative of turbidity levels during relatively calm-weather conditions.
Mean (average)	The mean represents the level of turbidity averaged across all weather and tidal conditions experienced at a monitoring site. Due to the event-driven nature of the turbidity signal at the GBR monitoring sites, the mean turbidity was typically more than a factor-2 higher than the median.
Sub-daily amplitude	The sub-daily amplitude represents the typical turbidity variation experienced during a tidal cycle. It was derived by calculating the Median Amplitude Deviation of the sub-daily fluctuation timeseries (similar to Standard Deviation but a more robust estimator in the presence of noise). The amplitude was calculated by multiplying the deviation statistic by 1.4 (i.e. the amplitude to deviation scale for a sinusoidal signal).
Event intensity	The mean turbidity value during resuspension "events" (refer (6) for "event" definition). Note that maximum turbidity during events are usually much higher than the mean event turbidity.
Event frequency	The average number of events in a 12-month period, with units of *events / year*.
Event duration	The average event duration, with units in *days*.

4.5 Port-Area Ambient Suspended Sediment Resuspension Rate

In addition to the suspended mass quantification comparisons described above, a line of comparison based on derived ambient resuspension rates has also been prepared for each of the ports. In broad terms, and apart from the influence of catchment sediment sources, there is a net balance between upward sediment resuspension fluxes and downward settling fluxes within the GBR inner shelf. Under certain conditions driven by wave/current action there may for a limited time be greater upward resuspension than downward settling and consequently the mass of sediment in suspension will increase. Conversely during other relatively calmer periods, the downward settling will exceed the upward resuspension and the mass of sediment in suspension will decrease. However, over the longer term the net exchange between the seabed and the water column is approximately zero, based on external sinks and sources being relatively minor influences on the overall system sediment budget (e.g. Larcombe and Ridd, 2015).

Maintenance dredging generates a similar but additional temporary resuspension of sediment into the water column. Maintenance dredging also represents a net-zero influence on the overall sediment budget. That is, it does not introduce any additional sediment into the active system and the sediment that is resuspended by maintenance dredging into the water column will eventually settle back to the seabed.

Due to these similarities meaningful comparisons can be made between upward resuspension rates generated by the ambient system (i.e. wave/current driven resuspension) and those generated by

dredging. In order to facilitate this comparison, ambient system upward resuspension rates were derived using sediment mass quantities described above, according to the formula:

Annual Ambient Resuspension Rate =
*(Event Mass – Median Mass) * Number of events per year +*
*Tidal Mass * Number of tides per year*

The units of the annual ambient resuspension rate are in *tonnes per year*. These are the same units as the catchment load inputs into the GBR (refer Section 3 of Summary Report). However, in contrast to the catchment load inputs, the annual ambient resuspension rate does not represent an additional source of material into the GBR sedimentary system.

4.6 GBR Scale Summary

A quantitative sediment budget was also developed for the entire GBR inner-shelf region, which extends along approximately 2,000 km of coastline out to approximately the 20 m depth contour. This involved summing up ambient (and dredging) contributions for each of the GBR ports, and calculating ambient quantities for the remaining inner-shelf areas not covered in the port-scale analysis. The derivation of the GBR inn-shelf region ambient resuspension quantity is detailed in Appendix G.

Based on the derived quantities, approximately 160 million tonnes of existing bed sediment is resuspended per annum within the GBR Inner Shelf region due to tidal currents and wind/wave conditions. Low magnitude resuspension occurs regularly due to tidal currents and typical wind/wave conditions, while higher magnitude resuspension occurs episodically due to spring tide and/or high energy wind/wave events (on average 25 events per year though not simultaneous across the entire GBR).

The derived GBR inner-shelf natural resuspension quantity is approximately 17-times higher than the input of new sediment from the catchment into the GBR (refer Section 3).

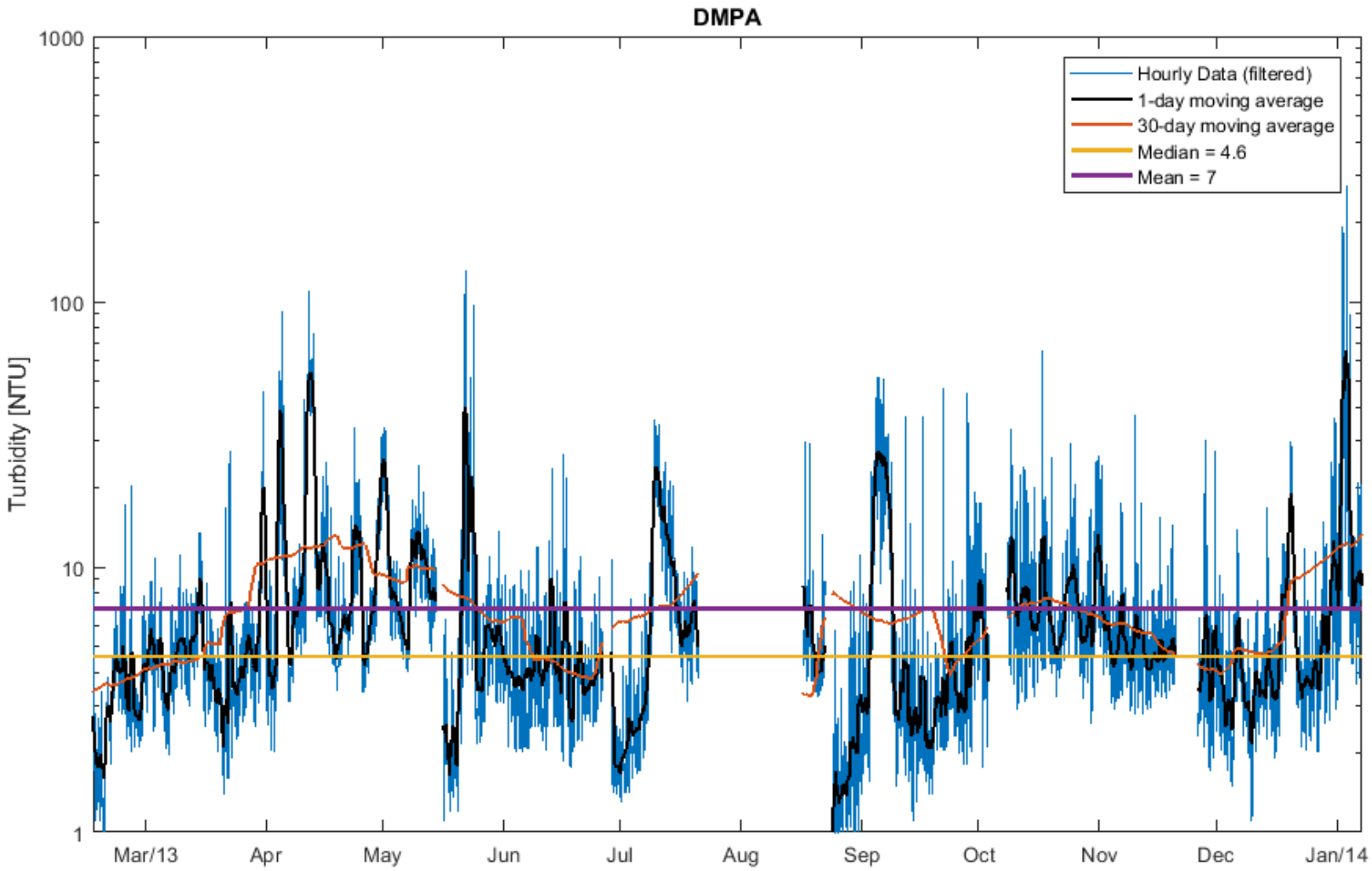

Figure 4-1 Turbidity timeseries offshore of Cairns (Depth = 14m). At this location sediment resuspension is dominated by wave events.

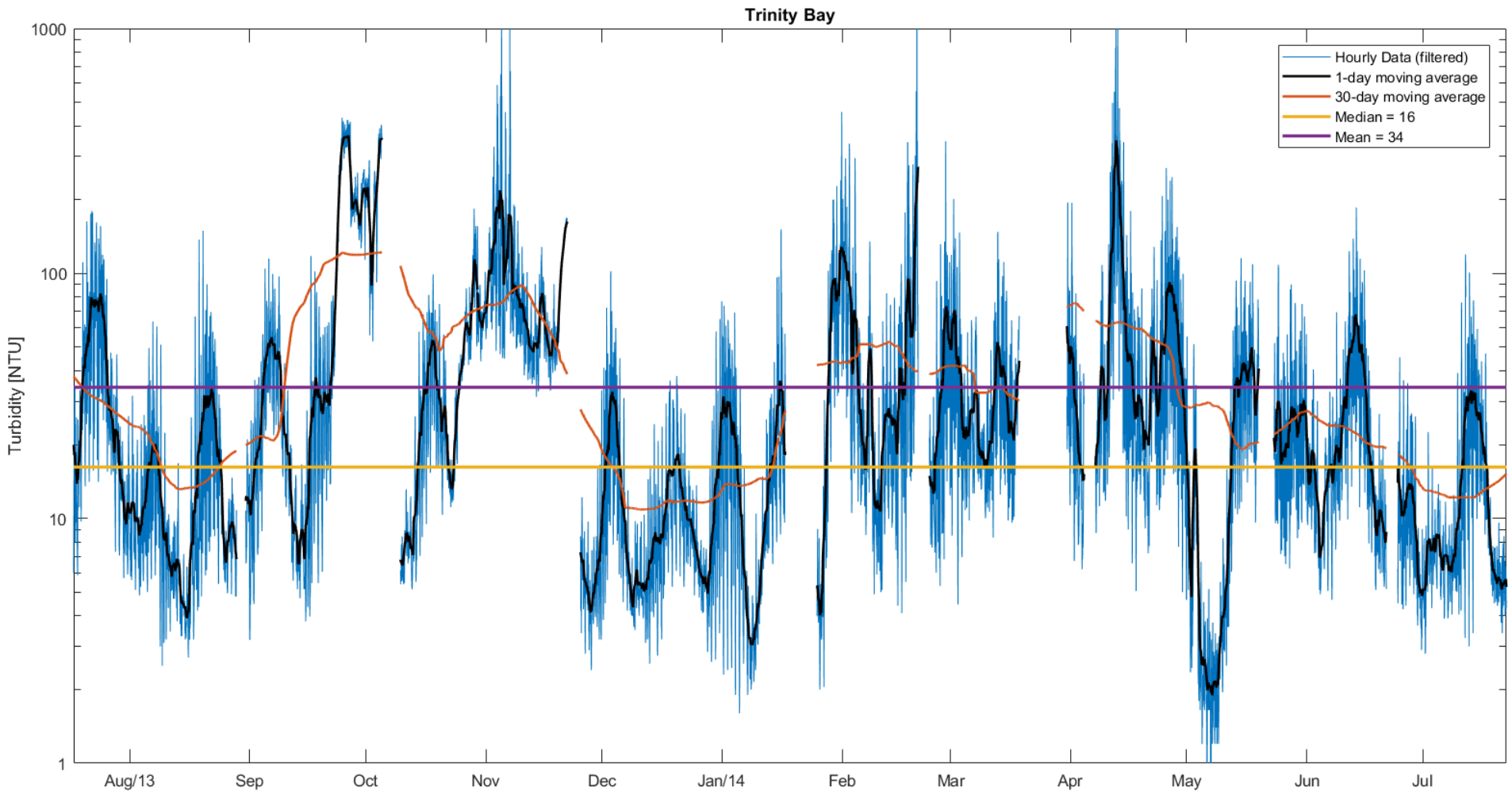

Figure 4-2 Turbidity timeseries in Trinity Bay, Cairns (Depth = 4m).
At this location sediment resuspension is driven by a combination of waves and tidal currents.

5 Port Maintenance Dredging Resuspension Quantities

5.1 Port Maintenance Dredging Suspended Sediment Mass

In order to answer WQA17 the mass of sediment resuspended by maintenance dredging activities was derived and summarised for each of the ports for comparison with the ambient resuspension sediment mass quantities discussed in the previous section. The mass of sediment in the water column due to maintenance dredging resuspension cannot be directly measured but has typically been estimated based on sampling and monitoring of individual plumes during maintenance dredging in combination with numerical dredge plume modelling of entire maintenance dredge campaigns (e.g. BMT WBM, 2013; BMT WBM, 2014).

The quantity (mass) of dredging related sediment in resuspension at a point in time depends on a number of factors, including:

- the mass of sediment resuspended by the dredging and placement activity, which in turn is dependent on factors including dredging plant, methodology, sediment characteristics, channel/berth geometry and productivity rate;
- the rate of dredge-plume material settling from the water column, which is dependent on both sediment characteristics and environmental conditions;
- the potential resuspension of previously deposited dredge-plume sediment, which is dependent on previous deposition history and on environmental forcing conditions;
- interaction of dredge-plume sediment with ambient sediment both in the water-column (potentially affecting settling rate) and in the benthos (affecting subsequent resuspension).

Numerical dredge plume modelling is required to integrate these factors into a prediction of dredge plume mass timeseries across a dredge campaign. An example timeseries from a modelled maintenance dredging campaign from the Port of Cairns is shown in Figure 5-1. The total mass of dredging-related sediment in suspension varies through time depending on the combined influence of factors described above.

Comparison of relative quantities of ambient and dredging-related SSC at the port-scale can provide a high-level summary of the relative significance of dredging to the overall quantity of suspended fine sediment within and adjacent to the GBR ports. A range of durations were considered, from a daily maximum dredge plume (load) estimate, to a campaign-mean dredge load estimate, and an annual-mean load estimate. These range of durations were evaluated in acknowledgement that both acute and chronic exposure may be relevant to the environmental effects of dredging. The following comparisons (Table 5-1) between ambient suspended sediment mass quantities are summarised in Section 6.

It should be noted that the individual GBR ports undertake detailed assessments of dredging activities and plume generation as part of ongoing maintenance dredging management. Numerical plume modelling results derived as part of these assessments have been interrogated in order to inform the high-level comparisons in the current study.

Table 5-1 Ambient and Dredge-related Suspended Sediment Mass Quantity Comparisons

Comparison Duration	Ambient Mass Quantity	Dredge-Related Mass Quantity
1 day	Event sediment mass • typical wind or tide event ambient sediment mass • occurs ~25 times per year • typically lasts for ~3-4 days	Maximum daily average • daily average dredge plume mass • exceeded once per campaign i.e. once per year (or less frequently)
4 weeks (typical campaign duration)	Annual mean sediment mass • the annual mean is essentially equivalent to the average monthly mean	Campaign average • this is the average dredge plume mass over the entire campaign
1 year	Annual mean sediment mass	Annual average • this is the average maintenance dredge plume mass over an entire year • includes SSC contributions from DMPA resuspension

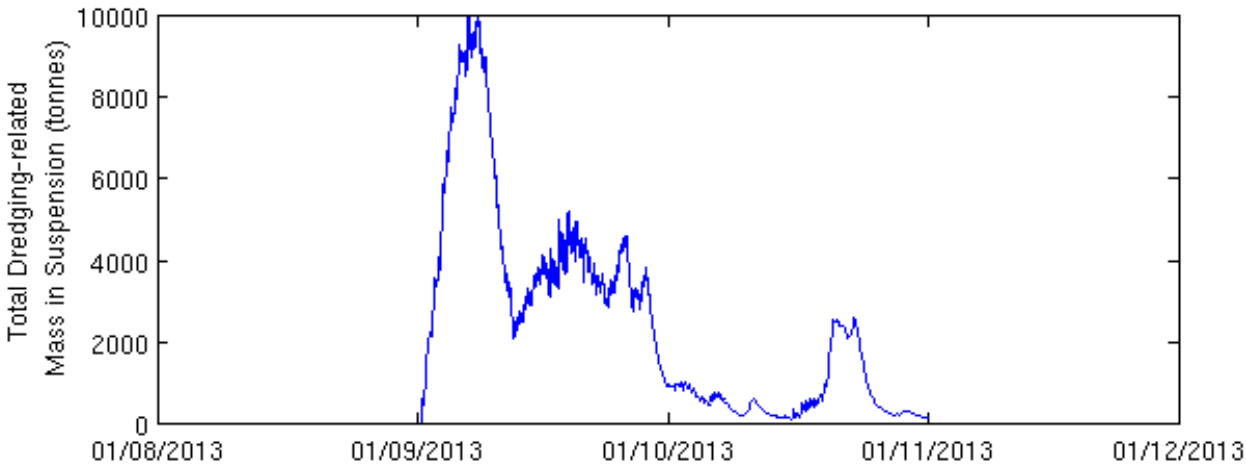

Figure 5-1 Total dredging-related sediment mass in suspension during a hindcast Port of Cairns maintenance campaign. The modelled campaign extended from 1/9/2013 to 29/9/2013.

5.2 Maintenance Dredging Resuspension Rates

Maintenance dredging resuspension rates have been derived as a percentage of the overall annual maintenance sediment load for each port (refer Appendices A to F). Two dredge-related resuspension components were separately quantified.

The first component relates to the generation of passive sediment plumes during dredging and placement. An upper-bound allowance for the passive plume spill associated with overflow TSHD dredging and hopper-release placement of fine maintenance material is approximately 20% of the total mass of fine sediment removed from the port.

Port maintenance dredging relocates most of port facility sedimentation to offshore dredged material placement areas (DMPA), which are also situated within the active sediment system. The relocation of port maintenance dredging material to DMPAs located within the active sedimentary system maintains ongoing transport of sediment along natural sediment pathways, with maintenance dredge material gradually re-assimilated into the ambient sedimentary system from which it originated.

The second dredge-related resuspension component relates to the mobilisation and transport of placed sediment from the DMPA by wave/current action. For highly dispersive DMPAs the second component may account for 100% of the remaining maintenance load not entering passive plumes during dredging and placement.

The two components have been derived separately as they have very different consequence for water quality. Dispersion of maintenance material from DMPAs occurs during periods of active ambient resuspension, and this factor along with the placement of DMPA locations away from sensitive receptor locations has the consequence that environmental risk associated with DMPA dispersion is typically lower than that associated with passive plumes during dredging, despite the annual resuspension quantities being in many cases several times greater.

6 Port-scale Quantitative Comparison

The quantitative assessment described in Sections 4 and 5 was applied individually to each of the six GBR ports. Material detailing the derivation of the sediment budget for each port is included in Appendix A to F of this report. The port-scale comparisons of ambient and dredging related suspended sediment mass and resuspension quantities are summarised in Section 6.1 and 6.2. Section 6.3 provides an overall summary of port-scale sediment interactions, including catchment sediment contributions. Section 6.4 considers the further line of evidence provided by numerical modelling of ambient sediment.

6.1 Suspended Sediment Mass Comparison

A quantitative comparison of sediment mass in suspension under natural (ambient) conditions and due to maintenance dredging for each of the GBR ports is summarised in Table 6-1. Comparisons were made for a range of timescales from daily to annual.

The short-term comparisons indicate that the maximum daily suspended sediment load during maintenance dredging can range between 2 to 8% of the typical sediment mass in suspension during spring-tide and/or high energy wind/wave events. As further context, the maximum daily dredge load is only exceeded once per campaign (typically every 1 to 3 years), while the ambient event quantity to which it is being compared occurs with a frequency of around 25 events per year and has typical durations of around 4 days.

Averaged over a typical maintenance dredge campaign (in the range 2 to 5 weeks), dredging related suspended sediment is in the range 4 to 10% of ambient quantities at the port-scale.

Over even longer time-scales the relative contribution of dredging becomes less significant compared with ambient suspended sediment quantities averaged over a similar period. Averaged over an entire year including a maintenance dredge campaign, the quantity of dredging related sediment in suspension at the port-scale ranges between 0.1 to 1% of ambient quantities.

6.2 Sediment Resuspension Comparison

Both ambient and dredging-related resuspension estimates are summarised for each of the GBR ports in Table 6-2. Dredging-related resuspension rates were derived by factoring the typical campaign loads for each of the ports as summarised in the Maintenance Dredge Strategy – technical supporting document (RHDHV, 2016). The resuspension units are in *tonnes per year*, which facilitates comparison with the port-scale catchment loads. However, in making these comparisons it is important to differentiate between the input of new sediment into the GRB Inner Shelf region from fluvial sources and the resuspension of existing bed sediment due to natural processes and dredging. It should be noted that the dredging related resuspension load estimates relate to years in which dredging occurs (Abbot Point, Mackay and Hay Point are not dredged annually) and include both sand-size and fine-grained sediment. At all the ports except Gladstone, the majority of the sediment removed by maintenance dredging is silt and clay sized.

Between 1.5 and 15 million tonnes of existing bed sediment is resuspended per annum within the GBR port regions due to tidal currents and wind/wave conditions. Low magnitude resuspension occurs regularly due to tidal currents and typical wind/wave conditions, while higher magnitude

resuspension occurs episodically due to spring-tide and/or high energy wind/wave events (on average 25 events per year). The relative contribution of these and the total resuspension mass is dependent on the port setting and local conditions.

Of the sediment naturally resuspended per annum, between 0.05 and 3% is predicted to be deposited within port dredged areas. As these areas are deeper than the surrounding areas more energy is required to transport the sediment and so limited resuspension occurs meaning that the sediment requires removal by maintenance dredging to ensure the dredged areas remain navigable. For ports where maintenance dredging is not required every year, it is assumed that the deposition occurs evenly over time.

The relative mass of sediment resuspended by maintenance dredging varies at each port. The ports with the highest sedimentation rates (Cairns, Townsville and Gladstone), typically undertake maintenance dredging on an annual basis. Hay Point and Mackay typically undertake maintenance dredging once every 3 years, while Abbot Point has an expected frequency of only once every 20 years. During years when maintenance dredging occurs, an upper estimate of the mass of sediment resuspended at the five ports directly by dredging and placement ranges from 2,800 to 56,000 tonnes. This estimate includes disturbance at drag head, propeller wash, overflow and losses during placement and represents 3.2 to 8.4% of the ambient resuspension expected over the campaign duration (in the range 2-5 weeks).

Including also the subsequent longer term natural resuspension of sediment relocated to the material placement areas, the estimate of sediment resuspension attributed to dredging increases to between 14,000 and 250,000 tonnes of sediment for the individual ports. Comparing the relative mass of sediment resuspended naturally to that from maintenance dredging at a port scale shows that maintenance dredging contributes the equivalent of between 0.7 and 2.9% of the natural resuspension per annum within the local port regions (assuming a year which includes dredging at the ports which only require maintenance dredging every third year).

6.3 Conceptual Summary

A conceptual summary of the port-scale sediment resuspension interactions was prepared using the derived quantities, and is shown in Figure 6-1. The conceptual summary presents the quantitative interactions between:

(1) Inner-shelf terrigenous sediment deposits;

(2) Contemporary catchment supply of fine-grained sediment;

(3) Natural resuspension of inner-shelf sediment; and

(4) Resuspension from dredging.

The range of values shown in the figure represent the variation across the six individual GBR ports. Individual conceptual summaries for each of the six ports are provided in the Appendices (A to F).

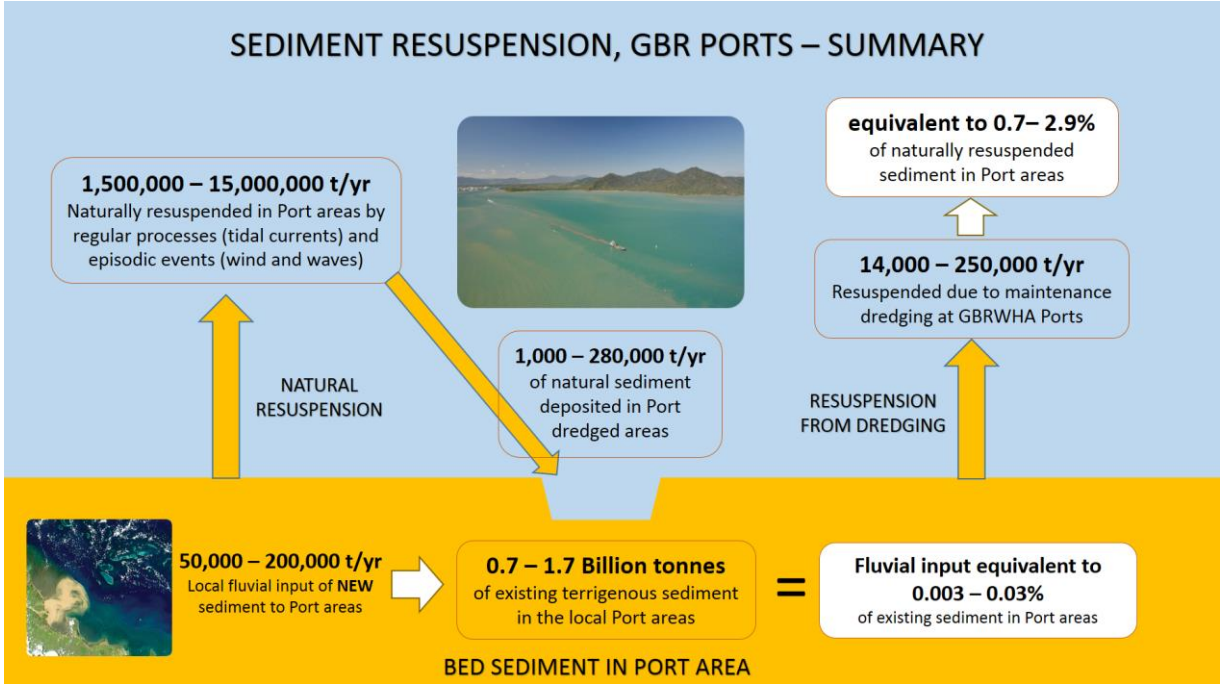

Figure 6-1 Quantitative Summary of Sediment Resuspension at GBR Ports

The terrigenous sediment wedge quantities were derived on the basis that Holocene deposits are generally a maximum of 4-5 m thick (Larcombe and Ridd, 2016) and extend across the inner-shelf region from the current day shoreline to the 20 m depth contour. Where location specific geological survey information was unavailable the average Holocene deposit thickness across the inner shelf was generally assumed to be half the maximum thickness (~2.5 m).

The port-scale fluvial inputs were derived from the P2R program catchment modelling outputs (refer Section 2). The catchment quantities included in the conceptual summary relate to the contemporary total annual loads of fine-grained sediment into the GBR lagoon. The annual fluvial inputs are negligible compared to the existing terrigenous sediment deposits within the GBR inner-shelf system, as the Holocene terrigenous deposits represent the accumulation of fluvial catchment loads over the past 10,000 years or more.

The conceptual summary depicts that natural resuspension of inner-shelf sediment deposits by tidal currents and episodic wave events is the primary contributor to sediment suspended into the water column. At a port scale the quantities being resuspended annually by these processes are estimated to be between 1.5 million tonnes at the Port of Abbot Point and 15 million tonnes at the Port of Gladstone.

These natural resuspension processes are also the primary mechanism for sedimentation of port infrastructure. The quantities being trapped in port facilities and requiring maintenance dredging constitute less than 3% of the sediment being resuspended by currents and waves at a port scale.

It is worth noting that the port-scale fluvial inputs are relatively insignificant compared with the natural resuspension rates, which helps explain why there is a negligible link between contemporary catchment flows and sedimentation rates at the six GBR ports (RHDHV, 2016).

The dredging related resuspension load estimates used in the conceptual summary includes the direct plumes generated during dredging and placement, and conservatively also includes the quantity estimated to be dispersed from the material placement area. It should also be noted that the dredging related resuspension load estimates relate to years in which dredging occurs (Abbot Point, Mackay and Hay Point are not dredged annually). The dredging related quantities also include all material removed from port infrastructure, including both sand-size and fine-grained sediment, whereas the catchment and ambient resuspension quantities relate only to the fine-grained sediment fractions (this difference is largest in Gladstone where sand size sediment is a significant proportion of the maintenance dredging task).

In terms of the ecosystem health, it is important to differentiate between the input of new sediment (and other pollutants) into the port region from fluvial sources, in contrast to the resuspension of existing marine benthic sediment due to either natural processes or maintenance dredging. Assimilation of new catchment loads into the GBR following flood events has been correlated with periods of regional, chronic, water quality decline (Fabricius *et al.,* 2016). In terms of these chronic effects, it seems likely that biogeochemical processes contributing to reductions in water clarity may be an important contributor (Alongi and McKinnon, 2005), however further research is required to understand these lines of effect.

6.4 Model Based Comparisons

As a second line of evidence comparisons of model based ambient resuspension quantities were made with the quantities derived from the long-term turbidity monitoring datasets (refer Appendix A to F). The modelled ambient resuspension quantities were in most cases higher than the data-based quantities.

That the model-based predictions were generally higher than the data-based quantities can in part be attributed to monitoring being undertaken at sensitive receptor locations, which are biased towards the less turbid regions. This second line of evidence supports a conclusion that the quantitative comparisons described above represent a conservative assessment of the relative contribution of dredging to suspended sediment quantities within the GBR.

Table 6-1 GBR Port-scale Suspended Sediment Mass (tonnes), Comparison of Dredging and Ambient Quantities

	Description	Gladstone	Hay Pt	Mackay	Abbot Pt	Townsville	Cairns
Ambient	Median Ambient Suspended Mass	37,000	14,000	13,000	3,500	20,000	25,000
	Event Ambient Suspended Mass	106,000	203,000	200,000	20,000	87,000	133,000
	Annual Mean Ambient Suspended Mass	51,000	53,000	52,000	7,500	35,000	62,000
Dredging	Campaign Maximum Dredge Suspended Mass	4,100	10,000	4,500	1,000	6,000	10,000
	Campaign Mean Dredge Suspended Mass	2,200	5,000	2,250	750	2,000	5,000
	Annual Mean Dredge Suspended Mass	400	250	120	5	400	750
Dredging % of Ambient	Dredging Campaign Maximum % of Ambient Event	3.9	4.9	2.3	5.0	6.9	7.5
	Dredging Campaign Mean % of Ambient Mean	4.3	9.4	4.3	10.0	5.7	8.1
	Dredging Annual Mean % of Ambient Mean	**0.8**	**0.5**	**0.2**	**0.1**	**1.1**	**1.2**

Table 6-2 GBR Port-scale Suspended Sediment Resuspension (tonnes/year), Comparison of Dredging and Ambient Quantities

	Description	Gladstone	Hay Pt	Mackay	Abbot Pt	Townsville	Cairns
Ambient	Annual ambient resuspension	15,400,000	6,400,000	6,700,000	1,500,000	8,700,000	14,000,000
	Ambient resuspension during dredging campaign	1,180,000	370,000	260,000	60,000	670,000	1,080,000
Dredging	Typical maintenance dredging campaign[8]	250,000	140,000	63,000	14,000	280,000	280,000
	Passive plume during dredging and placement	15%	20%	20%	20%	20%	20%
	DMPA dispersion	30%	20%	80%	80%	70%	20%
	Dredging resuspension during dredging campaign	37,500	28,000	12,600	2,800	56,000	56,000
	Annual dredging and DMPA resuspension	112,500	56,000	63,000	14,000	250,000	112,000
Dredging % of Ambient	Dredging % of Ambient Resuspension (Campaign)	3.2	7.6	4.8	4.7	8.4	5.2
	Dredging % of Ambient Resuspension (Annual)	**0.7**	**0.9**	**0.9**	**0.9**	**2.9**	**0.8**

[8] On average this quantity is dredged with the following frequency:
Cairns, Townsville and Gladstone – annually;
Mackay and Hay Point – every 3 years;
Abbot Point – estimated every 20 years, i.e. very infrequently.

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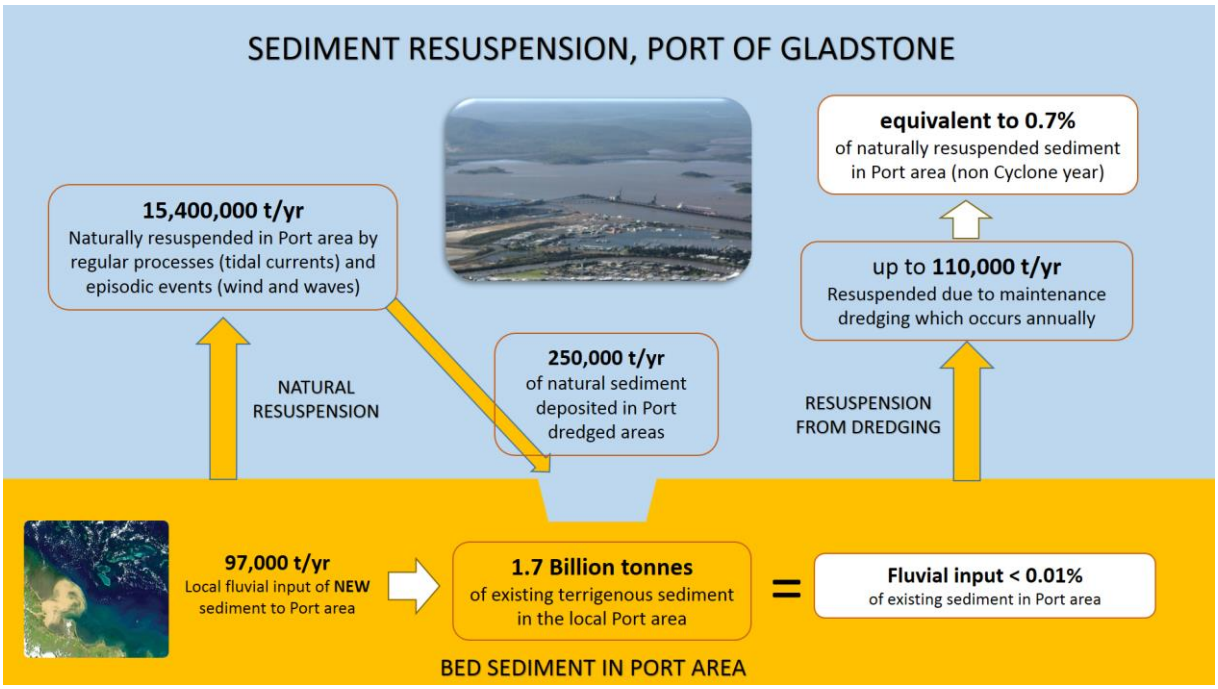
Appendix A Port of Gladstone

Summary



Assumptions

- The Gladstone ambient sediment quantities have been derived using a continuous turbidity monitoring dataset collected for the Port of Gladstone as part of the Channel Duplication Project EIS, together with additional turbidity datasets collected at Rodds Bay and Fishermans Landing which were provided by GPC.
- The turbidity instrument locations and sediment budget zones for the Port of Gladstone are shown in Figure A-1.
- Time series of measured ambient turbidity at sites CD1 (as an example of an offshore site) and P2B (an estuary site) are provided in Figures A-2 and A-3.
- The estuary turbidity dataset (P2B) shows the substantial variation around the 1-day moving average driven by tidal resuspension. The maximum turbidity during peak tidal flows may be approximately two times larger than the daily average during spring tide conditions.
- A turbidity to SSC factor of 1.6 has been applied, and an additional factor of 1.5 has been applied to convert from a surface measurement to a depth-averaged quantity. The factor of 1.5 was derived from the relationship between turbidity measurements near the surface with measurements near the bed (See Table A-1).
- Based on the Maintenance Dredge Strategy – technical supporting document (MDS) the average maintenance campaign quantity for the Port of Gladstone is 200,000m^3. Since the Western Basin port expansion this has been estimated to have increased to 250,000m^3.

- A density conversion of 1.0t/m^3 was used to convert the average Gladstone maintenance quantity to 250,000 tonnes/year. This is higher than the density conversion used for the other ports (0.7t/m^3) because of the higher sand content in Gladstone maintenance material.
- The dredge sediment mass quantity estimates in Table A-3 have been derived based on modelling of a 'typical' Gladstone maintenance dredging campaign with an approximate volume of 260,000m^3 (BMT WBM, 2017).
- The passive plume resuspended during dredging and placement was assumed to be 15% of the total maintenance quantity (Table A-4). This factor is lower than the other ports (20%) because of the higher sand content in Gladstone maintenance material.
- The time series of the total amount of dredged sediment in suspension for the analysed campaign is provided in Figure A-4.
- Annual resuspension rates were derived from Port of Gladstone numerical model simulations (BMT WBM, 2017) for comparison with the quantities derived from the turbidity logger datasets. The model derived rate for fine sediment resuspension of 14,200,000 tonnes/year is broadly consistent with the data based quantity of 15,400,000, which lends support to the quantitative comparisons presented in Table A-3 and A-4.
- Existing terrigenous sediment quantities were derived based on an average Holocene deposit thickness of 2.5m.

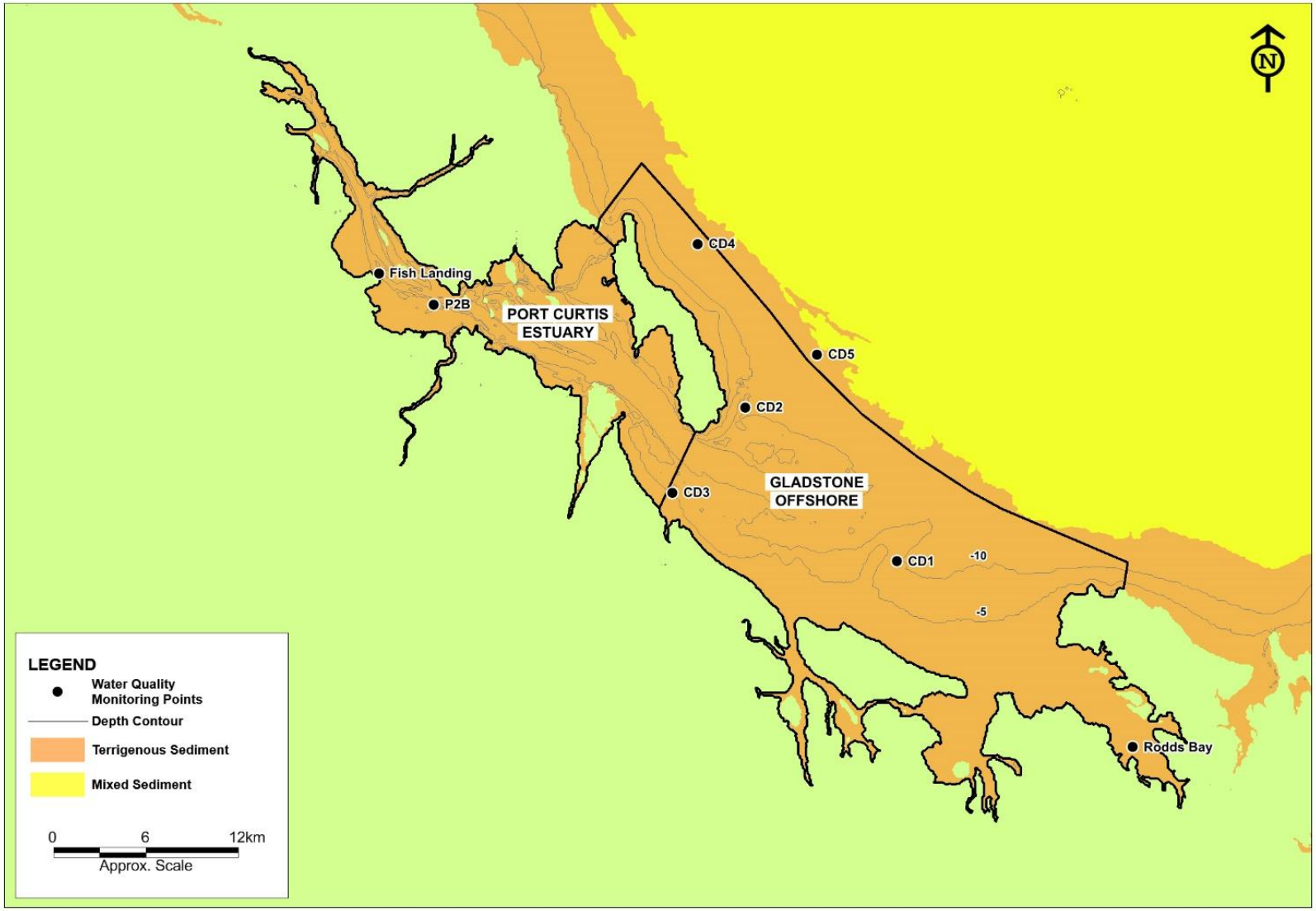


Figure A-1 Port of Gladstone Sediment Budget Zones and Turbidity Monitoring Locations

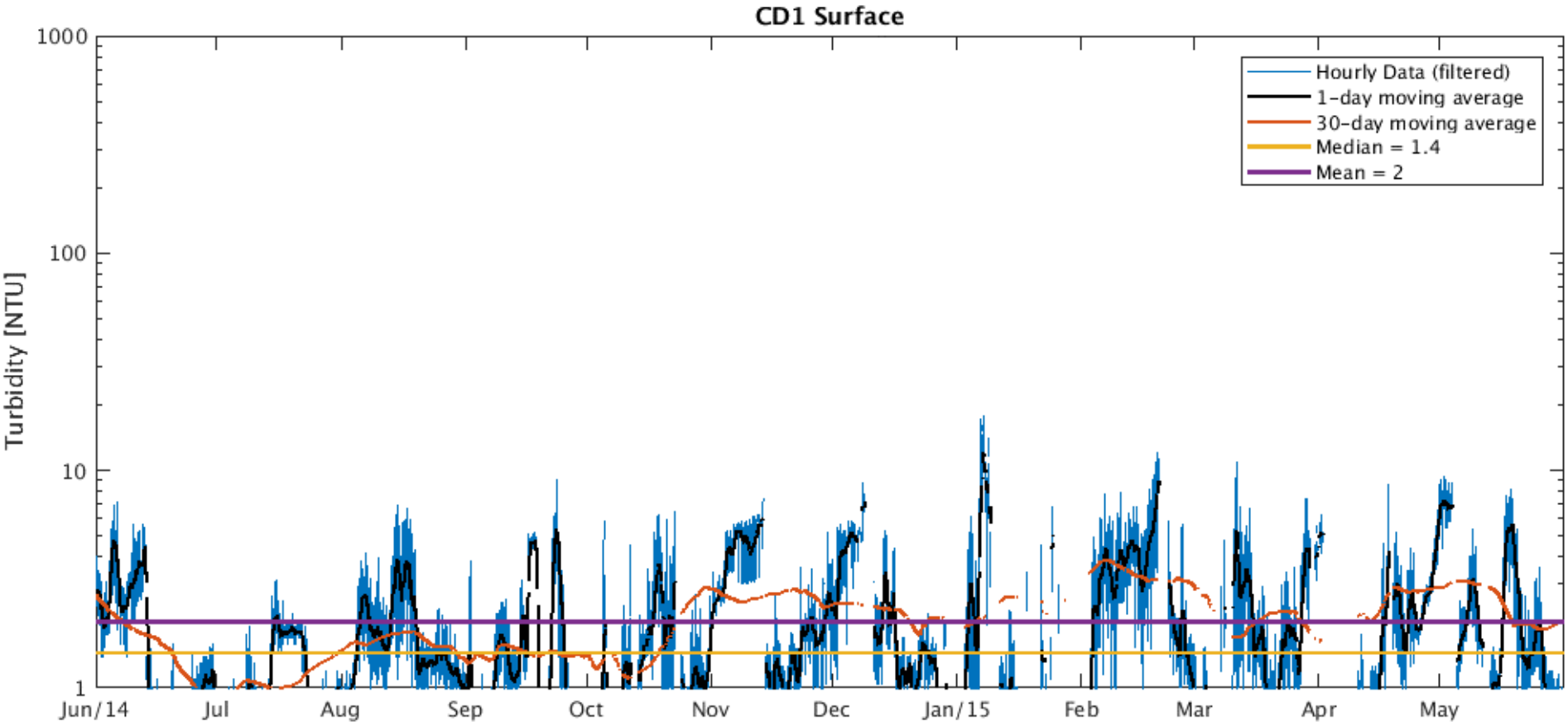


Figure A-2 Turbidity time series at Site CD1 outside Port Curtis (Depth = 5m). At this location sediment resuspension is dominated by wave events.

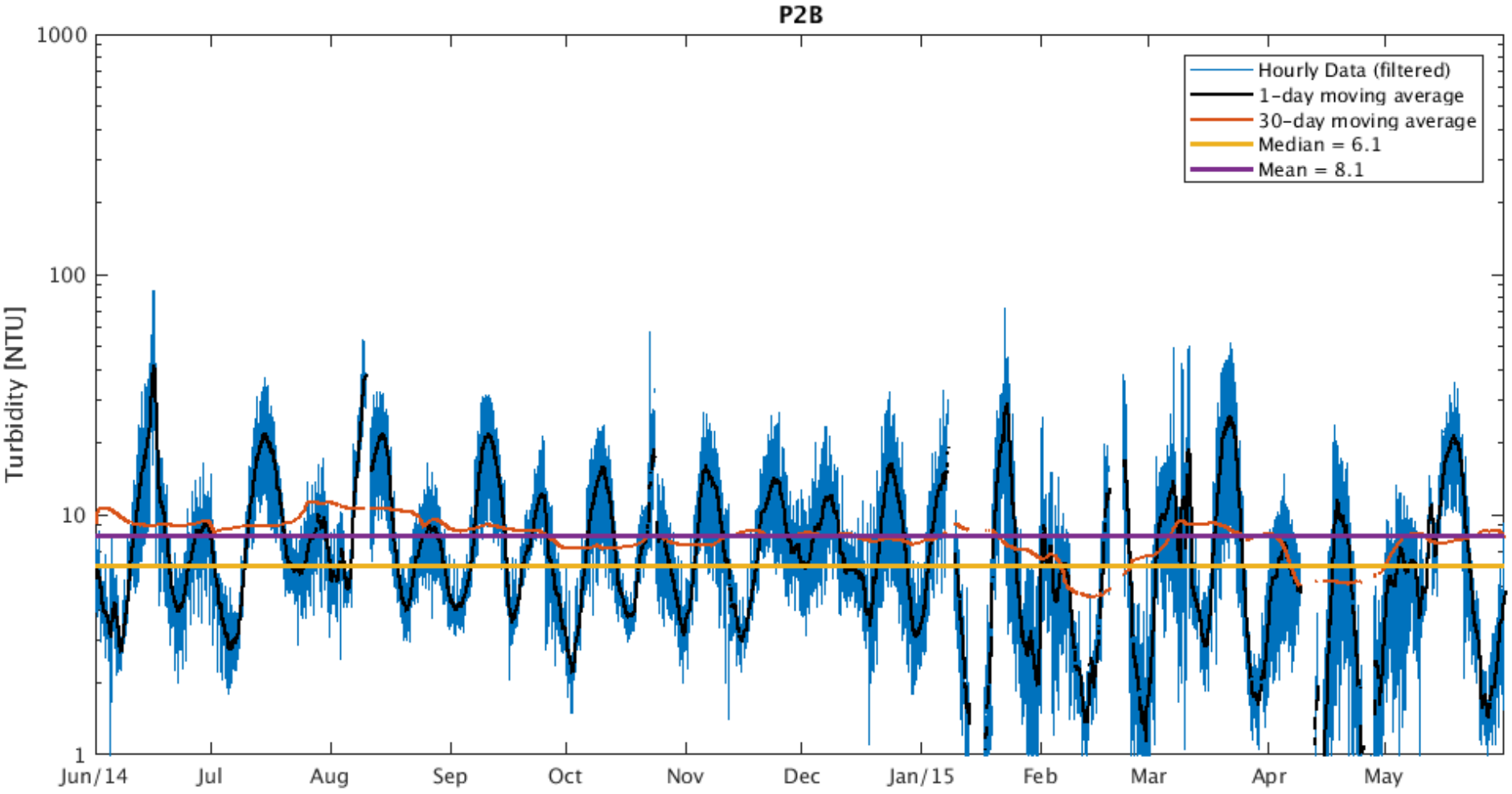


Figure A-3 Turbidity time series at Site P2B within Port Curtis (Depth = 7m). At this location sediment resuspension is dominated by tidal currents.

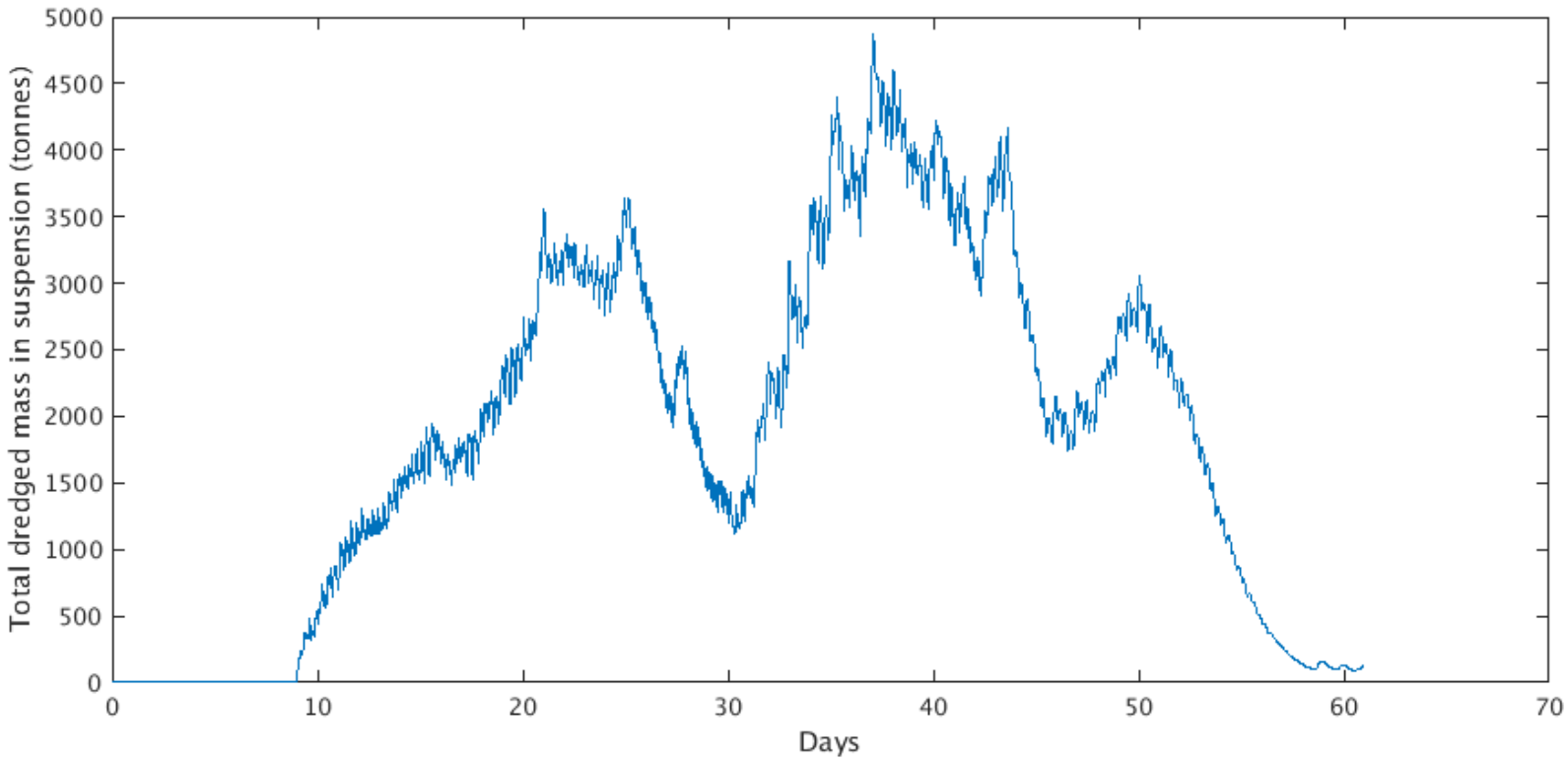


Figure A-4 Total Amount of Dredged Sediment in Suspension for the Modelled Maintenance Dredging Campaign (260,000m^3)

Table A-1 Gladstone Turbidity Statistics Summary

Site	Depth (mAHD)	Long-term Turbidity Statistics (NTU)						Turbidity Event Statistics (NTU)					
		Mean	1%ile	25%ile	Median	75%ile	99%ile	Sub-daily Amplitude	Event Threshold	Mean Event Turbidity	Frequency (events/y)	Mean Duration (days)	Primary Driver/s
P2B	7	8.1	0.9	3.9	6.1	10	33.1	3.6	8.1	13.9	29	4.6	Tide
RB1	3	8.8	0.0	2.5	4.3	7.1	62.2	2.2	8.8	29.9	16.4	4.1	Tide
Fish Landing	11	8.8	1.2	4.2	6.8	10.6	34.8	3.8	8.8	14.7	23.6	5.8	Tide
CD1 Surface	5	1.2	0.0	0.5	0.8	1.7	5.3	0.3	1.2	2.3	26	5.3	Waves
CD2 Surface	8	2.2	0.0	0.9	1.8	3.0	7.8	1.6	2.2	3.4	35	4.6	Waves/Tide
CD3 Surface	8	3.0	0.0	1.1	2.5	4.6	10.5	1.1	3.0	5.3	31	5.1	Waves/Tide
CD4 Surface	7	1.0	0.0	0.0	0.6	1.6	6.5	0.2	1.0	2.2	17	8.8	Waves
CD5 Surface	18	1.0	0.0	0.3	0.9	1.7	4.5	0.1	1.0	2.1	24	5.3	Waves
CD1 Benthic	8	2.9	0	0.9	1.9	3.45	21.6	0.8	2.9	6.2	25.3	4.7	Waves
CD2 Benthic	8	4.4	0.5	2	3.3	5.6	18.1	2.2	4.4	7.5	34.3	4	Waves/Tide
CD3 Benthic	7	5	0	1.3	3.4	7	24.9	1.7	5	9.7	35.7	3.9	Waves/Tide
CD4 Benthic	18	3	0	0.8	1.8	3.3	24.1	0.7	3	7.2	24	4.4	Waves
CD5 Benthic	18	1	0	0.4	0.7	1.3	5.4	0.3	1	2	31.1	4	Waves
Site Averages		**3.9**	**0.2**	**1.4**	**2.7**	**4.7**	**19.9**	**1.4**	**3.9**	**8.2**	**27.0**	**5.0**	

Table A-2 Port of Gladstone Ambient Sediment Mass and Resuspension Rate Quantities

Port Area Zones			Port Area SSC				Ambient Sediment Mass Estimates				Ambient Resuspension Estimate		
Description	Average Depth [m]	Area [km^2]	Median SSC [mg/L]	Mean SSC [mg/L]	Event SSC [mg/L]	Tidal SSC [mg/L]	Median SSC Mass [tonnes]	Mean SSC Mass [tonnes]	Event SSC Mass [tonnes]	Tidal SSC Mass [tonnes]	No. of Events [per year]	No. of Tides [per year]	Annual Resuspension [tonnes/y]
Port Curtis Estuary	7	200	13.8	20.5	46.8	7.7	19,253	28,739	65,536	10,730	25	700	8,667,798
Gladstone Offshore	12	460	3.2	4.0	7.3	1.6	17,487	22,257	40,539	8,744	25	700	6,696,864
Port Area Total		**660**					**36,740**	**50,996**	**106,075**	**19,473**			**15,364,662**

Table A-3 Port of Gladstone Suspended Sediment Mass, Comparison of Dredging and Ambient Quantities

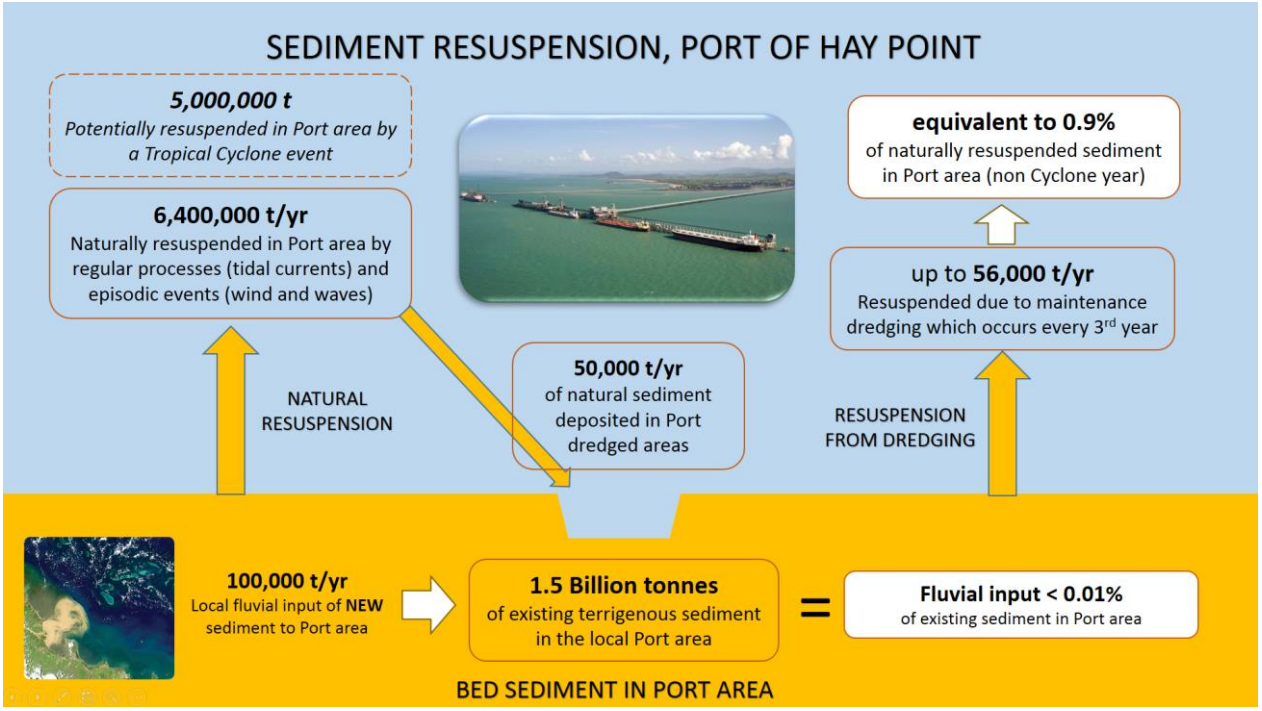
	Description	Quantity		Notes
Ambient	Median Ambient Mass	37,000	tonnes	Annual median turbidity represents relatively calm conditions.
	Event Ambient Mass	106,000	tonnes	Typical ambient event duration is 3-4 days. Event frequency is 25-30 per year. Much higher ambient suspension mass occurs during 1 in 1 year ARI events, and one to two orders of magnitude higher are expected during extreme Tropical Cyclone conditions. Note that in the tidally dominated Port Curtis Estuary higher (by more than a factor 2) ambient loads also occur for several hours 4 times a day during peak spring tide conditions.
	Annual Mean Ambient Mass	51,000	tonnes	Annual mean represents average across both calm conditions and events.
Dredging	Campaign Maximum Dredge Mass	4,100	tonnes	Typical duration would be less than 1 day. Event frequency is 1 per year. This quantity includes a significant component of natural resuspension of previously deposited dredge-plume and placed material and is therefore very sensitive to environmental conditions (i.e. natural resuspension events). However, during such events the total quantity of sediment in suspension is always dominated by the ambient component.
	Campaign Mean Dredge Mass	2,200	tonnes	Typical maintenance campaign duration is 3-4 weeks
	Annual Mean Dredge Mass	400	tonnes	Only low intensity dredging related plumes occur outside the campaign window.
Dredging % of Ambient	Dredging Campaign Maximum % of Ambient Event	3.9	%	This is a comparison of relatively short-term (acute) quantities. Note that the dredge quantity occurs approximately once a year, lasting for one day, while the ambient quantity is occurring around 25 times per year and lasting for four days.
	Dredging Campaign Mean % of Ambient Mean	4.3	%	This is a comparison on timescales of around 1 month.
	Dredging Annual Mean % of Ambient Mean	0.8	**%**	This comparison represents the long term average contribution of maintenance dredging to suspended sediment quantities at the port-scale.

Table A-4 Port of Gladstone Suspended Sediment Resuspension, Comparison of Dredging and Ambient Quantities

	Description	Quantity		Notes
Ambient	Annual ambient resuspension	15,400,000	tonnes/year	Estimated as the sum of multi-day resuspension events and sub-daily (tidal) resuspension quantities.
	Ambient resuspension during dredging campaign	1,180,000	tonnes/year	Assuming a typical 4 week campaign. Campaign frequency is typically annual.
Dredging	Annual maintenance dredging	250,000	tonnes/year	Based on historical maintenance dredging quantities.
	Passive plume during dredging and placement	15	%	Worst case TSHD overflow dredging of predominantly sandy sediments.
	DMPA dispersion	30	%	Gladstone DMPA is predominantly retentive.
	Dredging resuspension during dredging campaign	37,500	tonnes/year	Estimated as the sum of passive plume quantity and percentage of material dispersed from DMPA.
	Annual dredging and DMPA resuspension	112,500	tonnes/year	This is the total quantity resuspended during dredging, placement and transport of dredged material from the DMPA
Dredging % of Ambient	Dredging % of Ambient Resuspension (Campaign)	3.2	%	This is a comparison over typical maintenance campaign timescales.
	Dredging % of Ambient Resuspension (Annual)	0.7	**%**	This sediment resuspension comparison represents the annual quantity of sediment mobilisation compared with an equivalent derived ambient quantity.

Appendix B Port of Hay Point

Summary



Assumptions

- A maintenance dredging requirement of 200,000 m^3 every 3 years has been adopted. The MDS estimated a requirement of 300,000 m^3 but noted that this was based on limited information (2 incomplete dredge campaigns) and that detailed bathymetric analysis was being undertaken which would provide a better understanding of the requirement. Work undertaken as part of the Hay Point Bathymetric Analysis by RHDHV found that the sedimentation rate indicates a requirement of less than 150,000 m^3 every 3 years, but to be conservative a volume of 200,000 m^3 has been adopted.
- A dry sediment density of 0.7 t/m^3 (McCook *et al.,* 2015) was assumed for Hay Point maintenance sediment and the typical maintenance campaign quantity was therefore estimated as 140 t (every 3 years).
- The maintenance dredging calculations are based on the year when maintenance dredging campaign occurs rather than the annual average maintenance dredging requirement (as it is not an annual requirement at any of the three ports). This represents the worst case scenario in terms of potential impacts due to maintenance dredging.
- No scaling of SSC from near bed to depth averaged has been directly included in the calculations as at Hay Point and Mackay as the depths assumed in the calculations are relative to Chart Datum. As the tidal range exceeds 6.5 m the additional 3 to 3.5 m which corresponds to mean sea level would represent an increase in water volume in the

calculations of between 30 (offshore) and 65% (nearshore) which is assumed to correspond to the difference between the SSC at the bed and the depth averaged SSC.

- The frequency of tidal events at the Ports of Hay Point and Mackay are based on model results showing that limited resuspension occurs during smaller neap tides. As such, tidal resuspension has been assumed to occur for 10 days per fortnight, which with two tides per day equates to 520 events per year (this is further discussed in the sub-tidal variations section below).
- The dredge sediment mass quantity estimates in Table B-3 (maximum and average) are based on maintenance dredge plume modelling which has been undertaken for the Port of Hay Point for 200,000 and 100,000 m^3 of dredge material.
- A numerical model domain covering both the Port of Hay Point and the Port of Mackay was run for a 2.5 month period simulating ambient sediment transport processes. The annualised ambient resuspension quantity derived from the model simulation was 9,000,000 tonnes/yr for both ports, which is reasonably consistent with the 6,400,000 tonnes/yr derived for the Port of Hay Point (Table B-4).
- Existing terrigenous sediment quantities were derived based on an average Holocene deposit thickness of 2.5m.

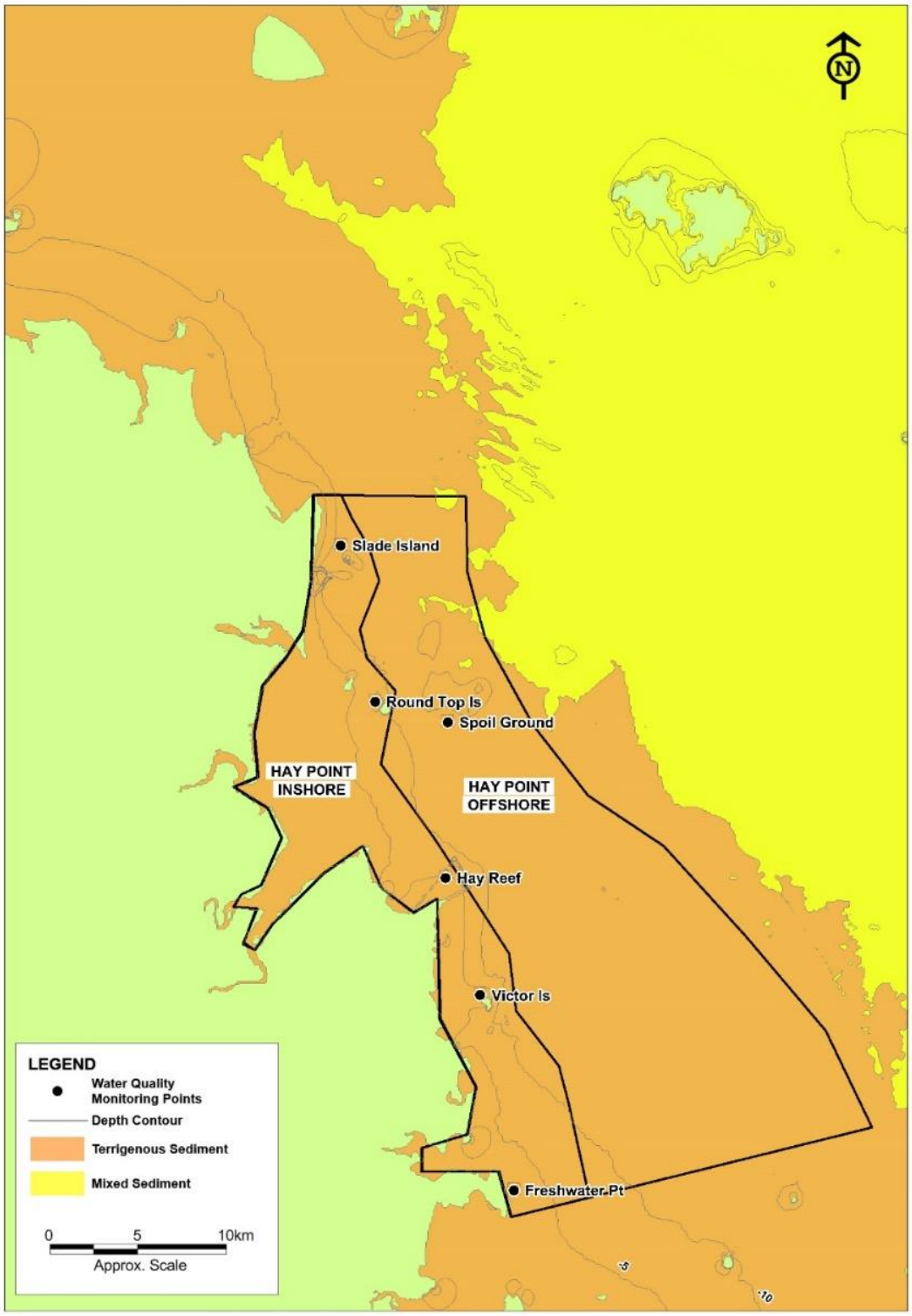


Figure B-1 Port of Hay Point Sediment Budget Zones and Turbidity Monitoring Locations

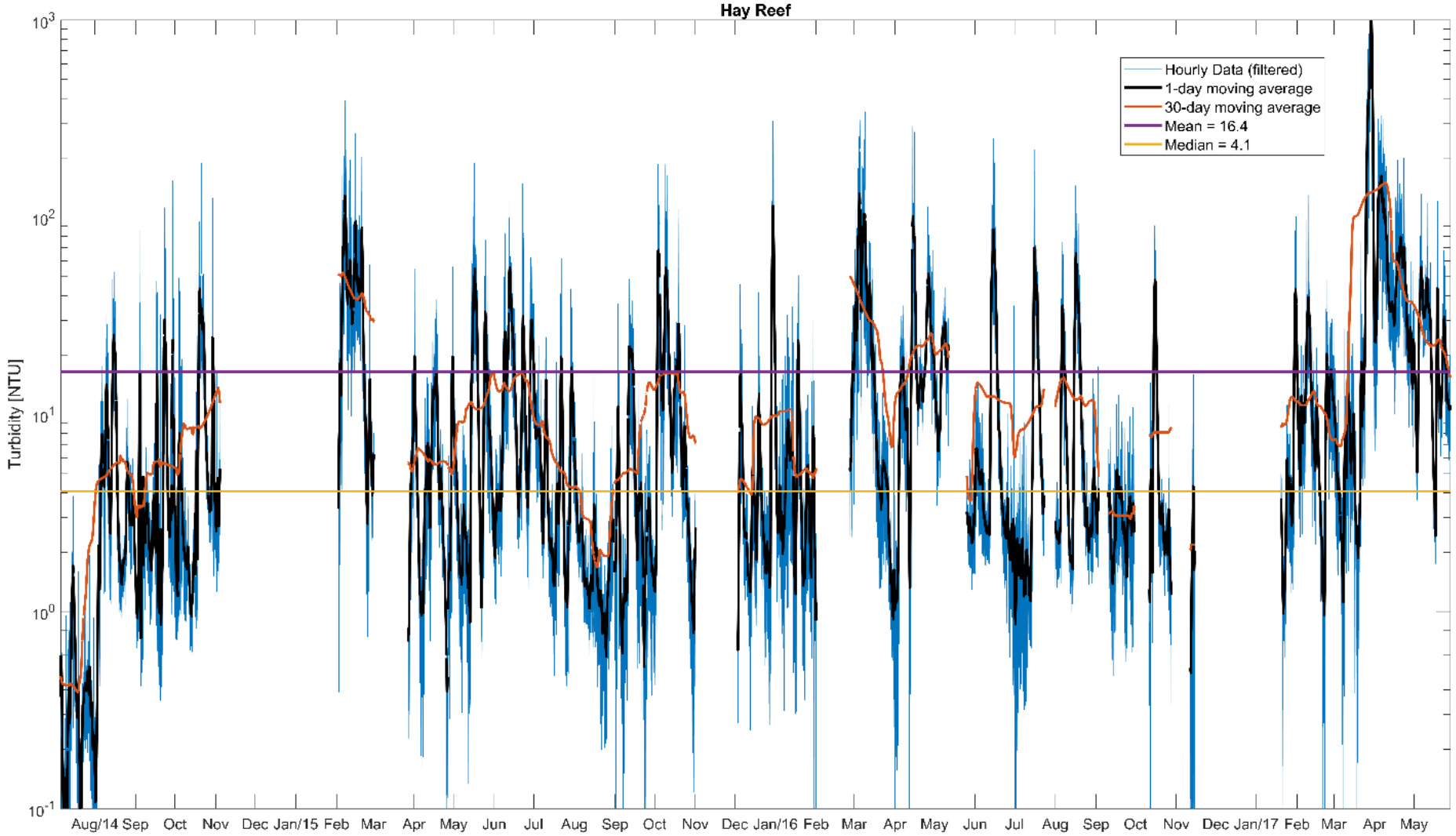


Figure B-2 Turbidity time series at Hay Reef (Depth = 11m)

Table B-1 Hay Point (and Mackay) Turbidity Statistics Summary

Site	Depth (mAHD)	Long-term Turbidity Statistics						Turbidity Event Statistics					
		Mean	1%ile	25%ile	Median	75%ile	99%ile	Sub-daily Amplitude	Event Threshold	Mean Event Turbidity	Frequency (events/y)	Mean Duration (days)	Primary Driver/s
Slade Islet	4.4	16.8	0.1	0.9	3.4	14.3	199.5	3.0	16.8	62.9	28	1.7	Waves/Tide
Round Top Island	12.0	3.7	0.0	0.5	1.0	2.9	40.1	0.6	3.7	21.3	25	0.3	Waves/Tide
Spoil Ground	16.8	12.0	0.1	0.9	2.3	6.6	239.9	1.8	12.0	26.5	27	1.0	Waves/Tide
Hay Reef	11.0	15.9	0.1	1.8	4.1	14.1	180.7	3.4	15.9	57.0	27	1.2	Waves/Tide
Victor Island	4.3	16.6	0.2	1.9	4.6	13.0	217.3	3.5	16.6	59.6	32	1.2	Waves/Tide
Freshwater Point	10.3	19.4	0.2	1.2	3.4	14.1	223.2	2.9	19.4	75.7	26	1.9	Waves/Tide
Site Averages		**14.1**	**0.1**	**1.2**	**3.1**	**10.8**	**183.4**	**2.5**	**14.1**	**50.5**	**27.5**	**1.2**	

Table B-2 Port of Hay Point Ambient Sediment Mass and Resuspension Rate Quantities

Port Area Zones			Port Area SSC				Ambient Sediment Mass Estimates				Ambient Resuspension Estimate		
Description	Average Depth	Area	Median SSC	Mean SSC	Event SSC	Tidal SSC	Median SSC Mass	Mean SSC Mass	Event SSC Mass	Tidal SSC Mass	Number of Events	Number of Tides	Annual Resuspension
	[m]	[km^2]	[mg/L]	[mg/L]	[mg/L]	[mg/L]	[tonnes]	[tonnes]	[tonnes]	[tonnes]	[per year]	[per year]	[tonnes/y]
Hay Pt - Inshore	5	210	4	15	60	3	4,200	15,750	63,000	3,150	25	520	3,108,000
Hay Pt - Offshore	12	390	2	8	30	0	9,360	37,440	140,400	0	25	520	3,276,000
Port Area Total		**600**					**13,560**	**53,190**	**203,400**	**3,150**			**6,384,000**

Table B-3 Port of Hay Point Suspended Sediment Mass, Comparison of Dredging and Ambient Quantities

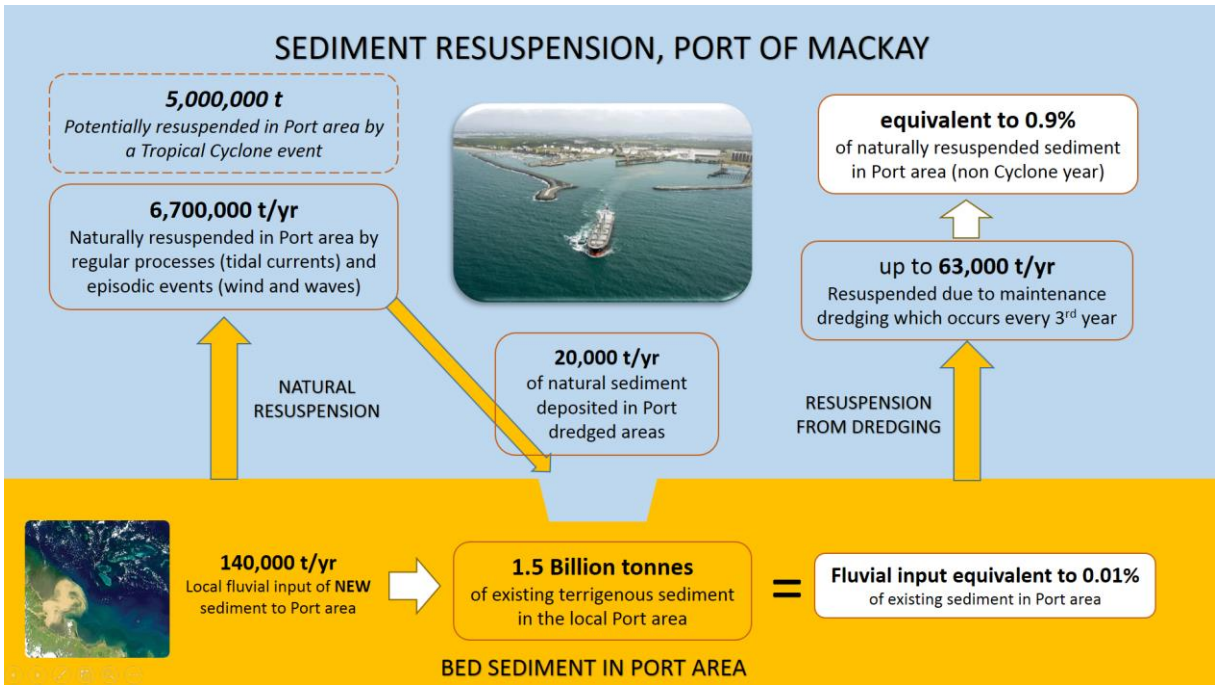
	Description	Quantity		Notes
Ambient	Median Ambient Mass	14,000	tonnes	Annual median turbidity represents relatively calm conditions.
	Event Ambient Mass	203,000	tonnes	Typical ambient event duration is 4 days. Event frequency is 25 per year Much higher ambient suspension mass occurs during 1 in 1 year ARI events, and one to two orders of magnitude higher are expected during extreme Tropical Cyclone conditions.
	Annual Mean Ambient Mass	53,000	tonnes	Annual mean represents average across both calm conditions and events.
Dredging	Campaign Maximum Dredge Mass	10,000	tonnes	Typical duration would be less than 1 day. Event frequency is 1 per year.
	Campaign Mean Dredge Mass	5,000	tonnes	Typical maintenance campaign duration is 2-3 weeks every 3 years.
	Annual Mean Dredge Mass	250	tonnes	Only low intensity dredging related plumes occur outside the campaign window.
Dredging % of Ambient	Dredging Campaign Maximum % of Ambient Event	4.9	%	This is a comparison of relatively short-term (acute) quantities. Note that the dredge quantity occurs approximately once a year, lasting for one day, while the ambient quantity is occurring around 25 times per year and lasting for four days.
	Dredging Campaign Mean % of Ambient Mean	9.4	%	This is a comparison on timescales of around 1 month.
	Dredging Annual Mean % of Ambient Mean	**0.5**	**%**	This comparison represents the long term average contribution of maintenance dredging to suspended sediment quantities at the port-scale.

Table B-4 Port of Hay Point Suspended Sediment Resuspension, Comparison of Dredging and Ambient Quantities

	Description	Quantity		Notes
Ambient	Annual ambient resuspension	6,400,000	tonnes/year	Estimated as the sum of multi-day resuspension events and sub-daily (tidal) resuspension quantities.
	Ambient resuspension during dredging campaign	370,000	tonnes/year	Assuming a 3 week campaign.
Dredging	Typical maintenance dredging campaign	140,000	tonnes/year	Based on historical maintenance dredging quantities. Campaign frequency is every 3 years.
	Passive plume during dredging and placement	20	%	Worst case TSHD overflow dredging of predominantly fine sediments.
	DMPA dispersion	20	%	Hay Point DMPA has been found to be 80% retentive over the long term.
	Dredging resuspension during dredging campaign	28,000	tonnes/year	Estimated as the sum of passive plume quantity and percentage of material dispersed from DMPA.
	Annual dredging and DMPA resuspension	56,000	tonnes/year	This is the total quantity resuspended during dredging, placement and transport of dredged material from the DMPA
Dredging % of Ambient	Dredging % of Ambient Resuspension (Campaign)	7.6	%	This is a comparison over typical maintenance campaign timescales.
	Dredging % of Ambient Resuspension (Annual)	**0.9**	**%**	This sediment resuspension comparison represents the annual quantity of sediment mobilisation compared with am equivalent derived ambient quantity.

Appendix C Port of Mackay

Summary



Assumptions

- Based on information provided in the MDS a maintenance dredging requirement of 90,000 m^3 every 3 years has been adopted;
- A dry sediment density of 0.7 t/m^3 (McCook *et al.*, 2015) was assumed for Port of Mackay maintenance sediment and the typical maintenance campaign quantity was therefore estimated as 63,000 t (every 3 years).
- No scaling of SSC from near bed to depth averaged has been directly included in the calculations as at Hay Point and Mackay the depths assumed in the calculations are relative to Chart Datum. As the tidal range exceeds 6.5 m the additional 3 to 3.5 m which corresponds to mean sea level would represent an increase in water volume in the calculations of between 30 (offshore) and 65% (nearshore) which is assumed to correspond to the difference between the SSC at the bed and the depth averaged SSC.
- The maintenance dredging calculations are based on the year when maintenance dredging campaign occurs rather than the annual average maintenance dredging requirement (as it is not an annual requirement at any of the three ports). This represents the worst case scenario in terms of potential impacts due to maintenance dredging.
- The dredge sediment mass quantity estimates (maximum and average) are based on maintenance dredge plume modelling which has been undertaken for the Port of Hay Point. It is expected that the sediment load would be less if it was modelled for the Port of Mackay as much of the sediment disturbed in the harbour would resettle in this area whereas at

Hay Point the material becomes advected by the strong currents in the area and therefore remains in the mobile system.

- A numerical model domain covering both the Port of Hay Point and the Port of Mackay was run for a 2.5 month period simulating ambient sediment transport processes. The annualised ambient resuspension quantity derived from the model simulation was 9,000,000 tonnes/yr for both ports, which is reasonably consistent with the 6,700,000 tonnes/yr derived for the Port of Mackay (Table C-4).
- Existing terrigenous sediment quantities were derived based on an average Holocene deposit thickness of 2.5m.

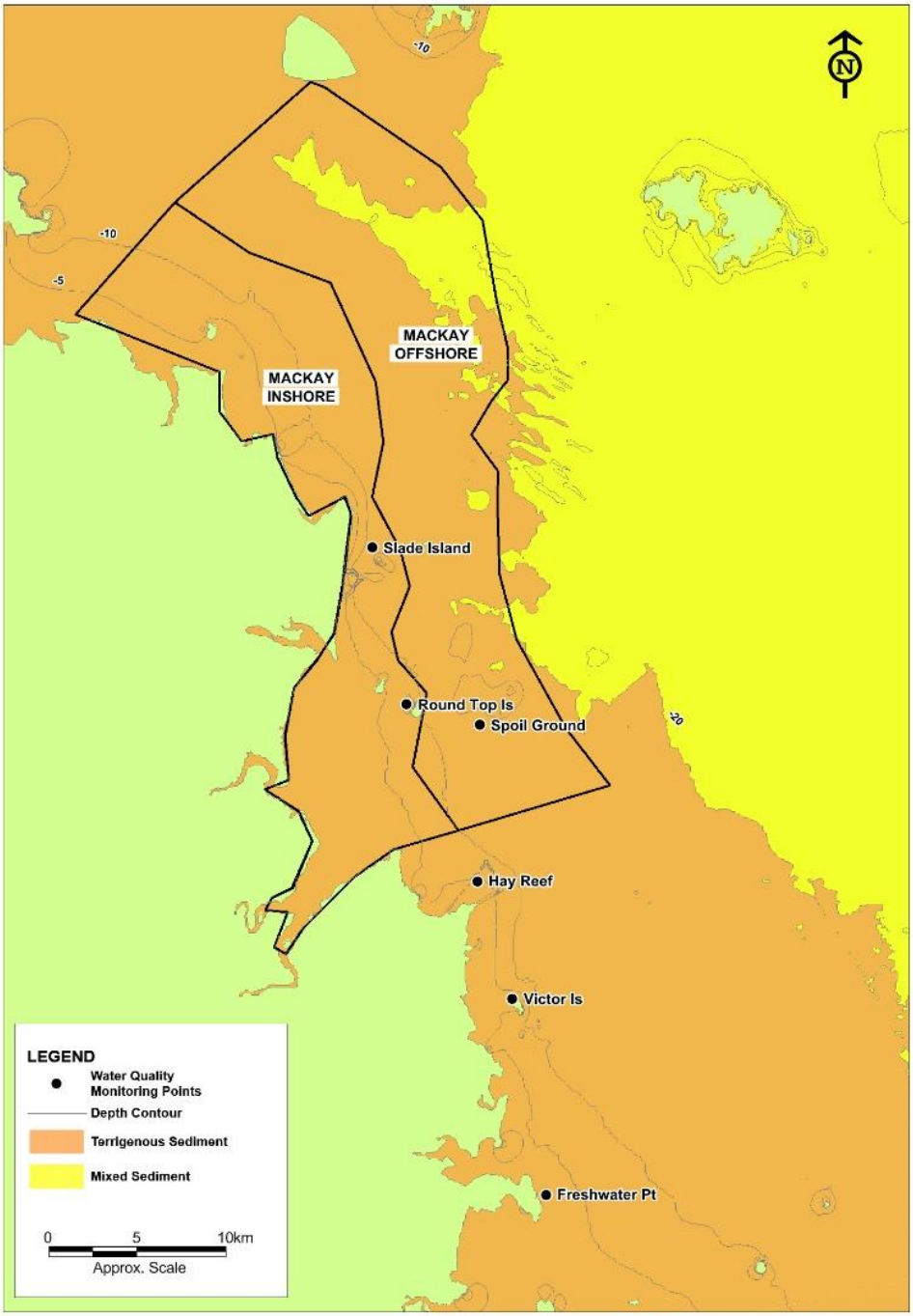


Figure C-1 Port of Mackay Sediment Budget Zones and Turbidity Monitoring Locations

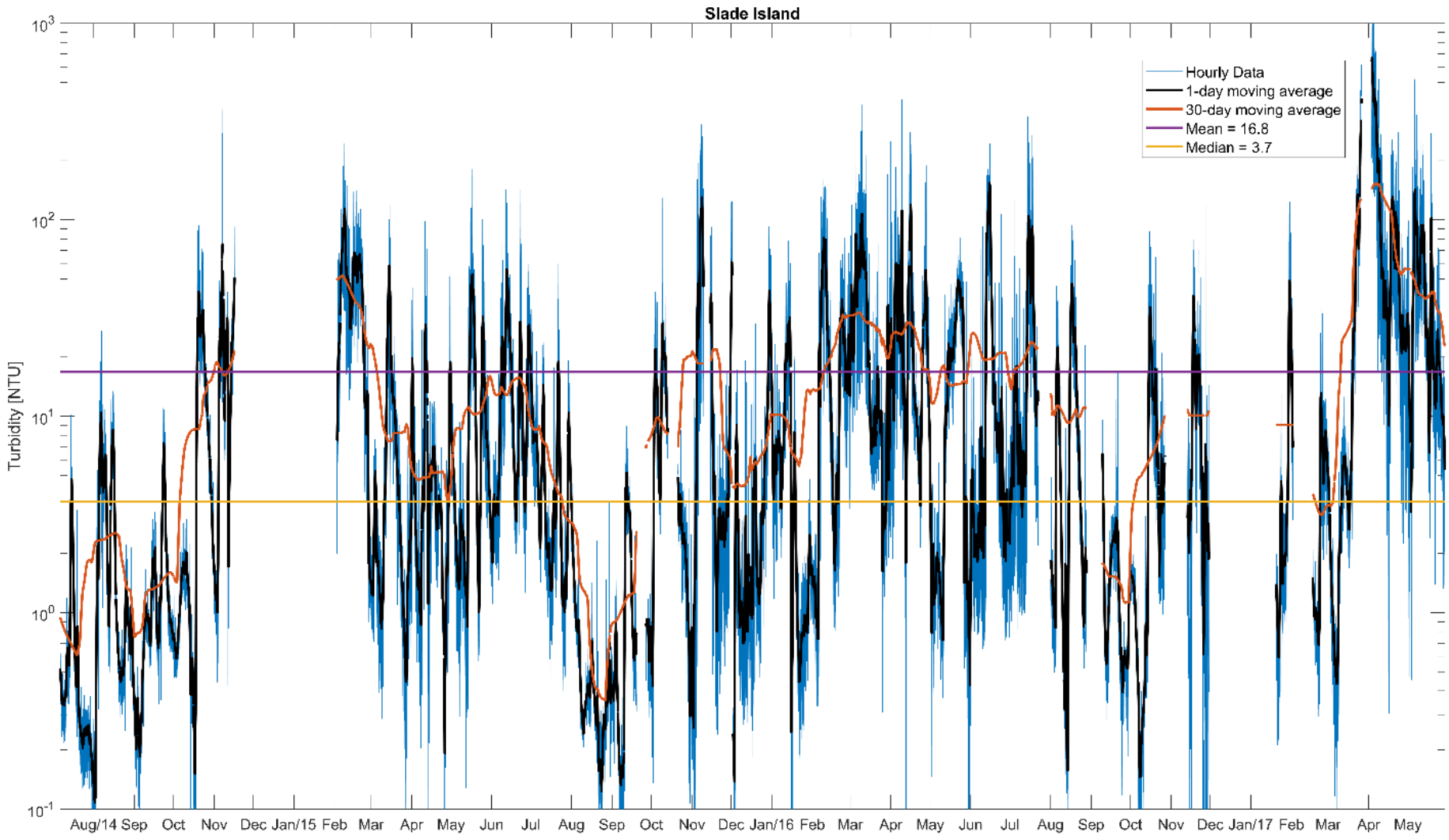


Figure C-2 Turbidity time series at Slade Island (Depth = 4m)

Table C-1 Mackay (and Hay Point) Turbidity Statistics Summary

Site	Depth (mAHD)	Long-term Turbidity Statistics						Turbidity Event Statistics					
		Mean	1%ile	25%ile	Median	75%ile	99%ile	Sub-daily Amplitude	Event Threshold	Mean Event Turbidity	Frequency (events/y)	Mean Duration (days)	Primary Driver/s
Slade Islet	4.4	16.8	0.1	0.9	3.4	14.3	199.5	3.0	16.8	62.9	28	1.7	Waves/Tide
Round Top Island	12.0	3.7	0.0	0.5	1.0	2.9	40.1	0.6	3.7	21.3	25	0.3	Waves/Tide
Spoil Ground	16.8	12.0	0.1	0.9	2.3	6.6	239.9	1.8	12.0	26.5	27	1.0	Waves/Tide
Hay Reef	11.0	15.9	0.1	1.8	4.1	14.1	180.7	3.4	15.9	57.0	27	1.2	Waves/Tide
Victor Island	4.3	16.6	0.2	1.9	4.6	13.0	217.3	3.5	16.6	59.6	32	1.2	Waves/Tide
Freshwater Point	10.3	19.4	0.2	1.2	3.4	14.1	223.2	2.9	19.4	75.7	26	1.9	Waves/Tide
Site Averages		**14.1**	**0.1**	**1.2**	**3.1**	**10.8**	**183.4**	**2.5**	**14.1**	**50.5**	**27.5**	**1.2**	

Table C-2 Port of Mackay Ambient Sediment Mass and Resuspension Rate Quantities

Port Area Zones			Port Area SSC				Ambient Sediment Mass Estimates				Ambient Resuspension Estimate		
Description	Average Depth	Area	Median SSC	Mean SSC	Event SSC	Tidal SSC	Median SSC Mass	Mean SSC Mass	Event SSC Mass	Tidal SSC Mass	Number of Events	Number of Tides	Annual Resuspension
	[m]	[km^2]	[mg/L]	[mg/L]	[mg/L]	[mg/L]	[tonnes]	[tonnes]	[tonnes]	[tonnes]	[per year]	[per year]	[tonnes/y]
Mackay – Inshore	5	260	4	15	60	3	5,200	19,500	78,000	3,900	25	520	3,848,000
Mackay - Offshore	12	340	2	8	30	0	8,160	32,640	122,400	0	25	520	2,856,000
Port Area Total		**600**					**13,360**	**52,140**	**200,400**	**3,900**			**6,704,000**

Table C-3 Port of Mackay Suspended Sediment Mass, Comparison of Dredging and Ambient Quantities

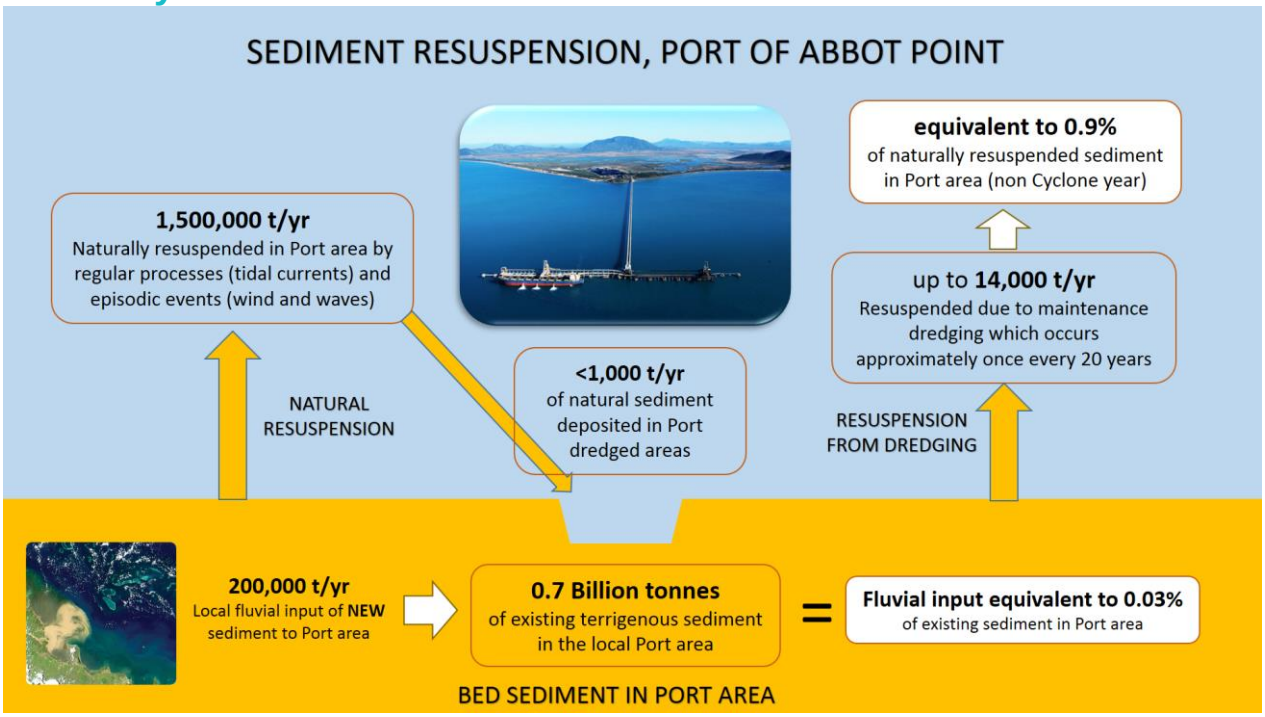
	Description	Quantity		Notes
Ambient	Median Ambient Mass	13,000	tonnes	Annual median turbidity represents relatively calm conditions.
	Event Ambient Mass	200,000	tonnes	Typical ambient event duration is 4 days. Event frequency is 25 per year. Much higher ambient suspension mass occurs during 1 in 1 year ARI events, and one to two orders of magnitude higher are expected during extreme Tropical Cyclone conditions.
	Annual Mean Ambient Mass	52,000	tonnes	Annual mean represents average across both calm conditions and events.
Dredging	Campaign Maximum Dredge Mass	4,500	tonnes	Typical duration would be less than 1 day. Event frequency is 1 per year.
	Campaign Mean Dredge Mass	2,250	tonnes	Typical maintenance campaign duration is 1 week every 3 years.
	Annual Mean Dredge Mass	120	tonnes	Only low intensity dredging related plumes occur outside the campaign window.
Dredging % of Ambient	Dredging Campaign Maximum % of Ambient Event	2.3	%	This is a comparison of relatively short-term (acute) quantities. Note that the dredge quantity occurs approximately once a year, lasting for one day, while the ambient quantity is occurring around 25 times per year and lasting for four days.
	Dredging Campaign Mean % of Ambient Mean	4.3	%	This is a comparison on timescales of around 1 month.
	Dredging Annual Mean % of Ambient Mean	**0.2**	**%**	This comparison represents the long term average contribution of maintenance dredging to suspended sediment quantities at the port-scale.

Table C-4 Port of Mackay Suspended Sediment Resuspension, Comparison of Dredging and Ambient Quantities

	Description	Quantity		Notes
Ambient	Annual ambient resuspension	6,700,000	tonnes/year	Estimated as the sum of multi-day resuspension events and sub-daily (tidal) resuspension quantities.
	Ambient resuspension during dredging campaign	260,000	tonnes/year	Assuming a 2 week campaign.
Dredging	Typical maintenance dredging campaign	63,000	tonnes/year	Based on historical maintenance dredging quantities. Campaign frequency is every 3 years.
	Passive plume during dredging and placement	20	%	Worst case TSHD overflow dredging of predominantly fine sediments.
	DMPA dispersion	80	%	Mackay DMPA has been found to be dispersive.
	Dredging resuspension during dredging campaign	12,600	tonnes/year	Estimated as the sum of passive plume quantity and percentage of material dispersed from DMPA.
	Annual dredging and DMPA resuspension	63,000	tonnes/year	This is the total quantity resuspended during dredging, placement and transport of dredged material from the DMPA
Dredging % of Ambient	Dredging % of Ambient Resuspension (Campaign)	4.8	%	This is a comparison over typical maintenance campaign timescales.
	Dredging % of Ambient Resuspension (Annual)	**0.9**	**%**	This sediment resuspension comparison represents the annual quantity of sediment mobilisation compared with am equivalent derived ambient quantity.

Appendix D Port of Abbot Point

Summary



Assumptions

- Based on information provided in the MDS a maintenance dredging requirement of 20,000 m^3 every 20 years has been adopted. The MDS indicates that the volume required is less than 20,000 m^3, but to be conservative a volume of 20,000 m^3 has been adopted.
- A dry sediment density of 0.7 t/m^3 (McCook *et al.,* 2015) was assumed for Port of Abbot Point maintenance sediment and the typical maintenance campaign quantity was therefore estimated as 14,000 t (every 3 years).
- No scaling of SSC from near bed to depth averaged has been directly included in the calculations as the Abbot Point conversion factor is 1.5, which is assumed to also be approximately representative of the difference between the SSC at the bed and the depth averaged SSC. The two conversion factors approximately cancel each other out and as such no conversion for either has been adopted.
- The dredge sediment mass quantity estimates (maximum and average) have been estimated based on the relative proportions shown by the modelling at the Port of Hay Point.
- Existing terrigenous sediment quantities were derived based on an average Holocene deposit thickness of 2.5 m.

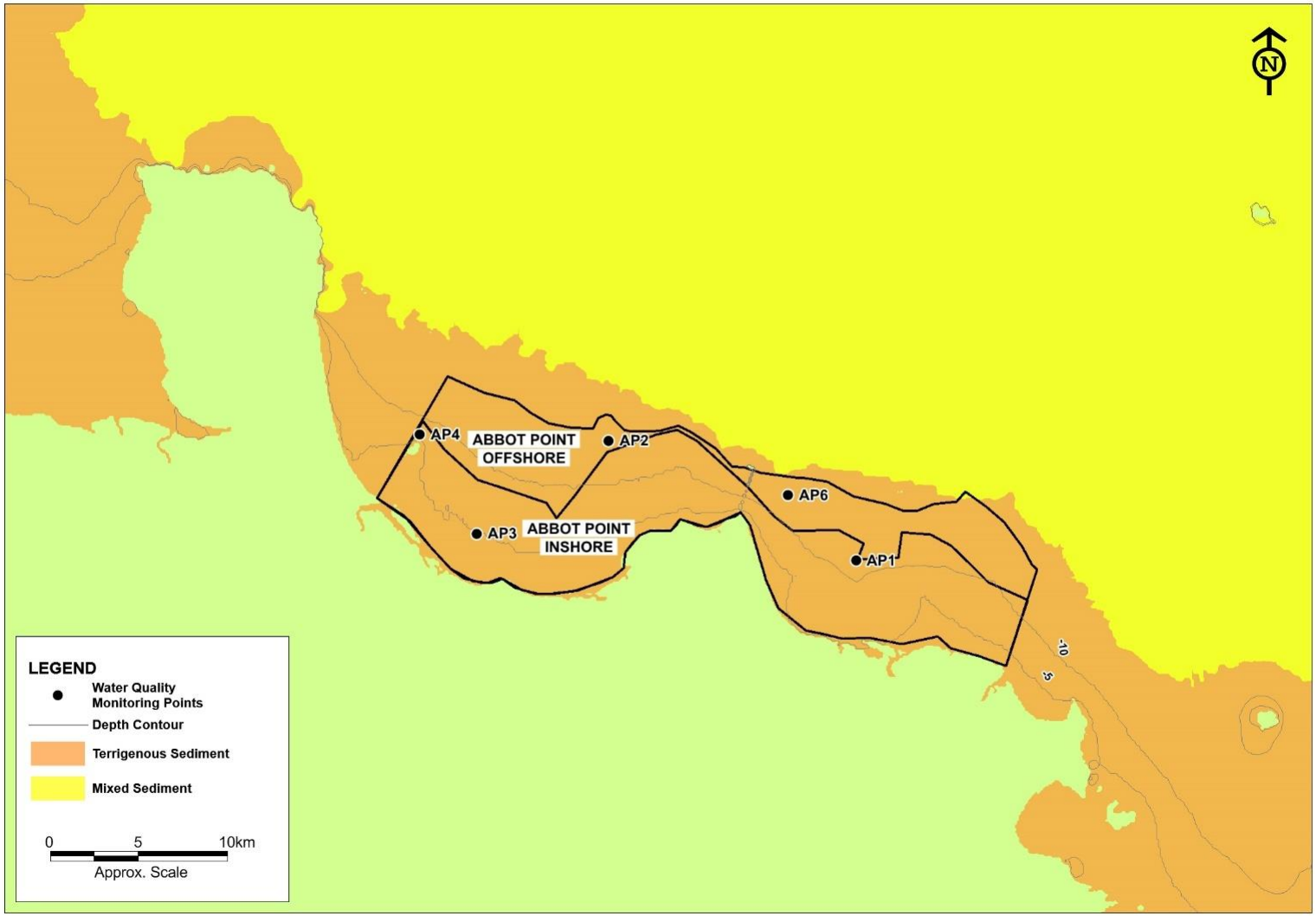


Figure D-1 Port of Abbot Point Sediment Budget Zones and Turbidity Monitoring Locations

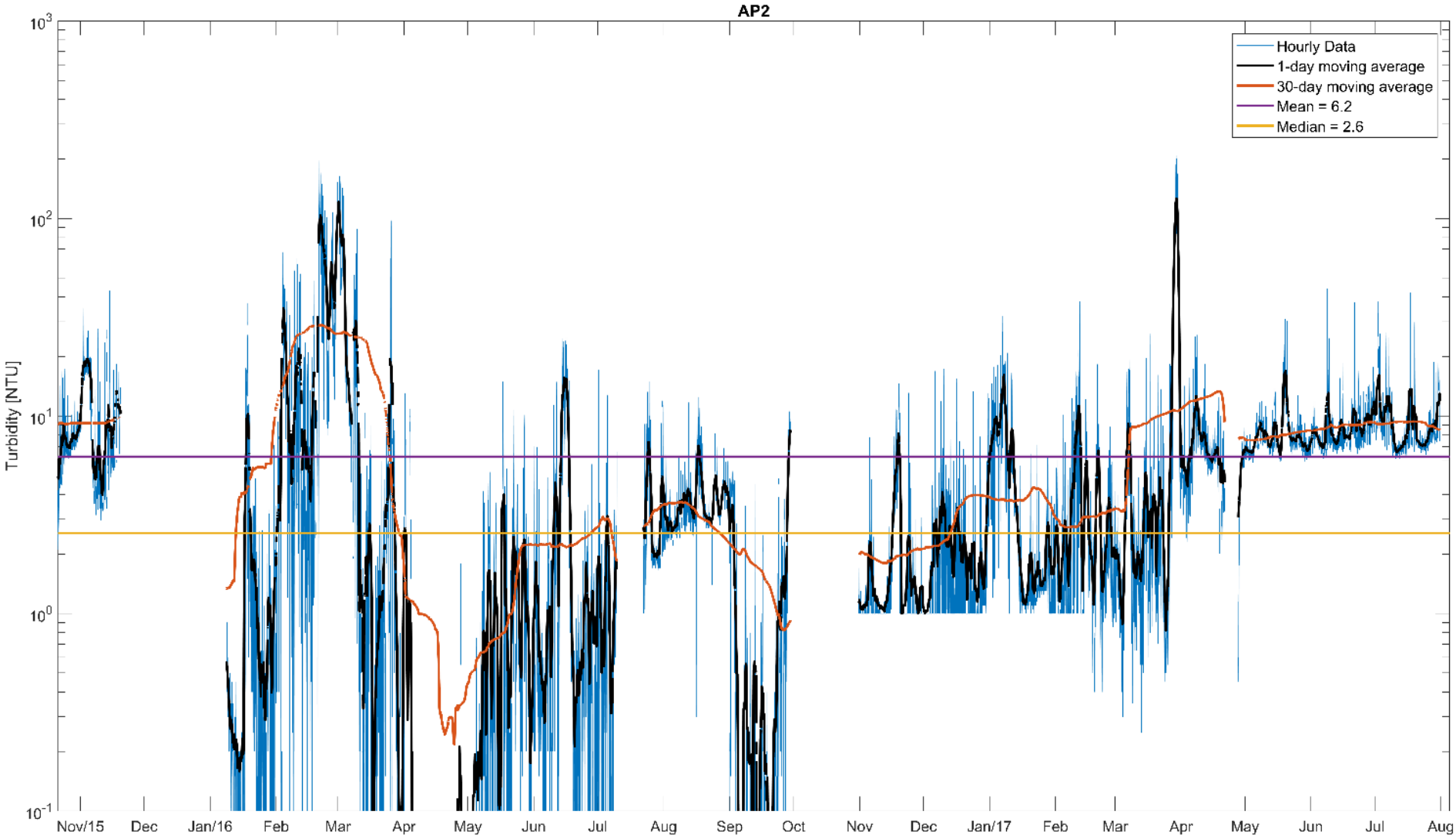


Figure D-2 Turbidity time series at AP2 (Depth = 12m)

Table D-1 Port of Abbot Point Turbidity Statistics Summary

Site	Depth (mAHD)	Long-term Turbidity Statistics						Turbidity Event Statistics					
		Mean	1%ile	25%ile	Median	75%ile	99%ile	Sub-daily Amplitude	Event Threshold	Mean Event Turbidity	Frequency (events/y)	Mean Duration (days)	Primary Driver/s
AP1	9.0	1.9	0.0	0.8	1.1	2.6	12.0	0.5	1.9	4.0	31	3.2	Waves/Tide
AP2	12.2	6.2	0.0	0.9	2.6	7.1	86.8	1.5	6.2	15.9	19	3.8	Waves/Tide
AP3	3.9	1.9	0.0	1.0	1.0	2.0	10.4	0.5	1.9	4.6	46	3.1	Waves/Tide
AP4	8.5	4.6	0.0	0.5	1.1	3.7	52.7	0.4	4.6	15.3	17	2.7	Waves/Tide
AP6	13.1	3.0	0.0	1.0	2.0	4.1	11.2	0.5	3.0	5.9	31	4.1	Waves/Tide
Site Averages		**3.5**	**0.0**	**0.8**	**1.6**	**3.9**	**34.6**	**0.7**	**3.5**	**9.1**	**28.9**	**3.4**	

Table D-2 Abbot Point Ambient Sediment Mass and Resuspension Rate Quantities

Port Area Zones			Port Area SSC				Ambient Sediment Mass Estimates				Ambient Resuspension Estimate		
Description	Average Depth	Area	Median SSC	Mean SSC	Event SSC	Tidal SSC	Median SSC Mass	Mean SSC Mass	Event SSC Mass	Tidal SSC Mass	Number of Events	Number of Tides	Annual Resuspension
	[m]	[km^2]	[mg/L]	[mg/L]	[mg/L]	[mg/L]	[tonnes]	[tonnes]	[tonnes]	[tonnes]	[per year]	[per year]	[tonnes/y]
Abbot Pt – Inshore	185	1.1	2.8	10	0.5	1,018	2,590	9,250	463	30	700	570,725	185
Abbot Pt - Offshore	90	2.3	4.6	10	1.0	2,484	4,968	10,800	1,080	25	700	963,900	90
Port Area Total	**275**					**3,502**	**7,558**	**20,050**	**1,543**			**1,534,625**	**275**

Table D-3 Port of Abbot Point Suspended Sediment Mass, Comparison of Dredging and Ambient Quantities

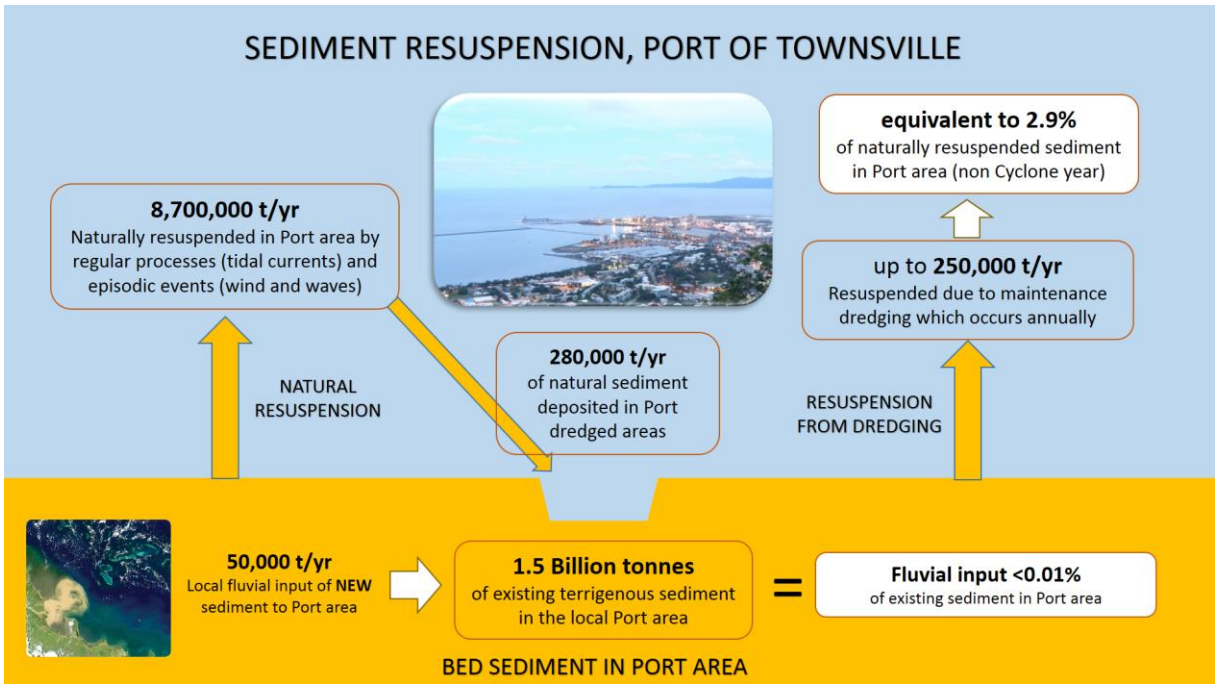
	Description	Quantity		Notes
Ambient	Median Ambient Mass	3,500	tonnes	Annual median turbidity represents relatively calm conditions.
	Event Ambient Mass	20,000	tonnes	Typical ambient event duration is 4 days. Event frequency is 25 per year. Much higher ambient suspension mass occurs during 1 in 1 year ARI events, and one to two orders of magnitude higher are expected during extreme Tropical Cyclone conditions.
	Annual Mean Ambient Mass	7,500	tonnes	Annual mean represents average across both calm conditions and events.
Dredging	Campaign Maximum Dredge Mass	1,000	tonnes	Typical duration would be less than 1 day. Event frequency is 1 per year.
	Campaign Mean Dredge Mass	750	tonnes	Typical maintenance campaign duration is 1 week every 3 years.
	Annual Mean Dredge Mass	5	tonnes	Only low intensity dredging related plumes occur outside the campaign window.
Dredging % of Ambient	Dredging Campaign Maximum % of Ambient Event	5.0	%	This is a comparison of relatively short-term (acute) quantities. Note that the dredge quantity occurs approximately once a year, lasting for one day, while the ambient quantity is occurring around 25 times per year and lasting for four days.
	Dredging Campaign Mean % of Ambient Mean	10.0	%	This is a comparison on timescales of around 1 month.
	Dredging Annual Mean % of Ambient Mean	**0.1**	**%**	This comparison represents the long term average contribution of maintenance dredging to suspended sediment quantities at the port-scale.

Table D-4 Port of Abbot Point Suspended Sediment Resuspension, Comparison of Dredging and Ambient Quantities

	Description	Quantity		Notes
Ambient	Annual ambient resuspension	1,500,000	tonnes/year	Estimated as the sum of multi-day resuspension events and sub-daily (tidal) resuspension quantities.
	Ambient resuspension during dredging campaign	60,000	tonnes/year	Assuming a 2 week campaign.
Dredging	Typical maintenance dredging campaign	14,000	tonnes/year	Based on historical maintenance dredging quantities. Campaign frequency is very infrequent estimated to be every 20 years.
	Passive plume during dredging and placement	20	%	Worst case TSHD overflow dredging of predominantly fine sediments.
	DMPA dispersion	80	%	Retentive nature of Abbot Point DMPA is unknown and so it has been conservatively assumed that all material will be dispersed.
	Dredging resuspension during dredging campaign	2,800	tonnes/year	Estimated as the sum of passive plume quantity and percentage of material dispersed from DMPA.
	Annual dredging and DMPA resuspension	14,000	tonnes/year	This is the total quantity resuspended during dredging, placement and transport of dredged material from the DMPA
Dredging % of Ambient	Dredging % of Ambient Resuspension (Campaign)	4.7	%	This is a comparison over typical maintenance campaign timescales.
	Dredging % of Ambient Resuspension (Annual)	**0.9**	**%**	This sediment resuspension comparison represents the annual quantity of sediment mobilisation compared with an equivalent derived ambient quantity.

Appendix E Port of Townsville

Summary



Assumptions

- The Townsville ambient sediment quantities have been derived primarily using a continuous turbidity monitoring dataset collected for the Port of Townsville as part of the Cleveland Bay Water and Light Monitoring Program. The period of data that was analysed was from September 2014 to June 2017.
- Time series of measured ambient turbidity at Virago Shoals and Florence Bay sites are provided in Figures E-1 and E-2.
- Three suspended sediment sub-zones were used in calculating port-scale ambient suspended sediment loads; Cleveland Bay – Inner, Cleveland Bay – Mid and Townsville offshore. The offshore zone was informed by measurements at the Magnetic Island monitoring locations, which were located in relatively shallow depths but adjacent to the offshore waters.
- Turbidity data collected offshore of The Strand during 2012/13 as part of the POTL Port Expansion EIS, and data collected offshore of the Ross River mouth during 2017 were also used to inform derivation of the Cleveland Bay – Inner suspended sediment metrics.
- A turbidity to SSC factor of 1.9 has been applied. Bed-mounted instrument datasets were multiplied by a factor 0.67 in order to derive a depth-averaged concentration.
- Based on the MDS the average maintenance campaign quantity for the Port of Townsville is 405,000m^3 (per year).

- A density conversion of 0.7t/m^3 (McCook *et al.,* 2015) was used to convert the Townsville maintenance quantity to 280,000 tonnes/year.
- The dredge sediment mass quantity estimates (maximum and average) have been derived from a compilation of 20 simulations of an intensive 480,000m^3 campaign carried out under different prevailing weather conditions (BMT WBM. 2016). Although this approach does account for the influence of variable weather conditions, it should be noted that the amount of dredged material in suspension does vary considerably depending on the characteristics of the campaign (how much is dredged in which areas) and also on the prevailing conditions (large quantities of dredged material may be resuspended in a wave event). However, the quantity of ambient sediment resuspended by wave events will always be much larger than the resuspension of previously dredged quantities.
- The time series of the total mass of dredged sediment in suspension for each of the 20 modelled simulations is shown in Figure E-3.
- Annual resuspension rates were derived from Port of Townsville numerical model simulations (BMT WBM, 2016) for comparison with the quantities derived from the turbidity logger datasets. The model derived rate for fine sediment resuspension of 20,000,000 tonnes/year is larger than the data based quantity of 8,700,000. This difference may be due to the location of turbidity monitoring instruments at predominantly sensitive receptor locations which are likely to have lower turbidity than the broader port environment. This result indicates that the quantitative comparison results presented in Table E-3 and E-4 should be conservatively high with respect to the contribution of maintenance dredging to suspended sediment quantities.
- Existing terrigenous sediment quantities were derived based on an average Holocene deposit thickness of 2.5m.

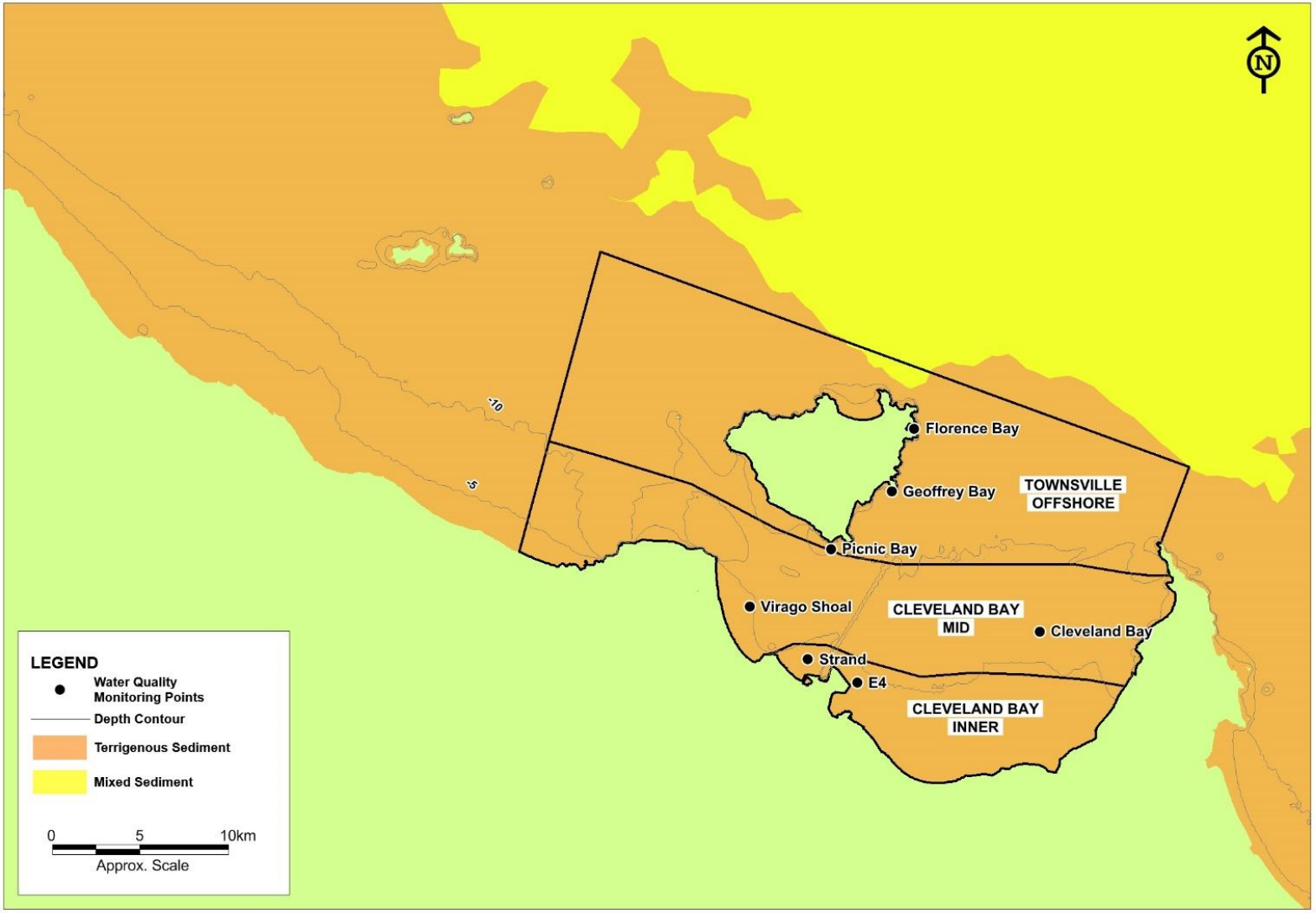


Figure E-1 Port of Townsville Sediment Budget Zones and Turbidity Monitoring Locations

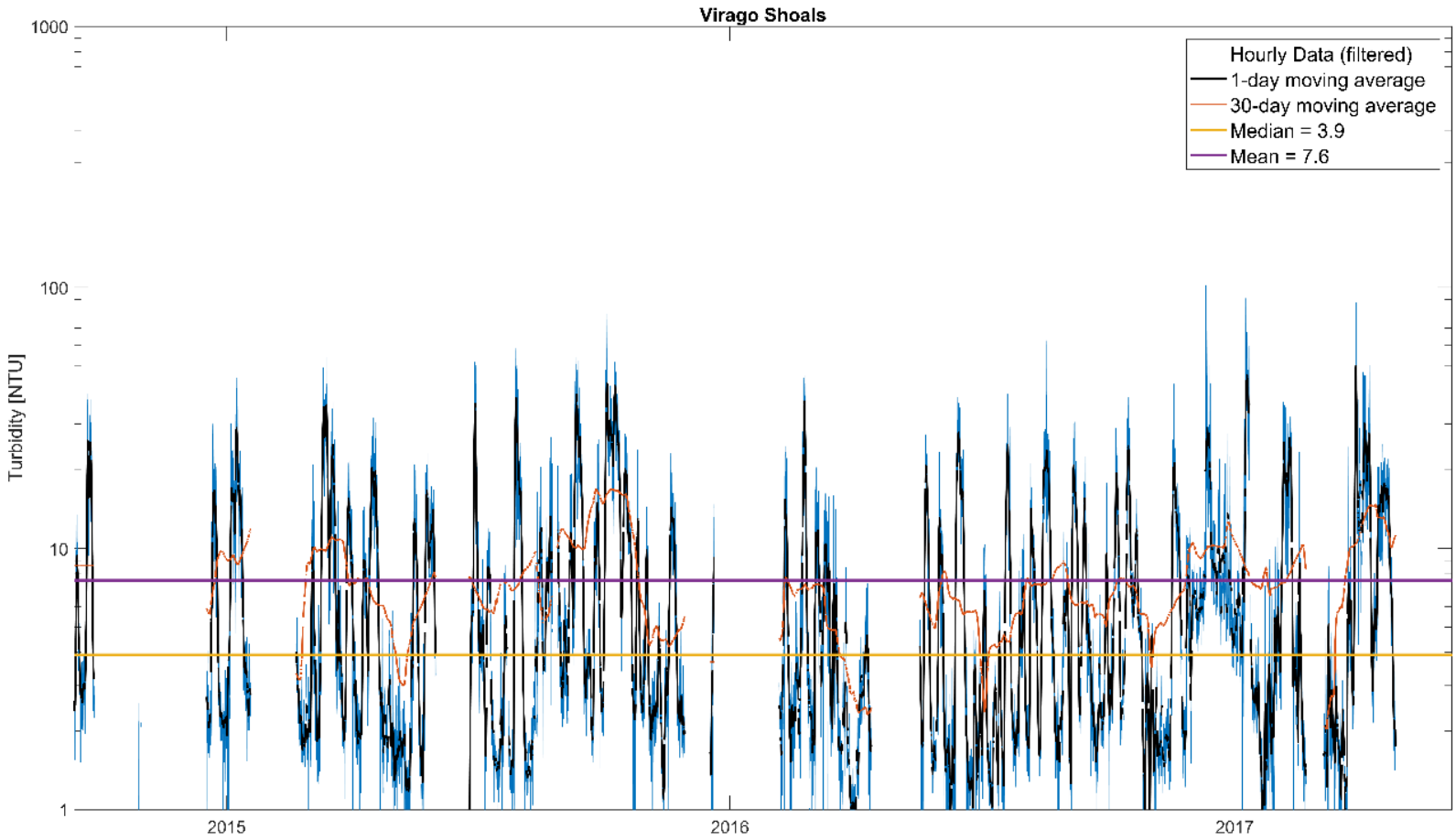


Figure E-2 Turbidity time series at Virago Shoals. This site was used in the derivation of Cleveland Bay – mid ambient suspended sediment quantities.

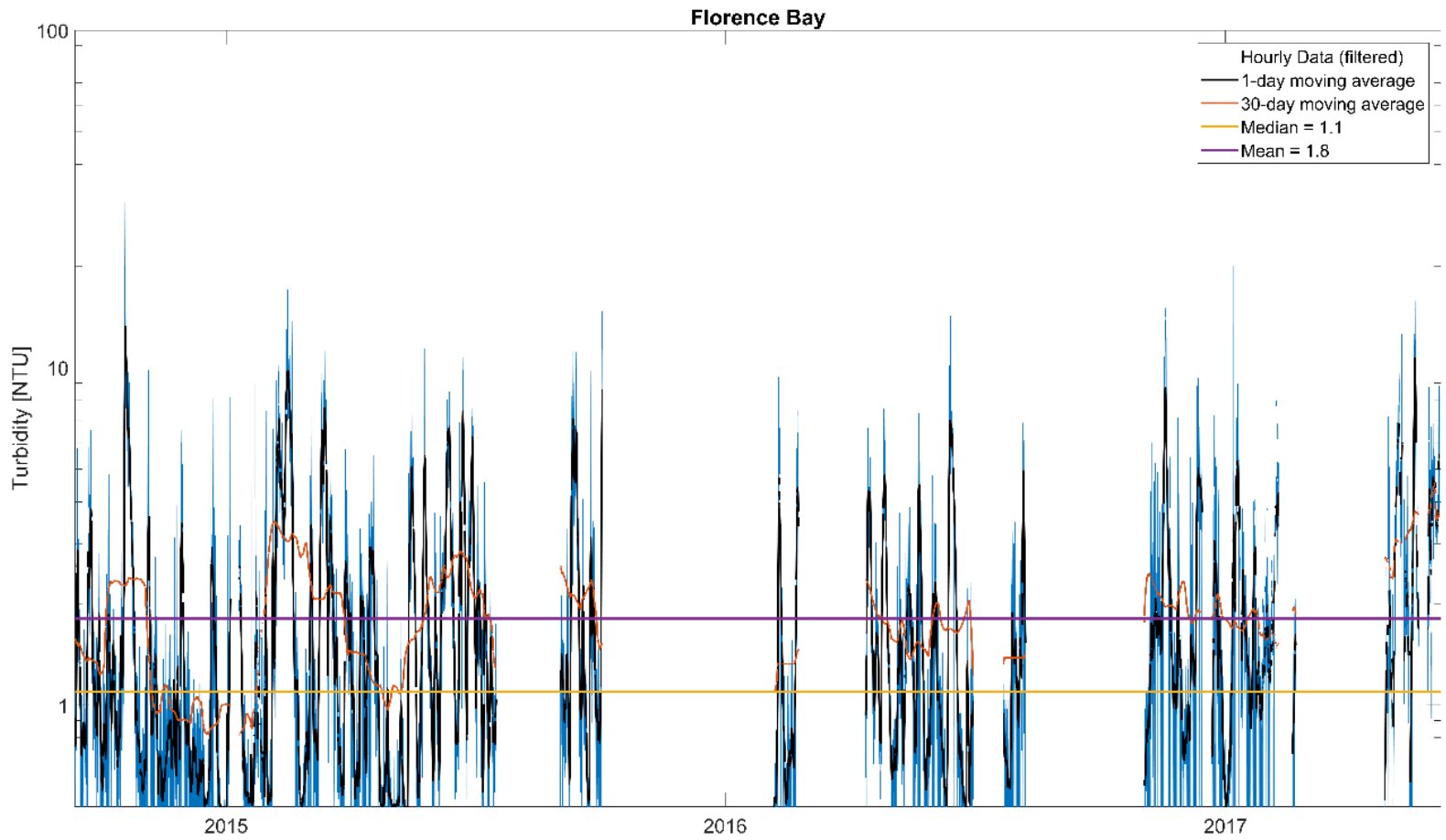


Figure E-3 Turbidity time series at Florence Bay (Magnetic Island). This site was used in the derivation of Townsville – offshore ambient suspended sediment quantities.

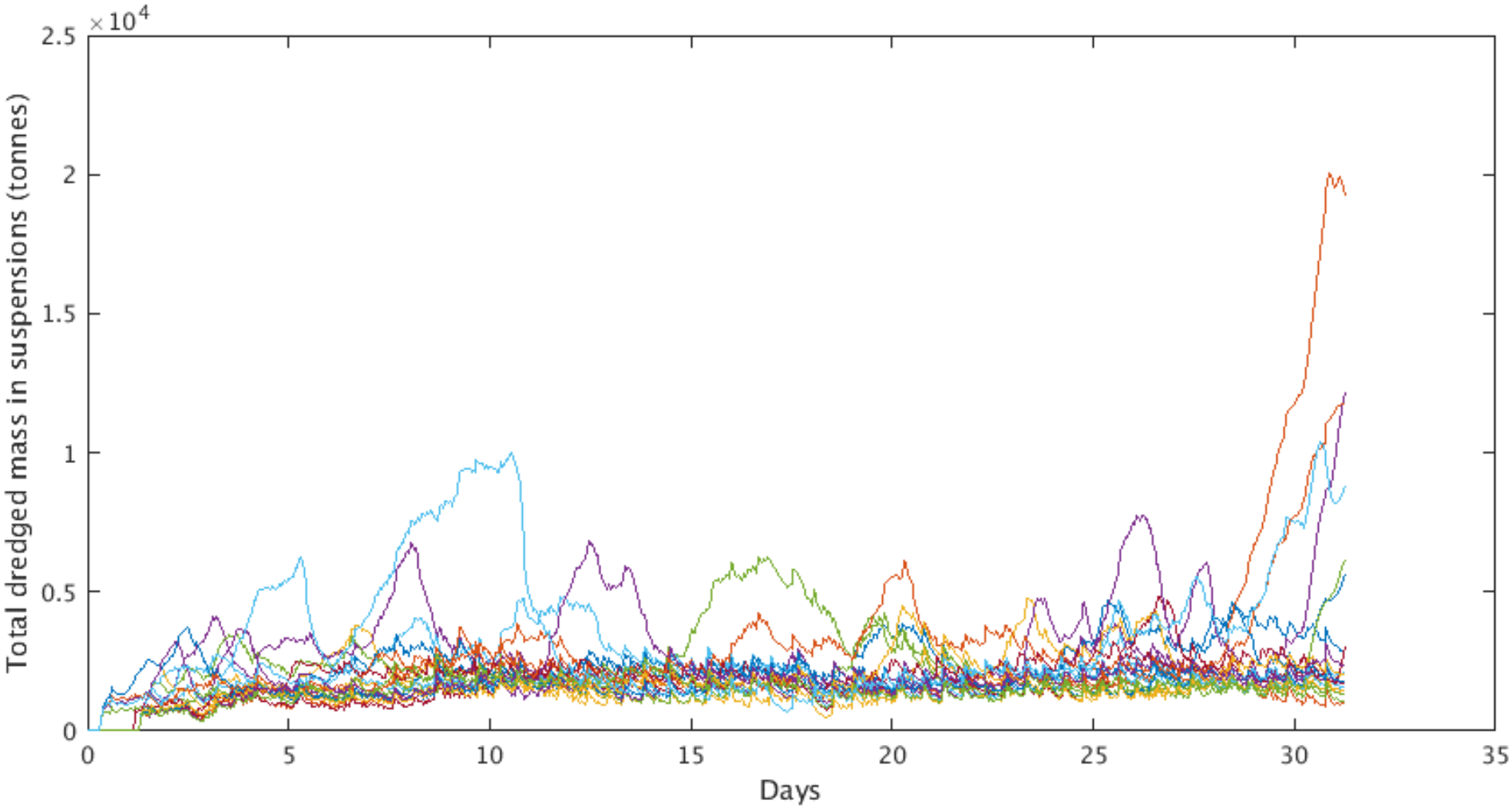


Figure E-4 Total Amount of Dredged Sediment in Suspension for the Modelled Maintenance Dredging Campaigns (480,000m^3)

Table E-1 Townsville Turbidity Statistics Summary

Site	Depth (mAHD)	Long-term Turbidity Statistics						Turbidity Event Statistics					
		Mean	1%ile	25%ile	Median	75%ile	99%ile	Sub-daily Amplitude	Event Threshold	Mean Event Turbidity	Frequency (events/y)	Mean Duration (days)	Primary Driver/s
The Strand	3	27.9	1.8	8.3	15.4	26.8	231.5	8.1	27.9	73.7	14	6.5	Waves/Tide
E4 (near Ross River)	3	16.4	2.4	6.2	9.5	13.1	212.9	4.0	16.4	54.0	14	4.4	Waves/Tide
Cleveland Bay	6	6.9	0.7	2.3	3.5	7.6	41.2	2.2	6.9	16.2	24	4.3	Waves/Tide
Virago Shoal	4	7.6	0.5	2.1	3.9	9.7	41.0	1.9	7.6	16.4	29	4.2	Waves/Tide
Picnic Bay	4	2.3	0.5	0.9	1.2	2.2	16.9	0.6	2.3	5.9	22	3.9	Waves/Tide
Geoffrey Bay	4	1.9	0.6	1.0	1.3	2.0	10.0	0.5	1.9	3.8	24	4.2	Waves/Tide
Florence Bay	3	1.8	0.5	0.6	1.1	2.1	9.3	0.6	1.8	3.7	31	3.6	Waves/Tide
Site Averages		**9.3**	**1.0**	**3.0**	**5.1**	**9.1**	**80.4**	**2.6**	**9.3**	**24.8**	**22.4**	**4.4**	

Table E-2 Townsville Ambient Sediment Mass and Resuspension Rate Quantities

Port Area Zones			Port Area SSC				Ambient Sediment Mass Estimates				Ambient Resuspension Estimate		
Description	Average Depth	Area	Median SSC	Mean SSC	Event SSC	Tidal SSC	Median SSC Mass	Mean SSC Mass	Event SSC Mass	Tidal SSC Mass	Number of Events	Number of Tides	Annual Resuspension
	[m]	[km^2]	[mg/L]	[mg/L]	[mg/L]	[mg/L]	[tonnes]	[tonnes]	[tonnes]	[tonnes]	[per year]	[per year]	[tonnes/y]
Cleveland Bay-inner	3	84	18	30	100	8.9	4,536	7,560	25,200	2,243	15	700	1,879,920
Cleveland Bay - mid	7	210	5	9	21	2.7	6,889	13,406	30,351	3,910	25	700	3,323,670
Townsville Offshore	12	306	2.3	3.8	8.6	1.1	8,372	13,954	31,396	4,186	25	700	3,505,842
Port Area Total		**600**					**19,798**	**34,920**	**86,946**	**10,339**			**8,709,432**

Table E-3 Port of Townsville Suspended Sediment Mass, Comparison of Dredging and Ambient Quantities

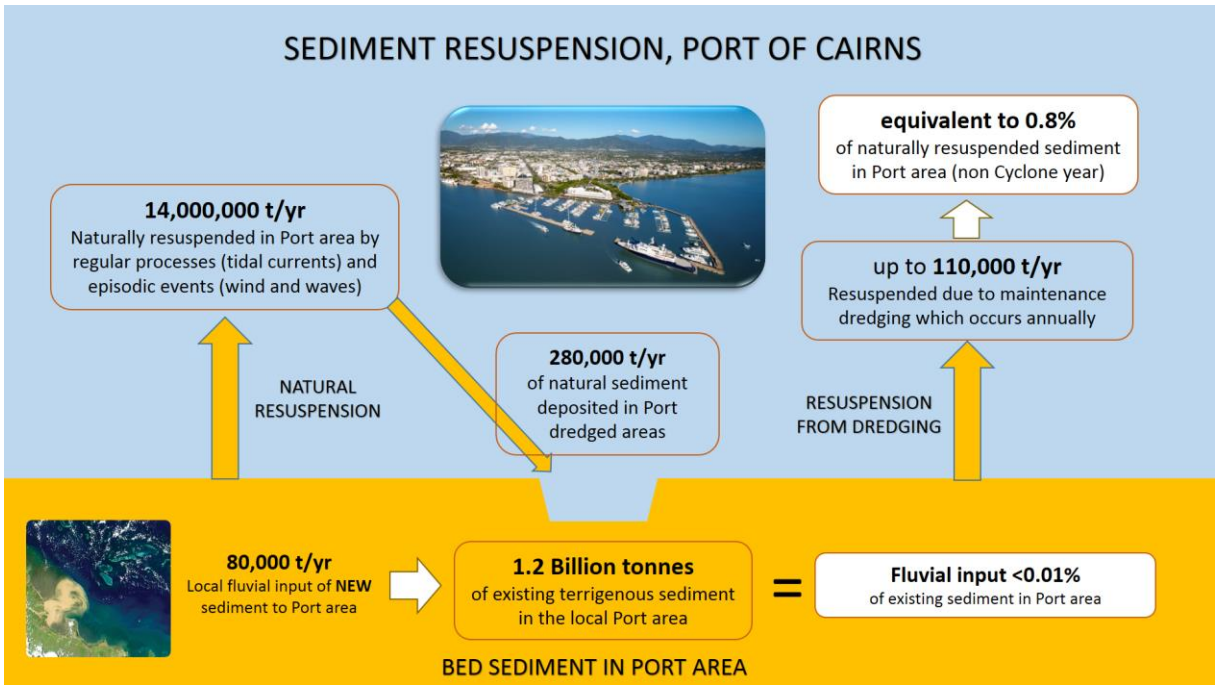
	Description	Quantity		Notes
Ambient	Median Ambient Mass	20,000	tonnes	Annual median turbidity represents relatively calm conditions.
	Event Ambient Mass	87,000	tonnes	Typical ambient event duration is 4 days. Event frequency is 25 per year. Much higher ambient suspension mass occurs during 1 in 1 year ARI events, and one to two orders of magnitude higher are expected during extreme Tropical Cyclone conditions.
	Annual Mean Ambient Mass	35,000	tonnes	Annual mean represents average across both calm conditions and events.
Dredging	Campaign Maximum Dredge Mass	6,000	tonnes	Typical duration would be less than 1 day. Event frequency is 1 per year. This quantity includes a significant component of natural resuspension of previously deposited dredge-plume and placed material and is therefore very sensitive to environmental conditions (i.e. natural resuspension events). However, during such events the total quantity of sediment in suspension is always dominated by the ambient component.
	Campaign Mean Dredge Mass	2,000	tonnes	Typical maintenance campaign duration is 3-4 weeks
	Annual Mean Dredge Mass	400	tonnes	Only low intensity dredging related plumes occur outside the campaign window.
Dredging % of Ambient	Dredging Campaign Maximum % of Ambient Event	6.9	%	This is a comparison of relatively short-term (acute) quantities. Note that the dredge quantity occurs approximately once a year, lasting for one day, while the ambient quantity is occurring around 25 times per year and lasting for four days.
	Dredging Campaign Mean % of Ambient Mean	5.7	%	This is a comparison on timescales of around 1 month.
	Dredging Annual Mean % of Ambient Mean	1.1	**%**	This suspended sediment mass comparison represents the long term average contribution of maintenance dredging to suspended sediment quantities at the port-scale.

Table E-4 Port of Townsville Suspended Sediment Resuspension, Comparison of Dredging and Ambient Quantities

	Description	Quantity		Notes
Ambient	Annual ambient resuspension	8,700,000	tonnes/year	Estimated as the sum of multi-day resuspension events and sub-daily (tidal) resuspension quantities.
	Ambient resuspension during dredging campaign	670,000	tonnes/year	Assuming a typical 4 week campaign.
Dredging	Typical maintenance dredging campaign	280,000	tonnes/year	Based on historical maintenance dredging quantities. Campaign frequency is typically annual.
	Passive plume during dredging and placement	20	%	Worst case TSHD overflow dredging of predominantly fine sediments.
	DMPA dispersion	70	%	Townsville DMPA is predominantly dispersive.
	Dredging resuspension during dredging campaign	56,000	tonnes/year	Estimated as the sum of passive plume quantity and percentage of material dispersed from DMPA.
	Annual dredging and DMPA resuspension	250,000	tonnes/year	This is the total quantity resuspended during dredging, placement and transport of dredged material from the DMPA
Dredging % of Ambient	Dredging % of Ambient Resuspension (Campaign)	8.4	%	This is a comparison over typical maintenance campaign timescales.
	Dredging % of Ambient Resuspension (Annual)	**2.9**	**%**	This sediment resuspension comparison represents the annual quantity of sediment mobilisation compared with an equivalent derived ambient quantity.

Appendix F Port of Cairns

Summary



Assumptions

- The Cairns ambient sediment quantities have been derived using a continuous turbidity monitoring dataset collected for the Port of Cairns as part of the Cairns Shipping Development Project EIS. The period of data that was analysed was from August 2013 to August 2014.
- A turbidity to SSC factor of 1.8 has been applied but it has been assumed that this is effectively cancelled by the conversion to a depth-averaged quantity for the near-bed turbidity sondes.
- Based on the MDS the average maintenance campaign quantity for the Port of Cairns is 390,000 m^3 (per year).
- A density conversion of 0.7t/m^3 (McCook *et al.,* 2015) was used to convert the Cairns maintenance quantity to 280,000 tonnes/year.
- The dredge sediment mass quantity estimates have been derived based on hindcast modelling of Port of Cairns maintenance dredge campaign occurring in 2013, which removed 280,000 tonnes of sediment (BMT WBM, 2015).
- Annual resuspension rates were derived from Port of Cairns numerical model simulations (BMT WBM, 2015) for comparison with the quantities derived from the turbidity logger datasets. The model derived rate for sediment resuspension of 21,000,000 tonnes/year is larger than the data based quantity of 14,000,000. This result indicates that the quantitative

comparison results presented in Table E-3 and E-4 should be conservatively high with respect to the contribution of maintenance dredging to suspended sediment quantities.

- Existing terrigenous sediment quantities were derived based on an average Holocene deposit thickness of 2.5m.

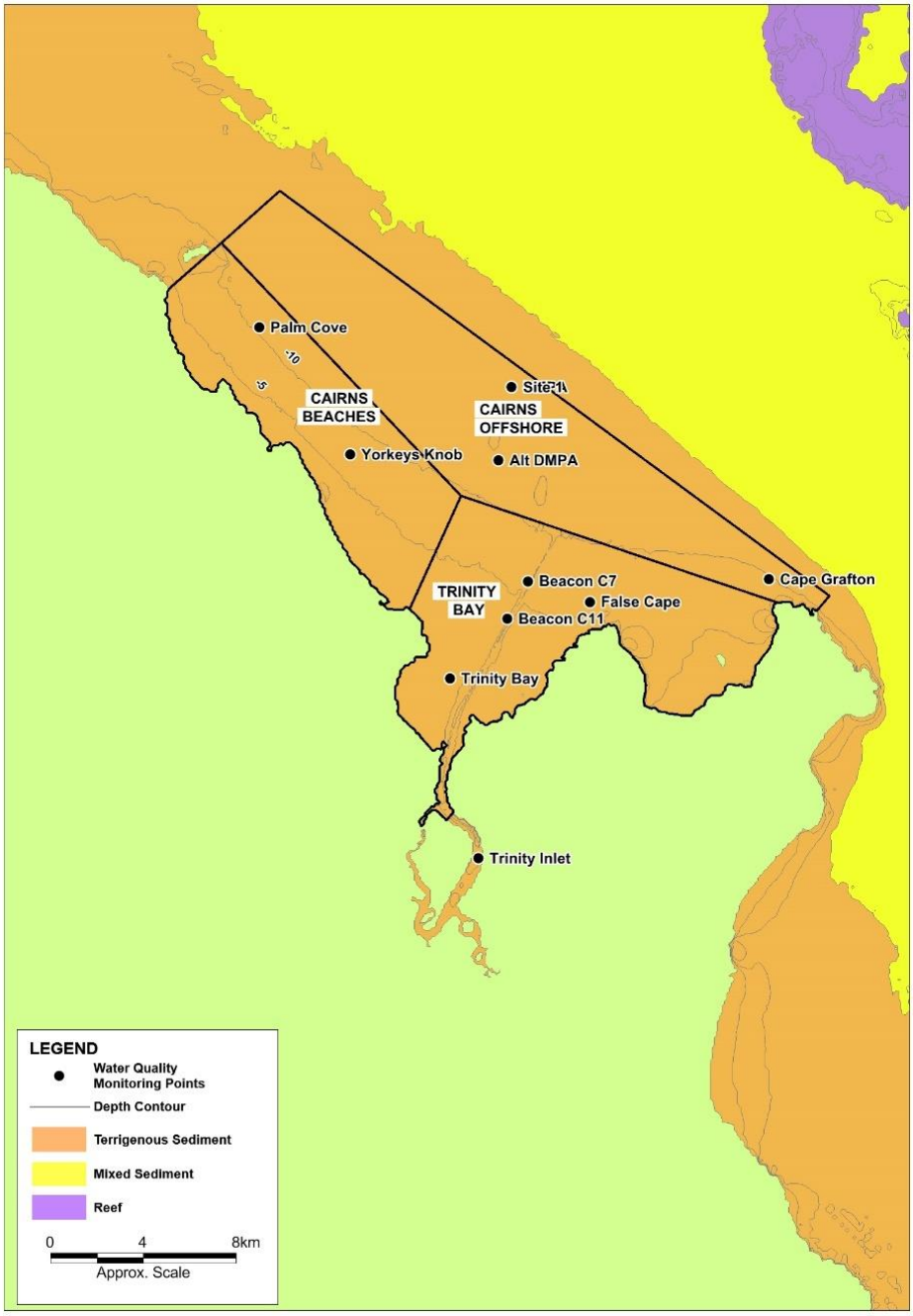


Figure F-1 Port of Cairns Sediment Budget Zones and Turbidity Monitoring Locations

Table F-1 Cairns Turbidity Statistics Summary

Site	Depth (mAHD)	Long-term Turbidity Statistics						Turbidity Event Statistics					
		Mean	1%ile	25%ile	Median	75%ile	99%ile	Sub-daily Amplitude	Event Threshold	Mean Event Turbidity	Frequency (events/y)	Mean Duration (days)	Primary Driver/s
DMPA	14	7	1.2	3.1	4.6	7.1	43.3	2.8	7.0	14.6	25	4.0	Waves
Alt DMPA	11	11.7	0.7	2.2	4.1	13.5	82.5	2.2	11.7	31.2	24	4.5	Waves
Beacon C7	6	18.2	1.1	4.3	11.8	26.3	83.6	11.5	18.2	32.9	34	4.4	Tide/Waves
Beacon C11	5	37.6	1.4	8.5	21.1	44.5	241.5	20.9	37.6	82.5	37	3.0	Tide
Palm Beach	10	33.9	0.7	4.9	14.5	39.9	262.9	10.3	33.9	82.6	39	3.0	Tide/Waves
Yorkeys Knb	9	36.6	0.9	5.6	18.0	45.9	248.5	12.2	36.6	84.6	32	3.8	Tide/Waves
Trinity Bay	4	34.3	2.1	7.7	16.2	37.3	300.4	18.1	34.3	83.5	31	3.3	Tide
Trinity Inlet	8	16.2	2.1	4.8	7.5	14.5	141.6	7.4	16.2	38.0	27	3.8	Tide
False Cape	7	90.4	1.0	12.5	39.9	86.4	1204.9	34.2	90.4	249.0	31	3.1	Tide/Waves
Cp Grafton	6	124.2	0.4	5.8	30.8	104.0	1336.5	35.9	124.2	403.0	32	2.8	Tide/Waves
Site Averages		**41.2**	**1.2**	**5.9**	**16.9**	**42.0**	**397.2**	**15.6**	**41.2**	**111.1**	**31.5**	**3.5**	

Table F-2 Port of Cairns Ambient Sediment Mass and Resuspension Rate Quantities

Port Area Zones			Port Area SSC				Ambient Sediment Mass Estimates				Ambient Resuspension Estimate		
Description	Average Depth	Area	Median SSC	Mean SSC	Event SSC	Tidal SSC	Median SSC Mass	Mean SSC Mass	Event SSC Mass	Tidal SSC Mass	Number of Events	Number of Tides	Annual Resuspension
	[m]	[km^2]	[mg/L]	[mg/L]	[mg/L]	[mg/L]	[tonnes]	[tonnes]	[tonnes]	[tonnes]	[per year]	[per year]	[tonnes/y]
Trinity Bay	7	98	20	50	100	15	13,720	34,300	68,600	10,290	30	700	8,849,400
Cairns Beaches	5	75	15	35	75	10	5,625	13,125	28,125	3,750	30	700	3,300,000
Cairns Offshore	12	122	4	10	25	1	5,856	14,640	36,600	1,464	25	700	1,793,400
Port Area Total		**295**					**25,201**	**62,065**	**133,325**	**15,504**			**13,942,800**

Table F-3 Port of Cairns Suspended Sediment Mass, Comparison of Dredging and Ambient Quantities

	Description	Quantity		Notes
Ambient	Median Ambient Mass	25,000	tonnes	Annual median turbidity represents relatively calm conditions.
	Event Ambient Mass	133,000	tonnes	Typical ambient event duration is 4 days. Event frequency is 25 per year.
	Annual Mean Ambient Mass	62,000	tonnes	Annual mean represents average across both calm conditions and events.
Dredging	Campaign Maximum Dredge Mass	10,000	tonnes	Typical duration would be less than 1 day. Event frequency is 1 per year. This quantity includes a significant component of natural resuspension of previously deposited dredge-plume and placed material and is therefore very sensitive to environmental conditions (i.e. natural resuspension events). However, during such events the total quantity of sediment in suspension is always dominated by the ambient component.
	Campaign Mean Dredge Mass	5,000	tonnes	Typical maintenance campaign duration is 3-4 weeks
	Annual Mean Dredge Mass	750	tonnes	Only low intensity dredging related plumes occur outside the campaign window.
Dredging % of Ambient	Dredging Campaign Maximum % of Ambient Event	7.5	%	This is a comparison of relatively short-term (acute) quantities. Note that the dredge quantity occurs approximately once a year, lasting for one day, while the ambient quantity is occurring around 25 times per year and lasting for four days.
	Dredging Campaign Mean % of Ambient Mean	8.1	%	This is a comparison on timescales of around 1 month.
	Dredging Annual Mean % of Ambient Mean	**1.2**	**%**	This suspended sediment mass comparison represents the long term average contribution of maintenance dredging to suspended sediment quantities at the port-scale.

Table F-4 Port of Cairns Suspended Sediment Resuspension, Comparison of Dredging and Ambient Quantities

	Description	Quantity		Notes
Ambient	Annual ambient resuspension	14,000,000	tonnes/year	Estimated as the sum of multi-day resuspension events and sub-daily (tidal) resuspension quantities.
	Ambient resuspension during dredging campaign	1,080,000	tonnes/year	Assuming a typical 4 week campaign.
Dredging	Typical maintenance dredging campaign	280,000	tonnes/year	Based on historical maintenance dredging quantities. Campaign frequency is typically annual.
	Passive plume during dredging and placement	20	%	Worst case TSHD overflow dredging of predominantly fine sediments.
	DMPA dispersion	20	%	Cairns DMPA is ~80% retentive.
	Dredging resuspension during dredging campaign	56,000	tonnes/year	Estimated as the sum of passive plume quantity and percentage of material dispersed from DMPA.
	Annual dredging and DMPA resuspension	112,000	tonnes/year	This is the total quantity resuspended during dredging, placement and transport of dredged material from the DMPA
Dredging % of Ambient	Dredging % of Ambient Resuspension (Campaign)	5.2	%	This is a comparison over typical maintenance campaign timescales.
	Dredging % of Ambient Resuspension (Annual)	**0.8**	**%**	This sediment resuspension comparison represents the annual quantity of sediment mobilisation compared with an equivalent derived ambient quantity.

Appendix G GBR Inner-Shelf

Assumptions

- Ambient sediment mass estimates from the six individual ports have been aggregated together with ambient estimates for the remaining GBR inner-shelf regions (see Table G-1)
- Ambient sediment mass estimates for the regions between ports have been conservatively interpolated based on SSCs for offshore water sub-regions at the adjacent ports.

Table G-1 GBR Inner-Shelf Ambient Sediment Mass and Resuspension Rate Quantities

GBR Inner-shelf Zones					SSC [mg/L]				Ambient Sediment Mass Estimates [tonnes]				Ambient Resuspension Estimates		
	Average Depth [m AHD]	Coastline Length [km]	20 m contour width [km]	Area [km²]	Median	Mean	Event	Tidal	Median	Mean	Event	Tidal	Number of Events [per year]	Number of Tides [per year]	Annual Resuspension [tonnes/y]
Cairns to Cape York	10	700	10	7,000	1	2	5	0.3	70,000	140,000	350,000	21,000	25	700	21,700,000
Port of Cairns	10	30	10	**295**					**25,201**	**62,065**	**133,325**	**15,504**			**13,942,800**
Cairns to Townsville	10	250	10	2,500	5	7	15	1	125,000	175,000	375,000	25,000	25	700	23,750,000
Port of Townsville	10	40	15	**600**					**18,706**	**34,063**	**76,922**	**10,051**			**8,491,347**
Townsville to Abbot Point	10	120	15	1,800	2	4	10	1	36,000	72,000	180,000	18,000	25	700	16,200,000
Port of Abbot Point	10	30	9	**275**					**3,502**	**7,558**	**26,065**	**1,543**			**1,698,875**
Abbot Point to Mackay	10	170	10	1,700	3	10	20	0.5	51,000	170,000	340,000	8,500	25	700	13,175,000
Port of Mackay	10	40	15	**600**					**13,360**	**52,140**	**200,400**	**3,900**			**6,704,000**
Port of Hay Point	10	40	15	**600**					**13,560**	**53,190**	**203,400**	**3,150**			**6,384,000**
Hay Point to Gladstone	10	350	15	5,250	2	5	10	0.5	110,250	262,500	525,000	26,250	25	700	28,743,750
Port of Gladstone	10	45	15	**660**					**36,740**	**50,996**	**106,075**	**19,473**			**15,364,662**
Gladstone to Bundaberg	10	90	15	1,350	2	3	5	0.3	28,350	36,450	67,500	4,050	25	700	3,813,750
GBR Total		**1,905**		**22,630**					**531,669**	**1,115,962**	**2,583,686**	**156,421**			**159,968,184**

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